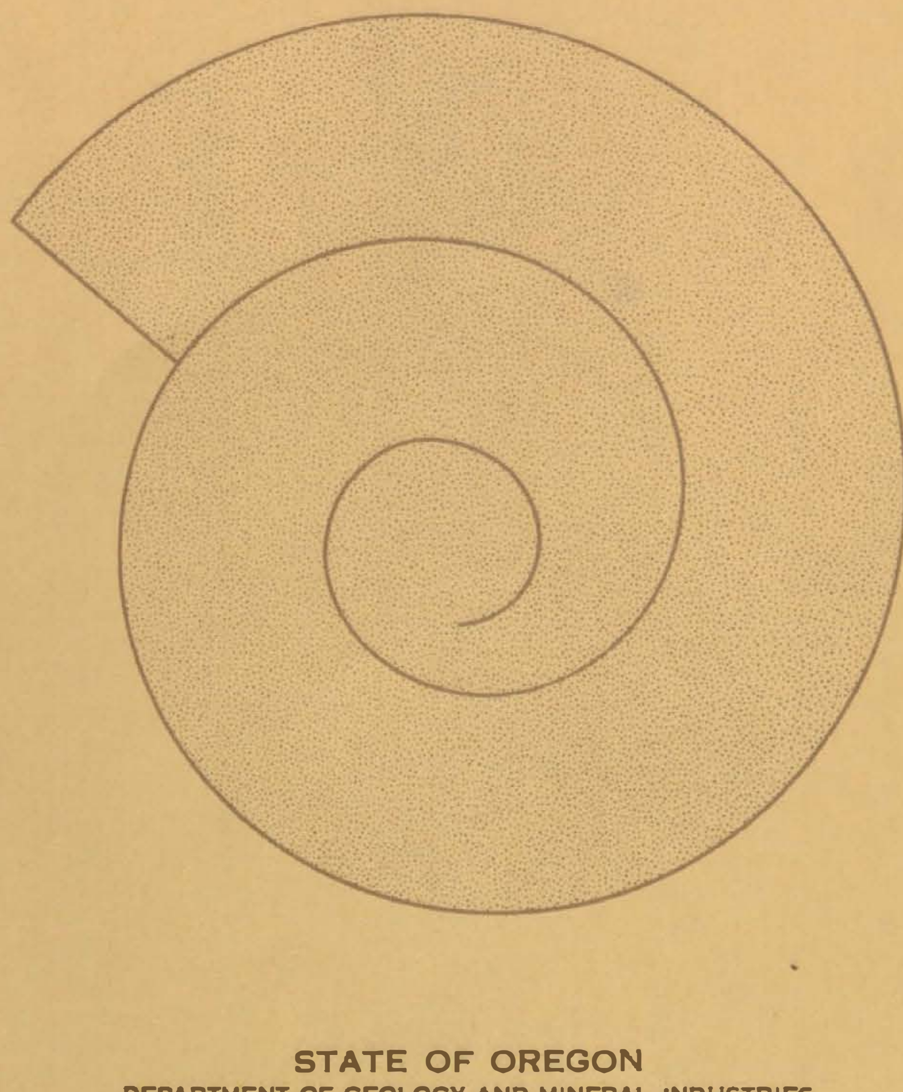
Bulletin No. 58

GEOLOGY OF THE SUPLEE-IZEE AREA

CROOK, GRANT, AND HARNEY COUNTIES, OREGON



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

1965

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1069 State Office Building
Portland Oregon - 97201

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GEOLOGY OF THE SUPLEE-IZEE AREA

CROOK, GRANT, and HARNEY COUNTIES, OREGON

By

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and

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FOREWORD

The Suplee-Izee area is a rather loosely defined region covering approximately 500 square miles in east-central Oregon. It is known to the citizens of the state as fine cattle country and it affords them excellent deer hunting. To the geologist it is one of the most intriguing regions in the state, because it is a "window" in a vast area covered by relatively young volcanics through which he can examine marine rocks, some of which are the oldest known in Oregon. These marine rocks range in age from Devonian (350 million years old) through Cretaceous (100 million years old), and they have undergone many disrupting earth movements which have complicated the geology to a high degree. Their exposure allows the geologist to look at the type of rocks and structures that might occur at depth under the widespread Tertiary volcanic material in the southeastern part of the state. Economically, these old rocks or their equivalents may contain deposits of oil and gas, but trying to evaluate their commercial possibilities through the blanket of difficult-to-penetrate lavas has discouraged drilling and exploration.

The "window" of ancient rocks in east-central Oregon has been known since 1865, when a cavalry expedition under Captain Drake collected fossils from the Crooked River and gave them to Dr. Thomas Condon (Oregon's first State Geologist). Dr. E. L. Packard, former Head of the Department of Geology at Oregon State University, was the first to recognize the tremendous geological possibilities of the area, and, in addition to being a pioneer worker there, encouraged further studies.

In the early years of geologic work, remoteness of the area, lack of base maps, and absence of paleontologic control limited geologic mapping. In more recent years easier access into the area, availability of aerial photographs, and better understanding of faunal sequences has made it possible to map this complex region in much greater detail. This present publication, a joint report by Drs. Dickinson and Vigrass, who chose the area for their doctoral dissertations, is certainly the most complete and definitive piece of work done to date on the Mesozoic rocks in the pre-Tertiary "window."

The Department considers this "window" of such importance that over the past six years it has had a highly experienced geologist working in some of the same area covered by this bulletin, but with more emphasis being placed on the Paleozoic rocks and their structures that occur to the south and west. It is hoped that the present bulletin and the work now in progress will bring forth the type of geological information that the region requires in order to promote further explorations for oil and gas in central Oregon.

Even though this publication and the work in progress will be a tremendous advancement of our knowledge on the area, much more study will be required if the extrapolation of the information is to be carried with confidence beneath the lava cover of central Oregon. Perhaps the publications of the Department will encourage industry to do some of the needed work.

Hollis M. Dole
State Geologist

October 29, 1965

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GEOLOGY OF THE SUPLEE-IZEE AREA

CROOK, GRANT, AND HARNEY COUNTIES, OREGON

By

William R. Dickinson and Laurence W. Vigrass

ABSTRACT

Detailed stratigraphic and structural mapping, supported by appropriate laboratory investigations, has greatly advanced knowledge of the pre-Tertiary geologic history of the Suplee-Izee district of 250 square miles in Crook, Grant, and Harney Counties of central Oregon. Besides affording a key to the geologic history of the region, the pre-Tertiary rocks exposed are among the least metamorphosed and most fossiliferous on the Pacific margin of North America. Geographically, the district lies on the divide between the John Day, Crooked, and Silvies drainages; geologically, it lies within the Blue Mountains system, wherein it occupies the southwesternmost of several erosional inliers of pre-Tertiary rocks surrounded by Cenozoic sedimentary and volcanic rocks.

The composite stratigraphic sequence includes at least 35,000 feet of Paleozoic, Mesozoic, and Cenozoic strata. Both the pre-Cenozoic marine strata and the Cenozoic continental strata include a high proportion of volcanic material, largely pyroclastic in the Mesozoic beds. Twelve unconformities break the continuity of the sequence and local facies changes are prominent in the marine strata. Repeated diastrophism, which was strongest in the Permian-Triassic, Early Jurassic, and Jurassic-Cretaceous times, has produced a complexly folded and faulted terrane in which the degree of deformation is roughly proportional to age.

Underlying a western upland of rolling hills near Suplee are undifferentiated Paleozoic strata consisting dominantly of flinty felsite including both lava and tuff, with subordinate chert, volcanic sandstone, and lenses of calcarenitic limestone containing lower Permian fusulinids. On Frenchy Butte north of Izee, greenstones of probable Paleozoic age are intruded by Permian-Triassic serpentine; both are overlain unconformably by fossiliferous Upper Triassic beds.

Occupying the core of the southwesterly plunging Mowich upwarp and a parallel upwarp to the northwest is a tightly folded lower Upper Triassic (Karnian) sequence that has been subdivided into two gradationally conformable units, which together underlie 100 square miles. Begg Formation (new name) rests unconformably on Paleozoic rocks and consists of at least 7,500 feet of strata, dominantly dark lutites but including resistant members of chert-grain sandstone and chert-pebble conglomerate; volcaniclastic rock and lava; polymictic conglomerate and sedimentary breccia; and rare, thin limestone lenses. Brisbois Formation (new name) is about 5,000 feet thick, and is of dominantly dark lutite in which beds of calcareous sandstone and sandy calcarenite are intercalated; a volcanic member of spilite lava, felsite tuff, and tuffaceous volcanic graywacke reaches a thickness of 2,000 feet locally.

Resting unconformably on the Karnian strata in the Vester Creek syncline are 1,000 feet of thin-bedded, dark, siliceous argillite and argillaceous tuff referred to the Rail Cabin Argillite (new name). Interbeds of bioclastic limestone contain Norian (Upper Triassic) fossils. The Rail Cabin is overlain with apparent conformity by the Graylock Formation (new name), which contains Hettangian (Lower Jurassic) fossils. The Graylock is at least 400 feet thick, and is dominantly dark siltstone, although thin beds of black limestone are intercalated in the basal 15 to 75 feet. Lithologically similar and possibly correlative strata, here described informally as the "Caps Creek beds," may be as young as Sinemurian.

The upper Lower Jurassic Mowich Group, exposed along the flanks of Mowich upwarp, is redefined to include Hyde Formation, as well as the underlying Robertson, Suplee, and Nicely Formations. The group is about 1,500 feet thick and rests unconformably on all the older Mesozoic units in the area. The Robertson Formation (0-350 feet) of basal conglomerate, andesitic sandstone, and biostromal limestone lenses is confined to the western part of the area. Abundant ammonites from the overlying Suplee Formation (25-75 feet) of fossiliferous calcareous sandstone and Nicely Formation (75-300 feet) of concretionary calcareous shale are Toarcian (Lower Jurassic). The Hyde Formation (1,000 - 1,200 feet), which accounts for most of the group, is formed of marine andesitic tuff and volcanic sandstone, largely unfossiliferous. Detritus from underlying Mesozoic strata forms the basal conglomerate of the Robertson Formation in the west and the Suplee Formation in the east where the Robertson is absent.

The Middle Jurassic Snowshoe Formation, as herein revised, rests conformably on the Mowich Group in the eastern part of the area near Izee, but overlaps westward onto older strata of Triassic and Paleozoic age in the Pine Creek downwarp near Suplee. Near Izee the type Snowshoe Formation includes three members: (a) a lower member (600 feet) of dark, calcareous, and radiolarian lutite of uppermost Toarcian (Lower Jurassic) and lower Bajocian (Middle Jurassic) age; (b) a middle member (1,000 feet) of interlaminated dark lutite and greenish volcaniclastic siltstone and fine-grained sandstone in graded layers, the whole of Bajocian (Middle Jurassic) age; and (c) an upper member (1,250 feet) of thin-bedded, dark lutite with thick intercalated beds of gray calcareous sandstone, in part of lower Callovian (lowermost Upper Jurassic) age. The middle member of the type section grades eastward into the Silvies Member (new name), a volcaniclastic wedge 1,500 feet thick at its type locality and characterized by thick

intercalations of resistant andesitic graywacke and conglomerate in graded beds. Near Suplee, where the base is an unconformity, the Snowshoe Formation is entirely Bajocian (Middle Jurassic) and includes four members: (a) the Weberg Member (formerly Formation) of abundantly fossiliferous calcareous sandstone, locally pebbly, and sandy limestone from 0 to 150 feet thick; (b) the Warm Springs Member (formerly Formation) of dark lutite 250 feet thick; (c) the Basey Member (new name) composed of andesitic volcaniclastic rocks with minor lava and having a thickness of 1,500 feet in its type locality; and (d) the Shaw Member (new name) of gray shale that contains minor limestone and sandstone intercalations and has a total thickness of less than 1,000 feet with an erosional top. The three members of the "Izee basin" on the east are facies equivalents of the four members of the "Suplee platform" on the west.

Resting unconformably on the Snowshoe Formation in the Lonesome syncline are 12,500 feet of nearly unfossiliferous lower Callovian (Upper Jurassic) strata. Trowbridge Formation, as redefined, is 2,250 to 3,250 feet thick and is dominantly black lutite with pencil fracture. Three members are recognized: (a) the basal Rosebud Member (new name) of massive black and green mudstone 0 to 500 feet thick; (b) Officer Member (new name) of mudstone with intercalated resistant sequences of vitroclastic felsite tuff in massive and laminated beds and of dacitic graywacke in graded and laminated beds, the whole from 100 to 500 feet thick; and (c) Magill Member (new name) of massive black mudstone 2,000 feet thick with thin intercalated beds of calcareous sandstone and limestone. The basal beds of Trowbridge Formation transgress westward from the upper to the middle member of type Snowshoe Formation, and the Officer Member overlaps the Rosebud Member in the same direction. The Lonesome Formation, approximately 10,000 feet of intercalated dark lutite and lithic (volcanic) graywacke in graded beds, rests conformably on the Trowbridge Formation and apparently represents the filling of a tectonic basin with turbidite strata.

Bernard Formation (new name) of lower Upper Cretaceous age rests unconformably on Paleozoic, Triassic, and Jurassic rocks and is overlain unconformably by Tertiary volcanic rocks. It consists dominantly of pebbly fossiliferous marine sandstone that is locally cross-bedded and conglomeratic, and is 1,500 feet thick.

Tertiary volcanic strata cropping out on peripheral lava plateaus and as residual butte cappings have an aggregate thickness of more than 1,000 feet. Five units have been recognized, each continental and bounded above and below by unconformities. About 200 feet of Eocene (?) mudflow breccia and amygdaloidal basalt crop out on Morgan Mountain. Picture Gorge Basalt of the Columbia River Group is porphyritic and aphanitic, reaches 1,500 feet in thickness, and is overlain outside the map area by pale tuffs probably correlative with the Mascall Formation; dolerite feeders form several dike swarms and isolated pipes cutting Mesozoic strata. About 200 feet of variegated lacustrine tuffs and claystones on Buck Mountain may be correlative with the Mascall Formation. A diktytaxitic olivine basalt flow from 50 to 100 feet thick in Howard Valley is probably Pliocene and thus older than the Ochoco Lavas. Welded soda-rhyolite tuff-breccia (0-100 feet) is correlative with welded sheets in the Rattlesnake and Danforth Formations of the John Day Valley and Harney Basin; the presence of sodic amphiboles and pyroxenes as crystal fragments is evidence of an alkaline parent magma.

Quaternary stream alluvium and mass movement deposits on hillsides mask many exposures of the bedrock units.

The major structural units of the Suplee-Izee district are: (1) mildly warped and faulted marine Cretaceous and continental Tertiary strata; (2) strongly folded and faulted Mesozoic strata including (a) mainly Jurassic volcaniclastic strata deformed only during a Jurassic-Cretaceous orogeny, and (b) mainly Triassic epiclastic strata deformed also during an Early Jurassic orogeny here named the Ochoco Orogeny; and (3) mildly metamorphosed Paleozoic marine strata first deformed and also intruded by serpentine during a Permian-Triassic orogeny.

The folds formed in Upper Triassic strata during the Ochoco Orogeny had northerly trends; they were nearly isoclinal in the west, but were more open toward the east. Active during the orogeny were three major reverse faults of a coparallel set trending north-northeast and dipping to the northwest, steeply in most areas but at low angles locally. Both folds and faults diverged to drape themselves about a buttress of Paleozoic greenstones intruded by serpentine on Frenchy Butte north of Izee. Movement on the major faults may have begun in the Late Triassic during the deposition of the Upper Triassic strata cut by the faults.

The Jurassic strata were strongly folded and diagenetically altered to zeolitic assemblages in Late Jurassic and/or Early Cretaceous time before the deposition of Bernard Formation. The folds formed have easterly trends. They are open, closely spaced, and have only moderate relief in the west. In the east, however, the Lonesome syncline is a great, overturned, nearly isoclinal downbuckle; minor transverse corrugations on its limb may be pre-orogenic gravitational slump folds that have been tipped on end. Upper Triassic strata that were first folded about northerly axes during the Ochoco Orogeny were refolded about easterly axes. In the west, where the divergence in trend was most marked, folds of complex configuration were produced during the refolding. Following the Jurassic-Cretaceous orogeny or during its latest phase, broad warping about northeasterly axes gave rise to the southwesterly plunging Mowich upwarp and Pine Creek downwarp, which control the gross outcrop pattern of Triassic and Jurassic rocks within the area.

In the early Tertiary, the Cretaceous Bernard Formation was tilted and an irregular erosion surface of locally high relief was formed before the eruption of the Picture Gorge Basalt. Renewed tilting and erosion preceded eruption of the Pliocene basalt and welded tuff. Finally, tilting and deep erosion of Pliocene strata accompanied Pleistocene deformation.

INTRODUCTION

Purpose and Scope of Report

Most of Oregon east of the Cascade Range is underlain by Cenozoic continental volcanic and sedimentary rocks. Paleozoic and Mesozoic stratified rocks are exposed only in isolated inliers surrounded by the younger deposits. In general, these older strata are intensively deformed, extensively metamorphosed, and invaded locally by igneous intrusions. An exception is the area of this report. The studies uponwhich the report is based were undertaken with the hope, now amply confirmed, that the results would fill some of the gaps in our knowledge of the pre-Tertiary geologic history of eastern Oregon. The area was attractive for three reasons: (1) It had not previously been mapped or studied in detail; (2) Metamorphism is slight and igneous intrusions are almost wholly lacking, hence, the original characters of the rocks and the details of their deformation are preserved; and (3) The fossiliferous Mesozoic sequence permits detailed correlations with other strata in the Pacific Coast region, precise dating of local diastrophic events, and an interpretation of facies relationships. The principal knowledge gained from the study can be divided into three general categories: (1) refinement and revision of the stratigraphy outlined by previous workers involving new correlations, re-defined formation boundaries, and the delineation of several newly recognized formations and mappable members; (2) evidence for the volcanic derivation of many of the Paleozoic and Mesozoic clastic strata and description of the petrology of these rocks; and (3) interpretation of the history of sedimentation, volcanism, and tectonism with appreciably more detail and accuracy than has been possible previously.

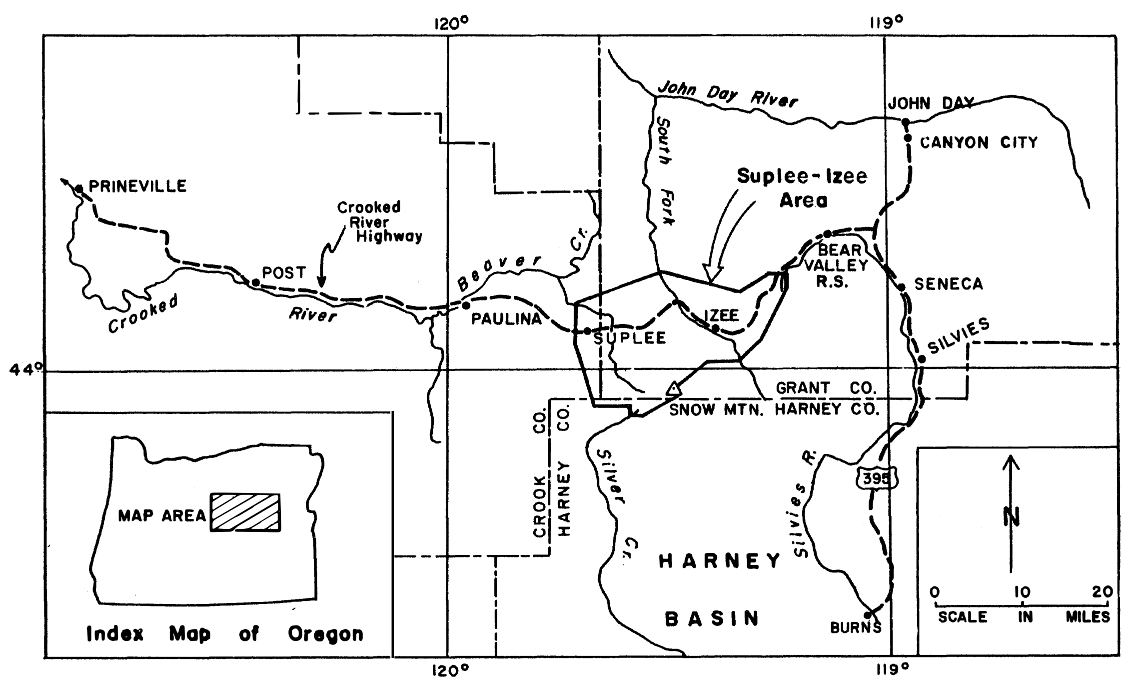


Figure 1. Location map of Suplee-Izee area.

Location and Access

The Suplee-Izee area embraces approximately 250 square miles of grazing and timber lands in Crook, Grant, and Harney Counties of east-central Oregon (figure 1). All-weather county roads lead into the area from Prineville on the west, via Paulina, and from U.S. Highway 395 between Burns and John Day on the east, via Bear Valley Ranger Station. In dry weather, one can travel to most parts of the area along numerous ranching and logging roads.

Geography

The area lies astride a multiple drainage divide capped by Snow Mountain (7,135 feet) at the southern edge of the area. South Fork of Beaver Creek drains the Suplee district westward to Crooked River; South Fork of John Day River drains the Izee district northward to John Day Valley. The southern and eastern extremities of the area drain southward into Harney Basin through Silver Creek and Silvies River. Most of the area is an intricately dissected upland lying at elevations of 5,000 to 6,000 feet, but South Fork of John Day River has trenched as low as 4,000 feet, creating local relief as great as 1,500 feet in its drainage basin (see figures 2 and 3).

The vegetation is typical of cool, semiarid continental climes. Sagebrush, bunch grass, and scattered junipers dominate the lowlands, whereas stands of ponderosa pine abound on summits and northern slopes of many uplands. Aspen groves and willow thickets line the watercourses, and meadows carpet the alluvial flats.

Regional Geologic Setting

The Suplee-Izee area is situated near the southwestern extremity of the Blue Mountains province, a complex system of highlands and intermontane basins in northeastern Oregon bounded on the north by the Columbia River Plateau of basaltic lavas and on the south by the southeastern Oregon volcanic provinces of lava plateaus, alluviated basins, and fault-block mountains. The northwestern part of the Blue Mountain province, including the Blue Mountains proper and the Ochoco Range of central Oregon, is underlain for the most part by warped Cenozoic continental volcanic and sedimentary rocks. Pre-Cenozoic rocks are most extensively exposed in the eastern- and southernmost parts of the Blue Mountains province as inliers surrounded by younger rocks. The Suplee-Izee area lies within the most southwestern of these inliers, as shown by figure 4.

Previous Work

Dr. E. L. Packard and his students at the University of Oregon were the first to explore systematically the pre-Cenozoic rocks near Suplee and Izee and the first to appreciate the great areal extent of these exposures (Packard, 1928). Packard (1932) described in a general way the Paleozoic rocks and Schenk (1934) the Triassic rocks. Lupher (1941) first took stock of the Jurassic rocks in a detailed and highly informative stratigraphic report. Since that date, as base maps have become available, several geologists have mapped areas of varying size within and near the ground described in this report (see figure 5).

Methods of Investigation

Geology was plotted on 1:20,000 air photos during 15 man-months of field work and compiled at 1:24,000 on U.S. Forest Service planimetric base maps. Vigrass mapped 110 square miles surrounding Suplee. Dickinson mapped 140 square miles surrounding Izee. Vigrass examined approximately 75 thin sections and Dickinson, approximately 250.

Figure 2. View from Morgan Mountain southwest across valley of South Fork of John Day River to Snow Mountain on skyline; visible relief is 3,000 feet.

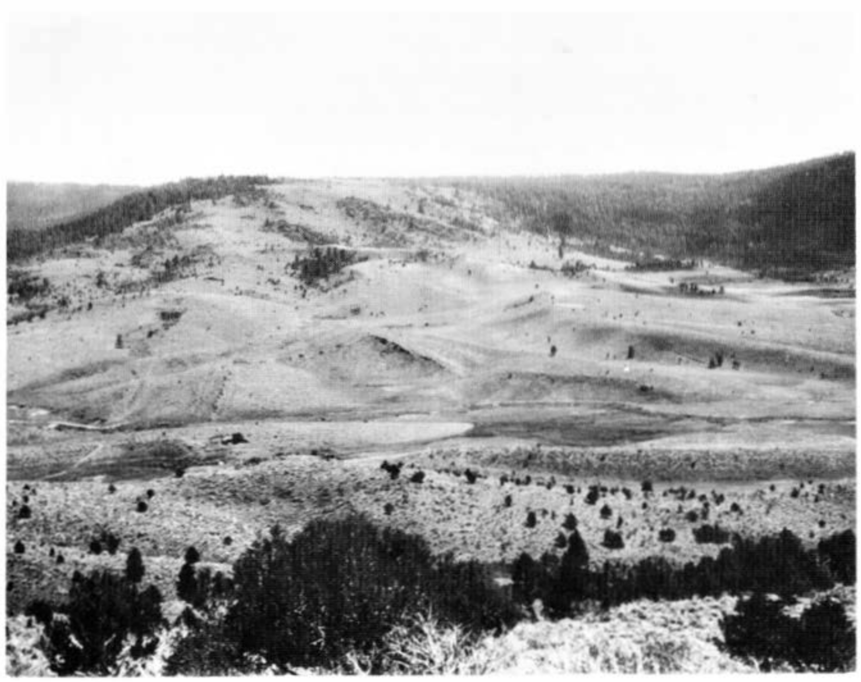


Figure 3. View east across volley of South Fork of Beaver Creek to Mowich Mountain copped by Columbia River Basalt; angular unconformity between Upper Triassic Begg Formation (left) and Lower Jurassic Mowich Group (right) in center.

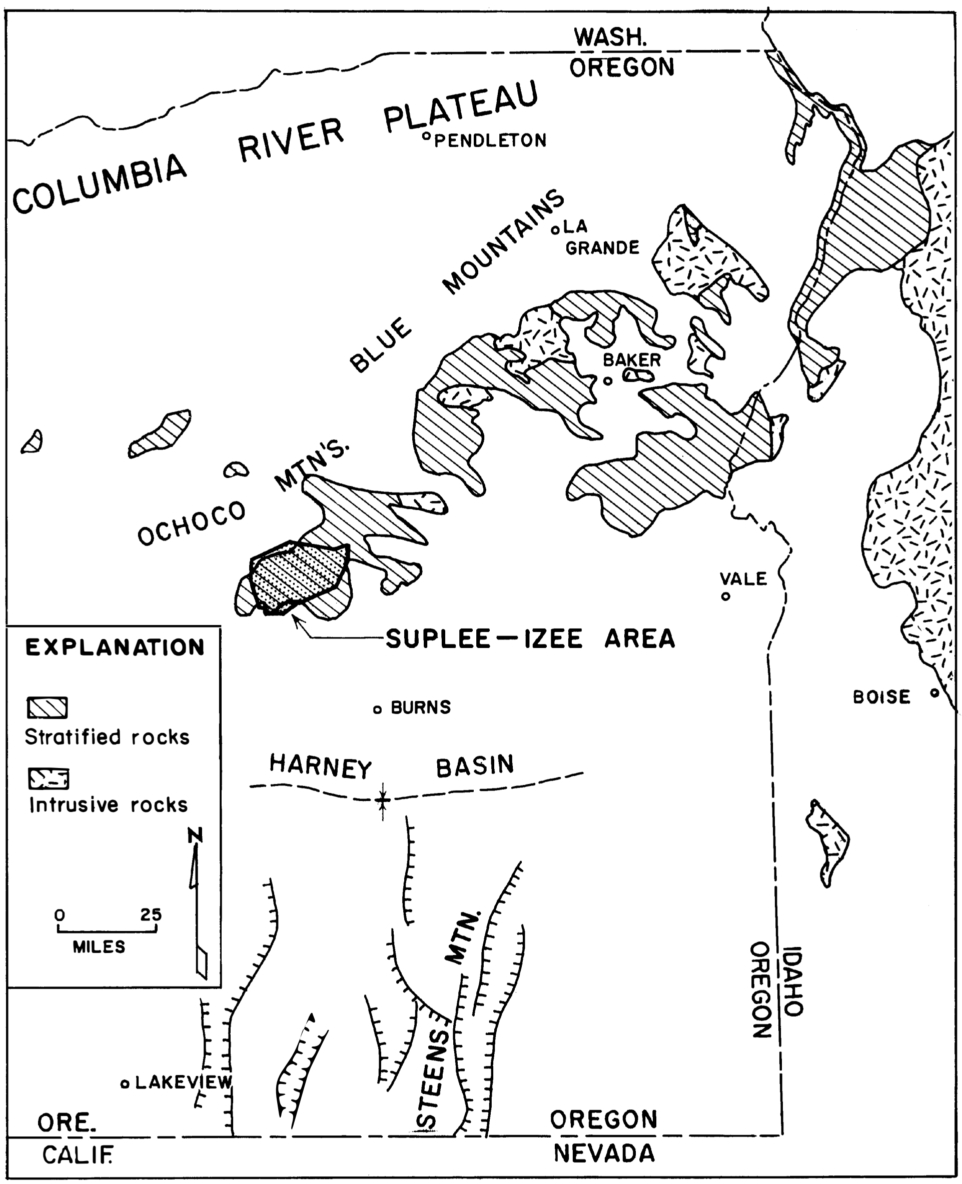


Figure 4. Pre-Cenozoic inliers of northeastern Oregon.

Acknowledgments

We take pleasure in calling the reader's attention to the many individuals and organizations whose assistance and support have made this report possible. The work upon which it is based was begun in 1956 as research in partial fulfillment of the requirements for our doctoral degrees at Stanford University. It was undertaken at the suggestion of Prof. S.W. Muller, who supervised the field work for most of the 1956 season, and was continued with the advice of Dr. Muller and of Prof. R. R. Compton.

Field, laboratory, and office expenses were borne in part by several organizations, but principally by Humble Oil & Refining Co. (for Dickinson, 1956; for Vigrass, 1956-57). Additional field work by

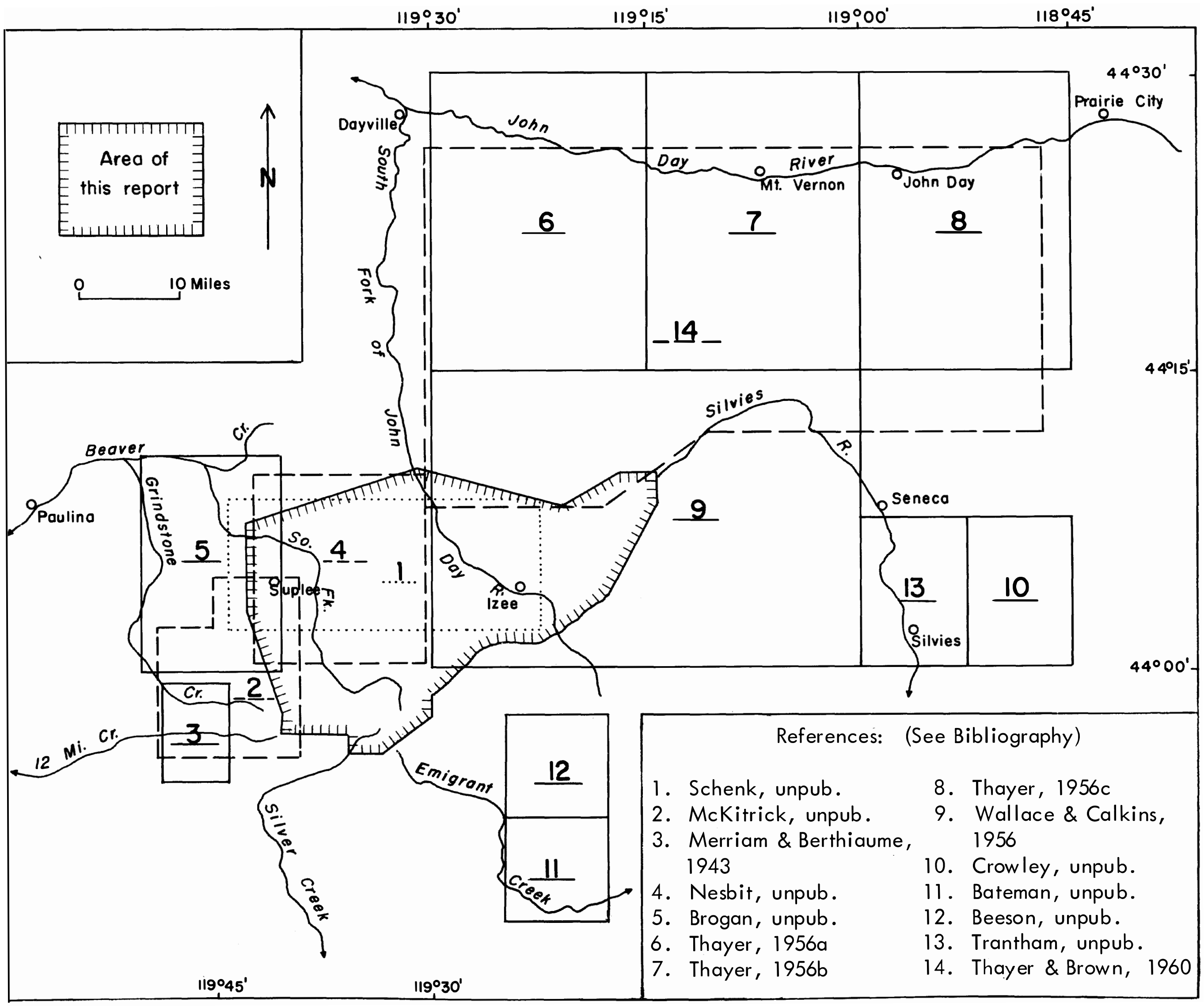


Figure 5. Available geologic mapping in Suplee-Izee area and vicinity.

Dickinson was supported by the National Science Foundation in 1957 and by a Gulf Oil Co. Aid to Education Grant in 1960. Laboratory and office expenses were borne in part by a grant from the Shell Oil Co. Fund for Fundamental Research at Stanford. Fellowship awards from the National Science Foundation (Dickinson, 1956-57), Standard Oil Co. of California (Vigrass, 1954-56), and Shell Oil Co. (Vigrass, 1956-57) made our research as graduate students possible.

Mr. J. H. Beeson of Humble participated in the field work of the 1956 season, and gave generously of knowledge and experience gained by previous work in the area with Mr. D.L. Morgridge of Humble. Mr. E.E. Larson of Humble ably assisted Vigrass during the 1957 season. Dr. R.M. Touring of Humble has been an interested and encouraging observer of the work since its inception.

We were extremely fortunate to have had the aid and advice of several outstanding paleontologists who identified the materials in our collections. Their opinions of the significance of the fossils form the basis for our interpretations of age relationships. These gentlemen and the collections they studied include: Drs. J.W. Skinner and G.L. Wilde of Humble Oil & Refining Co., Permian fusulinids; Dr. D.F. Squires of the American Museum of Natural History, Triassic coelenterates; Dr. N.J. Silberling of the U.S. Geological Survey, most Triassic collections; Dr. S.W. Muller of Stanford University, uppermost Triassic and lowermost Jurassic collections; Dr. R.W. Imlay of the U.S. National Museum and Geological Survey, most Jurassic collections; and Dr. D.L. Jones of the U.S. Geological Survey, Cretaceous collections.

We also benefited greatly from field conferences and discussions of problems in the area with a number of geologists who had worked in or near the area previously, or were working concurrently in nearby areas. These include Dr. E.L. Packard, Dr. R.L. Lupher, Dr. R.E. Wallace, Dr. T.P. Thayer, Dr. C.E. Brown, Dr. J.W. Harbaugh, Mr. W.P. Kleweno, Mr. T.P. Hughes, Mr. R.L. Bateman, Mr. C.I. Trantham, and Mr. M.O. Beeson. Active collaboration with Dr. R.W. Imlay, who spent several weeks collecting in the vicinity during the 1956 and 1957 field seasons, was especially beneficial.

The kindness of the ranchers of the Suplee and Izee communities was essential to the progress of our work, and was unfailing.

Mr. Ruperto Laniz, Stanford University, prepared all photographs of thin sections.

Finally, we must state our debt to Hollis M. Dole, State Geologist and Director of the State of Oregon Department of Geology and Mineral Industries. To his patient urging and enthusiastic cooperation must go the credit for the preparation of this joint report.

Fossil Collections and Localities

A number of geologists and paleontologists assisted us in the collection of fossils from nearly 250 localities. Although about 150 of the more important localities are shown on the geologic map (plate 1), space prevents a detailed description of each locality or proper credit to each colleague. The interested reader can find this information in our doctoral dissertations: "Geology of the Izee Area, Grant County, Oregon," by Dickinson (1958) and "Geology of the Suplee Area, Crook, Grant, and Harney Counties, Oregon," by Vigrass (1961), obtainable from University Microfilms, Inc., Ann Arbor, Michigan.

Geologic Terminology

For the general reader, an explanatory glossary of technical geologic terms is included at the back of this bulletin.

Petrologic Terminology

A few random comments concerning special, and perhaps controversial, aspects of the terminology of sedimentary and volcanic rocks are included here to clarify the usage in the text:

a) The terms quartz keratophyre, keratophyre, and spilite are used for soda-rich albitic analogues of dacite, andesite, and basalt, respectively.

b) Calcirudite, calcarenite, and calcilutite are textural terms applied to calciclastic rocks (fragmental limestones) and are analogous to conglomerate, sandstone, and mudstone; sandy calcarenites, etc., contain admixtures of terrigenous siliciclastic detritus.

c) Lutites: shale is fissile lutite, mudstone is non-fissile lutite, argillite is strongly indurated lutite analogous to slate except that it breaks into blocky angular fragments. Siltstone is either well-sorted rock composed of silt grains or poorly sorted rock with median size in the silt range but containing both sand and clay.

d) For petrographic descriptions of sandstones, the terminology of Gilbert (1954, p. 289-297) has been adopted.

e) For megascopic descriptions of sandstones, the sorting terminology of Compton (1961, p. 214) has been adopted.

f) For discussions of fragmental rocks of volcanic derivation (clastic volcanic or volcaniclastic rocks), the grain size limits proposed by Fisher (1961, p. 1411) have been adopted. Moreover, as regards clastic materials and rocks in the stratified column:

1. "Pyroclastic" refers to materials forcibly expelled from volcanic vents as fragmental ejecta, set in motion initially by explosive eruption, and owing their grain morphology to processes of eruptive disintegration (most typically, vesiculation).

2. "Epiclastic" refers to materials, of either volcanic or nonvolcanic derivation, which owe their particulate nature, their grain shapes, and their movement to processes of surficial weathering, erosion, and aqueous transport.

3. "Volcaniclastic" refers to materials of volcanic derivation, whatever their history, with no connotation as to their pyroclastic or epiclastic origin; which means volcaniclastic beds may be either tuff or sandstone, etc.

4. "Vitroclastic" refers to volcaniclastic materials having the distinctive curvilinear grain margins and branching, arcuate shapes of glass shards.

5. "Tuff," lapilli-tuff," "tuff-breccia," etc., refer to volcaniclastic rocks composed of pyroclastic debris so little modified by sedimentary processes of sorting or rounding that the original composition and texture of the ejecta are preserved essentially unchanged.

6. "Volcanic sandstone," "volcanic conglomerate," etc. refer to volcaniclastic rocks whose composition, texture, or structure give clear indication of surficial reworking sufficient to appreciably modify the original volcanic character of the source materials.

7. "Sandy tuff," "tuffaceous sandstone," etc., refer to rocks composed of mixed pyroclastic and epiclastic debris in which the former or the latter is respectively the more abundant.

PART ONE

STRATIGRAPHY, PETROLOGY, AND SEDIMENTATION

In this section of the report, information is assembled on the stratigraphic relations, the sedimentary and volcanic petrology, and the history of sedimentation of the rock units of the area. Plate I shows the outcrop pattern of the various units. Reference to Plate III, "Geologic History of the Suplee-Izee Area," will clarify the position occupied by each rock unit with respect to the structural evolution and tectonic history of the area. Reference to figure 6 will fix the major structural subdivisions of the area in the reader's mind. In Part One, unconformities are noted where present, but are described more fully in Part Two.

GENERAL STATEMENT

Stratified rocks of the Suplee-Izee area have an aggregate thickness of at least 35,000 feet (see figure 7), although such a thick prism of strata may not be present beneath any one place. Lithologic variations and structural relations record a complex history of diversified sedimentation, recurrent volcanism, and nearly continuous diastrophism from the Permian to the Pleistocene. Active volcanism contributed to deposition during each geologic period except the Cretaceous. Pre-Cenozoic strata are dominantly clastic sedimentary rocks and are probably entirely of marine origin. Cenozoic strata are of continental origin and are dominantly lavas and tuffs. Twelve unconformities that differ greatly in their respective angularity and stratigraphic hiatus have been recognized in the sequence (see Part Two). On the basis of structural relations, peak periods of orogenic deformation are inferred for Permian-Triassic time, the Sinemurian Age (Early Jurassic), and Late Jurassic and/or Early Cretaceous time (see Part Two). With local exceptions, the degree of structural deformation is proportional to age, the oldest strata being the most complexly folded and faulted, while younger and younger rocks are progressively less deformed. Despite the long history of repeated orogenic deformation, metamorphism of the rocks is slight. Mesozoic rocks of volcanic parentage were affected most by diagenetic alterations, but even in these rocks original textures are preserved almost intact and metamorphic schistosity is absent. Appreciable mineralogic reconstitution of pre-Cretaceous volcanic and volcaniclastic rocks has led to assemblages characteristic of the "zeolite facies" of Coombs and others (1959) or the "zeolitic facies" of Turner (1958, p. 215-217; Turner and Verhoogen, 1960, p. 532).

In the following account, the greatest emphasis is placed on the Mesozoic strata, particularly the Jurassic rocks, which have been studied in the most detail. Detailed descriptions of key stratigraphic sections of Jurassic strata are given in the Appendix, pages 90 to 96.

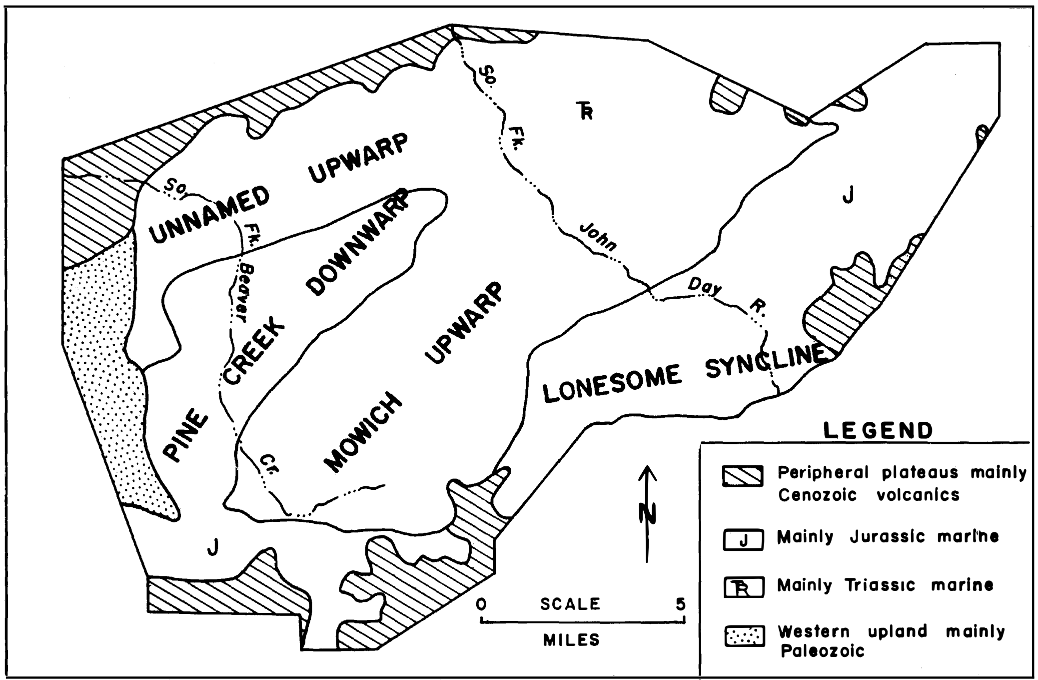


Figure 6. Major structural divisions of the Suplee-Izee area:

The western Paleozoic upland is a belt of up-faulted Paleozoic rocks along the western edge of the area.

Pine Creek downwarp is a synclinorium of down-folded Jurassic strata lying mainly east of the western Paleozoic upland and flanked on the northwest and southeast by exposures of Upper Triassic rocks.

Mowich upwarp is an anticlinorium, cored by Upper Triassic rocks and flanked by Jurassic strata, that trends from southwest to northeast across the heart of the area, and is thus the dominant structural feature of the area. An unnamed companion upwarp of folded Triassic rocks lies along the northwestern edge of the area.

Lonesome syncline is a deep structural trough of Jurassic strata lying southeast of Mowich upwarp along the southeastern edge of the area.

The peripheral lava plateaus are discontinuous uplands of gently dipping Tertiary basalt and tuff that ring the area on the north, east, and south.

Period	Symbol	Name	Approx. Ft.	General Lithology	Data on Age
TERTIARY	Twt, Tdb, Tlb, Tpg, Tmb	Tertiary volcanic rocks	2,000	rhyolitic welded tuff, olivine basalt, lacustrine beds, basalt, mudflow breccia	no fossils, continuous and/or correlative with nearby Pliocene, Miocene & Eocene(?)
CRETACEOUS	Kb	Bernard Fm.	1,500	pebbly lithic sandstone	ammonites and pelecypods of Cenomanian Stage
JURASSIC	Jlo	Lonesome Fm.	10,000	intercalated gray lithic (volcanic) sandstone in graded beds and black mudstone	ammonites of Callovian Stage
	Jt	Trowbridge Fm.	3,000	black mudstone with intercalated volcaniclastic rocks.	ammonites of Callovian Stage
	Jsn	Snowshoe Fm.	3,000 to 4,000	intercalated andesitic volcaniclastic rocks with minor lava and laminated argillaceous rocks	ammonites of Callovian, Bajocian, and uppermost Toarcian Stages
	Jm	Mowich Group	1,500	andesitic tuff and sandstone with minor shale, limestone, conglomerate	ammonites of Toarcian Stage
	Jg	Graylock Fm.	500	dark siltstone with minor limestone	ammonites of Hettangian Stage
TRIASSIC	TRrc	Rail Cabin Argillite	1,000	black to green argillite and felsitic tuff	ammonites of Norian Stage
	TRbr	Brisbois Fm.	5,000	black, gray, and green mudstone with intercalated sandy ls., calcareous ss., and volcaniclastic rocks and lava	pelecypods, coelenterates, ammonites of Karnian Stage
	TRbg	Begg Fm.	7,500	gray to green lutite with intercal. chert-grain ss. and chert-pebble cg., polymictic breccia & cg., volcaniclastic rocks and minor lava, & rare bioclastic limestone.	mollusks and coelenterates of Karnian(?) Stage
PERMIAN	Psv	Paleozoic Rocks	?	varicolored flinty felsite, limestone, and chert	Permian fusulinids; contiguous exposures include Devonian, Mississippian, & Pennsylvanian.

Figure 7. Generalized columnar section, Suplee-Izee area.

PALEOZOIC ROCKS (Psv)

Poorly exposed Paleozoic rocks of complex structure crop out in gently rolling uplands along the western edge of the mapped area near Suplee and on Frenchy Butte north of Izee. In neither area is the base of this Paleozoic sequence exposed. In both areas, the strata are overlain with angular unconformity by coarse clastic rocks assigned to the Upper Triassic Begg Formation. The exposures near Suplee contain Permian fusulinids and are continuous with the extensive exposures of Devonian, Carboniferous, and Permian carbonate rocks, volcanic rocks, cherts, and clastic sedimentary rocks in the Grindstone Creek-Twelvemile Creek district to the west studied by Merriam and Berthiaume (1943), Kleweno and Jeffords (1961), and Dr. J.W. Harbaugh (oral communication, 1958). The unfossiliferous exposures on Frenchy Butte were mapped as "basement complex" by Wallace and Calkins (1956) and are continuous with the "Permian metavolcanic rocks" of Thayer (1956a) in the Aldrich Mountains to the north. The two terranes of Paleozoic rocks presumably join beneath the Mesozoic exposures of the Suplee-Izee area. Neither the original stratigraphic thickness nor the actual tectonic thickness of the Paleozoic sequence can be estimated with confidence from any work to date. Gross structural and stratigraphic uncertainties are compounded by intricate small-scale brecciation found in nearly all exposures.

Lithologic description

In apparent order of abundance, the Paleozoic rocks near Suplee include felsite, limestone, chert, and volcaniclastic sedimentary rocks.

Craggy outcrops of varicolored, brecciated, flinty felsite locally veined by white chalcedony and quartz account for the bulk of the Paleozoic exposures. The felsites are microporphyritic quartz keratophyres in which embayed albite and quartz microphenocrysts are set without preferred orientation in a felted groundmass of albite and quartz. The aphanitic groundmass, which locally displays spherulitic and fluxion structures in thin section, assumes various shades of cream, gray, tan, brown, green, and purple in hand specimen. Primary structures visible in thin section, but usually not discernible in the field, indicate that the felsites include flow-banded lavas, flow-breccias, and laminated, strongly compacted tuffs.

The limestones crop out as isolated patches or discontinuous bands and are apparently lenses interbedded with felsite flows and tuffs. Most outcrops are subdued, but some form prominent rounded or craggy knobs. There are two common lithologic subtypes: 1) Most abundant is gray, massive or indistinctly bedded fragmental limestone ranging from calcarenite to calcirudite. Terrigenous debris in the form of sand grains or pebbles of quartz, chert, and felsite is common, and there is local gradation to subfeldspathic lithic arenite cemented by calcite. The calcarenite generally consists of crinoidal debris set in a matrix of calcilutite. The less abundant calcirudite consists of subrounded to subangular pebbles and cobbles of calcarenite set in a matrix of calcarenite or calcilutite. Fusulinids and encrusting bryozoa occur sparingly in the calcarenite and within the coarse fragments in the calcirudite. 2) Considerably less abundant is thin-bedded calcilutite containing sparse brachiopods and rugose corals.

Laminated red and green chert occurs sparingly in the Paleozoic sequence. The chert bears some resemblance to the flinty felsite, but in hand specimen the chert is more translucent, has a more glassy luster, breaks on more perfectly conchoidal fractures, has a less grainy appearance under the lens, and lacks the tiny quartz and feldspar phenocrysts characteristic of the felsite. In thin section, the chert is seen to be laminated chalcedony containing relict ghosts of monaxial and triaxial spicules, spheroidal radiolarians, and chalcedony pseudomorphs of chambered foraminiferal tests.

Rare volcaniclastic strata similar in many respects to those of the overlying Begg Formation appear to be intercalated with undoubted Paleozoic strata at several localities, most notably below the Begg strata half a mile south of Suplee in the SE$\frac{1}{4}$ sec. 26, T. 17 S., R. 25 E. These Paleozoic rocks include moderately sorted volcanic sandstones, sedimentary breccias of felsite and argillite fragments and olive-green mudstones. The grains of the sandstones are dominantly felsite and greenstone accompanied by varying amounts of chert, argillite, and volcanic plagioclase.

The Paleozoic rocks on Frenchy Butte north of Izee are dominantly massive, dark-green aphanitic lavas, flow-breccias, and agglomerates or pillow breccias best described in the field as greenstones. Calcite and chalcedony amygdules, veinlets, and irregular replacement nodules are abundant. The lavas are microporphyritic keratophyres containing widely spaced microphenocrysts of dusty albite set in a pilotaxitic groundmass of albite microlites and interstitial microcrystalline chlorite, the latter probably pseudomorphous after pools of glass. A fine-grained variolitic fabric is locally developed and fluxion structure defined by the preferred orientation of albite laths and elongate amygdules is prominently displayed. The breccias are composed of angular and subangular fragments of microporphyritic quartz keratophyre felsite set in a murky, argillaceous matrix. In this rock, scarce resorbed quartz microphenocrysts and scattered dusty albite microphenocrysts are set in a felsitic groundmass of poorly formed albite laths, anhedral quartz, and minor clots of granular epidote.

Origin

The sporadic, but widespread, intercalations of marine limestone and chert suggest that the entire exposed Paleozoic sequence is of marine origin. The calcarenites are composed dominantly of the disintegrated skeletal debris of sessile organisms that probably dwelt in shallow, aerated waters. The lithology of the calcirudites suggests that their constituent fragments were derived from an area where wave action was sufficient to disaggregate newly consolidated bioclastic limestone and to redistribute the coarse detritus formed in that manner. The associated fusulinids are forms considered to have lived in shelf seas, rather than in open oceans (Dunbar, 1957). The poor sorting and rounding of the fragmental calcareous debris indicate that working and winnowing before deposition were slight. This fact might be held to discredit an interpretation of shallow water deposition, were it not for the fact that many modern carbonate bank deposits, such as some types in the Bahama Islands, are equally poorly sorted although deposited in shallow waters. The association of albitic soda-rich volcanic rocks and radiolarian cherts has long been regarded as characteristic of deposition in eugeosynclinal belts, often with connotation of deep waters at the site of accumulation. There is no evidence that the calcareous debris of shallow water derivation was subsequently transported into deep water. The available data suggest that the Paleozoic sequence near Suplee accumulated in waters of shallow to moderate depths during a time of continuing intermittent volcanism within and near the site of deposition.

Age and correlation

Undescribed fusulinid species of the genera *Boultonia*, *Pseudofusulinella*, and *Schwagerina* were collected from the calcarenites and from clasts in the calcirudites at five localities near Suplee (see table 1). *Schwagerina* ranges through most of the Permian, *Pseudofusulinella* is abundant in lower Permian rocks of the western United States, and *Boultonia* is known only from rocks of late Wolfcampian to early Leonardian age, although information on its range is limited (Thompson, 1954, p. 33). These data suggest that the fossiliferous Permian limestones near Suplee are correlative in whole or in part with the following units along the west coast: Coyote Butte Formation of the nearby Grindstone Creek-Twelvemile Creek district (see Bostwick and Koch, 1962, p. 420); limestones of Elkhorn Ridge Argillite near Sumpter in northeastern Oregon (Taubeneck, 1955b), McLoud Limestone of Shasta County, California (Thompson and others, 1946); Havallah Formation of north-central Nevada (Roberts and others, 1958); and Cache Creek Group of British Columbia (Armstrong, 1949). These units form parts of a vast eugeosynclinal terrane of upper Paleozoic sedimentary and volcanic rocks deposited along the Pacific margin of North America within the Fraser Belt of Kay (1951).

TABLE 1. Fusulinid collections from Paleozoic limestones. (Identifications by J. W. Skinner and G. L. Wilde of Humble Oil & Refining Co.)

Locality[1]	V185	V188	V192	V193	V415
Location[2]					
--¼ of	SW	NE	NE	NE	NW
--¼ of	NE	SW	NE	SW	NW
Section	10	34	12	6	7
Township (S)	18	17	17	17	17
Range (E)	25	25	25	26	26
Forms					
Boultonia sp.	----	----	----	x	x
Pseudofusulinella sp.	----	x	----	x	x
Schwagerina sp.	x	x	x	x	x

[1] See Plate I for map location.
[2] All localities are small limestone knobs.

TABLE 2. Thickness data for Begg Formation (see text for discussion).

	Little Bear Anticline (type locality)	Divide Anticline (sec. 35, T. 17 S., R. 26 E.)	Frenchy Butte-Peewee Creek (secs. 25-28, 33-34, T. 16 S., R. 27 E.)
Strata above argillite unit	est. 4,700 ft.	est. 4,200 ft.	est. 2,500+ ft. (faulted)
Argillite unit	est. 800+ ft. base not exposed	est. 2,000+ ft. base not exposed	est. 500+ ft. (faulted)
Strata below argillite unit	0 (not exposed)	0 (not exposed)	est. 2,000+ ft. (faulted)
Total strata exposed	est. 5,500 ft.	est. 6,200 ft.	est. 5,000+ ft.

SERPENTINE (Trsp)

Slickensided green serpentine intrudes the Permian (?) greenstones on Frenchy Butte and is overlain unconformably by sandstones and conglomerates of the Upper Triassic Begg Formation. The rock is similar to numerous serpentine bodies of varying sizes and shapes which intrude the Permian (?) metavolcanic and metasedimentary rocks in the Aldrich and Strawberry Mountains to the northeast (Thayer, 1956a, b, c). The serpentines there are associated with dunite, peridotite, pyroxenite, gabbro, and minor quartz diorite. From its gross structural relations, the whole plutonic complex appears to have intruded deformed Paleozoic rocks during a Permian-Triassic orogenic episode prior to Late Triassic deposition.

BEGG and BRISBOIS FORMATIONS

A tightly folded, conformable sequence of Upper Triassic strata, dominantly clastic and probably entirely of Karnian age, is exposed as the core of the southwesterly plunging Mowich upwarp (see fig. 6) in a belt 5 miles wide extending in a northeasterly direction across the center of the area. The same rocks are exposed in a parallel belt of similar size lying to the northwest of the adjacent Pine Creek downwarp. To the northeast, the two belts of outcrops merge near South Fork of John Day River and the sequence passes to the north into the Deer Creek drainage, where it has been mapped as the "lowest member (Unit 1) of the lower division" of the Upper Triassic strata of the Aldrich Mountains by Thayer and Brown (1960). The sequence underlies about 100 square miles of the Suplee-Izee area, is about 12,500 feet thick, and has been divided into two gradationally conformable new formations, Begg and Brisbois. Thayer and Brown (written communication, 1963) intend to describe equivalent and lithologically similar strata in the Aldrich Mountains as Vester Formation, in which case the units here named Begg and Brisbois can properly be regarded as members of the Vester.

Begg Formation (Trbg)

The new name "Begg Formation" is here applied to the oldest recognized Triassic strata that unconformably overlie Paleozoic rocks in the area. The base of the formation is exposed in only two places: on Frenchy Butte at the northern edge of the area, and near the western edge of the area. The Begg Formation is characterized by resistant layers of sandstone, conglomerate, sedimentary breccia, pyroclastic rocks, and lava that are intercalated with more abundant and more easily eroded mudstone and siltstone. The resistant ledge-forming units range individually from a few feet to several hundred feet in thickness. The thicker ones form distinctive strike ridges of craggy outcrops which stand above the smooth soil-covered slopes underlain by the less resistant strata.

The exposures on the south-plunging nose and southeast limb of Little Bear anticline in the northwestern part of the area in secs. 7, 8, 17, 18, 19, and 20, T. 17 S., R. 26 E., and sec. 24, T. 17 S., R. 25 E., are designated as typical of the Begg Formation. The name is taken from Begg Creek, which flows into South Fork of Beaver Creek within the type area.

Thickness

Table 2 presents estimated figures for the thickness of different parts of Begg Formation at (a) the type locality, (b) on the northwest flank of Divide anticline 5 miles southeast of the type locality, and (c) at Frenchy Butte on the northern edge of the area where the base is exposed resting unconformably on Paleozoic rocks intruded by serpentine. As the entire formation is not exposed in simple stratigraphic sequence at these or any other localities, the key to an estimate of overall thickness is the recognition of a distinctive member composed almost entirely of thin-bedded, gray siliceous argillite. This member lacks the intercalated resistant beds so characteristic of the rest of the formation. The data outlined in the table indicate that 7,500 feet is a reasonable estimate for the total thickness of Begg Formation. There is a suggestion that the formation may thin progressively from west to east within the area.

Lithologic description

From 50 to 70 percent of Begg Formation is poorly exposed fine-grained sandstone, siltstone, mudstone, and argillite. Of the remainder, the following rock types form the estimated relative proportions indicated: (a) chert-grain sandstone and chert-pebble conglomerate, 25 percent; (b) volcaniclastic rocks and minor lava, 10 percent; and (c) polymictic conglomerate and sedimentary breccia, 5 percent. Rare thin layers of gray bioclastic and biostromal limestone occur locally.

Fine-grained clastic rocks: The predominant fine-grained sedimentary rocks of Begg Formation are characteristically soft, poorly sorted, generally noncalcareous, carbonaceous siltstones and mudstones of somber hue. The rocks are typically dark gray or dark green, but weather to gray green or olive brown. Bedding is indistinct, but is usually visible as imperfect, lenticular lamination; some laminae are fine-grained sandstone.

Chert-grain sandstone and chert-pebble conglomerate: Most of the conspicuous resistant layers in Begg Formation are well-indurated, dark-gray to gray-green sandstone and pebble conglomerate in beds from 2 to 12 feet thick. The rocks are most commonly noncalcareous and weather to drab olive green or brown. The sand grains and pebbles are commonly subrounded and moderately to well sorted. Bedding is characteristically indistinct, revealed only by slight variations in grain size and the crudely planar orientation of tabular rock fragments. Cross-bedding and sole markings were seen locally and some beds are graded (see figure 8).

The rocks are subfeldspathic lithic arenites composed of the following grain types, most typically in the approximate proportions cited: chert, 60 percent; argillaceous rock fragments ranging from pelitic slate to siliceous argillite, 12.5 percent; felsite, including both keratophyre and quartz keratophyre, 10 percent; quartz and quartzite, 10 percent; mafic chloritic metavolcanic rocks (spilite?), 5 percent; cloudy albite, 2.5 percent; and traces of detrital limestone.

Upon cursory examination in hand specimen, most of the rocks convey the impression of poorly sorted graywackes. Pale gray and green chert, felsite, and quartz grains appear to be imbedded in an abundant dark detrital matrix. The appearance is illusory, however, for the "matrix" is in reality a mass of deformed argillaceous and metavolcanic grains of the same detrital size and shape as the other grains. The unusual texture is a result of extreme compaction, during which the less competent grains were mashed and squeezed between the more competent chert and felsite grains. The weaker thus came to occupy spaces interstitial to the stronger, undeformed grains, much as cement or matrix might, and the margins of the argillaceous and metavolcanic grains are now molded to the confines of the "diagenetic interstices" bounded by the more competent grains. The irregular, attenuated outlines of the deformed grains, the draping of deformed grains about rigid ones, and the penetration of weaker grains by undeformed ones are all striking aspects of the distinctive texture produced by compaction (see figure 9).

Figure 8. Graded conglomerate and sandstone bed of Begg Formation, South Fork of Beaver Creek; view along strike, upright bed dips parallel to hammer handle.

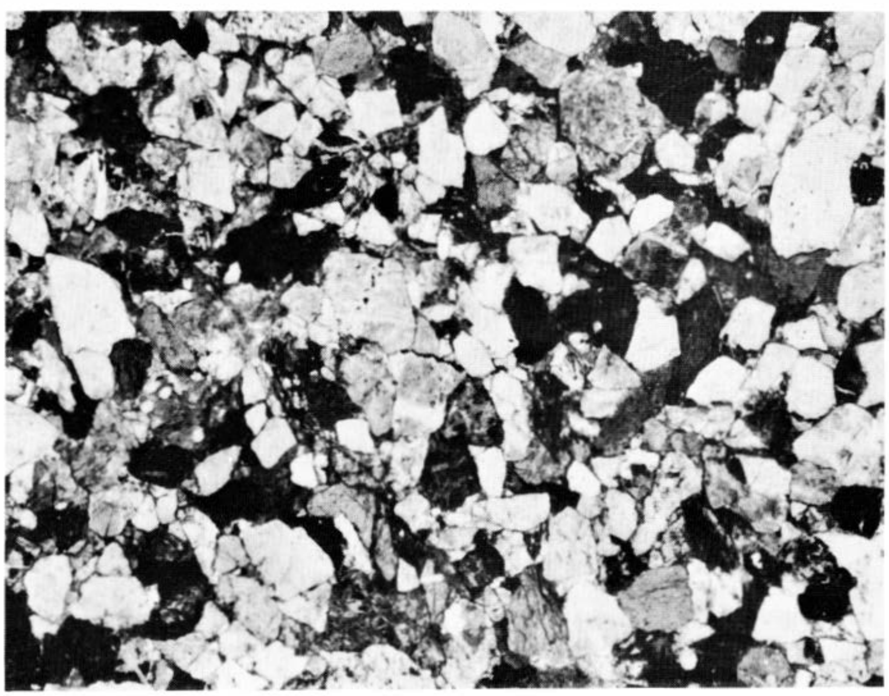


Figure 9. Diagenetic "matrix" of soft lithic grains (dark) deformed by compaction to conform to interstices between hard chert grains (pale) in chert-grain sandstone of Begg Formation (plain light; about 15 X).

Volcaniclastic rocks: Volcaniclastic rocks of varying grain size occur sporadically in most Begg sequences. They are particularly abundant and overshadow other resistant types in the upper thousand feet of the formation in the most southeasterly exposures, as on Big Flat and along the Poison Creek - Dry Soda Creek divide. Two lithologic subtypes can be recognized: (1) coarse tuff and lapilli tuff interpreted as the product of submarine eruption, and (2) fine felsitic tuff interpreted as the product of subaerial eruption. The rocks are considered to be of pyroclastic derivation, partly because of their association with minor lavas but mainly because they occur as thin sheets (2 to 200 feet thick) of essentially pure volcanic debris interstratified with rocks composed entirely of epiclastic detritus. Very little mixing of volcanic and nonvolcanic debris was noted, but slight rounding of some grains and fair to good sorting of the grains suggest local working, winnowing, and redistribution of the pyroclastic materials before final burial.

The coarse tuffs and lapilli tuffs are massively bedded strata that are black to light green on freshly broken surfaces but that weather to crumbly tan or brown outcrops. Sand-sized crystals of white plagioclase, locally concentrated into feldspathic laminae, are conspicuous in hand specimens and form as much as a third of the rock. The fragmental character of many of the rocks is not readily apparent in hand specimen, because the volcanic rock fragments making up the bulk of the rock are much deformed by compaction similar to that which has affected the less competent grains in the chert-grain sandstones. It appears that the mesostasis of the volcanic rock fragments has behaved incompetently during compaction, so that most of these fragments are deformed and tightly pressed against one another (see figure 10). In addition to this deformation effect, there has been such a strong diagenetic recrystallization of glassy materials that many rocks megascopically resemble porphyro-aphanitic lavas. Upon thin-section examination, however, the coarse tuffs are found to be reasonably well sorted, fragmental rocks containing 5 to 10 percent material of "clay" and "fine silt" size. Petrologically, most are keratophyre and quartz keratophyre lithic-crystal tuffs containing 25 to 35 percent cloudy albite, 0 to 15 percent quartz which is commonly resorbed, and 55 to 75 percent pilotaxitic to hyalopilitic lithic fragments composed of cloudy albite laths set in the diagenetic recrystallization products of an originally glassy groundmass. A few tuffs containing unaltered plagioclase suggest that the rocks were dacitic and andesitic at the time of deposition. Some of the lithic fragments in the coarse tuffs and lapilli tuffs have relict internal structures suggestive of the forms common in curdy, amygdular palagonite formed during submarine eruption.

The fine felsitic tuffs are pale tan or green, thin-bedded, hard, tough rocks with subconchoidal fracture. They are aphanitic quartz keratophyre tuffs composed of albite and quartz crystal fragments set in a cloudy microcrystalline aggregate of albite, chlorite (?), and quartz recrystallized from glass shards and argillaceous impurities. Relict vitroclastic textures in the fine felsitic tuffs suggest subaerial eruption and delivery to the site of deposition in clouds of airborne ash.

Lavas: Minor lavas associated with the volcaniclastic rocks are stubby flows of porphyro-aphanitic pyroxene keratophyre. Abundant albite (10 to 25 percent) and sparse augite (5 percent) phenocrysts are set in a hyalopilitic to pilotaxitic groundmass of albite laths and interstitial chlorite. The flows crop out as tan, green, and gray units 10 to 75 feet thick.

Polymictic conglomerate and sedimentary breccia: Massive beds of polymictic rudite composed of poorly sorted, angular to subrounded gravel floating freely in a poorly sorted sandy matrix occur sporadically, but are especially abundant in the more northwesterly exposures. The rocks occur in lenticular units 10 to 100 feet thick within which bedding is shown only by weak orientation of flat cobbles and slabby blocks (see figure 11). Lamination and cross bedding are rare; grading is inconsistent. Where the beds are abundant, a cyclic stratification is seen to consist of a breccia layer sharply overlain and locally channeled by massive, coarse-grained sandstone which grades upward to flaggy or platy fine-grained sandstone, which is in turn overlain by mudstone and siltstone. The fact that breccia bodies can seldom be traced individually along strike for more than a mile suggests pronounced lenticularity.

The sand fraction of the polymictic rudites resembles the chert-grain sandstones in composition. The gravel fraction is mostly fragments of chert, limestone, sandstone, and conglomerate or breccia, but fragments of felsite, porphyry, quartzite, slate, schist, marble, serpentine, and granitoid rocks also occur. The largest boulders are sandstone and limestone. Blocks and slabs of these that are 2 to 3 feet across are common and limestone blocks 10 to 20 feet across are encountered occasionally. Some of the limestone

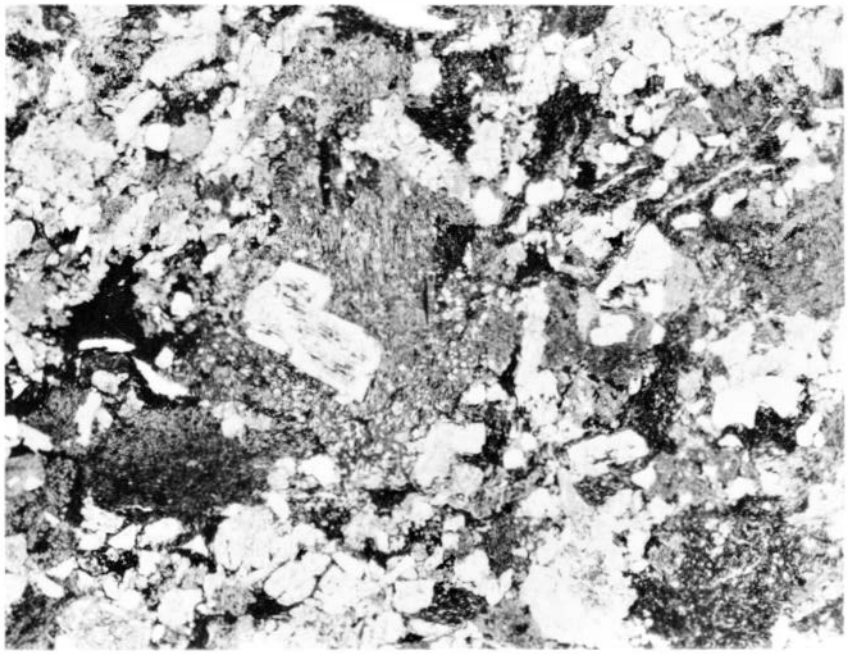


Figure 10. Andesitic volcaniclastic rock (submarine tuff?) of Begg Formation showing deformation of lithic grains (plain light; about 10 X).

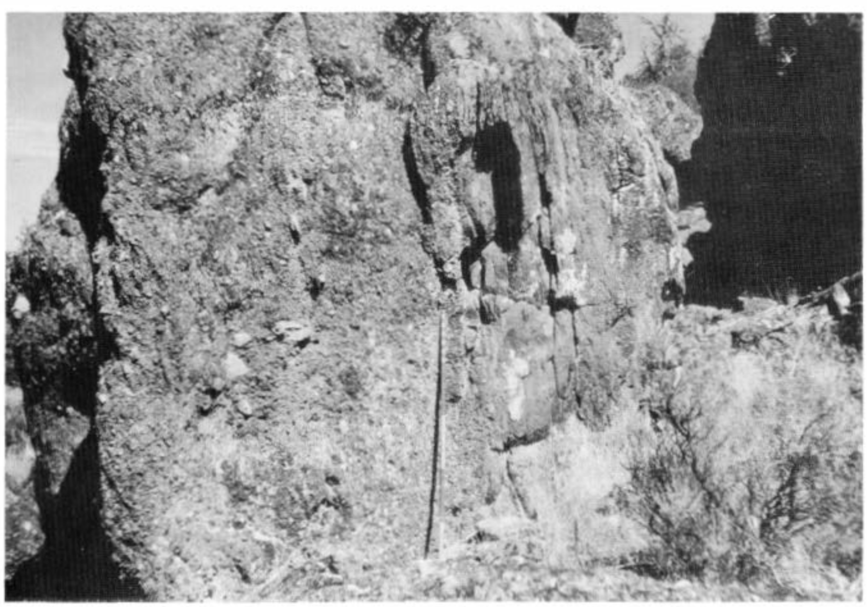


Figure 11. Polymictic sedimentary breccia of Begg Formation near Clear Creek; bedded sandstone (right) fills channel cut in top of vertically dipping breccia; scale stick five feet long.

TABLE 3. Fossils from Begg Formation
(Molluscan identifications by N. J. Silberling, March 26, 1958;
coelenterate identifications by D. F. Squires.)

Locality[1,2]	V421	V238	V137	V418	V124
Location[3]					
--¼ of	SW	SW	NE	SE	NW
--¼ of	SW	SW	SW	SE	NE
Section	21	21	21	10	9
Township (S)	18	18	18	17	18
Range (E)	26	26	26	26	26
Forms					
Proclydonautilus sp.	x	----	----	----	----
Myophoria sp.	----	x	----	----	----
Spiriferina cf. *S. coreyi* Smith	----	x	----	----	----
Spiriferina sp.	----	x	x	----	----
Spongiomorpha cf. *S. dendriformis*	----	----	----	x	----
Heptastylis cf. *H. stromatoporoides* Frech	----	----	----	----	x
Spongiomorphids		x	x		

1 See Plate I for map location.
2 Localities V421, V238, V137 lie along same limestone band an estimated 2,000-3,000 feet below upper contact; V418 an estimated 1,000 feet below upper contact; V124 an estimated 250 feet below upper contact.
3 All localities are small limestone outcrops.

fragments contain Permian fusulinids and others contain the Mississippian brachiopod *Striatifera*. One contained finely ribbed pelecypods resembling the Upper Triassic genus *Halobia*.

Origin

The sporadic occurrence of bioclastic and biostromal limestones which contain rare belemnoids, brachiopods, spongiomorphid coelenterates, pelecypods, and nautiloid cephalopods, all suggest that Begg Formation is of marine origin (table 3). Evidence bearing on depth of water is inconclusive; during the deposition of such a thick sequence, water depth may well have been variable. The nature of the polymictic breccias suggests a proximal source area of rugged relief for at least some of the detritus. Submarine landslides analogous to subaerial mudflows may well have moved some of this coarse debris to its final site of burial. The nature of the more abundant chert-grain sandstones, however, suggests movement and deposition by tractive bottom currents capable of winnowing sand clean of fines. Although local and nearby volcanism contributed some debris to the basin of deposition, most of the formation is composed of detritus whose rock fragments of chert, greenstone, felsite, and limestone can be matched with exposures of upper Paleozoic sedimentary and volcanic rocks or Permian-Triassic intrusive and metamorphic rocks exposed in adjoining areas (Merriam and Berthiaume, 1943; Thayer, 1956 a,b,c; Wallace and Calkins, 1956). It is our tentative suggestion that Begg Formation was deposited rapidly in the shallow waters of a subsiding basin of tectonic origin. The debris was shed into this basin from eroding tectonic highlands which were rising nearby and which were composed of Paleozoic strata and Permian-Triassic intrusive rocks like those one now sees exposed in the vicinity.

Brisbois Formation (Trbr)

The new name "Brisbois (Briz-bo) Formation" is here proposed for the sequence of dark mudstone and siltstone, with intercalated beds of calcareous sandstone and calcarenite, that conformably overlies Begg Formation in the Suplee-Izee area. Owing to extreme structural complexity, no continuous section is exposed. The exposures along South Fork of John Day River between the mouths of Morgan and Dry Soda Creeks, a distance of 3 miles, are designated the type area. The name is taken from the historic Brisbois ranch at Dry Soda Creek. Intricate deformation makes a thickness determination difficult, but an estimated 5,000 feet of Brisbois Formation is believed to be present in the area. The lower contact with Begg Formation is gradational and difficult to define. In the field it was placed arbitrarily at a horizon such that all closely spaced, resistant, noncalcareous coarse clastic beds were below it, and such that only widely spaced calcareous sandstone or calcarenite beds were intercalated in the mudstones and siltstones above it.

Lithologic description

Brisbois Formation is composed dominantly of black, gray, and green mudstones that crop out poorly on subdued slopes. Fresh roadcuts, such as that at the Brisbois ranch, reveal that thin, tuffaceous layers now altered to punky, white or tan zeolites are intimately interstratified with the clayey rocks. Gray calcareous sandstone beds that weather tan or brown and gray, sandy calcarenite beds that weather gray or brown are intercalated with the finer grained rocks. Sandstones are the more abundant of the two intercalated lithologies in the type area and vicinity, but the limestone beds are the more abundant in the northwestern part of the map area. Strata composed of mixed terrigenous detrital material and calcarenitic debris are common. Both sandstone and limestone beds crop out as angular, resistant ledges with gritty surfaces.

The sandstones of the Brisbois Formation are compositionally similar to the chert-grain sandstones of the underlying Begg Formation, except that volcanic feldspars and rock fragments seem somewhat more common. The rocks are cemented by abundant calcite and show none of the compactional deformation of grains that is so characteristic of the Begg rocks. Many of the Brisbois sandstone beds are markedly graded throughout their thickness, commonly 1 to 5 feet, from pebble conglomerate or coarse sandstone at the base progressively upward to siltstone at the top (see figure 12). The sandstones also grade laterally in a few places to lenticular units of calcareous conglomerate.

The calcarenite beds (see figure 13) consist largely of bioclastic debris, chiefly of fragmental brachiopod, pelecypod, gastropod, and crinoid shells. The calcarenites grade laterally in a few places to massive bodies of coquinoid or reefoid limestone, which are most abundant in the exposures northwest of Pine Creek. In the northernmost of the exposures along Camp Creek, poorly sorted calcirudite submarine slide (?) breccias recur within a sequence 75 feet thick.

Volcanic member

Isolated exposures along fold axes and faults in the north-central part of the area show that a huge lens of volcaniclastic rocks and spilite lavas occurs in the medial part of the Brisbois Formation. The spilites attain an aggregate thickness of 600 feet and the entire volcanic member reaches nearly 2,000 feet locally. The assemblage of strata includes the following types, which vary in proportion from place to place:

(1) Hard, dark-green, aphanitic to diabasic spilite lava: typically massive but locally pillowed; typically intergranular to intersertal but locally variolitic; 30 to 40 percent cloudy albite in slender, commonly skeletal, laths with plumose margins; 25 to 35 percent fresh titanaugite in columnar, locally feathery, sheaves of elongate, locally acicular, prisms; 15 to 25 percent chlorite in interstitial pools; 5 to 10 percent titaniferous ore in branching columns and barbed needles; 2 to 3 percent granular sphene; local relict plagioclase in the cores of laths; local analcite from alteration of margins of laths.

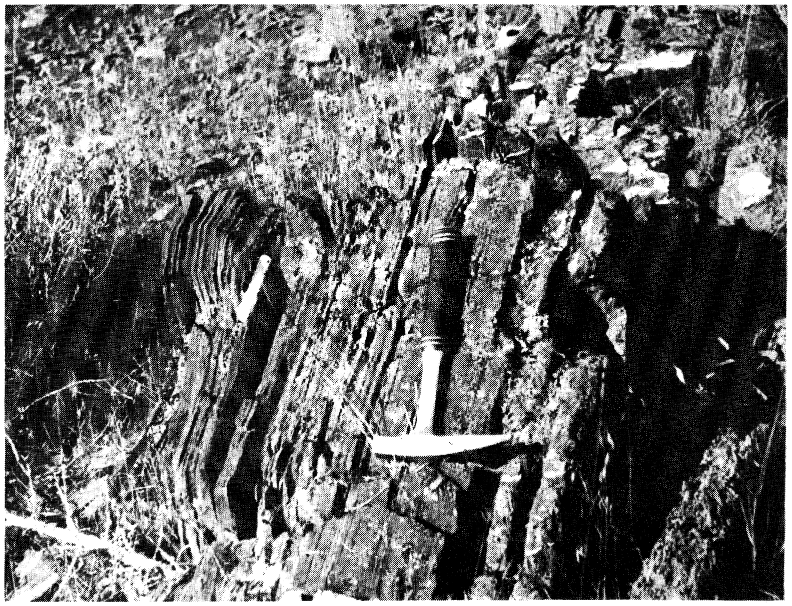


Figure 12. Graded calcareous bed of Brisbois Formation on Dry Soda Creek; dip nearly vertical with massive pebble conglomerate base to right, flaggy coarse- to medium-grained sandstone center beneath hammer, and platy fine-grained sandstone top to left.

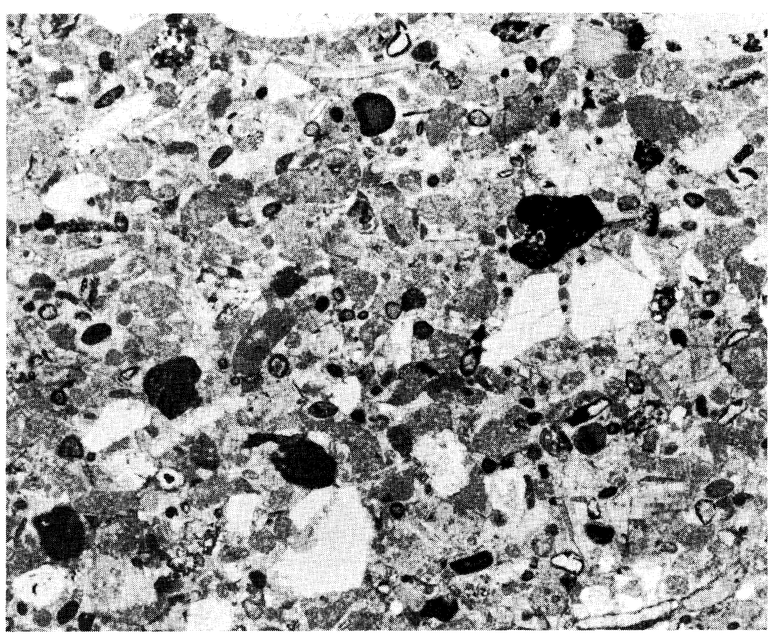


Figure 13. Sandy calcarenite from Brisbois Formation on Pine Creek (plain light; about 25 X).

(2) Pale-green aphanitic quartz-bearing felsic keratophyre lava.

(3) Albite dolerite and albite granophyre sills, probably feeders for spilite and keratophere lavas.

(4) Pale tan and green felsitic quartz keratophyre tuff.

(5) Massive beds of tuffaceous volcanic graywacke (chloritic detrital matrix 10 to 15 percent) in which keratophyric volcanic debris is mixed in varying proportions with epiclastic lithic debris of the type common in the remainder of Begg and Brisbois Formations (see figure 14).

(6) Intercalated dark mudstone.

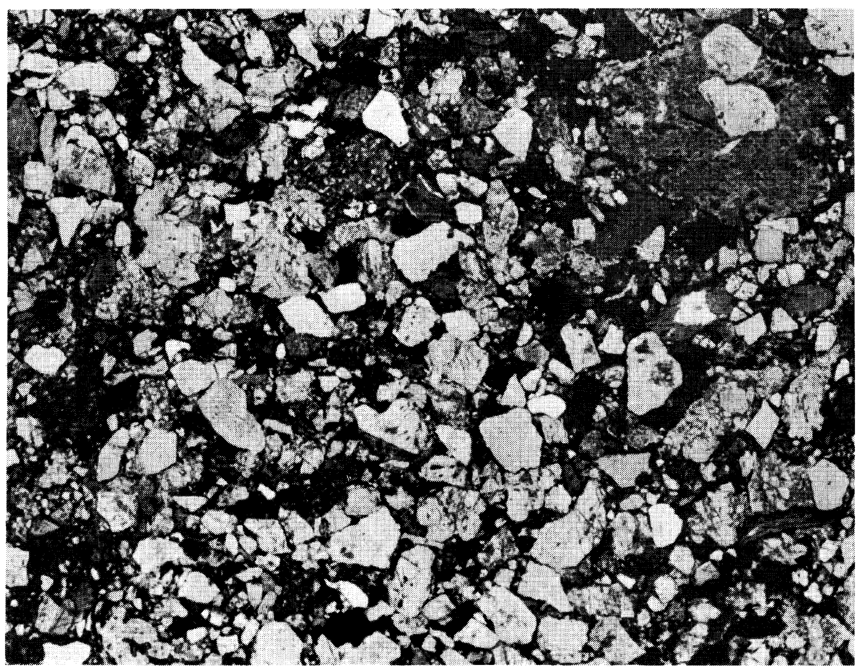


Figure 14. Graywacke of mixed chert-grain and volcanic detritus, volcanic member of Brisbois Formation on Morgan Creek. (Plain light; about 25x)

TABLE 4. Fossils from Brisbois Formation (Identifications by N. J. Silverling of U. S. Geological Survey March 26, 1958, except as noted).

Locality [1, 2]	D14[3]	D3-D7[4]	D8-D11[5]	V427	V144	V232	V417	V231, V247 V248[6]	V422	V246	V133	V175	V132	V177	V215	V224
Stratigraphic position (est. ft. above base of fm.)	500	?	750	750	800	800	900	1000	1500	1600	1750	1750	1800	1950	2000	2750
Locations																
--¼ of	NE	-	SE	SW	SE	SE	SE	-	SE	SE	NE	SW	NW	SE	SE	NW
--¼ of	SW	SE	NW	NE	SW	NE	NE	SE	NE	NE	NE	SE	NW	SW	NE	SW
Section	29	8	8	8	34	11	23	11	7	7	2	36	1	36	26	36
Township (S.)	17	18	18	17	17	17	17	17	17	17	18	17	18	17	17	17
Range (E.)	27	27	27	27	26	26	25	26	27	27	25	25	25	25	25	25
Ammonites:																
Arcestes sp.	----	x	----	----	----	----	----	x	----	----	----	x	----	x	x	----
Discotropites sp.	----	----	----	----	?	----	----	?	----	----	----	----	----	----	----	----
Discotropites cf. D. sengeli Mojsisovics	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----
Discotropites aff. D. theron Dittmar	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x	x
Gymnotropites sp.	----	----	----	----	----	----	----	----	----	----	----	x	----	x	----	----
Homerites semiglobosus (Hauer)	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----
Juvavites sp.	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	x
Juvavites (Anatomites) intermittens Mojsisovics	----	----	----	----	----	----	----	----	----	----	----	----	----	x	----	----
Parahauerites ashleyi (Hyatt & Smith)	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----
Paratropites antiselli Smith	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x
Tropites sp.	----	----	----	----	----	----	----	x	----	----	x	x	----	x	----	----
Tropitid	----	x	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Pelecypods:																
Carditids	----	x	----	----	----	----	----	x	----	----	----	----	----	----	----	----
Cassianella sp.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x
Chlamys sp.	----	----	----	----	----	?	----	?	----	----	----	----	----	----	?	?
Halobia sp.	----	----	----	----	x	----	----	----	----	----	----	----	----	x	x	x
Isognomonids	----	x	x	----	----	----	----	----	----	----	----	----	----	x	x	----
Mysidioptera sp.	----	----	x	----	----	----	----	----	----	----	----	----	----	----	----	----
Ostreids	----	?	x	----	----	----	----	----	----	----	----	----	----	----	----	?
Trigoniids	----	x	----	----	----	----	----	----	----	----	----	----	----	----	----	x
Brachiopods:																
Rhynchonellids	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----
Spiriferids	x	----	x	x	----	x	x	x	x	x	?	----	----	----	x	----
Terebratulids	----	----	x	----	----	----	----	x	----	----	----	----	----	----	----	----
Coelenterates:																
Scleractinian colonial corals	----	----	----	----	----	----	----	----	----	----	x	----	x	----	----	----
Spongiomorphs	----	----	x	x	----	----	----	x	x	----	----	----	----	----	----	----

1 See Plate 1 for map location. 2 See also Schenk (1935) for locality about 250 feet above base of formation in SW¼ SW¼ sec. 29, T. 17 S., R. 27 E.
3 Field identification by Dickinson; other material available in outcrop.
4 Localities extend for about 2,000 feet along strike of a folded limestone bed on Big Flat; the ammonites were collected from the bold outcrop known variously to previous workers as "Fort Rock," "Castle Rock," or "Limestone Knob," and erroneously reported to be of Paleozoic age by Packard (1932) on the basis of limestone cobbles containing Paleozoic fossils weathering from nearby Upper Triassic clastics. Bivalves identified in field by S. W. Muller of Stanford University.
5 Localities extend for about 2,000 feet along strike of a single limestone horizon. Bivalves identified in field by S. W. Muller of Stanford University.
6 Localities in same limestone bed tightly folded in complex syncline along Jackass Creek.

Origin

The fossiliferous marine limestones of Brisbois Formation suggest deposition in shallow waters of the neritic zone. Specific indicators include: thick-shelled oysters in some beds, algal and coralline biostromal frameworks in some beds, the widespread occurrence of minor oölites in calcarenites, and the presence, in the associated mudstones, of the brachiopod Lingula, a typical tidal-flat genus in present-day seas. The scarcity of limestone east of South Fork of John Day River and the characteristic graded bedding shown by the sandstones of that area may indicate that waters were deeper there and shelved to the northwest. The sources of sediment continued to be the same late Paleozoic terrane which contributed to Begg Formation, augmented by local volcanic eruptions.

Fossils and Age of Begg and Brisbois Formations

As reference to table 4 will indicate, several ammonite collections at wide stratigraphic spacings in Brisbois Formation are all indicative of the Tropites subbullatus Zone, uppermost Karnian Stage of the lower Upper Triassic. No ammonites collected suggest a different age for any part of the formation and all other fossils collected are consistent with this age assignment. The sparse fauna collected from the underlying Begg Formation (table 3) does not permit precise dating. The nautiloid Proclydonautilus is known only from Upper Triassic rocks, the spiriferinid brachiopods and spongiomorphid coelenterates of Begg Formation are comparable to those of Brisbois Formation, and the two units are conformable. Accordingly, Begg Formation is provisionally assigned to the Karnian Stage below the zone of T. subbullatus, with the knowledge that some basal part of the unit could extend down into the Middle Triassic. If the 12,500 feet of Begg and Brisbois Formations are, indeed, entirely of Karnian age, the sequence is one of the thickest and coarsest known from the west coast region.

RAIL CABIN ARGILLITE and GRAYLOCK FORMATION

Erosional remnants of an apparently conformable sequence of dominantly fine-grained clastic rocks that spans the Triassic-Jurassic systemic boundary crop out in the northern part of the area. The exposures lie in a crenulated synclinal trough of north-northeasterly trend that extends from Morgan Mountain across Morgan Creek to Graylock Butte. As discussed below, the sequence overlies lower Upper Triassic rocks with angular unconformity and, in turn, is overlain with angular unconformity by upper Lower Jurassic strata. The sequence has been divided into two new formations, Rail Cabin Argillite and Graylock Formation, on purely lithologic grounds.

Rail Cabin Argillite (Trrc)

The new name "Rail Cabin Argillite" is here proposed for a sequence of thin-bedded argillites and argillaceous felsitic tuffs that is approximately 1,000 feet thick and rests upon Brisbois Formation throughout its outcrop belt. The name is taken from Rail Cabin Creek in sec. 31, T. 16 S., R. 28 E., but the exposures on the upper slopes of Morgan Mountain, whose peak is in the SE$\frac{1}{4}$ sec. 11, T. 17 S., R. 27 E., are here designated the type locality. Strata typical of the unit are well exposed in the big steep gulch on the southwest side of the mountain in the NW$\frac{1}{4}$ sec. 14, T. 17 S., R. 27 E. The basal contact is nowhere well exposed, but appears to be a sharp lithologic break between comparatively soft mudstones of the underlying Brisbois Formation and hard argillites and tuffs above. The contact is interpreted here as an angular unconformity for three reasons: (1) Bedding attitudes in Brisbois Formation and Rail Cabin Argillite are markedly divergent in outcrops near the troughs of synclines, for example, around Graylock Butte and on the south slope of Morgan Mountain; (2) from place to place, varying stratigraphic thicknesses of Brisbois Formation are exposed between Begg Formation, which underlies Brisbois Formation in gradational conformity, and the overlying Rail Cabin Argillite; and (3) Rail Cabin Argillite on Graylock Butte has been mapped as a part of the "middle division (unit IV)" of the Upper Triassic rocks of the Aldrich Mountains by Thayer and Brown (1960); correlative rocks 10 miles to the northeast are separated from correlatives of Brisbois or Begg Formations by 15,000 to 25,000 feet of intervening strata (Thayer and Brown, 1960).

Lithologic description

Rail Cabin Argillite is characterized by hard green and black siliceous argillite in massive beds typically from 1 to 3 inches thick. The rock breaks and weathers to angular fragments bounded by flat, rectilinear joint sets along which films of iron and manganese oxides are commonly present. Exposures are mostly rubbly colluvium of these small blocks. A typical rock might be composed of 70 percent turbid argillaceous material rich in dark-brown organic matter, 5 percent angular quartz and feldspar silt, and 25 percent tests of siliceous micro-organisms. Most of the latter have the subspherical and helmet shapes typical of radiolarians, but are now mostly recrystallized to dense orbicular bodies of chalcedony 0.003 to 0.010 mm in diameter. Some tests appear to have been filled with fine mud that has recrystallized to microcrystalline brown chloritic (?) clay. Varied types of siliceous sponge (?) spicules occur as well, but are less abundant.

Abundant, finely laminated, thin beds of gray or pale green argillaceous quartz keratophyre tuff and tuffaceous argillite are interbedded with the darker siliceous argillites. Such rocks are tougher and break along subconchoidal arcuate fractures. The pyroclastic debris in the rocks consists of quartz and albite crystal fragments, similar to the silt in the nontuffaceous rocks, and abundant devitrified shards with curvilinear boundaries that contrast strongly with associated spicular rods.

Two types of limestone occur as minor intercalations in the unit. The most abundant type occurs as massive, gray, bioclastic beds, of knobby appearance in outcrop, commonly brecciated, and locally grades to a coquinite of brachiopod shells. Individual beds seldom persist more than a few hundred yards, although they are commonly 2 to 8 feet thick and locally attain thicknesses of 50 feet or more. Some contain oölitic layers. In the upper part of the formation, rare beds of dense, black calcilutite less than a foot thick occur at wide intervals. They can be recognized by their brown, weathered surfaces.

Origin

The pods of bioclastic limestone in Rail Cabin Argillite may well have been banklike accumulations that built up as small knolls and shoals above the general level of a shallow mud bottom. The mixture of fine terrigenous detritus, pelagic organic debris, and airborne shards indicates a site of deposition sheltered from the influx of coarse detritus. Whether the unit accumulated far from shore or in a protected embayment cannot be determined from available evidence.

Fossils and age

The following assemblage of Upper Triassic Norian Stage fossils was collected and identified by Dr. S. W. Muller from the upper half of Rail Cabin Argillite on the west slope of Elkhorn Creek canyon (loc. D15, NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 13, T. 17 S., R. 27 E.): *Arcestes* sp., *Distichites* (?) sp., *Halorella* sp., *Metasibirites* sp., *Monotis* sp., *Placerites* sp., *Sirenites* (?) sp., and *Steinmannites* (?) sp. According to Dr. N. J. Silberling, the *Halorella* is cf. *H. amphitoma* Bronn. The Rail Cabin Argillite appears to be conformably overlain by the lowermost Jurassic Graylock Formation and may include unfossiliferous beds of the Rhaetian Stage (uppermost Triassic) as well as the fossiliferous beds assigned to the Norian Stage.

Graylock Formation (Jg)

The new name "Graylock Formation" is here proposed for the sequence of thin-bedded, dark gray to black siltstone that contains intercalated thin beds of black argillaceous limestone in its lower part and rests with apparent conformity on Rail Cabin Argillite. The name is taken from Graylock Butte, a hill underlain by Rail Cabin Argillite in the NE$\frac{1}{4}$ sec. 36, T. 16 S., R. 27 E., and exposures of Graylock Formation occur near a logging road less than a mile northeast of the summit. The better exposures on the Elkhorn Creek-Morgan Creek divide in sec. 12, T. 17 S., R. 27 E., are, however, designated the type locality (both "Morgan" and "Elkhorn" are preoccupied as stratigraphic names). The lower contact is placed at the bottom of a basal member of interbedded limestone and siltstone that ranges from 15 to 75 feet in thickness. The contact is everywhere sharp but apparently conformable, for lenses of massive, reef-like bioclastic limestone like those in the underlying Rail Cabin Argillite are locally included within this basal limestone and siltstone member. Approximately 400 feet of Graylock Formation are present in the type locality beneath an angular unconformity with rocks of Mowich Group. The discordance of the upper contact is clearly shown by the fact that Mowich Group rests directly on Rail Cabin Argillite on Morgan Mountain less than a mile from the type locality of Graylock Formation, and truncates Graylock Formation in the exposures northeast of Graylock Butte.

Lithologic description

The siltstones of Graylock Formation are firm, dark, poorly sorted rocks. The strata are laminated, cross-laminated, and channeled on a fine scale, although the bedding is indistinct in most exposures. The rocks are neither as hard nor as tough as the underlying Rail Cabin Argillite, and their fracture is hackly rather than blocky or subconchoidal. Typical siltstone, which coarsens locally to very fine-grained volcanic graywacke, is composed of the following constituents: partly chloritized felsic volcanic rock fragments (keratophyre ?), 50 percent; albite grains, 20 percent; quartz grains, 5 percent; mica flakes, 2 percent; sphene, 1 percent; and an argillaceous detrital matrix containing dark-brown organic matter, 20 to 25 percent. Many of the siltstones have a spotted or mottled appearance caused by the presence of small, tan ovoid areas about 1 mm in diameter that coalesce locally to form irregular scalloped blotches. These pale spots and blotches stand out megascopically in the otherwise dark rock and are abundant enough to form a characteristic and distinctive lithologic feature of the formation. The pale spots are polycrystalline, diagenetic sieved porphyroblasts of anhedral laumontite that has grown at the expense of the abundant felsite rock fragments, apparently expelling dark organic and clayey substances to the surrounding unaltered rock as it grew.

The basal 50 to 75 feet of the formation at the type locality, 25 to 30 feet on Morgan Creek, and 15 to 20 feet near Graylock Butte, is 60 to 75 percent thin-bedded limestone that is intercalated with siltstone similar to that in the monotonous sequence above. The limestone is dark gray, even-textured, finely laminated calcilutite that occurs in layers 6 inches to 2 feet thick. In thin section, the rock is seen to be somewhat argillaceous, clearly fragmental lime-siltstone that is laminated, cross-laminated, and channeled on a fine scale, much in the same manner as the overlying siltstones. The sorting is also similar to that of the siltstones, and dark-brown organic matter is similarly concentrated in a marly matrix.

Origin

The delicate depositional structures of Graylock Formation indicate that it was deposited in gently agitated water that disturbed only a thin layer of bottom sediment. The laminated structures indicative of some winnowing and the dominant silt size of the detritus do suggest, however, that the unit was deposited in an area of more effective current action than was the underlying, finer grained Rail Cabin Argillite. The presence of the inarticulate brachiopod Discina in the black siltstones above the basal calcareous member suggests that the waters may have been brackish. The formation may well have been deposited in a shallowing embayment transitional to an estuarine environment.

Fossils and age

The following ammonites characteristic of the Hettangian Stage (lowermost Lower Jurassic) were collected by Dr. S. W. Muller from the basal limestone and siltstone member in the type locality and in Morgan Creek canyon (loc. D18, NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 12, T. 17 S., R. 27 E.; and loc. D20, SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 6, T. 17 S., R. 28 E.): Paracaloceras sp., Phylloceras sp., Psiloceras sp., and Waehneroceras sp. This ammonite fauna is similar to that reported from the basal 75 feet of Sunrise Formation in western Nevada (Muller and Ferguson, 1939). No younger fossils were found in the Graylock Formation of the Suplee-Izee area, but it is worth noting that the "upper division (unit V)" of the "Upper Triassic" rocks of the Aldrich Mountains (Thayer and Brown, 1960) is believed to include strata correlative with Graylock Formation and also includes beds of probable Sinemurian age (Thayer and Brown, written communications, 1961, 1962). Thus, some upper part of the type Graylock Formation may be Sinemurian and some of the strata described below as Caps Creek beds may be correlative with part of Graylock Formation.

Caps Creek Beds (JTrc)

Along Poison and Caps Creeks and in the headwaters of Rosebud Creek (contiguous ground in the northeastern part of the area), approximately 5 square miles are underlain by poorly exposed strata whose stratigraphic relations are uncertain. These "Caps Creek beds" are in contact with Begg and Brisbois Formations along a fault which pre-dates the Lower Jurassic Mowich Group. The strata underlie the Suplee Formation of late Early Jurassic age with apparent angular unconformity. The rocks are dominantly thin-bedded calcareous sandstone, siltstone, and mudstone of somber hue. Discontinuous calcirudite beds composed principally of reworked Upper Triassic and Paleozoic detritus are exposed locally. Abundant reworked Karnian fossils have been identified by Dr. N. J. Silberling from a locality near the Smith ranch on Poison Creek (loc. D1, NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 19, T. 17 S., R. 28 E.). Thayer (written communication, 1961) has recently collected Lower Jurassic ammonites of probable Sinemurian age from road cuts along a new logging road in the headwaters of Rosebud Creek.

From their lithology, geographic position, and geologic relations, the Caps Creek beds are believed to be the same unit as the "upper division (unit V)" of the "Upper Triassic" rocks of the Aldrich Mountains as mapped by Thayer and Brown (1960). As such, they probably include no beds older than Norian and are probably in part correlative with Graylock Formation but, as their lithology is different, they are mapped separately. They are not formally named here, in the belief that this step should await the resolution of the stratigraphic relations of their more extensive exposures in the Wickiup Creek-Keller Creek district northeast of the mapped area.

MOWICH GROUP (Jm)

Revision of Nomenclature

Mowich Group of upper Lower Jurassic strata was originally defined by Lupher (1941, p. 235-242) as consisting, in ascending order, of the conformable Robertson, Suplee, and Nicely Formations. The type locality of these three units is in secs. 26, 27, 28, and 29, T. 18 S., R. 26 E., around the junction of Freeman Creek with South Fork of Beaver Creek (see Appendix A for measured section). Mowich Group is here redefined to include Hyde Formation, whose type locality is 12 miles to the northeast at South Fork Bridge on South Fork of John Day River in sec. 30, T. 17 S., R. 28 E. Hyde Formation was originally defined by Lupher (1941, p. 255) and assigned by him to his "Izee Group" of Middle Jurassic age. This erroneous age assignment was based on a miscorrelation of type Hyde Formation, in which he found no fossils, with fossiliferous Middle Jurassic beds of similar lithology lying high in the sequence exposed on Freeman Creek and separated from Mowich Group by several hundred feet of intervening strata and an angular unconformity (see Basey Member of Snowshoe Formation). Mapping discloses, however, that type Hyde Formation is in reality traceable along strike into lithologically similar beds that rest conformably on Nicely Formation of Mowich Group along Freeman Creek. These beds, accordingly mapped here as Hyde Formation, were designated "incertae sedis" by Lupher (1941, p. 251), who correctly inferred their conformable relation with Nicely Formation and regarded them as "post-Nicely beds of the Mowich coming in beneath the . . . unconformity." Our inclusion of Hyde Formation in Mowich Group is thus not in fundamental conflict with Lupher's concept of the group, but proceeds solely from a clarification of the stratigraphic relations of Hyde Formation.

Stratigraphic Relations

The base of Mowich Group is an angular unconformity and the group rests locally upon each of the older bedded Mesozoic map units in the area. Mowich Group is overlain by Snowshoe Formation (for redefinition, see below) of Middle Jurassic age along a contact that is conformable in the eastern part of the area but passes into an angular unconformity in the western part. Mowich Group is progressively overlapped to the west by these younger Jurassic rocks and is absent northwest of the axis of Pine Creek downwarp. Mowich Group crops out in discontinuous patches beneath the unconformity along the northwest flank of Mowich upwarp and forms a thin, nearly continuous, belt of exposures for a distance of 25 miles along the southwesterly plunging nose and the southeast flank of Mowich upwarp. Reconnaissance indicates that this belt of exposures continues to the east along a zone partly masked by lava caps for at least another 5 miles to Wickiup Creek. Isolated exposures occur in downfolded synclines within Mowich upwarp, and along Vester Creek syncline in the northern part of the area.

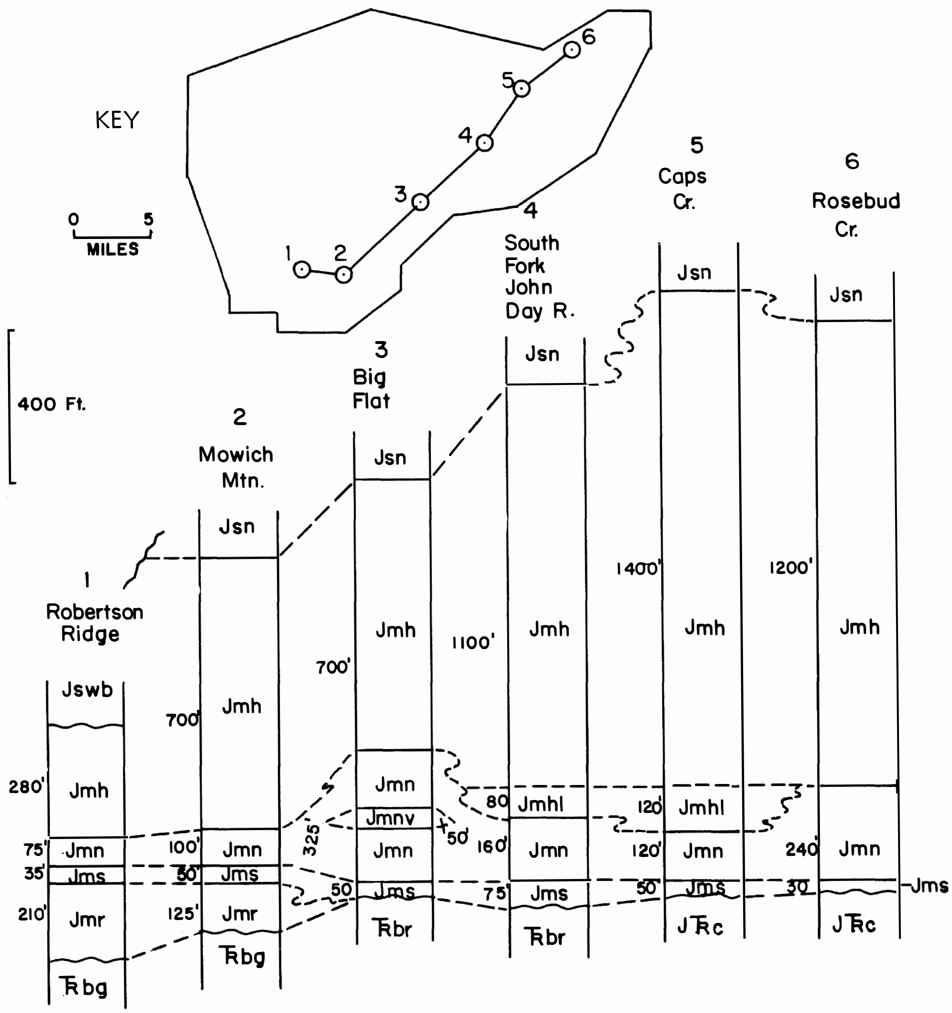
Robertson Formation is the basal unit of Mowich Group in the western part of the area. Along the southeast flank of Mowich upwarp, the Robertson Formation is absent and the Suplee Formation is the basal unit of the group. The mapped relations almost certainly represent facies change within the basal part of Mowich Group, rather than overlap of Robertson beds by Suplee Formation. The stratigraphic relations and thickness variations of Mowich Group are shown by figure 15.

Robertson Formation (Jmr)

Robertson Formation forms the base of Mowich Group along the northwest flank and around the southwesterly plunging nose of Mowich upwarp. The unit includes three rock types: basal polymictic conglomerate; somber green and brown volcanic sandstone; and gray limestone, largely biostromal. Bodies of the different rock types are lenticular and intertongue with one another along strike, such that the lithologic sequence within the formation varies markedly in detail. The variation is shown by figure 16. Descriptions of the thickest, most variable, and most fossiliferous sections are given in Appendixes A to D.

<u>Thickness</u>

Robertson Formation is about 225 feet thick on "Robertson Ridge," a low spur in SE$\frac{1}{4}$ sec. 28, T. 18 S., R. 26 E., within the type area. The thickness varies rapidly along strike and reaches a maximum of



LEGEND

Superjacent

Jswb: Weberg Mem. of Snowshoe Fm.
Jsn: Snowshoe Fm.

Mowich Group

Jmh: Hyde Fm.
Jmhl: Calc. ss. of basal Hyde Fm.
Jmn: Nicely Fm.
Jmnv: lava in Nicely Fm.
Jms: Suplee Fm.
Jmr: Robertson Fm.

Subjacent

JŦ̄Rc: Caps Creek beds
Ŧ̄Rbr: Brisbois Fm.
Ŧ̄Rbg: Begg Fm.

Figure 15. Stratigraphic relations and thickness variations, Mowich Group.

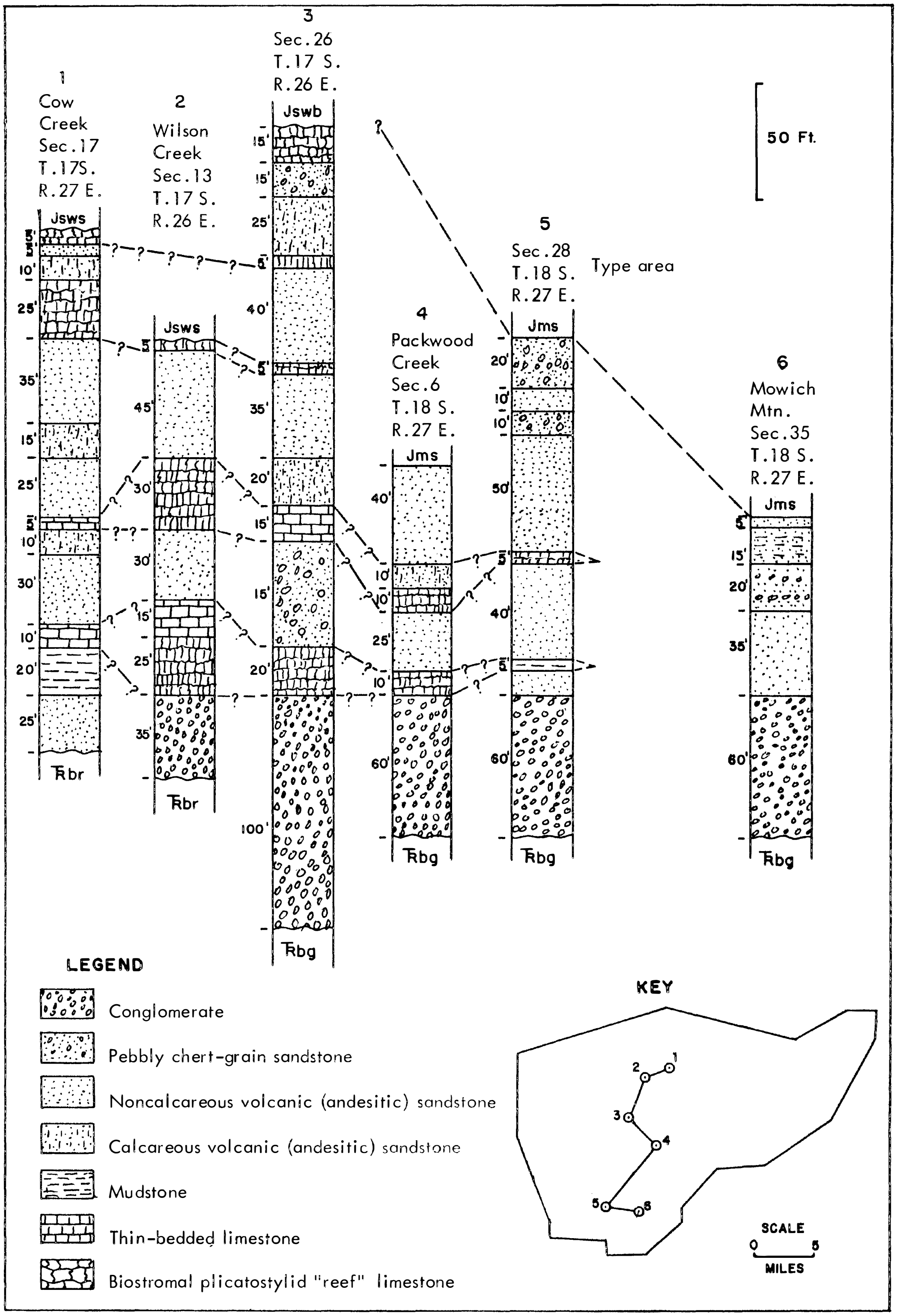


Figure 16. Stratigraphic relations and thickness variations, Robertson Formation.

335 feet between Swamp and Pine Creeks in the SW$\frac{1}{4}$ sec. 26, T. 17 S., R. 26 E. The formation thins rapidly to the east, from 225 to 150 feet within the type area alone, and is not mappable east of a meridian line passing through Snow Mountain, a prominent landmark on the south edge of the area. On the nose of Mowich upwarp, the rate of thinning is about 50 feet per mile. Intercalations of green volcanic sandstone of Robertson Formation lithology do occur, however, in the lower 20 feet of Suplee Formation as far east as Big Flat.

Lithologic description

Conglomerate: A basal member of massive, resistant, sandy pebble conglomerate, locally imbricated and cross-bedded, containing layers of cobbles and rare boulders, and ranging from 10 to 100 feet in thickness occurs wherever Robertson Formation rests unconformably on Begg Formation. Only at the northern end of the exposures where Robertson Formation rests unconformably on Brisbois Formation is the basal conglomerate absent. The gravel fraction consists of rounded and subrounded fragments of green and gray chert, green and black felsophyre, dark argillite, gray limestone, and gray chert-grain sandstone in varying proportions. The sand fraction consists of grains of albite, chert, felsite, argillite, mafic andesite or basalt, and quartz. Although the gross composition of the basal conglomerate is similar to that of many conglomerate beds in the underlying Begg Formation, the Robertson conglomerate is consistently better rounded and its bedding is better defined. Thus, in mapping the basal contact of Robertson Formation, reliance need not be placed on angular discordance, although such is readily apparent in most areas and approaches 90° in parts of the type area.

The basal conglomerate accounts for 20 to 40 percent of Robertson Formation. In addition, fine-grained pebble conglomerate and pebbly chert-grain sandstone of similar composition are intercalated at various horizons within the overlying, dominantly volcanic, sandstones. These beds account for an estimated additional 5 to 10 percent of the formation.

Volcanic sandstone: The dominant sandstones of Robertson Formation, accounting for 45 to 65 percent of the formation, are massive, locally cross-laminated, well-sorted volcanic arenites composed dominantly of subangular to subrounded grains of volcanic plagioclase, originally glassy volcanic rock fragments of hyalopilitic to pilotaxitic texture, and minor volcanic augite. Typically less than 5 percent, and commonly none, of the detrital grains are quartz, limestone, felsite, and chert. The rocks are cemented by calcite or, more commonly, by chlorite and celadonite (see figure 17). Calcareous rocks are gray and weather brown; those with iron-bearing phyllosilicate cement are green and form the typical green beds of aphanitic appearance that serve to distinguish Robertson sandstones from conformably overlying Suplee Formation, from unconformably overlying Weberg Member of Snowshoe Formation, and, along Pine Creek, from gray calcareous siltstones and fine-grained sandstones of the unconformably underlying Brisbois Formation.

Some volcanic sandstones of Robertson Formation are unaltered andesite arenites. Most, however, have been thoroughly albitized and might better be termed keratophyre arenites. Sieved porphyroblasts of prehnite and anastomosing webs of diagenetic laumontite have given rise locally to spotted and mottled tan and green rocks, especially in the northerly exposures. In several sectioned specimens, an appreciable percentage of the volcanic rock fragments appear to be abraded andesitic shards. These grains are grossly equant, but have smoothly rounded re-entrants suggestive of vesicle walls and smoothly rounded protuberances that are best interpreted as the result of abrasion of attenuated filaments.

Limestone: Lenses of gray, biostromal and massive bioclastic limestone, locally as thick as 30 feet individually, are a distinctive feature of Robertson Formation. The poorly bedded lenses appear to grade laterally into thinner sequences of calcilutite. Although the limestones form less than 5 percent of the formation in the southern part of the exposures, including the type area, they account for 10 to 40 percent of the formation in the north.

The biostromal beds of reefoid limestone are composed almost exclusively of closely packed, elongate lower valves of the aberrant sessile pelecypod *Plicatostylus gregarius* Lupher and Packard, 1930, in upright growth position (see figure 18). As many as five separate biostromes of plicatostylid limestone occur in sections of Robertson Formation exposed along the northwest flank of Mowich Upwarp. Body chambers

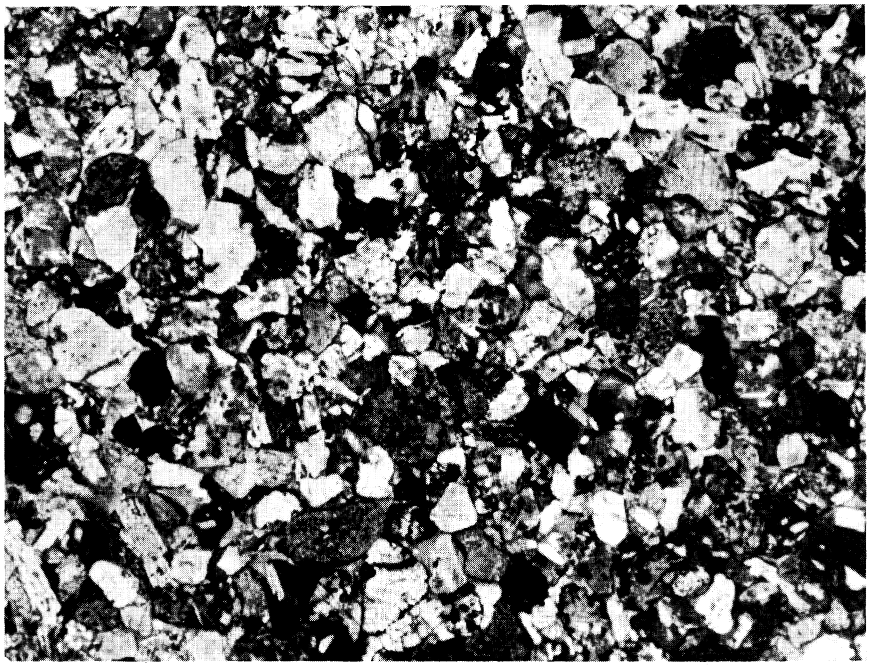


Figure 17. Diagenetically albitized andesite arenite of Robertson Formation; well-sorted and subrounded framework grains are volcanic plagioclase and andesitic rock fragments, cement is clear chlorite and celadonite (plain light; about 25 X).

Figure 18. Biostromal reef limestone of Robertson Formation near Swamp Creek; composed mainly of lower valves of the aberrant sessile pelecypod Plicatostylus.

of plicatostylid shells and interstices between valves in the reefoid limestones are filled with sandy calcarenite or calcareous sandstone. The massive reefoid rocks grade laterally to beds of sandy calcarenite and calcilutite containing scattered plicatostylid shells strewn parallel to bedding. Some of this layered limestone contains shells of the gastropod Nerinea, pelecypods other than Plicatostylus, and terebratulid brachiopods. Thin-bedded, locally nodular, dark gray, argillaceous calcilutite layers a foot or two thick also occur within volcanic sandstones of Robertson Formation. Although clear evidence of the relationship of these unfossiliferous limestones to the reefoid bodies was not obtained, they occur at the same horizons and probably represent yet more distal equivalents of the reefoid lenses than do the fossiliferous calcarenites.

Fossils and age

The abundant pelecypod Plicatostylus gregarius Lupher and Packard and the abundant gastropod Nerinea sp. do not provide a basis for closely dating Robertson Formation. The lower part of the formation on Cow Creek in the northern part of the area contains Weyla questionably referrable to W. unca, which has a known range extending through the Sinemurian and Pliensbachian Stages of the Lower Jurassic (S. W. Muller, oral communication, 1958). The pelecypod genera Ostrea, Pinna, Trigonia, Modiolus, Isocyprina, Pholadomya, Camptonectes, Pleuromya, Lucina, Lima, Astarte, and Coelastarte also occur in northern exposures, but are of doubtful age significance.

On Silvies River, 25 miles southeast of the area, the Donovan Formation (Lupher, 1941) contains upper Sinemurian eoderoceratid and echioceratid ammonites (R. W. Imlay, written communication, 1957) at a horizon about 475 feet stratigraphically below a limestone bed containing Plicatostylus.

On the basis of the occurrence of Weyla on Cow Creek, the ammonites from below plicatostylid limestone of the Donovan Formation, and conformity with the overlying Suplee Formation, Robertson Formation is provisionally assigned to the Pliensbachian Stage (Lower Jurassic) with the reservation that some upper portion may be Toarcian (Lower Jurassic).

Suplee Formation (Jms)

Suplee Formation consists of fossiliferous gray calcareous sandstone and sandy limestone. Some beds are gray-green or tan and weathered surfaces are commonly yellowish. The unit rests conformably on Robertson Formation in the western part of the area but lies directly on older Mesozoic rocks with angular unconformity farther east. The changing stratigraphic relations at the base of Suplee Formation are probably due in part to onlap, but the intercalation of noncalcareous green volcanic sandstones within the lower part of Suplee Formation on Big Flat suggests that some lower part of Suplee Formation in the east is at least a partial lateral equivalent of Robertson Formation in the west. Thickness variations within Suplee Formation are consistent and compatible with this view: the unit is only 30 to 35 feet thick above Robertson Formation in the type locality, but thickens to 50 feet at Big Flat and to 75 feet between South Fork and Poison Creek. Still farther east, the thickness decreases again to 50 feet at Caps Creek and to 30 feet in the headwaters of Rosebud Creek. The lower contact with Robertson Formation is placed at the top of the highest plicatostylid limestone or at the top of the highest noncalcareous green volcanic sandstone or pebble conglomerate. As Suplee Formation is a homogeneous and distinctive unit, the contact is not hard to define in most localities.

Lithologic description

Suplee Formation grades from calcareous volcanic sandstone in the west where it overlies Robertson Formation to calcareous lithic sandstone in the east where it overlies older rocks. Bedding is everywhere massive and indistinct. Grains are subrounded to rounded and in most exposures are fine sand, although medium sand is not rare and pebbly beds occur at the base of the unit in a few places in the eastern part of the area.

Fossils and age

Abundant fossils are a characteristic lithologic attribute of Suplee Formation. The large pecten, Weyla, is most characteristic and can be found, at least as incomplete specimens, in virtually every outcrop of the unit. The pelecypods Astarte (Coelastarte) sp., Camptonectes sp., Pleuromya sp., and Trigonia sp., as well as bicostate rhynchonellid brachiopods, are also abundant throughout the area. Near South Fork, Gryphaea sp. is abundant, forming local coquinite along the outcrop belt between Schoolhouse Gulch and Hole-in-the-Ground, but was not found elsewhere. Similarly, Meleagrinella sp. is virtually restricted to the Snow Mountain-Mowich Mountain area in the southwest, where it is abundant. Common forms throughout the area include Gervilleia sp., Homomya sp., and Ostrea sp. Less common forms are included in table 5.

Ammonites are rare in Suplee Formation in comparison to the bivalves, but good specimens have been obtained in about 10 localities (table 5) spread throughout the area. The ammonite genera are characteristic of the lower part of Toarcian Stage (Lower Jurassic) (R. W. Imlay, written communication, 1957). On the other hand, a Gryphaea resembling G. cymbium Lamarck, which is characteristic of the upper Pliensbachian Stage in Europe (R. W. Imlay, written communication, 1957), has been found at two localities and the Weyla specimens are most probably a Pliensbachian assemblage (S. W. Muller, oral communication, 1956). Gryphaea cf. G. cymbium is most common in the lower part of the unit and has not been found above the middle, but Weyla occurs throughout. At no single place, however, has either Weyla or Gryphaea been collected from beds above an ammonite locality. Available data thus suggest that Suplee Formation is in part of early Toarcian Age but may include upper Pliensbachian beds as well.

Nicely Formation (Jmn)

Nicely Formation consists dominantly of black mudstone and shale with subordinate intercalations of sandstone. Large concretions as much as 2 feet in diameter are abundant in some exposures. The basal contact with Suplee Formation is conformable and is placed at the top of the continuous sequence of underlying sandstone and sandy limestone, which is broken only by minor shale or mudstone partings. The unit is 75 to 100 feet thick at the type locality, but ranges from 100 to 300 feet in the eastern part of the area (figure 15).

Lithologic description

In the type locality, Nicely Formation is almost entirely black, flaky shale. To the east, mudstone and thin, intercalated beds of calcareous siltstone and sandstone are included within the unit. In many exposures, black spheroidal limestone concretions that weather gray or white are abundant. The concretions and the lutites are virtually massive, with little or no trace of lamination.

On Big Flat, a submarine lava flow of porphyro-aphanitic pyroxene andesite occurs within Nicely Formation. The flow is about 50 feet thick, is exposed for 5 miles along strike, and is composed of white labradorite and black augite phenocrysts set in a blue-gray to green groundmass that weathers brown: In section, the groundmass is a turbid hyalopilitic mass of partly devitrified brownish glass in which andesine microlites, clinopyroxene grains, and ore are imbedded. In some parts of the flow, plagioclase is largely albitized and the groundmass largely chloritized. As far as a mile away from the edge of the flow along strike, a thick, derived bed of moderately to poorly sorted andesitic and keratophyric sandstone occurs at the same horizon in Nicely Formation.

Fossils and age

Voluminous collections of ammonites have been assembled by breaking open the calcareous concretions (table 6). The assemblage obtained is early to middle Toarcian (Early Jurassic) in age, not younger

TABLE 5. Fossils from Suplee Formation of Mowich Group.

Locality [1,2,3]	V212	D 30	D 31	D 34	D 35	D 36	D 37	D 39	D 40	D 42
Location										
--¼ of	SW	SW	NE	NE	NW	SW	SE	SE	SW	SW
--¼ of	SW	SW	SE	NW	SE	SE	SE	SE	NW	SE
Section	28	28	28	36	30	30	30	4	3	34
Township (S.)	18	18	18	18	18	18	18	18	18	17
Range (E.)	26	26	26	26	27	27	27	27	27	27
Ammonites:										
Harpoceratoides(?) sp.	----	----	----	----	----	----	----	----	----	----
Hildaites sp.	----	----	----	----	----	----	----	x	----	----
Hildaites cf. H. serpentinum (Reinecke)	----	x	----	----	----	----	----	x	----	----
Hildaites cf. H. subserpentinum Buckman	----	----	----	----	----	----	----	----	----	----
Orthildaites sp.	----	----	----	----	----	----	----	----	----	----
Orthildaites cf. O. orthus Buckman	----	----	----	----	----	----	----	----	----	----
Phylloceras sp.	----	----	----	----	----	----	----	----	----	----
Whitbyiceras(?) cf. W. pingue (Simpson)	----	----	----	----	----	----	----	----	----	----
Pelecypods:										
Astarte sp.	x	----	x	----	----	----	----	----	----	----
Astarte (Coelastarte) sp.	----	----	----	----	x		x	----	----	----
Camptonectes sp.	----	----	x	----	----	x	x	----	x	----
Cardinia sp.	----	----	----	----	----	----	----	----	----	----
Gervillia sp.	----	----	----	----	----	----	x	----	----	----
Goniomya sp.	----	----	----	----	----	----	----	----	----	----
Gryphaea sp.	----	----	----	----	----	----	----	----	----	----
Gryphaea cf. G. cymbium Lamarck	----	----	----	----	----	----	----	----	----	----
Homomya sp.	----	----	x	----	----	----	----	----	----	----
Lima sp.	----	----	----	x	----	x	----	----	----	----
Mactromya sp.	----	----	----	----	----	----	----	----	----	----
Meleagrinella sp.	----	----	----	x	x	----	x	x	----	----
Modiolus sp.	----	----	x	----	----	----	----	----	----	----
Ostrea sp.	----	----	----	----	----	----	----	----	----	----
Parallelodon sp.	----	----	x	----	----	----	----	----	----	----
Phacoides sp.	----	----	----	----	----	----	----	----	----	----
Pinna sp.	----	----	x	----	----	----	----	----	----	----
Pleuromya sp.	x	----	x	----	----	x	x	----	----	----
Trigonia sp.	x	x	----	----	----	----	----	----	x	x
Weyla sp.	----	x	x	----	----	x	x	----	x	x
Brachiopods:										
Rhynchonellids (bicostate)	x	----	x	x	x	x	x	x	x	x
Terebratulids	----	----	----	----	----	----	----	----	----	x

[1] See Plate I for map location.
[2] Localities yielding only Weyla sp. omitted.
[3] Localities listed from west to east along southeast flank of Mowich upwarp.

(Identifications by R. W. Imlay of U. S. Geological Survey; some pelecypod identification in field by W. R. Dickinson)

D 46	D 49	D 51	D 53	D 55	D 57	D 58	D 61	D 63	D 64	D 65	D 66	D 67 D 68	D 69	D 73	D 74
SE	NW	NE	SE	SE	SE	NW	NW	NW	SE	SW	NE	NW	SE	cen-	SE
SE	SE	SW	NE	SW	NW	NE	SE	SW	NW	SE	NE	NW	SW	ter	SW
26	25	30	30	20	16	16	3	2	2	35	2	1	36	12	30
17	17	17	17	17	17	17	17	27	17	16	17	17	16	17	16
27	27	28	28	28	28	28	28	28	28	28	28	28	28	27	28
----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	x	x	----	----
----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----
----	----	----	----	----	x	----	----	----	----	----	----	x	----	----	----
----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	x	x	----	----
----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----
----	x	----	----	----	----	----	----	x	----	x	----	----	----	----	----
----	----	----	----	----	x	----	x	----	----	----	x	x	x	x	----
----	----	x	x	----	----	----	x	----	x	----	x	x	x	----	x
----	----	----	----	----	----	----	----	----	----	----	----	----	----	x	x
x	----	----	----	----	----	----	x	----	----	----	----	x	x	----	----
----	----	----	----	----	x	----	----	----	----	----	x	x	----	----	----
----	x	----	x	----	----	----	----	----	----	----	----	----	----	----	----
x	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----
x	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----
----	----	----	----	----	----	----	----	----	x	----	----	x	x	----	----
----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	x	x	----	x	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	x	x	x	----	----
x	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x
x	----	----	----	----	x	x	----	----	x	x	----	x	x	x	x
x	----	----	----	----	----	x	----	----	----	----	----	x	x	x	x
x	x	x	x	x	----	x	x	x	x	x	x	x	x	x	x
x	----	----	----	x	----	x	----	x	----	x	----	----	x	x	----
x	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

TABLE 6. Fossils from Nicely Formation of Mowich Group (Identifications by R. W. Imlay of U. S. Geological Survey)

Locality [1,2]	"L"[3]	V 72	D 76	D 77	D 79	D 80	D 81	D 82	D 83	D 84	D 85	D 86
Location:												
--¼ of	----	SE	NW	NE	SE	SE	SE	NW	----	NW	SW	NE
--¼ of	----	SE	SW	NE	SW	SW	NW	NE	SW-NW	NE	NE	NE
Section	28-29	29	35	35	25	20	16	16	36-1	1	14	14
Township (S.)	18	18	17	17	17	17	17	17	16-17	17	17	17
Range (E.)	26	26	27	27	27	28	28	28	28	28	27	27
Ammonites:												
Catacoeloceras sp.	x	----	----	----	----	----	----	----	x	----	----	?
Catacoeloceras cf. *C. annuliferum* (Simpson)	x	----	----	----	----	----	----	----	----	----	----	----
Dactylioceras cf. *D. directum* (Buckman)	----	----	----	----	----	----	----	----	----	----	----	x
Dactylioceras cf. *D. kanense* McLearn	----	----	----	----	----	----	----	----	----	----	x	x
Dactylioceras cf. *D. tenuicostatum* (Young & Bird)	----	----	----	----	----	----	----	----	----	----	----	x
Eleganticeras sp.	----	----	x	----	----	----	----	----	----	----	----	----
Eleganticeras cf. *E. pseudoelegans* Buckman	----	----	----	----	----	----	----	----	x	----	----	----
Fanninoceras cf. *F. fannini* McLearn	x	----	----	----	----	----	----	----	x	----	----	----
Fanninoceras cf. *F. kunae* McLearn	x	----	----	----	----	----	----	----	----	----	----	----
Harpoceras cf. *H. exaratum* (Young & Bird)	x	----	----	----	x	----	----	----	x	----	----	----
Harpoceras (*Ovaticeras*) sp.	x	----	----	----	----	----	----	----	----	----	----	----
Hildaites sp.	x	----	----	----	x	----	x	x	----	x	----	x
Hildaites cf. *H. serpentinum* (Reinecke)	x	x	----	x	----	----	----	----	x	----	x	----
Hildaites cf. *H. subserpentinum* Buckman	x	----	x	----	----	----	x	----	x	----	----	----
Lytoceras sp.	----	----	----	----	----	----	----	----	x	----	----	----
Orthildaites cf. *O. orthus* Buckman	----	----	----	x	----	----	----	----	x	----	----	----
Protogrammoceras(?) sp.	----	----	----	----	----	----	----	----	----	----	----	x
Subcollina(?) sp.	----	----	----	----	----	----	----	----	x	----	----	----
Zugodactylites cf. *Z. braunianum* (d'Orbigny)	x	----	----	----	----	x	----	----	x	----	----	x
Pelecypods:												
Otapira(?) cf. *O. marshalli* (Trechman)	x	x	----	x	----	----	x	----	x	----	----	x
Brachiopods:												
Rhynchonellids	----	x	----	x	----	----	----	----	----	----	----	----

1 See Plate I for map location.
2 Localities listed from west to east.
3 Collections of R. L. Lupher in period 1926-1937 from type locality near Jim Robertson ranch.

than the European zone of Hilderoceras bifrons (R. W. Imlay, written communication, 1957). As Hildoceras is absent, the formation may be entirely older than this zone.

Hyde Formation (Jmh)

At the type locality on South Fork of John Day River and in contiguous exposures extending for 15 miles along strike, Hyde Formation is composed dominantly of thick, massive beds of blue-gray andesitic marine tuff and tuffaceous volcanic graywacke and averages 1,000 to 1,200 feet in thickness. The unit is the most resistant in the Jurassic sequence and supports prominent hogback ridges. The formation rests conformably on Nicely Formation and is overlain by Snowshoe Formation. The upper contact is conformable except along Freeman Creek in the southwest, where Weberg Member of Snowshoe Formation overlies Hyde Formation unconformably along a contact with mappable angularity. The upper and lower conformable contacts, both gradational through about 25 feet of strata, were placed at the top and base, respectively, of the highest and lowest massive andesitic tuff or sandstone bed in a continuous sequence of similar strata.

Lithologic description

At the type locality hard, tough, resistant volcaniclastic beds composed of dominantly sand-sized andesitic debris account for 90 percent of the formation. These homogeneous rocks are blue-gray where fresh, but weather green or greenish brown and form spheroidal exfoliation nodules ranging from 5 to 15 inches in diameter. The resistant beds range from 1 to 10 feet in thickness and are separated by intercalated layers of dark, laminated volcanic siltstone and mudstone 1 inch to 2 feet thick. The coarse volcaniclastic beds are massive throughout most of their thickness. Their uppermost parts, however, grade into the overlying lutite intercalations by a decrease in grain size and the appearance of faint laminations. Some beds grade downward into lutite in similar fashion, but others have abrupt bottoms. In rare instances, layers of angular andesitic lapilli occur within some thick beds.

The predominant volcaniclastic andesitic strata of Hyde Formation are best described texturally as moderately sorted, medium-grained sandstones. Most grains are subangular, but angular and subrounded grains are both represented. Some rock fragments are equant andesitic shards with cuspate margins formed of arcuate indentations and pointed projections. Other fragments appear to be somewhat abraded shards. The degree of sorting is difficult to estimate, because interstitial areas between framework sand grains are occupied jointly by chlorite and celadonite formed in part by recrystallization of detrital matrix and in part as authigenic cement grown in open pores. Apart from minor admixtures of nonvolcanic quartz, chert, and argillite grains in amounts less than 5 percent and most commonly less than 1 percent, the predominant rocks are composed entirely of clastic andesitic debris. This material consists of abundant plagioclase crystals that are commonly albitized, common fresh augite, rare fresh hornblende, and abundant fine-grained, originally glassy, rock fragments of hyalopilitic and vitrophyric texture. The relative proportions of these different constituents are remarkably constant and hold near the following values in most rocks: plagioclase, commonly albitized, 25 percent; andesitic rock fragments, 55 percent; and augite and minor hornblende, 4 percent. Interstitial matrix and cement account for the remaining 15 to 20 percent (figure 19).

The andesitic strata of Hyde Formation have undergone intense diagenetic alterations (for details, see Dickinson, 1962b). Originally glassy portions of rock fragments are replaced by zeolites, celadonite, and chlorite. The plagioclase in many rocks is partly or entirely altered to albite clouded with inclusions of pumpellyite and prehnite. Of the volcanic materials, only augite and hornblende are fresh; on fresh surfaces, augite is readily visible as small, sparkling black crystals. Local migration of lime during alteration (see Dickinson, 1962b) has given rise to a variety of segregations and spotted or mottled strata: (1) Spheroidal calcareous concretions occur in some beds; (2) prehnite porphyroblasts appear as pale ovoid spots in some siltstone intercalations; (3) pale prehnite and laumontite veinlets transect some massive volcaniclastic beds; and (4) anastomosing webs, parallel bands, and massive blocks of pale laumontite after

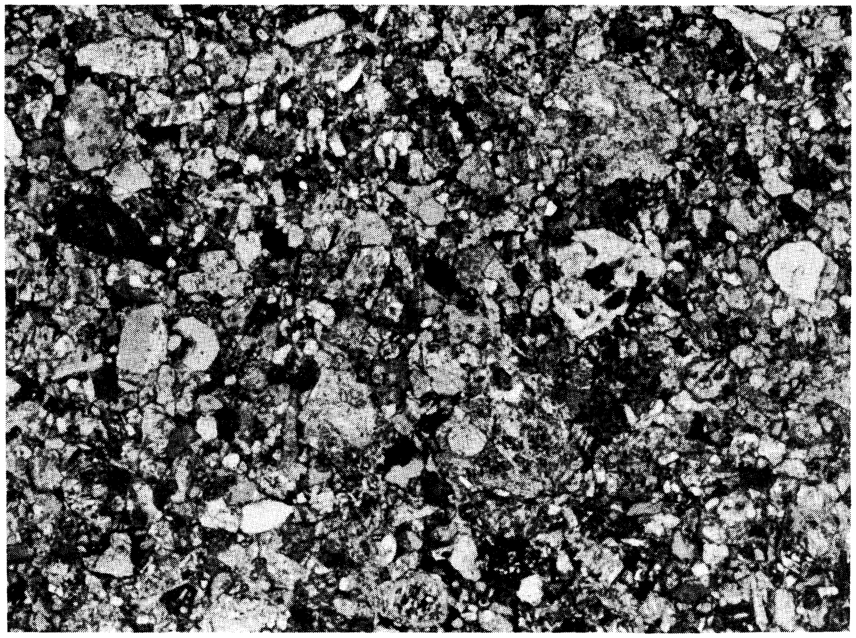


Figure 19. Diagenetically albitized marine andesite tuff of Hyde Formation; moderately sorted and subangular framework grains are chiefly volcanic plagioclase and andesitic rock fragments with minor augite; cement and matrix is mainly chlorite and celadonite (plain light; about 25 X).

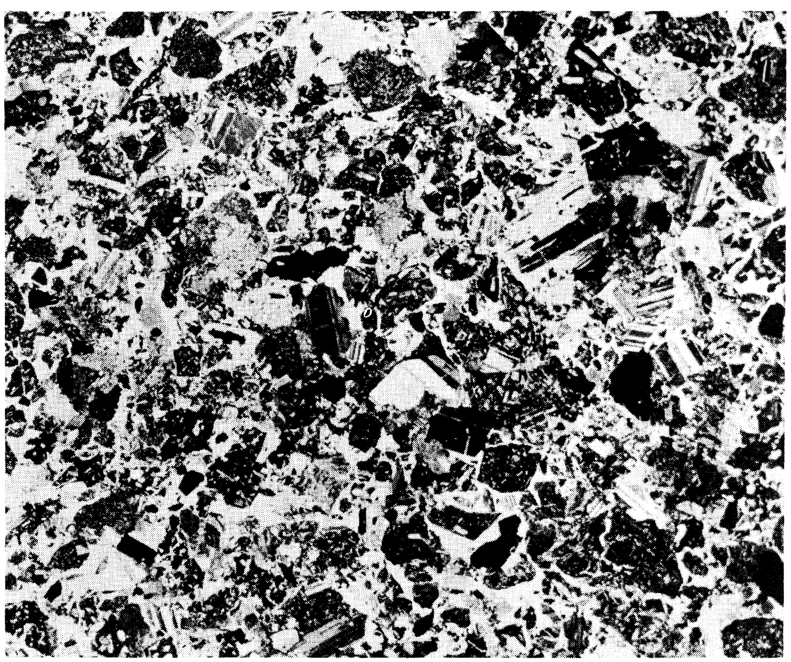


Figure 20. Basal calcareous andesitic sandstone of Hyde Formation (crossed nicols to show presence of calcite cement and lack of detrital matrix); grain types same as Figure 19 except plagioclase unaltered (note albite twinning) (about 25 X).

plagioclase and zeolitized glass have given rise locally to mottled tan and green rocks, banded tan and green rocks, and massive tan rocks. The diagenetic growth of easily weathered laumontite is most notable in the area around Mowich Mountain and Freeman Creek, hence the Hyde graywackes of that area are softer and less resistant than elsewhere.

Lithologic variants

East of Big Flat within the mapped area, Hyde Formation is lithologically homogeneous, although the thickness varies from 700 to 1,500 feet (figure 15). West of Big Flat, the proportion of lutite in the unit increases, and on Freeman Creek the formation consists of alternating members, each 50 to 100 feet thick, of tuffaceous volcanic graywacke and poorly sorted volcanic siltstone or mudstone. Similarly, lutite intercalations increase in abundance toward Bear Valley outside the mapped area to the east.

In the drainage of South Fork of John Day River, the lower 25 to 100 feet of Hyde Formation (figure 15), and the upper 10 to 25 feet, are dominantly well-sorted calcareous volcanic sandstone (andesite arenite) composed also of subangular grains (see figure 20). These beds are also massive, like the noncalcareous beds, but outcrops weather typically to gritty, brown, angular surfaces that contrast with the nodular, dark green surfaces typically formed on the noncalcareous beds in the bulk of the formation. Moreover, the relative proportion of plagioclase grains and andesitic rock fragments appears to vary more in the calcareous rocks, perhaps reflecting a greater degree of hydraulic sorting of the volcanic debris. The calcareous arenites appear to grade locally to sequences of dark mudstone with intercalated calcareous sandstone beds mapped as upper Nicely Formation.

In places, lenses of volcanic pebble conglomerate occur in the basal beds of the formation.

Fossils and age

No diagnostic fossils have been found in Hyde Formation. With the exception of bicostate rhynchonellid brachiopods near Izee (loc. D87) and poorly preserved hildoceratid (?) ammonites from Freeman Creek and the type locality, the unit has proved barren. Early to middle Toarcian ammonites from the conformably underlying Nicely Formation and an assemblage of late Toarcian (Lytoceras jurense Zone) ammonites from the basal part of the conformably overlying Snowshoe Formation indicate, however, that Hyde Formation is Toarcian and, despite its thickness, may well represent only the Hildoceras bifrons Zone of that stage.

Origin of Mowich Group

Mowich Group was deposited in a transgressing sea that inundated an erosional surface of low relief during the late Early Jurassic. Ammonites from the group and from the overlying Snowshoe Formation indicate that deposition occupied a geologically brief period from late Pliensbachian to middle or late Toarcian time. In Robertson and Suplee Formations, there are abundant ecologic indicators of shallow marine waters. Chief among these are (a) biostromes of the aberrant sessile pelecypod Plicatostylus in Robertson Formation; (b) Gryphaea coquinites in Suplee Formation; (c) the presence of other massive, thick-shelled pelecypods such as Weyla, Ostrea, and Trigonia; and (d) the presence of rhynconellid and terebratulid brachiopods, known to be abundant in neritic deposits elsewhere (Imlay, 1957, p. 498). These forms, as well as the clean texture and coarse grain size of the rocks, suggest that Robertson and Suplee Formations were deposited in shallow, wave-agitated waters. The restriction of the Robertson Formation reefoid limestones to the western part of the area may possibly indicate shoaling in that direction. The finer grain size of Nicely Formation suggests deposition in quieter, but not necessarily notably deeper, waters farther offshore. The fossils of Hyde Formation are too sparse and fragmentary to permit valid ecologic interpretations, but the thickness of the unit requires prior or concurrent subsidence in excess of 1,000 feet.

The basal conglomerate of Robertson Formation is probably composed largely of detritus reworked from directly underlying Upper Triassic conglomerates of Begg Formation. The supposition is strengthened by the fact that the basal conglomerate is absent where Robertson Formation rests on finer grained strata of Brisbois Formation. Likewise, the nonvolcanic sand of Suplee Formation in the eastern part of the area was likely derived from underlying strata.

Andesitic debris of similar microscopic appearance is overwhelmingly predominant in Mowich Group as a whole. Convergent lines of evidence suggest that the debris was derived from contemporaneous pyroclastic deposits: (a) It is almost wholly absent from the basal Robertson Formation and from the eastern exposures of Suplee Formation for which an epiclastic source from the substrate can be postulated with confidence; (b) it is microscopically unlike Paleozoic and Triassic volcanic rocks exposed nearby; (c) it closely resembles younger Jurassic andesite debris present higher in the column; (d) augite andesite lava of similar groundmass texture is intercalated within Nicely Formation on Big Flat and provides positive evidence of contemporaneous eruption of similar andesite magma; (e) fresh shards and abraded shards in Robertson and Hyde Formations provide direct evidence of some pyroclastic activity; and (f) the remarkable homogeneity of Hyde Formation and, to a somewhat lesser degree, of the volcanic sandstones of Robertson Formation, suggests derivation from homogeneous ash with only slight reworking.

The locations of the pyroclastic vents are unknown. Andesitic debris appeared first in the west, where it is interstratified with nonvolcanic lithic sandstone and limestone of Robertson Formation. Intercalations of andesitic sandstone in basal Suplee Formation on Big Flat, but not eastward, suggest not only that Robertson Formation to the west is a lateral equivalent of lower Suplee Formation to the east, but also that andesitic debris from the west was intertonguing with nonvolcanic detritus being deposited to the east. Hyde Formation represents a later flood of slightly reworked pyroclastic debris, much of which may well have been erupted initially into the sea and redistributed only by bottom currents. The general thickening of Hyde Formation toward the northeast may possibly reflect a source in that direction, although vagaries of bottom topography could equally well account for thickness changes.

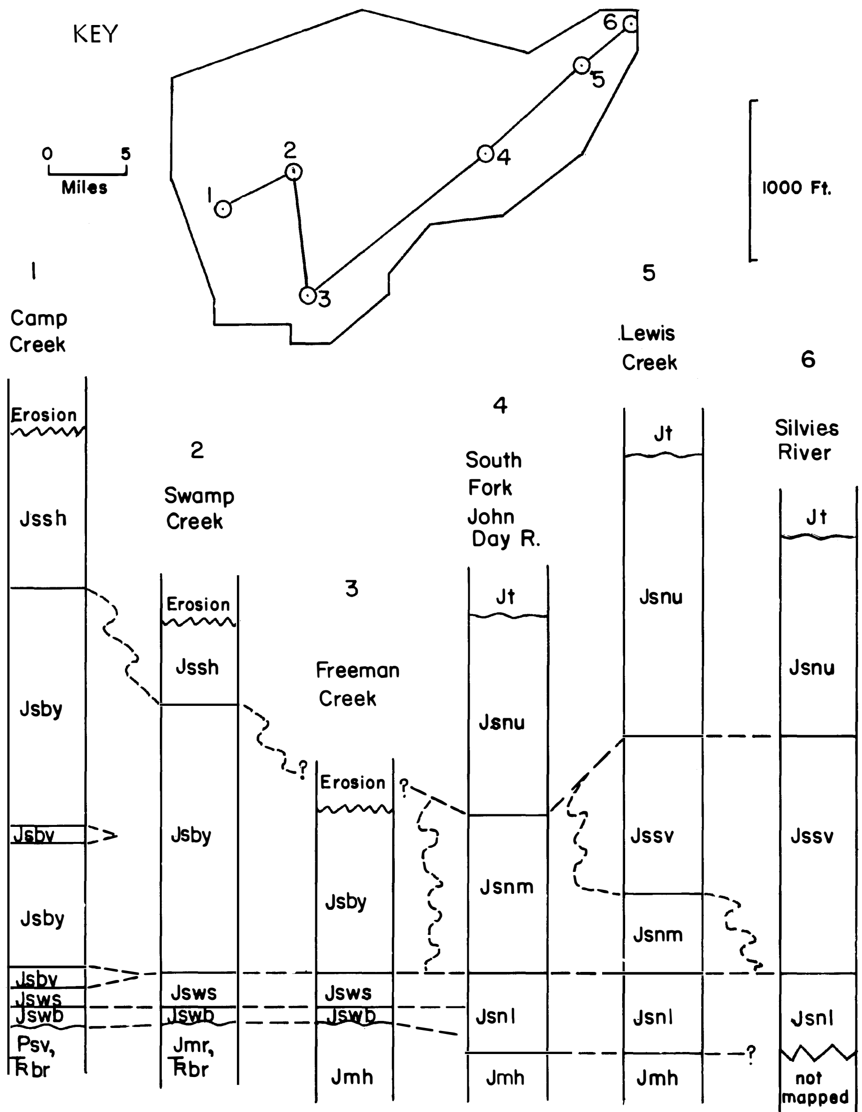
SNOWSHOE FORMATION (Js)

Revision of Nomenclature

Snowshoe Formation is a heterogeneous, conformable assemblage of Middle Jurassic strata. It rests conformably on Hyde Formation along the southeast flank of Mowich upwarp, unconformably on Hyde Formation and older units of Mowich Group near the axis of Mowich upwarp, unconformably on Upper Triassic strata in Pine Creek downwarp where Mowich Group is overlapped, and unconformably, finally on Paleozoic rocks near the western edge of the area. In the Izee district, the unit is overlain unconformably by Trowbridge Formation. In the Suplee district, no younger Jurassic rocks are present above it, but locally the formation is overlain unconformably by Upper Cretaceous strata.

As here described, Snowshoe Formation represents a major revision of the usage of Lupher (1941), in that several units he defined as separate formations are included as members of Snowshoe Formation. As the units in question are lateral facies equivalents of type Snowshoe Formation and are known to have only limited extent, the usage proposed here represents a desirable simplification of Lupher's terminology, yet retains and clarifies the critical lithologic distinctions which he recognized. The stratigraphic relations and thickness variations of the various members of Snowshoe Formation are shown by figure 21.

Snowshoe Formation was established by Lupher (1941, p. 259) for the sequence of well-bedded strata, dominantly laminated siltstone and mudstone but including sandstone intercalations, that conformably overlies Hyde Formation and is overlain by Trowbridge Formation along South Fork of John Day River at Izee. Hyde and Snowshoe Formations were bracketed together in "Izee Group" by Lupher (1941); in view of our present assignment of Hyde Formation to Mowich Group (see above) we have abandoned the term "Izee Group." In the type locality at Izee, three lithologically distinctive members have been informally recognized but not mapped, within Snowshoe Formation: (a) a lower member of dark lutite, (b) a middle



LEGEND

Subjacent and superjacent	Snowshoe Formation
Jt: Trowbridge Fm.	Jsnu, Jsnm, Jsnl: upper, middle, and lower members of the type locality at Izee
Jmh: Hyde Fm.	Jssv: Silvies Member
Jmr: Robertson Fm.	Jssh: Shaw Member
₮br: Brisbois Fm.	Jsby: Basey Member (Jsbv: lava)
Psv: Paleozoic rocks	Jsws: Warm Springs Member
	Jswb: Weberg Member

member of interlaminated dark lutite and greenish volcaniclastic siltstone and sandstone, and (c) an upper member of interbedded dark lutite and gray calcareous sandstone.

To the east of the type locality at Izee, the middle part of Snowshoe Formation grades by intertonguing into a sequence of interbedded lutite and volcaniclastic graywacke and conglomerate. For this sequence, the new name "Silvies Member of Snowshoe Formation" is proposed below.

To the west of the type locality at Izee, the conformable lower contact with Hyde Formation passes into an angular unconformity overlain by gray calcareous sandstone that is a lateral facies equivalent of a horizon somewhat above the base of type Snowshoe Formation. This transgressive sandstone unit, which successively overlaps the formations of the underlying Mowich Group, was named Weberg Formation by Lupher (1941), but is here described as "Weberg Member of Snowshoe Formation." Above Weberg Member are dark lutites similar in lithology and partly equivalent in age to those of the lower member of type Snowshoe Formation. These strata were named Warm Springs Formation by Lupher (1941), but are here described as "Warm Springs Member of Snowshoe Formation." Lupher (1941) bracketed his Weberg and Warm Springs "Formations" in "Colpitts Group," a term we have abandoned. Above Warm Springs Member in the western part of the area is a sequence of andesitic lavas and volcaniclastic rocks that intertongue eastward into a laterally equivalent part of the middle member of type Snowshoe Formation. For these strata, the new name "Basey Member of Snowshoe Formation" is proposed below. These strata were incorrectly referred to Hyde Formation by Lupher (1941), who erroneously dated Lower Jurassic Hyde Formation as Middle Jurassic on the basis of ammonite collections from Basey Member (see Appendix A for the relative stratigraphic position of the two units where both are present in the same vertical succession). For lutites that overlie Basey Member in the western part of the area, the new name "Shaw Member of Snowshoe Formation" is proposed below.

All these units of diverse lithology are included within Snowshoe Formation on the basis of the following reasoning. The transgressive Weberg Member is limited to a few square miles in the western part of the mapped area and contiguous ground to the west, and a good purpose appears to be served by terminology that reflects its relation to type Snowshoe Formation. The volcaniclastic Basey and Silvies Members intertongue completely with lutites of type Snowshoe lithology and appear to be the result of volcanism contemporary with Snowshoe sedimentation; similar volcaniclastic accumulations may well occur at various horizons in lutites of Snowshoe lithology eastward in central Oregon. Warm Springs and Shaw Members could not be mapped separately were it not for the intervening Basey Member. Erosion over Mowich Upwarp has largely removed the facies transition from Warm Springs, Basey, and Shaw Members eastward to undifferentiated Snowshoe Formation, and resort must be made to an "arbitrary cut-off" (Wheeler and Mallory, 1956) to delimit the eastern extent of these members at Mowich Mountain.

Snowshoe Formation (Jsn) at Izee

In the type locality along South Fork of John Day River at Izee, Snowshoe Formation includes approximately 2,750 feet of dark, thin-bedded, poorly exposed strata that underlie smooth, sage-covered slopes. Three gradational but lithologically distinctive members can be recognized.

Lower member

The basal 600± feet are dominantly soft, dark-gray to black, thin-bedded mudstone, shale, and siltstone. Upon weathering, these fine-grained rocks exhibit a bedding parting that yields platy slabs. In some exposures, casts of ammonites and of the pelecypod Posidonia are abundant on parting planes.

The rocks consist largely of fragments of crystals and groundmass of andesitic rocks and of clays inferred to have been derived from weathering of andesitic materials. Occasional devitrified shards are seen, but most of the recognizable clastic grains are angular silt grains of irregular shape. Small quantities of quartz silt may represent an admixture of nonvolcanic detritus. To the terrigenous detritus are added several kinds of organic debris. Volumetrically most important are tests of radiolarians, which comprise 10 to 25 percent of the rocks that have been examined in thin section. All the tests observed have been recrystallized to fibrous chalcedony or replaced by calcite, with one or the other modification occurring to the exclusion of the other in any given section. The derivation of the bodies from radiolarian tests can be inferred with reasonable confidence from their ovoid, bell-shaped, or helmet-shaped outlines and from their pitted or grainy appearance. In addition to the preserved tests, dark organic material is widely and abundantly dispersed throughout the fine clays interstitial to silt grains and tests. Bedding is shown in thin section by the alternation of thin laminae of contrasting grain size, a condition that doubtless gives rise to the platy parting so characteristic of the strata.

Most of the lutites of the lower member are calcareous to some degree. Locally, nodular concretions have formed by replacement. Remnants of more silty laminae are preserved in these concretions and are etched into relief on weathered surfaces. In exposures near Big Flat, thin beds of limestone from a few inches to a few feet in thickness are spaced at wide intervals of a hundred feet or more within the member. These relatively competent layers have been severely brecciated by the deformation which the rocks have undergone and, for this reason, their origin is difficult to ascertain. Some appear to represent coalesced chains of concretions formed along a specific horizon. Others contain fragmental calcareous fossils and may represent recrystallized bioclastic layers.

The lower member can be traced without significant lithologic change westward to Big Flat and eastward beyond the edge of the mapped area to Wickiup Creek near Bear Valley. Throughout this span, a distance of some 20 miles, the unit maintains a thickness of 500 to 750 feet. The Warm Springs Member of the Suplee district is similar in lithology and presumably is a western tongue of the upper part of the lower member of the Izee district.

Middle member

The middle 1,000± feet are dark-gray to black lutite, interlaminated with gray to green volcaniclastic siltstone and fine-grained sandstone, with the alternating laminae on the order of 1 to 10 mm thick. The dark lutite layers, like the strata of the lower member, are composed of a mixture of terrigenous silt and clay, recrystallized or replaced radiolarian tests, and dispersed dark organic material. The coarser volcaniclastic layers lack abundant organic matter, contain no radiolarian tests, and are typically graded from sandy or silty bottoms to clayey tops. The coarse layers are composed entirely of andesitic plagioclase that is largely albitized, and rock fragments that were originally glassy but are now zeolitized. Vitroclastic texture is not apparent in the volcaniclastic layers. Common bleached spots or patches in the siltstone and fine-grained sandstone layers are the result of the porphyroblastic growth of diagenetic laumontite; locally entire vitroclastic laminae are converted to the pale mineral.

The middle member can be traced without significant lithologic change westward to Big Flat and eastward to upper Rosebud Creek. Farther west it grades laterally to Basey Member of the Suplee district, and farther east it grades laterally to Silvies Member near the eastern edge of the area.

Upper member

The upper 1,250± feet are dominantly thin-bedded dark mudstone and siltstone with thick intercalated beds of gray calcareous sandstone. The sequence is poorly exposed and has been little studied. Sparse data suggest it contains both volcaniclastic and nonvolcanic detritus, but the proportions are unknown. To the west, the member is progressively overlapped by the Trowbridge Formation and does not reach to Big Flat. To the east, more and more strata appear beneath the sub-Trowbridge unconformity so that thicknesses of 1,500 to 2,000 feet are present where the member is poorly exposed on upper Rosebud and Lewis Creeks. A long roadcut on Lewis Creek opposite the mouth of Johnie Creek exposes an interbedded sequence in which green, gray, or black siltstone alternates with gray sandstone at intervals of 1 to 6 inches. Lamination, defined by color banding of carbonaceous layers, alternating feldspathic and lithic layers, and alternating gray-green and dark-gray layers, occurs on a scale of 1 to 5 mm. Sandy beds tend to contain calcareous cement and display small-scale cross bedding. The coarser beds are thickest and tend to be graded without lamination, except in their upper parts where fine laminae and cross-laminae are present in very fine-grained sandstone. Weathered surfaces range from somber brownish tones to pale hues of buff and cream.

TABLE 7. Fossils from lower member of Snowshoe Formation in South Fork of John Day River basin.
(Identifications by R. W. Imlay of U. S. Geological Survey)

Locality[1]	D104	D111	D105	D106	D107	D113	D112	D108	D129	D109	D110
Stratigraphic position (Feet above base of member)	75	100-125	125	150-175	200	225	250	250	375	500	500
Location											
--¼ of	NW	SW	SW	SW	SW	SW	SE	SW	NW	SE	SE
--¼ of	NW	NW	SW	SW	SW	SE	SW	SW	SE	SW	NW
Section	15	36	10	10	10	30	30	10	1	3	3
Township (S)	18	17	18	18	18	17	17	18	17	18	18
Range (E)	27	27	27	27	27	28	28	27	28	27	27
Ammonites											
Catulloceras cf. C. dumortieri (Thoiolliere)	----	x	----	----	----	----	----	----	----	----	----
Grammoceras cf. G. striatulum (Sowerby)	x	x	----	----	----	----	----	----	----	----	----
Grammoceras cf. G. toarcense (D'Orbigny)	x	x	----	----	----	----	----	----	----	----	----
Harpoceras cf. H. exaratum (Young & Bird)	x	x	----	----	----	----	----	----	----	----	----
Haugia cf. H. variabilis (D'Orbigny)	x	x	----	----	----	----	----	----	----	----	----
Erycites (?) sp.	----	----	----	----	x	----	----	----	----	----	----
Hammatoceras (?) sp.	----	----	----	----	x	----	----	----	----	----	----
Lytoceras (?) sp.	----	----	----	x	x	----	----	----	----	----	----
Phymatoceras (?) sp.	----	----	----	x	----	----	----	----	----	----	----
Tmetoceras cf. T. scissum (Benecke)	----	----	x	x	x	----	----	----	----	----	----
Stephanoceras sp.	----	----	----	----	----	----	----	----	x	----	----
Witchellia sp.	----	----	----	----	----	x	x	x	----	x	x
Pelecypod											
Posidonia ornati (Quenstedt)	x	x	x	x	----	x	x	x	----	x	----

[1] See Plate I for map location.

Fossils and age

In the drainage of South Fork of John Day River, fossil ammonite collections ranging in age from late Toarcian (Early Jurassic) to early Callovian (Late Jurassic) have been collected from exposures of Snowshoe Formation contiguous with the type locality. The pelecypod Posidonia is associated with the ammonites throughout the sequence.

The oldest faunule occurs in the basal 100± feet of the lower member (table 7) and has been collected from localities on Flat Creek (D104) and near Sheep Creek (D111). The presence of Harpoceras is good evidence that the faunule is Early Jurassic and the other ammonites are characteristic of the Lytoceras jurense Zone, the uppermost zone of Toarcian Stage (R.W. Imlay, written communication, 1957). This Toarcian portion of the lower member may well continue east of Izee where diagnostic fossils were not found, but thickening of the underlying Hyde Formation suggests that the gradational basal contact may rise into the Bajocian Stage.

Somewhat higher in the formation on Flat Creek, early Bajocian (Middle Jurassic) ammonites probably representative of the Tmetoceras scissum Zone (R. W. Imlay, written communication, 1957) were collected at three localities (D105, D106, D107) spaced from 125 to 200 feet above the base of the lower member (table 7).

Above the basal 200 feet, the middle Bajocian ammonites Witchellia sp. and Stephanoceras sp. have been collected from a number of localities in the lower member (table 7).

The middle member has yielded few fossils, but middle Bajocian ammonites were found at four localities (table 9, following page 56). The presence of Stephanoceras (Skirroceras) sp. at two localities suggests the Otoites sauzei Zone.

Abundant large concretions in the upper member yielded several ammonites at a locality (D115, SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 14, T. 17 S., R. 28E.) on a hill slope in the drainage of Rosebud Creek. The forms are characteristic, in Alaskan assemblages, of the lower part of the Callovian Stage (Upper Jurassic) and include the following: Calliphylloceras sp., Choffatia sp., Gowericeras cf. G. spinosum Imlay, Lilloettia sp., Lilloettia sp. juv., and Xenocephalites vicarius Imlay. With the ammonites are associated Posidonia and Ostrea (R. W. Imlay, written communication, 1957).

Silvies Member (Jssv)

The new name "Silvies Member of Snowshoe Formation" is here proposed for the thick lens of volcaniclastic strata characterized by abundant intercalations of andesitic sandstone and conglomerate that crop out in the headwaters of Silvies River. Between the thick graywacke and conglomerate sequences, which individually attain thicknesses in excess of 100 feet, are sequences of laminated volcaniclastic siltstone similar to the strata of the middle member in the type locality of Snowshoe Formation. The type locality designated for Silvies Member embraces the four quarter-sections surrounding the juncture of secs. 21, 22, 27, and 28, T. 16 S., R. 29 E., where Silvies River and a small tributary from the west have cut steep-sided, well-exposed canyons across the strike of the unit. At the type locality, approximately 1,500 feet of strata are exposed within Silvies Member; the upper and lower contacts are placed at the highest and lowest ledges of massive andesitic sandstone or conglomerate (see Appendix G for a detailed lithologic description of the type section). The extent of Silvies Member to the east is not known; to the west, it grades laterally by intertonguing to finer grained volcaniclastic strata comprising the middle member of type Snowshoe Formation. The facies change occurs in the headwaters of Lewis Creek (see plate 1).

Lithologic description

The lutite intercalations of Silvies Member are identical in lithology to the strata of the middle

Figure 22. Diagenetically albitized andesitic sandstone of Silvies Member of Snowshoe Formation; grains are mainly volcanic plagioclase and andesitic rock fragments with minor augite and rare quartz and detrital carbonate; note grain deformation and pressolved grain contacts (plain light; about 25 X).

member of type Snowshoe Formation and will not be described separately. The sandstones and conglomerates are massive, hard, blue-gray rocks that weather green or brown. They occur in graded depositional units that are typically 1 to 12 feet thick and are commonly separated by 1 to 25 feet of dark volcaniclastic siltstone and mudstone. Some of these depositional units consist of a single graded bed, but others are composed of two or more graded subunits or beds in vertical succession. In the compound units, the base of each graded bed above the basal one rests with scoured contact on sandstone or conglomerate of the subjacent graded subunit. As many as five graded beds, each 2 to 10 feet thick, have been observed thus in a single depositional unit, the whole aggregating 25 feet or more. Internal laminations caused by the alternation of layers of slightly different grain size or composition are common within graded sandstone beds, and these laminations are especially abundant in the upper parts of the beds. The laminae range from $\frac{1}{4}$ to 1 inch in thickness, the coarser laminae being correlated with coarser grain size and the finer laminae with finer grain size.

The grain size of the coarse volcaniclastic strata ranges up to cobble conglomerate, but coarse-grained sandstone is perhaps most typical. The rocks are moderately sorted and composed of subrounded to subangular grains. They are composed predominantly of andesitic debris in the form of plagioclase grains that are now largely albitized, devitrified zeolitic and chloritic rock fragments of originally hyalopilitic and vitrophyric texture, and minor augite and hornblende grains. Minor admixtures of nonvolcanic quartz and chert are common. Abraded calcite grains, many clearly of organic derivation as viewed in thin section, are characteristically present in amounts of 1 to 5 percent. Authigenic calcite is rare, for the rocks were lithified principally by compaction which pressed the framework sand grains tightly together, deforming some lithic grains and causing minor pressolution at grain contacts. The percentage of interstitial detrital matrix of clay and fine-silt size is variable, but is generally less than 10 percent (see figure 22).

The strata of Silvies Member superficially resemble similar massive, andesitic, volcaniclastic rocks of Basey Member and of Hyde Formation. Silvies Member, however, has the following lithologic attributes that differentiate it from the other two units: (1) Conglomerate beds are present and pebbly lenses and layers are common; (2) a greater variation in the proportions of feldspar grains and lithic fragments from bed to bed is evident, and some beds have more feldspar grains than lithic fragments; (3) small-scale laminations, especially feldspathic ones, are more common in the sandstones; (4) graded bedding is characteristic, especially the compound units made up of several graded beds; (5) median grain size is coarser (coarse sand versus medium sand) in the typical thick sandstone beds; and (6) weathered surfaces often display a speckled aspect of white feldspar grains against a dark background.

Lithologic variants

As Silvies Member grades westward to the middle member of type Snowshoe Formation, two separate conglomeratic tongues extend across Tamarack Creek (see plate I). Still farther west, conglomerate beds and stringers exposed along Rosebud Creek probably represent even more distal equivalents.

To the east of the type locality and outside the area mapped, Silvies Member thickens and, south of Seneca along U.S. Highway 395, includes intercalated andesitic lavas and flow-breccias similar to those in Basey Member of the Suplee district.

Fossils and age

No fossils were found at the type locality. Middle Bajocian (Middle Jurassic) ammonites have been collected, however, from similar strata near Seneca. This fact, together with the demonstrated lateral facies relation to the middle member of type Snowshoe Formation, leaves little doubt that Silvies Member is middle Bajocian.

Weberg Member (Jswb)

Weberg Member is a thin, transgressive unit of fossiliferous calcareous sandstone and sandy limestone that appears at the base of Snowshoe Formation only in the western part of the area where the base of the formation is an unconformity. Throughout most of the Pine Creek downwarp the member varies from 50 to 200 feet in thickness, presumably because of erosional relief on the surface of unconformity beneath it. The member thins eastward around the nose of Mowich upwarp and pinches out on the west slope of Mowich Mountain, where the unconformity between Hyde and Snowshoe Formations also disappears. The member is onlapped by the conformably overlying Warm Springs Member at the northeastern end of Pine Creek downwarp and locally in Smith Basin syncline at the western edge of the area. The contact with Warm Springs Member is gradational and was placed at the top of the highest calcareous sandstone or sandy limestone bed in a continuous sequence of these rocks and was drawn so as to exclude all but thin intercalations of dark lutite. On the southwesterly plunging nose of Mowich upwarp, Weberg Member rests unconformably on units of Mowich Group, which it progressively overlaps toward the west. The member rests on Upper Triassic strata throughout much of Pine Creek downwarp and on Paleozoic rocks near the western edge of the area.

Weberg Member was established (as Weberg "Formation") by Lupher (1941, p. 249), who designated the east side of Warm Springs Creek valley in secs. 19, 20, 29, and 30, T. 18 S., R. 26 E., as the type locality. A complete section of the member is exposed in the SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 19 on the north side of a gully that empties into Warm Springs Creek at the north boundary of sec. 30. This exposure is here designated the type section of Weberg Member and is described in Appendix E.

Two lithologic divisions can be recognized within Weberg Member: a lower division composed dominantly of calcareous sandstone and sandy pebble conglomerate, and an upper division composed dominantly of silty and sandy limestone. The lower division is thin or absent where the member rests on Mowich Group, but is invariably present elsewhere and locally accounts for the entire member. At the type locality, the lower division is nearly 110 feet thick, the upper division 90. The lower division thins to 15 feet where the Weberg Member overlies shaly Brisbois strata a mile and a half northwest of the type section. Along the southeast flank of Mowich upwarp, where Weberg Member lies unconformably on Mowich Group, the lower division is absent and the upper division ranges from 150 feet in sec. 28, T. 18 S., R. 26 E. to about 50 feet east of Freeman Creek. Only the lower division is present on Ontko anticline, where the thickness ranges from 60 to 105 feet. The Weberg Member ranges from 60 to 140 feet in thickness along the southeast flank of the Pine Creek downwarp. In this vicinity, the lower division is generally absent or less than 10 feet thick where the Weberg overlies Mowich Group, but is as much as 25 feet thick where Triassic rocks form the substrate. The upper division occurs only locally in Smith Basin and along the northwest flank of the Pine Creek downwarp. The Weberg Member is locally 60 feet thick in Smith Basin, but is absent as a result of onlap by Warm Springs Member in the NE$\frac{1}{4}$ sec. 33, T. 17 S., R. 25 E. About 100 feet of Weberg strata, probably including both lower and upper divisions, is present in the NE$\frac{1}{4}$ sec. 1, T. 18 S., R. 25 E., but the member thins rapidly northeastward and there is only 25 feet of chert-pebble conglomerate belonging to the lower division in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 31, T. 17 S., R. 26 E. The Weberg Member is absent at the northeast end of the Pine Creek downwarp, and Warm Springs strata lie directly upon Mowich Group or upon Triassic rocks.

Thicknesses of the upper and lower divisions change rapidly, even where the thickness of the entire member remains fairly constant over a local area. It is also apparent, as pointed out earlier by Lupher (1941, p. 248), that the distribution of the two divisions is controlled in part by lithology of the rocks below the sub-Snowshoe unconformity. These observations strongly suggest that the two divisions are, in part, facies equivalents.

Lithologic description

The lower division is dominantly resistant gray, yellowish-gray, or brownish-gray, medium- to coarse-grained, well sorted calcareous sandstone which occurs in beds 6 inches to 2 feet thick. Detrital grains of the sandstone, generally well sorted, are mostly gray and green chert and felsite, but grains of quartz, albite, and biogenic calcite are also common. The grains are generally subrounded to subangular, but the detritus in some beds near the base of the unit is conspicuously angular. Many of the sandstones are pebbly, and sandy conglomerate commonly occurs as a massive layer as much as 5 feet thick at the base of the unit or as thinner layers higher in the lower division. The conglomerates consist largely of subangular to rounded pebbles of chert, felsophyre, and limestone set in a matrix of calcareous sandstone. Cobbles and slabby boulders of chert and limestone occur locally in the basal beds of the lower division. Thick-shelled pelecypods, including Ostrea and fragmentary Pinna, and abraded bioclastic detritus are abundant in parts of the lower division. Rhynchonellid brachiopods and belemnite guards occur locally.

The upper division is dominantly gray or grayish-brown, silty or sandy limestone that commonly weathers to tan or yellowish-buff, flaggy or nodular blocks imbedded as residuals in a mantle of soil. The limestone is composed largely of fibro-lamellar bivalve fragments and monocrystalline echinoderm plates with clear, optically continuous, authigenic overgrowths set in a matrix of turbid microcrystalline calcite, probably largely derived from lime mud. The terrigenous detritus includes subangular quartz and plagioclase grains and subrounded fragments of chert, felsite, argillite, and dark volcanic rock. Glauconite, authigenic pyrite, and brown phosphorite are present in amounts of 1 percent or less.

The upper division is abundantly fossiliferous and casts of pelecypods in varying states of preservation can be found in almost all exposures. Rhynchonellid brachiopods are common and belemnite guards occur sporadically. Large terebratulid brachiopods and large ammonites are locally abundant in the upper division. Reptilian vertebrae and carbonized plant remains occur sparingly.

Fossils and age

The lower division contains no fossils diagnostic of age, but voluminous collections have been made from the upper division (table 8). The ammonites are indicative of lower to middle Bajocian Stage (Middle Jurassic). Absence of reliable marker beds and suspected facies changes prevent the arrangement of the collections in a firm stratigraphic order. It is worthy of note, however, that Tmetoceras occurs low in the division, and both Stemmatoceras and Stephanoceras occur very near the contact with Warm Springs Member. These data suggest that Weberg Member may include the Tmetoceras scissum Zone (collections

TABLE 8. Fossils from upper division of Weberg Member of Snowshoe Formation (Identifications by R. W. Imlay of U. S. Geological Survey).

Locality[1,2,3]	V158	V155	V130	V128	V120	V154	V123	V 16	V162	V 20	V 19	V 8	V152	V 14	D 88	D 89	V205	D 90	D 92
Location																			
--¼ of	SW	SW	SE	NE	SW	NE	NW	NE	SE	NE	SE	SW	SE	NE	SE	SW	SE	SE	NE
--¼ of	NE	NE	NW	SW	SW	NW	SW	NE	NE	NE	NE	NW	NE	SE	SE	SW	SW	NE	NE
Section	25	34	34	34	34	1	3	19	19	30	30	29	30	30	28	27	29	34	3
Township (S.)	17	17	17	17	17	18	18	18	18	18	18	18	18	18	18	18	18	18	19
Range (E.)	26	26	26	26	26	25	26	26	26	26	26	26	26	26	26	26	26	26	26
Ammonites:																			
Docidoceras cf. D. biforme Buckman	x	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----
Docidoceras cf. D. planulatum Buckman	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----
Euhoploceras cf. E. acanthodes (Buckman)	----	----	----	x	----	----	----	x	----	x	----	----	x	----	----	----	----	----	----
Euhoploceras cf. E. crassispinata (Buckman)	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----	----
Euhoploceras cf. E. dominans (Buckman)	----	----	----	----	x	----	----	----	----	----	----	----	----	x	----	----	----	----	----
Euhoploceras cf. E. gibbera (Buckman)	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----
Euhoploceras cf. E. gibberosa (Buckman)	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----	----
Euhoploceras cf. E. modesta (Buckman)	----	----	----	----	x	----	----	----	x	x	x	----	----	x	----	----	----	----	----
Papilliceras(?) sp.	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Phylloceras(?) sp.	----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	x
Praestrigites cf. P. deltotus (Buckman)	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x	----	----
Stephanoceras(?) sp.	----	----	----	----	----	----	----	x	----	?	----	----	----	----	----	x	----	----	----
Stephanoceras (Skirroceras) sp.	----	----	x	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----
Tmetoceras scissum (Benecke)	x	x	----	----	x	----	----	----	----	----	----	----	----	----	x	----	----	----	----
Witchellia cf. W. albidus (Buckman)	----	----	----	----	----	----	----	x	----	x	----	x	----	----	----	----	----	----	----
Witchellia cf. W. zugophorus (Buckman)	----	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----	----	----
Witchellia sp.	----	----	----	----	x	----	----	x	x	----	----	----	x	----	----	x	x	----	----
Pelecypods:[4]																			
Astarte, sp.	----	----	----	----	x	----	----	----	----	----	----	----	----	----	x	----	----	x	x
Camptonectes sp.	x	----	----	----	x	----	----	----	----	x	----	----	----	----	x	----	----	----	x
Gervillia sp.	x	x	----	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----
Homomya sp.	----	----	----	----	----	----	----	----	----	x	----	----	----	----	x	----	----	----	x
Isocyprina sp.	?	----	----	----	x	----	----	----	----	----	----	----	----	----	?	----	----	----	----
Ostrea sp.	----	----	----	----	x	----	----	----	----	----	----	----	----	----	x	----	----	x	x
Pleuromya sp.	x	x	----	----	x	----	----	----	----	x	----	----	----	----	x	----	----	----	x
Trigonia sp.	----	----	----	x	x	----	----	----	----	----	----	----	----	----	x	----	----	x	x
Brachiopods:																			
Rhynchonellids	----	----	----	----	x	----	----	----	----	x	----	----	----	x	x	----	x	----	----
Terebratulids	----	----	----	----	----	----	----	----	----	x	----	----	----	----	x	----	----	----	----

[1] See Plate I for map location. [2] Only significant or voluminous collections listed. [3] Localities listed from north to south.

[4] The following pelecypods were collected in only one locality listed:
Anomia sp. (V20); Cardinia sp. (D88); Goniomya sp. (D88); Mactromya sp. (V158); Lima sp. (V205); Lucina sp. (V120); Mytilus sp. (D88); Parallelodon sp. (D88); Pinna sp. (D88, D92); Protocardia sp. (D88); Velata sp. (V19).

with Tmetoceras alone), Ludwigia murchisonae and Graphoceras concavum Zones (collections with Tmetoceras, Praestrigites, and Docidoceras associated), lower Sonninia sowerbyi Zone (collections with Euhoploceras and Witchellia), and upper Sonninia sowerbyi Zone (collections with Stemmatoceras and Stephanoceras) (R. W. Imlay, written communication, 1957).

Warm Springs Member (Jsws)

Warm Springs Member is a unit of dark lutite that presumably represents a thin tongue of the lower member of type Snowshoe Formation extending westward into the Pine Creek downwarp. The member rests conformably with gradational contact on Weberg Member, or unconformably on Mowich Group and Upper Triassic strata where Weberg Member is absent. The Warm Springs Member is overlain conformably with gradational contact by Basey Member, a relationship discussed more fully in the description of Basey Member. The eastern limit of Warm Springs Member is an arbitrary vertical cut-off (Wheeler and Mallory, 1956) passing north-south beneath the lava cap of Mowich Mountain, thence northeast along the axis of Mowich upwarp. The thickness of the member varies from about 200 feet near the plunging nose of Mowich upwarp to about 300 feet in the northeast end of Pine Creek downwarp.

Warm Springs Member was established (as Warm Springs "Formation") by Lupher (1941, p. 249), who designated the east side of Warm Springs Creek valley in secs. 19, 20, 29, and 30, T. 18 S., R. 26 E., as the type locality. The member is easily eroded and occupies topographic depressions.

Lithologic description

In the type area, sporadic exposures indicate the member consists of gray, silty, calcareous shale and mudstone with subordinate intercalated gray calcareous siltstone and fine-grained limestone. Most beds are finely laminated and weather to gray or brown platy flakes and sheets. Flattened shells of the pelecypod Posidonia are abundant along bedding planes. Massive, blocky calcareous siltstones and mudstones are abundant in the member outside of the type area. In thin section, the rocks are seen to consist of the following in varying proportions: murky argillaceous material, dark brown organic matter, radiolarian (?) tests, microcrystalline calcite, and subangular lithic silt and minor sand. Terrigenous silt particles include quartz, albite, biotite, chert, felsite, andesitic rock fragments, and argillite.

Fossils and age

Warm Springs Member is abundantly fossiliferous, but does not contain the variety of forms present in the underlying Weberg Member (table 9). Posidonia is present in most exposures. Gradational relations with the Weberg and Basey Members, and ammonites that are abundant locally, suggest correlation with the upper part of the Sonninia sowerbyi Zone and the lower part of the Otoites sauzei Zone of the middle Bajocian (R. W. Imlay, written communication, 1963). Of the forms present, Euhoploceras is most common in the Sonninia sowerbyi Zone, Stephanoceras is unknown below the upper Sonninia sowerbyi Zone, Stemmatoceras and Skirroceras are not likely to be older than the Otoites sauzei Zone, and Parabigotites occurs in the lower Otoites sauzei Zone in Alaska.

Basey Member (Jsby)

The new name, "Basey Member of Snowshoe Formation," is here proposed for the sequence of interstratified andesitic lava and volcaniclastic rocks exposed in the vicinity of the Basey ranch at the head of Camp Creek. The member is typically exposed in secs. 1, 12, and 13, T. 18 S., R. 25 E. (see Appendix

Figure 23. Outcrop of Basey Member of Snowshoe Formation near Camp Creek showing spheroidal weathering forms typical of massive marine tuff units.

Figure 24. Partly albitized marine andesite tuff of Basey Member of Snowshoe Formation; mainly pale volcanic plagioclase grains and dark andesitic rock fragments; minor augite grains and interstitial chlorite-celadonite (plain light; about 25 X).

F for detailed lithologic description in type locality). The member underlies approximately 30 square miles of the mapped area, occupying the troughs of Pine Creek downwarp and Smith Basin syncline, and dipping off the plunging nose of Mowich upwarp. East of Freeman Creek on the nose of the upwarp, the coarse volcaniclastic beds that permit the recognition of Basey Member lens out into the uniformly fine-grained rocks of the middle member of type Snowshoe Formation. Accordingly, the eastern extent of the member is an arbitrary cutoff (Wheeler and Mallory, 1956) passing north-south beneath the lava cap of Mowich Mountain, thence northeast along the axis of Mowich upwarp. Basey Member has been traced in reconnaissance west of the mapped area into the Twelvemile Creek area and was noted beneath the lava cap on Wade Butte near Grindstone Creek. Its extent to the south is unknown.

Basey Member is approximately 2,500 feet thick at the type locality, but thins rapidly toward the east and is only 500 feet thick on the Wilson Creek anticline at the northeast end of Pine Creek downwarp. Mapping in Pine Creek downwarp and around the nose of Mowich upwarp indicates eastward thinning of the member at the rate of 250 to 500 feet per mile.

Lithologic description

The most characteristic and abundant strata in Basey Member are hard, massive marine volcaniclastic rocks, with median size in the sand range, that are devoid of bedding for thicknesses as great as 200 feet. The strata are dark gray or blue-gray on fresh surfaces, but weather gray-green, green, or rust brown. Weathered outcrops have a nodular appearance formed by closely spaced ellipsoidal and spheroidal exfoliation cells (see figure 23). Some rocks are marked by mottles as much as a quarter of an inch across, caused by the diagenetic growth of alteration minerals. The beds are composed of the following constituents: (a) 30 to 50 percent plagioclase grains, clear labradorite or albite clouded with pumpellyite inclusions; (b) 40 to 70 percent rock fragments of originally hyalopilitic or vitrophyric texture but now zeolitized and chloritized: (c) 3 to 6 percent augite grains; (d) 1 to 3 percent fragmental calcite grains; and (e) 0 to 1 percent admixtures of quartz grains. Most grains are subangular to subrounded, although a few lithic fragments have the shapes of blocky andesitic shards (see figure 24). Many of the strata are probably only slightly reworked marine tuffs, but they grade laterally to softer tuffaceous andesitic sandstones, some of which contain abundant chert, quartz, and calcite grains and all of which display more distinct stratification. Like the similar rocks of Hyde Formation, the whole assemblage can be described texturally as moderately sorted volcanic sandstone. Diagenetic changes are marked. Compaction and deformation of lithic grains are pronounced in many of the rocks. Some of the better-sorted andesitic sandstones contain abundant calcareous cement. In noncalcareous rocks, the diagenetic growth of new minerals such as albite, pumpellyite, celadonite, and zeolites is widespread. Some of the mineralogic changes in medium-grained volcaniclastic rocks from Freeman Creek have been described by Dickinson (1962b).

Intercalated between the layers of massive volcaniclastic rock are sequences of thin-bedded, greenish volcaniclastic siltstone and mudstone. The rocks are blocky, contain graded volcaniclastic layers, and closely resemble the strata of the middle member of type Snowshoe Formation into which they pass laterally around the plunging nose of Mowich upwarp. The finer-grained strata are especially abundant in the lower 500 to 1,000 feet of Basey Member.

In the western part of the area, two porphyro-aphanitic andesite lava flows occur within Basey Member (figure 21). One flow, as much as 200 feet thick, occurs at the base of the member and the other, up to 100 feet thick, occurs about 1,000 feet above the base. Both flows are widely distributed, the basal flow occurring in the type area and in Smith Basin, and the upper flow in the type area and near the south end of the area in sec. 26, T. 18 S., R. 25 E. The flows grade locally to flow breccia with a calcareous matrix. The rocks consist of labradorite phenocrysts (20 to 30 percent), augite microphenocrysts (3 to 5 percent), hypersthene microphenocrysts (0 to 1 percent), and olivine (?) pseudomorphs (1 to 3 percent) set without preferred orientation in a hyalopilitic groundmass (60 to 75 percent) of andesine and clinopyroxene imbedded in brownish glass or devitrified glass. Residual glass has an index of 1.53 to 1.56, suggesting an andesitic composition.

Beds of bright green or gray flinty aphanitic tuff, each 5 to 20 feet thick, occur sporadically in Basey Member, particularly in the northeast part of Pine Creek downwarp. The rocks contain about a third of angular plagioclase crystals (0.03 to 0.1 mm) set in a felsitic groundmass displaying ghosts of shards. Most such layers are entirely massive, but some contain laminations and cross laminations half an inch to

TABLE 9. Fossils from Warm Springs, Basey, and Shaw Members of Snowshoe Formation near Suplee and the middle member of Snowshoe Formation near Izee.
(Identifications by R. W. Imlay of U. S. Geological Survey)

Locality [1,2]	V149	V164	V163	V 18	V166	V403	V168	D 94	D 95	D 96	D 97	D 98
Member	WARM SPRINGS											
Location												
--¼ of	SW	SE	NW	SE	SE	SW	NE	SE	NE	NE	NE	SE
--¼ of	SW	NW	NE	NE	NW	SW	NW	SE	SW	SW	NW	NW
Section	8	25	34	30	29	29	32	28	34	34	3	3
Township (S.)	17	17	17	18	18	18	18	18	18	18	19	19
Range (E.)	27	26	26	26	26	26	26	26	26	26	26	26
Ammonites:												
Emileia(?) sp.	----	----	----	----	----	----	----	x	----	----	----	----
Euhoploceras sp. juv.	----	----	----	----	x	----	----	----	----	----	----	----
Holcophylloceras sp.	x	----	----	----	----	----	----	----	----	----	----	----
Lissoceras sp.	----	----	----	----	----	----	----	----	----	----	----	----
Papilliceras(?) sp.	----	----	----	----	----	----	----	----	----	----	----	----
Papilliceras cf. P. papillatum (Buckman)	----	----	----	x	----	----	----	----	----	----	----	----
Parabigotites sp.	----	----	x	----	----	----	----	x	----	x	----	x
Sonninia sp. juv.	----	----	----	----	----	----	----	----	----	----	----	----
Stemmatoceras sp.	----	----	----	x	----	----	----	----	x	----	----	----
Stephanoceras sp.	----	----	----	x	----	----	?	----	----	----	----	----
Stephanoceras sp. juv.	----	----	----	----	----	----	----	----	----	----	----	----
Stephanoceras (Skirroceras) sp.	----	----	----	----	----	----	----	----	----	----	----	----
Stephanoceras (Skirroceras) cf. S. leptogyrale (Buckman)	----	----	----	----	----	----	----	----	----	----	----	----
Witchellia sp.	----	----	----	----	----	x	----	x	x	----	----	----
Witchellia sp. juv.	x	x	----	x	----	x	----	----	----	----	----	----
Witchellia cf. W. zugophorus (Buckman)	----	----	----	----	----	----	----	----	----	----	x	----
Witchellia cf. W. felix (Buckman)	----	----	----	----	----	----	----	----	----	----	----	----
Pelecypods:												
Ostrea sp.	----	----	----	----	----	----	----	----	----	----	----	----
Posidonia ornati (Quenstedt)	x	x	----	----	----	----	----	x	x	----	----	----

Locality [1,2]	V402	V401	V170	V169	V147	V146	V412	D 99	D100	D101	V230	V138	D102	D103	D114	D118	D130	D119
Member	BASEY										SHAW		MIDDLE MEMBER					
Location																		
--¼ of	NE	NW	NW	SW	NW	NE	SE	SE	SE	NE	NE	SW	SE	SW	NE	SW	SE	NE
--¼ of	NE	NW	SW	SW	SE	NE	NW	SE	NW	SW	SE	NW	NW	NW	NE	NW	NE	SW
Section	13	23	24	24	28	33	13	28	34	3	14	24	15	15	31	11	1	31
Township (S.)	17	17	17	17	17	17	18	18	18	19	17	17	18	18	17	17	17	16
Range (E.)	26	26	26	26	26	26	25	26	26	26	26	26	27	27	28	28	28	29
Ammonites:																		
Emileia(?) sp.	x	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Euhoploceras sp. juv.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Holcophylloceras sp.	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----
Lissoceras sp.	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----
Papilliceras(?) sp.	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----
Papilliceras cf. P. papillatum (Buckman)	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Parabigotites sp.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Sonninia sp. juv.	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----
Stemmatoceras sp.	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----
Stephanoceras sp.	----	----	----	?	?	----	----	x	----	----	----	----	----	----	----	----	x	----
Stephanoceras sp. juv.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Stephanoceras (Skirroceras) sp.	----	x	x	----	----	----	----	----	----	----	x	----	x	----	----	----	----	x
Stephanoceras (Skirroceras) cf. S. leptogyrale (Buckman)	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----
Witchellia sp.	----	----	----	----	----	?	----	----	x	----	----	----	----	----	x	----	----	----
Witchellia sp. juv.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Witchellia cf. W. zugophorus (Buckman)	----	----	----	----	----	----	x	----	----	x	----	----	----	----	----	----	----	----
Witchellia cf. W. felix (Buckman)	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x
Pelecypods:																		
Ostrea sp.	----	----	----	----	----	----	----	----	----	----	----	x	----	----	----	----	----	----
Posidonia ornati (Quenstedt)	----	----	----	----	----	----	x	----	----	x	----	x	----	x	----	x	----	----

1 See Plate I for map location.
2 Localities listed from north to south within each member near Suplee and from west to east in middle member.

an inch apart. In places, these altered tuffs have been almost entirely replaced by pale tan or buff laumontite to form massive layers as much as 20 feet thick. The interlocking laumontite crystals are sieved anhedral individuals 1 to 2 mm in diameter, each containing myriads of dusty inclusions.

Contacts

The basal contact with Warm Springs Member is placed at the base of the lower andesite lava where it is present. Elsewhere, the contact is broadly gradational and can be drawn only with difficulty, for it is typically located within a nonresistant sequence of fine-grained rocks. It is placed at the lowest horizon of tough, brittle, green, laminated, fine-grained volcaniclastic strata, or rarely at the lowest massive, coarse volcaniclastic layer, and is drawn so as to exclude beds of those types from the underlying softer, darker lutites of Warm Springs Member. The upper contact with Shaw Member is located in similar fashion.

The coarser volcaniclastic strata of Basey Member are remarkably similar to the typical rocks of Hyde Formation. The two units can be distinguished readily in the field or in thin section, because the andesitic debris in Basey Member includes a few percent of bright orange and red shards, now largely devitrified. These brightly colored grains can be spotted as tiny red flecks with a hand lens and, in our experience, serve as an infallible field criterion to distinguish Basey rocks from Hyde rocks. In thin section the task is easier: most rock fragments in Basey Member are colored brownish, whereas most rock fragments in Hyde Formation are partly replaced by chlorite and celadonite and hence have a greenish cast.

Fossils and age

Basey Member is only sparingly fossiliferous. Collections from 10 widely spaced localities (table 9) all substantiate assignment of the unit to the middle part of the Bajocian age (Middle Jurassic) and suggest that it belongs to the Otoites sauzei Zone (R. W. Imlay, written communication, 1963). Of the forms present, Papilliceras and Witchellia are unknown above that zone, but Stemmatoceras and Skirroceras are uncommon below that zone.

Shaw Member (Jssh)

The new name "Shaw Member of Snowshoe Formation" is here proposed for the sequence of gray shale with minor limestone and sandstone intercalations that conformably overlies Basey Member in Pine Creek downwarp. The strata crop out best at the northeast end of the downwarp, where they are typically developed in exposures near the mouth of Shaw Creek in sec. 24, T. 17 S., R. 26 E. The top of the unit is nowhere exposed and less than 1,000 feet are present within the area mapped. The member is nonresistant to erosion and generally exposures are poor.

Lithologic description

Shaw Member consists dominantly of gray or dark brownish-gray, platy to fissile shale that weathers to small gray flakes and chips. Some fissile green shale and thin beds of hard gray calcareous mudstone, siltstone, and sandstone occur locally. Ellipsoidal gray calcareous concretions, some fossiliferous, are concentrated along certain horizons. Widely spaced brown or brownish gray sandy calcarenite and gray microcrystalline limestone beds a foot or two thick form about 5 percent of the member. Scattered beds of green volcaniclastic sandstone occur in the lower part of the member.

Fossils and age

Only two localities yielded diagnostic fossils (table 9). The ammonite genera Sonninia, Stemmatoceras, and Stephanoceras show that the member belongs to the middle part of the Bajocian Stage (Middle Jurassic). The subgenus Skirroceras suggests the Otoites sauzei Zone (R.W. Imlay, written communication, 1957).

Origin of Snowshoe Formation

The patterns of lithologic variation in Snowshoe Formation within the area point to a complicated depositional history. The rock record suggests four general interpretations: (1) That the sequence in the Suplee district on the west was deposited during the Bajocian Age on a relatively shallow platform which had been emergent during the latest Toarcian (Early Jurassic) or earliest Bajocian (Middle Jurassic) Ages; (2) that the sequence in the Izee area on the east was deposited in a relatively deeper basin separated from the "Suplee platform" by a sloping "hinge" located near the present axis of Mowich upwarp; (3) that much of the detritus in the formation was derived from contemporaneous volcanic eruptions; and (4) that Silvies Member, lying largely outside the area to the east, is a thick volcaniclastic wedge deposited on a slope leading out of the "Izee basin" toward an eastern rise of volcanic construction.

Lower member and Weberg and Warm Springs Members

In the Izee district, the conformable lower contact with Hyde Formation and the local occurrence of late Toarcian fossils in the basal 100 feet of the Snowshoe Formation suggest continuous deposition from late Early Jurassic into Middle Jurassic time. The homogeneous lower member of the type Snowshoe, composed of 500 to 750 feet of dark lutites, suggests that quiet and probably slow deposition of suspended andesitic silt, clay, and pelagic organic remains occurred more or less continuously in the "Izee basin" from late Toarcian to mid-Bajocian time. The whole tract of country from Big Flat to Bear Valley, a distance of 20 miles, probably experienced the same colorless history.

Conditions were quite different in the Suplee district, where the oldest strata of the Snowshoe Formation are fossiliferous sandstones and limestones of the Weberg Member. The Weberg Member is of Bajocian age and strata correlative with the basal 100 feet or so of the lower member of the Izee district are absent. An unconformable lower contact, basal conglomerate and coarse sandstone, good sorting of the sandstones and limestones, and oyster beds and voluminous remains of other thick-shelled pelecypods show that the Weberg Member was deposited in shallow, neritic waters of a transgressive sea. The epiclastic detritus in the Weberg suggests local derivation from older Mesozoic and Paleozoic strata like those upon which the member rests. The Warm Springs Member, which rests conformably on the Weberg, is correlative with and similar in lithology to the upper part of the lower member of the type Snowshoe in the Izee district.

The record of the rocks shows, therefore, that while the lower member was deposited in the "Izee basin," the following sequence of events took place only a few miles to the west: (1) The "Suplee platform" was formed by tectonic warping and the progressive westward removal of Mowich Group and unknown thicknesses of older rocks by erosion; (2) the neritic terrigenous and calcarenitic sands of Weberg Member were spread as an irregular sheet over the erosional surface by renewed transgression; and (3) a regime of dark lutite sedimentation similar to that which prevailed throughout the deposition of the lower member in the "Izee basin" was finally established near mid-Bajocian time (probably time of deposition of *Sonninia sowerbyi* Zone) with the deposition of Warm Springs Member.

The laminated fine-grained sediments of the lower member in the "Izee basin" and Warm Springs Member on the "Suplee platform" were doubtless deposited in quiet water. The depth of water, however, need not have been great and, possibly, was still within the neritic zone. Abundant *Posidonia* in both members suggest the presence of sessile seaweeds to which these small pelecypods could have attached themselves with byssal threads. The abundance of dark organic matter perhaps lends credence to this interpretation. Occasional specimens of *Ostrea* in calcareous beds and rare *Lingula* in mudstone beds of Warm Springs Member offer corroborating evidence of shallow waters on the "Suplee platform," evidence that is lacking in the lower member of the "Izee basin." It seems likely that Warm Springs Member may have been deposited in shallower water several miles closer to shore than was the lower member near Izee.

Middle member and Silvies and Basey Members

Much of the terrigenous detritus in the lutites of lower Snowshoe Formation is andesitic debris similar to that contained in older and younger Jurassic volcaniclastic strata. The lowest Middle Jurassic rocks that show clear evidence of contemporaneous volcanic activity, however, are assigned to the middle part of the Bajocian Stage, possibly including only the Otoites sauzei Zone. This suggests that the andesitic volcanism contemporaneous with the deposition of the Lower Jurassic Mowich Group subsided in latest Toarcian or earliest Bajocian time and was not renewed until mid-Bajocian time. The predominantly volcaniclastic middle Bajocian members of Snowshoe Formation are Basey Member on the "Suplee platform," the middle member in the "Izee basin," and Silvies Member farther east.

Basey Member includes submarine lavas and flow-breccias, massive tuffs, and volcanic sandstones and siltstones. The following observations suggest that Basey Member was deposited in relatively shallow waters: (1) Off the edges of submarine flows, debris from the flows has been reworked as coarse clastic tongues intercalated within finer volcaniclastic strata; (2) some of the volcanic sandstones are well-sorted calcareous andesite arenites, a lithology suggestive of working in shallow water by currents of high energy; (3) the scattered occurrence of Posidonia in laminated volcaniclastic siltstones suggests possible shallow waters; and (4) scattered oysters in the overlying Shaw Member suggest shallow waters, and indicate the likelihood that the volcanic construction of Basey Member kept pace, roughly speaking, with the gradual subsidence of the "Suplee platform," so that water depths remained shallow to moderate throughout its deposition.

Basey Member lenses out rapidly toward the east into finer grained strata of the middle member of the "Izee basin"; the belt of intertonguing near the present axis of Mowich upwarp is interpreted as a limit imposed by deepening waters on the offshore movement of coarse volcaniclastic debris. Judging from the eastward wedging-out of the member and the occurrence of Basey lavas and flow breccias in the west, the locus of Basey volcanic activity lay to the west of the Suplee district. Feeders for the lava flows or vents for pyroclastic eruptions have not been identified, but a sill of analcite-bearing diabase intruded along the unconformable contact between Paleozoic rocks and Weberg Member in the SE$\frac{1}{4}$ sec. 25, T. 18 S., R. 25 E. may be a manifestation of minor intrusive activity which accompanied the Middle Jurassic eruptions.

Silvies Member, though generally similar in overall composition to both Basey Member and Hyde Formation, gives evidence by its stratification of a radically different mode and environment of deposition. The conspicuous graded bedding observed in beds of all grain sizes from silt to gravel is strongly suggestive of deposition by turbidity currents. Although the equally characteristic scour features and widespread lamination are not considered typical of turbidity current deposits by many geologists, Gorsline and Emery (1959, p. 285-286) have reported exactly analogous stratification features in Quaternary subsea fan turbidites in the San Pedro and Santa Monica Basins off southern California. It seems likely that scour and lamination might well be common in deposits laid down by turbidity currents of high energy in sites where turbidity currents could spread bed load as well as suspension load along their course of travel. The facies relations of Silvies Member are suitable for the interpretation that it is a wedge-shaped apron of andesitic detritus deposited by turbidity currents moving downslope toward the "Izee basin" from a constructional volcanic pile lying more than 25 miles east of Izee beyond Seneca. The following data are offered in support of the hypothesis:

(1) Silvies Member thickens markedly toward the east. It grades laterally to lutite near Lewis Creek within the area mapped in detail, but is about 1,500 feet thick at its type locality on Silvies River, less than 5 miles to the east. Reconnaissance suggests that the member is in excess of 5,000 feet thick near Seneca on U.S. Highway 395, about 15 miles east of the type locality. These data indicate an eastward thickening of the volcanic wedge at the rate of 250 to 500 feet per mile.

(2) Silvies Member coarsens to the east, as conglomeratic layers become more abundant.

(3) There is some evidence that scour may be appreciably more intense toward the east, but no statistically significant data have been gathered.

(4) To the east, near Seneca, andesitic lavas and flow-breccias indistinguishable from those of Nicely Formation and Basey Member are interstratified with andesitic conglomerates and sandstones referable with confidence to Silvies Member.

Silvies Member grades westward by intertonguing into the middle member of type Snowshoe Formation, a sequence of interbedded dark lutite and volcaniclastic siltstone. The volcaniclastic siltstone occurs in graded layers and contains andesitic debris similar to that of Silvies Member, except for the finer average grain size. The graded volcaniclastic siltstone layers of the middle member of type Snowshoe Formation are interpreted as the deposits of the disperse distal ends of turbidity flows as they slowed and stopped in the "Izee basin" after traversing the area of deposition of Silvies Member. The dark intercalated lutites in the middle member and in Silvies Member are interpreted as the normal pelagic deposits of suspended terrigenous detritus and organic remains that settled to the floor and slopes of the "Izee basin" during the relatively long intervals between the arrival of coarser volcaniclastic sheets as turbidity currents.

Upper member and Shaw Member

In comparison to the underlying members, little is known of the upper member and the Shaw Member of Snowshoe Formation. Shaw Member of the "Suplee platform" appears largely to interfinger with and to be equivalent in age to the upper part of Basey Member. The upper member of the "Izee basin," however, seems to be a conformable succession, with beds near the base assigned to the upper part of the Bajocian Stage and beds near the top assigned to the Callovian Stage. Rare oysters in calcareous beds of both members suggest shallow-water environments.

Progressive westward overlap of the upper member by the unconformably overlying Trowbridge Formation along the southeast flank of Mowich upwarp is regarded as evidence that renewed upwarping of the "Suplee platform" occurred after the deposition of Snowshoe Formation. The record of both pre-Snowshoe and post-Snowshoe uplift and erosion of the Suplee district strengthens the interpretation of Snowshoe facies relationships in terms of western shelf deposits and eastern basinal deposits.

TROWBRIDGE and LONESOME FORMATIONS

Along South Fork of John Day River southeast of Izee, a conformable sequence of Jurassic rocks about 12,500 feet thick rests unconformably on Snowshoe Formation and forms the trough of Lonesome syncline. The sequence is composed dominantly of noncalcareous, moderately sorted lithic (volcanic) sandstone and dark mudstone. Trowbridge Formation, dominantly mudstone, forms the lower 20 to 25 percent of the sequence and the remainder is interbedded sandstone and mudstone of Lonesome Formation. In contrast to much of the underlying thinner Jurassic section, both units are only sparingly fossiliferous.

Trowbridge Formation (Jt)

The name Trowbridge Formation was established by Lupher (1941, p. 263) for the thick sequence dominated by black lutite with pencil fracture that overlies Snowshoe Formation along South Fork of John Day River. The type area is along the valley of South Fork in the vicinity of Rosebud Creek. Exposures form a continuous band that lies within the complex homocline between Mowich upwarp and Lonesome syncline, from Snow Mountain at the south edge of the area northeast for 12 miles to Officer Creek at the eastern edge of the area. The strata crop out in barren hills of subdued relief. Reconnaissance indicates that additional exposures are present in the headwaters region of Silvies River as far east as Bear Valley, 5 miles from the edge of the area mapped. Within the area mapped, Trowbridge Formation thickens toward the northeast at a rate slightly less than 100 feet per mile, from 2,250 feet on Flat Creek below Snow Mountain to 2,750 feet on South Fork in the type area and to 3,250 feet on Lewis Creek. The basal contact is sharp between laminated mudstone, siltstone, and sandstone of the underlying Snowshoe Formation and massive black or green mudstone of basal Trowbridge Formation.

Members

Trowbridge Formation is here subdivided into three newly named, lithologically distinctive, and mappable members, in ascending order as follows:

(a) Rosebud Member (Jtr) of massive black and green mudstone; type locality in type area of formation on spur along line between SW$\frac{1}{4}$ sec. 28 and SE$\frac{1}{4}$ sec. 29, T. 17 S., R. 28 E.; thickness 400 to 500 feet except southwest of Sheep Creek, where it is progressively onlapped by overlying member; name from Rosebud Creek.

(b) Officer Member (Jto) of massive black and green mudstone with 35 to 55 percent intercalated resistant volcaniclastic rocks; type locality in Cottonwood Draw (tributary to Rosebud Creek) in the NW$\frac{1}{4}$ sec. 22, T. 17 S., R. 28 E. (see Appendix H for generalized section at the type locality); thickens to the northeast at 50 feet per mile from 100 feet on Flat Creek to 400 feet on South Fork, then continues with but slight change to 500 feet on Lewis Creek; name from Officer Creek.

(c) Magill (Ma-gill') Member (Jtm) of massive black mudstone with sparse and thin intercalated beds of calcareous sandstone and limestone; type locality is type area of formation; about 2,000 feet thick; name from Magill Creek in type area in NE$\frac{1}{4}$ sec. 32, T. 17 S., R. 28 E.

The units are mapped as members because only the presence of resistant volcaniclastic strata, probably restricted in extent, serves to distinguish Officer Member and to set it surely apart from the other two. Officer Member thins rapidly toward the southwest and may not persist far in that direction. Toward the northeast, however, reconnaissance indicates its presence as far away as Bear Valley 5 miles beyond the area mapped.

Rosebud Member (Jtr)

Rosebud Member is composed dominantly of hard, faintly laminated dark mudstone with characteristic pencil fracture. Though massive in appearance, some exposures display indistinct bedding planes 3 to 6 inches apart. The rock is composed chiefly of illitic (?) clay and silt of volcanic derivation. The volcanic silt consists of plagioclase crystal fragments and tiny devitrified brownish rock fragments, the latter intergrown on their margins with the surrounding clay. Less abundant angular quartz grains may be volcanic or an admixture of nonvolcanic detritus. The colors of the rocks vary from black to green depending upon the proportion of disseminated dark organic material present. Recrystallized chalcedonic tests of radiolarians are dispersed in small quantities throughout the terrigenous detritus. In the type locality, a 50-foot sequence of soft, gray-green, biotitic, tuffaceous (?) siltstone and interlayered fine-grained sandstone occurs in an interval between about 35 and 85 feet below the top of the member. Two horizons of ellipsoidal calcareous concretions, each 1 to 3 feet in diameter, occur 20 and 40 feet above the base in the type locality.

Officer Member (Jto)

Officer Member is about half black and green mudstone seemingly identical to that in Rosebud Member. The other half is made up of resistant volcaniclastic strata. The two rock types occur in alternating sequences, each 25 to 100 feet thick, that give rise to a ridge and swale topography. Within the mapped area, the basal resistant sequence is a ledge-forming felsite tuff unit (see figure 25) informally named "Buck Creek felsite tuff" (Dickinson, 1962a), that maintains a thickness of 60 to 75 feet throughout the area east of Sheep Creek, but thins rapidly to a feather edge to the west. Resistant sequences higher in the member, of which three are prominent and traceable from South Fork to Lewis Creek, are dominantly moderately sorted volcanic sandstone, but commonly contain felsite tuff in their upper portions. The upper and lower contacts of Officer Member are placed at the top and bottom, respectively, of the highest and the lowest sequences of hard, resistant volcanic sandstone or felsite tuff.

The felsite tuffs of Officer Member are hard, tough microcrystalline rocks of stony or sugary aphanitic appearance in hand specimen, and they break with difficulty on subconchoidal fractures. Thin layers of softer tuffaceous mudstone are visible as minor widely spaced intercalations in boldly outcropping ledges. Much of the rock is massive but some is indistinctly laminated, the laminated rock occurring in sequences from a few inches to 3 feet in thickness spaced at intervals of 2 to 10 feet in the massive rock. Cross-lamination is rare but is present locally. The tuffs were deposited as accumulations of vitric shards including minor quantities of andesine, quartz, and biotite crystal fragments. A sequence of diagenetic alterations has thoroughly changed the original mineralogy and chemistry of the tuffs (for details, see Dickinson, 1962a). Consequently, four varieties of felsite representing four successive stages of alteration are now seen in outcrop: (1) Dark green or, if organic material is abundant, black heulandite-rich

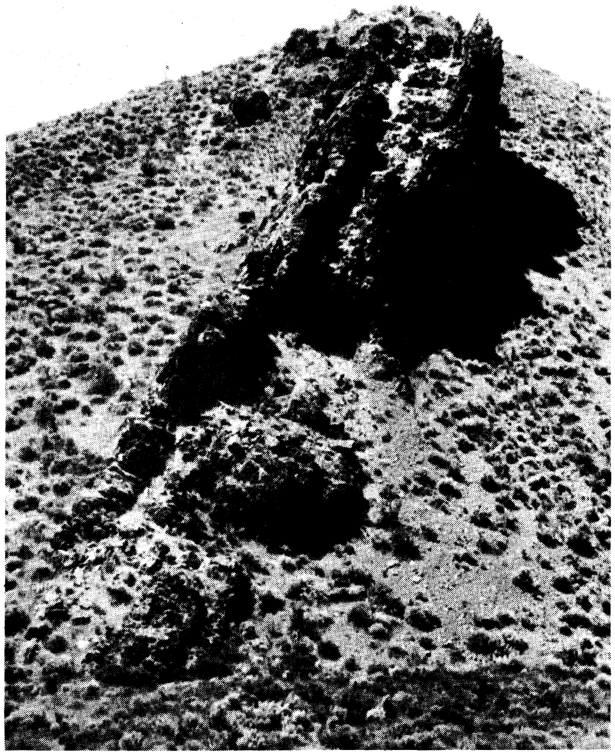


Figure 25. Bold ledge outcrop of basal felsitic marine tuff ("Buck Creek felsite tuff") sequence of Officer Member of Trowbridge Formation on Buck Creek.

Figure 26. Partly albitized volcanic graywacke, Officer Member of Trowbridge Formation; subangular detrital grains are mainly volcanic plagioclase and felsic dacitic lithic fragments; note pressolved grain contacts and distorted clayey films of matrix (plain light; about 25 X).

rhyodacitic rock resembling argillite and representing the least altered phase is common; (2) soft tan or cream laumontite-rich rock is rare and occurs chiefly as compound porphyroblasts, spheroidal nodules, and irregular concretionary bodies in the heulandite-rich rock; (3) hard, brittle, albite-rich quartz keratophyric rock of pale green, gray, tan, or cream hue is most abundant; and (4) flesh-pink adularia-rich rock is rare and occurs chiefly as veinlets and irregular replacement bodies in albite-rich rock.

Relict vitroclastic textures are well shown in thin section by all the rocks (for illustrations, see Dickinson, 1962a). Primary quartz crystal fragments persisted unchanged throughout the alterations. Other constituents are more or less recrystallized, as follows: Plagioclase is fresh in heulanditic rocks, but is altered to laumontite in laumontitic rocks and to albite and pumpellyite in albitic rocks; biotite is fresh in zeolitic rocks but is altered to chlorite in feldspathic rocks; glass shards and triturated glassy dust are altered to zeolites plus celadonite and chlorite in zeolitic rocks, and to quartz plus albite or adularia with lesser chlorite in feldspathic rocks. The altered tuffs are of considerable petrologic interest in that they represent a clear-cut case of the metasomatic conversion of rhyodacitic ash to quartz keratophyre felsite during diagenesis (see Dickinson, 1962a).

The volcanic sandstones of Officer Member are moderately sorted, gray to black, dacitic graywackes containing 10 to 15 percent dark, clayey, interstitial detrital matrix now recrystallized to a murky aggregate of largely chloritic materials (see figure 26). The sand grains are chiefly angular and subangular fragments of plagioclase crystals and felsic volcanic rock fragments, originally vitrophyric and hyalopilitic dacite but now largely recrystallized to spherulitic and felsitic quartz keratophyre. Less abundant quartz grains may have come in part from the same volcanic sources, but scattered argillite and chert grains represent admixtures of nonvolcanic detritus or accidental pyroclastic debris. Minor devitrified shards, generally smaller than the bulk of the sand grains, give evidence of contemporaneous volcanism. Moreover, the volcanic sandstone sequences commonly grade to felsitic tuff in their upper portions. The interpenetration of adjacent grains along sutured grain boundaries and the distortion of thin clay films between grains give evidence of extensive pressolution during compaction.

The nature of the bedding in the volcanic sandstone sequences is distinctive. The sequences are typically 25 to 50 feet thick individually and are laminated throughout. Alternating layers $\frac{1}{4}$ to $\frac{1}{2}$ an inch thick are composed of dark, relatively poorly sorted, dominantly lithic fragments, and light-colored, relatively well-sorted, dominantly feldspathic fragments. Despite the persistent lamination, there is a progressive and continuous gradation in grain size from coarse, even pebbly, sandstone at the base of each unit to fine-grained sandstone or siltstone and finally to felsitic fine tuff and dark mudstone at the top and above. As the grain size lessens in an upward direction, so the scale of lamination grows progressively finer in a sympathetic manner, from laminae as coarse as 1 inch near the base to laminae as fine as 1/8 of an inch near the top. In many places, the lowermost foot or two of each sequence is massive, without lamination, and on the soles of these basal massive layers flute casts, indicating bottom currents flowing toward the southwest, and load casts are visible in artificial cuts.

Magill Member (Jtm)

The dominant rock type of Magill Member is black mudstone similar to the dark mudstones of Rosebud Member. Within the mudstones are intercalated thin, graded beds of dark volcanic sandstone, commonly calcareous, and knobby, lenticular beds of black argillaceous limestone that locally pass laterally into chains of subspherical concretions aligned parallel to bedding. Isolated black limestone concretions are dispersed widely in the mudstones. The limestones appear to have formed by diagenetic replacement of terrigenous mudstone and siltstone, as shown by residual plagioclase grains and calcareous pseudomorphs of radiolarians commonly visible in thin section. The sandstones are poorly sorted, fine grained, and composed dominantly of dacitic or andesitic detritus, chiefly quartz, biotite, plagioclase, and brownish volcanic rock fragments.

Origin

Rosebud Member, although fine grained, is demonstrably a transgressive unit: Snowshoe Formation beds lying unconformably beneath its base are truncated at the rate of 250 stratigraphic feet per mile between South Fork and Big Flat 5 miles to the west. In the same distance, Rosebud Member thins to a feather edge as a result of onlap, and the conformably overlying Officer Member finally lies directly on Snowshoe Formation. The depositional environment of Rosebud Member is not definitely known, but its fine grain size, transgressive nature, lack of fossils, and black color suggest that it was deposited in a lagoon or broad bay, perhaps brackish or even euxinic, off a lowland coast.

The tuffaceous mudstones and sandstones and felsitic tuffs of Officer Member record a period of episodic dacitic volcanism. In times of quiescence in the volcanic sources, fine muds continued to accumulate. Northeastward thickening of the whole member and, in general, of its individual volcaniclastic sequences, suggests that the volcanic sources lay in that direction. The fine tuffs, such as "Buck Creek felsite tuff," are composed of ash so pure and so clearly vitroclastic as to suggest deposition from successive showers of airborne ash settling from eruption clouds into quiet waters. Minor redistribution of ash by bottom currents is indicated by faint lamination in parts of the deposits and by local cross-lamination.

The volcanic sandstones are more enigmatic. Slight abrasion of the particles, lack of vitroclastic texture except for minor amounts of admixed shards, admixed nonvolcanic epiclastic detritus, and the distinctive bedding structures described above all suggest hydraulic transport for an appreciable distance. The manner in which the sandstone layers commonly grade upward to felsitic tuffs suggests that the arrival of volcanic sand in the site of deposition was linked to episodes of explosive volcanism. Evidence as to the mode of transport of the sands is inconclusive, but it seems conceivable that they were deposited by turbidity currents triggered by the oversteepening of submarine slopes in the volcanic source area during major periods of eruptive activity. If so, the presence of the sandstones, which are most abundant and coarsest east of South Fork, suggests deepening waters here, even though Officer Member rests unconformably on Snowshoe Formation 5 miles to the west. On Flat Creek, all of the resistant volcaniclastic strata are fine tuff, and this lack of sandstone in the western thin extremity of the member is at least consistent with the hypothesis of an eastern source for the sand.

From its lithology and that of the overlying Lonesome Formation, Magill Member appears to have been deposited in deep, offshore waters where quiet settling of fine muds was interrupted at rare intervals by the influx of thin turbidity flows carrying volcanic sand and silt.

In summation, Trowbridge Formation is interpreted to have been formed by the fine clastic deposits laid down on an erosion surface of low relief as it foundered rapidly beneath the sea. The supply of clastic detritus apparently did not keep pace with the sinking, so that waters deepened during Trowbridge deposition. Contemporaneous rhyodacitic volcanism contributed appreciable sediment to the basin, largely during periodic outbursts of explosive eruption.

Lonesome Formation (Jlo)

The name Lonesome Formation was proposed by Lupher (1941, p. 265) for the thick sequence of interbedded gray sandstone and black mudstone at the top of the Jurassic sequence exposed along South Fork of John Day River. The unit underlies about 20 square miles within the area, entirely in the trough of Lonesome syncline. Lupher designated the rugged hills north of Flat Creek between Spoon Creek on the west and South Fork of John Day River on the east as the type locality. The well-exposed section along the steep-walled canyon of South Fork is here designated the type section, for the greatest known thickness of approximately 10,000 feet is present there, although the stratigraphic top is not exposed. The formation rests conformably with gradational contact on Trowbridge Formation. The contact mapped is not the same as that defined by Lupher (1941), who chose a particular pebbly sandstone bed on South Fork in the north limb of Lonesome syncline as the base of Lonesome Formation. This bed he erroneously correlated with a conglomerate bed much higher in the formation in the south limb of Lonesome syncline. Mapping discloses that the pebbly sandstone regarded as the base of the formation by Lupher is no different from a number of other similar beds within the unit. Accordingly, the basal contact was dropped approximately 1,500 feet to a horizon of significant lithologic change, and is here redefined as an arbitrary horizon at the base of the lowest massive gray sandstone bed in a continuous sequence of intercalated sandstone and mudstone. Beneath are the mudstones of Trowbridge Formation. A certain lack of precision in placing the contact is inevitable, owing to the gradational nature of the contact, which was caused by arrival of the first sheets of sand at different times in different parts of the site of deposition. Once well begun, however, intermittent sandstone deposition continued, so that the stratigraphic doubt at the contact is no greater than 25 to 75 feet, only 1 to 2½ percent of Trowbridge Formation and less than 1 percent of Lonesome Formation.

Lithologic description

Lonesome Formation is a singularly monotonous alternation of moderately sorted, graded sandstone beds, ranging from an inch or less to 10 feet or more in thickness, with massive, dark mudstone layers of about the same range in thickness. The two rock types are about equally abundant. Except for the appearance of pebble conglomerates in the upper few hundred feet of the exposed section, no systematic vertical changes in lithology were noted, even though the relative proportions of mudstone and sandstone vary erratically. Reconnaissance of Lonesome Formation exposures within an area of 200 square miles south of the Suplee-Izee district revealed no systematic lateral variations in lithology.

The sandstones of Lonesome Formation are hard, massive, gray rocks that form resistant ribs on hill slopes. Pale blue-gray on fresh surfaces and dull green, gray, or buff where weathered, their grain size ranges from coarse pebbly sand to fine silty sand. They are lithic (volcanic) graywackes in which the proportion of fine-grained detrital matrix interstitial to the sand grains ranges from 10 to 17½ percent. In most rocks, authigenic calcite cement in amounts as high as 5 percent occupies part of the interstitial areas. One-half to two-thirds of the framework grains are composed of plagioclase crystals, largely albitized, and andesitic rock fragments. The other grains present are chiefly quartz, chert, felsite, and argillite in variable but approximately equal proportions. Many of the softer argillaceous and volcanic fragments have been deformed between harder grains during compaction (see figure 27). The andesitic detritus in the rocks resembles the andesitic debris so common in older Jurassic units within the area. The remaining grains, including rare detrital limestone, are formed only of materials common in the Paleozoic rocks of central Oregon and in nearby Upper Triassic sandstones composed of reworked Paleozoic debris.

Near the top of the exposed section, several graded pebbly graywacke and pebble conglomerate beds occur. Nearly all the pebbles are hard, gray or green chert and felsite. In one thin section that was examined, the ratio of felsite grains to chert grains was 3 to 2.

The finer grained rocks of Lonesome Formation are dark colored, massive siltstones, mudstones, and claystones that contain abundant organic matter. Although constituent clay flakes display some degree of preferred orientation in thin section, no fissility was noted in the field.

Sedimentary structures

Many of the volcanic graywacke beds are distinctly graded upward from medium-grained or coarse-grained graywacke at their sharply defined bottoms to finer grained graywacke and lastly to mudstone (see figure 28). Within many of the beds the gradation is difficult to observe, because the abundance of volcanic rock fragments imparts an aphanitic appearance to rocks of any grain size. A systematic variation in grain size is typically best developed and certainly most visible in the upper parts of graywacke beds where they pass gradationally upward to mudstone. Grading is apparent in beds of graywacke that are from 1 inch to 10 feet in thickness. Some very thick beds of graywacke, a few rare ones more than 25 feet thick, appear completely massive in outcrop.

Bedding surfaces within the formation are parallel, even, and smooth except for the presence of sole markings on the bottoms of graywacke beds. The sole markings are especially well displayed along South Fork in the overturned strata of the upper part of the unit. Continuous, subparallel, linear groove casts form coherent patterns over areas as large as 10 square feet of the lower surfaces of beds. Flute casts and irregular flow markings are also common. One unusual group of lineations has the appearance of groove casts in reverse and may be longitudinal ripple marks.

Because of poor exposures, few measurements of the attitude of directional current lineations could be made. In 10,000 feet of section exposed along Antelope Creek and South Fork, well-exposed linear sole markings could be measured in only 20 separate outcrops. The beds from which the lineations were recorded were graphically restored to the horizontal by a single rotation, using the stereonet technique.

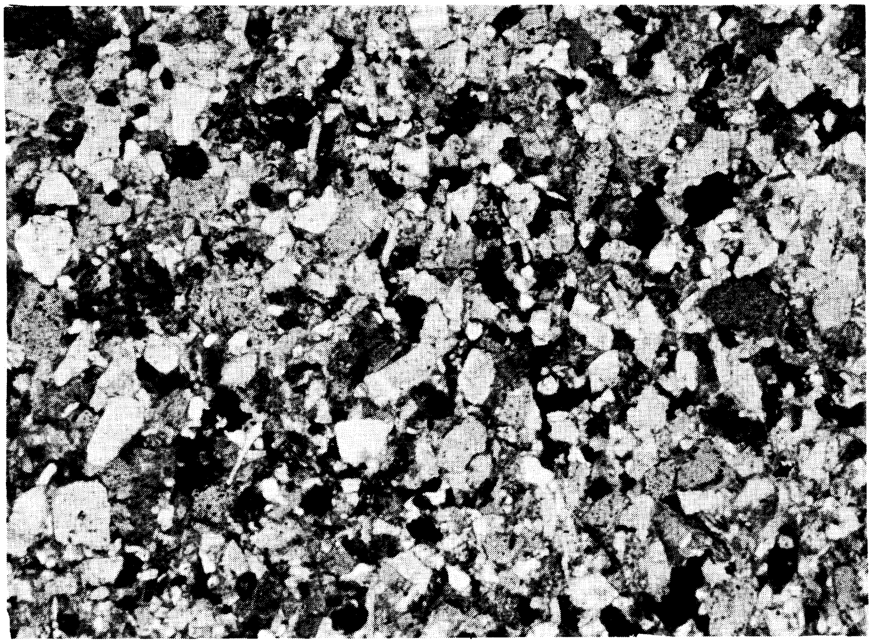


Figure 27. Albitized volcanic graywacke, Lonesome Formation; about two-thirds of grains are volcanic plagioclase and rock fragments; remainder are mainly chert, felsite, and argillite (plain light; about 35 X).

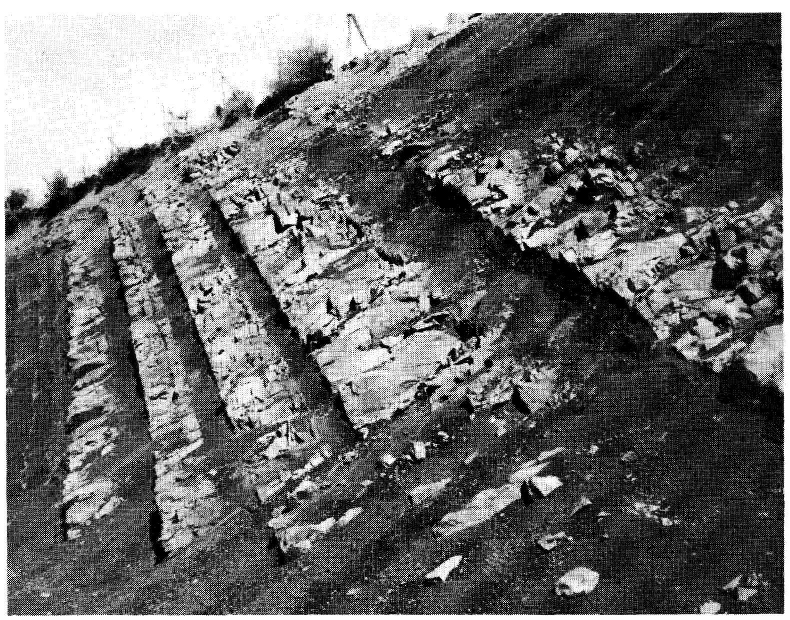


Figure 28. Graded volcanic graywacke beds (upright) and black mudstone of Lonesome Formation in roadcut on Antelope Creek.

The resulting azimuths of the current lineation trends were plotted on a rose diagram. The results show considerable scatter, perhaps because complex folding twisted beds, thus distorting reference axes. However, there is a strong suggestion that the depositing currents came from a northerly source and flowed in a southerly direction.

Origin

The cyclic interstratification of dark mudstone and volcanic graywacke in Lonesome Formation suggests that deposition of the sequence involved alternation of mud and sand supply. Characteristic graded bedding in volcanic graywacke layers suggests that sand reached the site of deposition in discrete pulses. The regular, parallel, and even character of bedding surfaces suggests that the pulses of sand arrived as widespread sheets of sediment-laden water. Abundant groove casts, flute casts, longitudinal ripples (?), and other sole markings of current lineation types suggest that the sand-laden sheets of water were moving along the bottom and were scouring the substratum before they began depositing volcanic sand upon it. The mud substratum was firm enough to preserve flow markings, but plastic enough to deform into small load-cast structures, many of them flute casts modified by sediment flowage.

The absence of slump structures and the scarcity of other evidence of deformation of unconsolidated sediments suggest that slopes were gentle in the site of deposition. This conclusion is supported indirectly by the nature of the graded bedding. Individual volcanic graywacke layers represent single, complete graded units whose basal contacts with mudstone are sharp, but whose upper contacts with mudstone are gradational. The absence of superposed graded units within any individual volcanic graywacke layers suggests that currents did not scour the bottom deeply. The absence of lamination in the graded graywacke beds, even in their uppermost portions, suggests that each graywacke layer was the result of a single, simple depositional event. Judging from these details of the bedding, the site of deposition may have been a flat, deep basin floor that extended outward from the base of a submarine slope upon which turbidity currents were generated to flow out on the basin floor and there to deposit their loads quietly as their velocity decreased. Thus, the mudstone layers may represent the accumulation of slowly settling clastic detritus dispersed in suspension throughout the basin waters, and the sandstone beds may denote the load of turbidity currents which arrived at intervals during the deposition of the unit.

Composition of the formation suggests a compound source area where rocks similar to older strata of the region were exposed. Indications of current direction suggest that the source may have lain to the north. Considering the great thickness of the unit, the implications are that the source may have been a tectonic highland which rose as an eroding welt while the site of deposition sank. The andesitic detritus in the sandstones may have been derived from pyroclastic blankets maintained by continuing volcanism in the source area.

Fossils and Age of Trowbridge and Lonesome Formations

The only fossils discovered in Trowbridge Formation were collected from the north slope of Flat Creek canyon in sec. 15, T. 18 S., R. 27 E., near the middle of Magill Member. They include the pelecypod *Arcomya* sp. (loc. D 120) and the lower Callovian (Upper Jurassic) ammonites *Gowericeras* cf. *G. spinosum* Imlay (loc. D 122) and *Lilloettia buckmani* (Crickmay) (loc. D 121). The Callovian ammonite *Xenocephalites* sp. was collected from Lonesome Formation at five localities (D 123 to D 127) along South Fork of John Day River. One specimen was specifically identifiable as *X. vicarius* Imlay (loc. D 124). The five localities are spaced stratigraphically from the lower part of Lonesome Formation along Antelope Creek to the trough of Lonesome syncline, in which the youngest beds known are exposed. As Callovian ammonites were also found in the upper member of type Snowshoe Formation below, consistent though admittedly sparse data indicate that the entire 12,500 feet of Trowbridge and Lonesome Formations are of Callovian age.

BERNARD FORMATION (Kb)

The new name "Bernard (Ber-nard') Formation" is here proposed for the Cretaceous beds exposed northwest of Suplee. The name is taken from the Andrew Bernard ranch on South Fork of Beaver Creek in the SE$\frac{1}{4}$ sec. 11, T. 17 S., R. 25 E. Strata typical of the unit are exposed near the Andrew Bernard ranch house, in Smith Basin, and north of Camp Creek near Soda Spring. The elongate outcrop belt, which occupies approximately 4 square miles, is largely obscured by soil, alluvium, and colluvium. The poor exposures preclude an accurate determination of the thickness, but geologic mapping indicates that as much as 1,500 feet of the formation may be present within the area. Bernard Formation rests with angular unconformity on Paleozoic, Upper Triassic, and Middle Jurassic strata and is overlain, also with angular unconformity, by Tertiary lavas and tuffs.

Lithologic description

Bernard Formation consists dominantly of yellowish-brown, calcareous and limonitic pebbly sandstone that grades locally to sandy "roundstone" conglomerate. Minor amounts of white and gray clayey sandstone, poorly consolidated gravel and sand, bentonitic clay, gray mudstone, and brown shale are also present in the sequence.

The pebbly or cobbly sandstone most characteristic of the formation occurs in massive units as much as 200 feet thick. The sand matrix is fine to medium grained and generally fairly well sorted. Many of the sands are tightly cemented by calcite, but others are friable and have large porosities and high permeabilities. The coarse fragments, commonly pebbles or cobbles but grading locally to small boulders, are generally well rounded and are dominantly aphanitic porphyry of intermediate composition (andesite?), chert, granitic rocks, and metaquartzite. In many of the sands and sandstones these coarse fragments are not in contact but "float" in the sand matrix.

Petrographic examination of two sandstones, both lithic arenites, yielded the following estimates of relative percentages of major allogenic grain types: quartz (10 to 30); chert and felsite (5 to 30); plagioclase (12 to 30); hyalopilitic andesitic (?) aphanite (30 to 35); and argillaceous sedimentary rocks (5 to 12). Traces of potash feldspar and metaquartzite are present. Prominent heavy accessory minerals include epidote group (1 to 5 percent), and traces of colorless garnet and blue-green hornblende.

Origin

Primary sedimentary features and the fauna of Bernard Formation suggest deposition of detritus moved principally in traction transport by currents sweeping a wave-washed shallow bottom. Cross-bedding, good sorting and rounding, the abundance of the thick-shelled marine pelecypod *Trigonia evansana*, and the transgressive stratigraphic relations of the unit are all suggestive of such an environment.

The detritus in the unit was derived from a compound source. Many of the lithic fragments were derived from the erosion of rock types similar to the Paleozoic, Triassic, and Jurassic strata exposed nearby. A number of the grain types, however, are not represented in the older sequences present in the area, and these give evidence of contributions from a provenance of silicic plutonic rocks and associated metamorphic rocks. This type of source contrasts strongly with the dominantly volcanic parentage of the pre-Cretaceous strata exposed in the area. Chief among the grain types that make their first appearance in any quantity in Bernard Formation are the following: (a) pebbles and cobbles of granitic rock; (b) metaquartzite fragments; (c) grains of plutonic quartz containing crystal inclusions, including acicular rutile

TABLE 10. Fossils from Bernard Formation.
(Identifications by D. L. Jones of U. S. Geological Survey, except as noted)

Locality[1]	V407	V409	V171	*
Stratigraphic position: (Est. ft. above base of fm.)	20-30	100-200	500-600	?
Location:				
--¼ of	NW	NW	SE	
--¼ of	SW	NW	NE	
Section	6	23	11	
Township (S.)	17	17	17	
Range (E.)	26	25	25	
Forms:				
Ampullina cf. A. pseudoalveata Packard	----	----	----	x
Anthonya cultriformis Gabb	x	x	----	x
Calva varians (Gabb)	----	----	----	x
Dentalium stramineum Gabb	----	----	----	x
Desmoceras (Pseudouhligella) sp.	x	----	x	x
Exogyra parasitica Gabb	----	----	----	x
Gervillia sp.	----	----	----	x
Hemiaster cf. H. californicus Clark	----	----	----	x
Homomya concentrica Gabb	----	----	----	x
Inoceramus sp.	----	----	----	x
Linearia multicosta (Gabb)	----	----	----	x
Meekia sp.	x	----	----	----
Ostrea malleiformis Gabb	----	----	----	x
Periplomya (?) oregonensis (Gabb)	----	----	----	x
"Tellina" sp.	x	----	----	----
Tenea inflata (Gabb) (?)	----	----	----	x
Trigonia evansana Meek	----	----	x	x
Trigonocallista cf. T. regina (Popenoe)	x	x	----	----
Turrilites oregonensis Gabb (= T. acutus Passy)	x	----	x	----

1 See Plate I for map location.

* Collection of Washburne (1903) on Charles Bernard (now Andrew Bernard) ranch on South Fork of Beaver Creek; identifications by R. W. Imlay.

needles and hairs, and lacking the ragged inclusions of altered glass common in the quartz grains of older sequences in the area; (d) oligoclase-andesine of probable plutonic origin; (e) abundant biotite and muscovite; and (f) detrital epidote and zoisite. Taubeneck (1955a) has presented evidence that Late Jurassic or Early Cretaceous granitic rocks of Bald Mountain batholith in the Elkhorn Mountains of northeastern Oregon were exposed to erosion by mid-Cretaceous time. This body, or some generally correlative body, of granitic rock was presumably the source for the plutonic debris in Bernard Formation.

Fossils and age

The occurrence of Turrilites and Pseudouhligella in the lower 500 to 600 feet of Bernard Formation (table 10) clearly indicates that this basal portion of the unit belongs to the Cenomanian Stage, lowermost Upper Cretaceous. The following considerations strongly suggest further that this part of the unit belongs to the lower part of the Cenomanian Stage: (a) Turrilites acutus is restricted to the lower part of the Cenomanian Stage in England (zone of Schloenbachia varians); (b) the subgenus Pseudouhligella ranges from upper Albian through Cenomanian, but the undescribed species from locality V407 occurs in southern Oregon in rocks of lower Cenomanian age (D. L. Jones, written communication, 1958); and (c) Anthonya cultriformis occurs with the lower Cenomanian ammonite Mantelliceras near Jacksonville, Oregon (R.W. Imlay, written communication, 1958). In the absence of faunal evidence, the upper 1,000 feet of Bernard Formation is assigned provisionally to the Cenomanian also. It is worth noting, however, that Turonian beds are present above similar Cenomanian strata less than 25 miles north of Suplee along Battle Creek in sec. 3, T. 13 S., R. 26 E. (R. W. Imlay, written communication, 1958).

TERTIARY ROCKS

Tertiary volcanic strata having an aggregate thickness in excess of 1,000 feet underlie high peripheral plateaus near the margins of the mapped area, and their erosional remnants locally cap isolated buttes in the interior of the area. The base of each of five continental volcanic units recognized in the Suplee-Izee area is an erosional unconformity and each unit rests locally upon Mesozoic strata with angular unconformity. The stratigraphy and petrology of these rocks were not studied in detail, but brief descriptions are included here, hopefully as a guide and impetus to the future work of others. The thin, discontinuous volcanic cover of the Suplee-Izee area and the neighboring plateaus affords a connecting link between the thick Tertiary sequences of the John Day River valley to the north, the Strawberry Mountains to the east, Harney Basin to the south, and the Crooked River lowland to the west.

Mudflow Breccia (Tmb)

On Morgan Mountain north of Izee, approximately 200 feet of mudflow breccias and intercalated amygdaloidal basalts rest unconformably on Mesozoic strata and are overlain with angular discordance by flows of Picture Gorge Basalt. The breccias are composed of angular pebbles and cobbles of black mafic volcanic rocks, which weather brown or red and which are set in a friable, tan to brown, clayey matrix of finer grained debris. Triassic mudstone and siltstone blocks are included in subordinate amounts. Bedding is indistinct, marked only by layers rich in the coarser grained debris interspersed at 6- to 10-foot intervals in the deposit. The associated lavas weather readily to a purplish hue and form soft, friable outcrops that contrast strongly with the ledge exposures of the overlying and more resistant Picture Gorge Basalt flows. The mudflow breccias thus appear to be channel or slope deposits of pre-Miocene age. They may well be correlative with the Eocene "volcanic conglomerate" mapped by Thayer (1956a,b,c) in the John Day River valley to the north and northeast.

Picture Gorge Basalt (Tpg)

Stratigraphy

Dark-gray to black aphanitic and porphyro-aphanitic basalt lavas underlie high timbered plateaus around the margins of the area and crop out on the crests of a few hills in the interior of the area. These flows are here assigned to the Picture Gorge Basalt Formation (Waters, 1961; equals Columbia River Basalt of Merriam, 1901) of the Columbia River Group (Waters, 1961). The unit rests with angular unconformity on various Mesozoic formations and attains a maximum exposed thickness approaching 1,500 feet in the northwestern part of the area. Immediately to the west of the mapped area, along Camp Creek in secs. 16 and 21, T. 17 S., R. 25 E., basalt lavas continuous with exposures in the Suplee-Izee area are overlain concordantly by semiconsolidated pale tuffs probably correlative with Mascall Formation of the John Day River valley (Brogan, 1952). As this stratigraphic relation duplicates the situation in the type area of the Picture Gorge Basalt, the flows of the Suplee-Izee area are probably of lower to middle Miocene age, as are those in the type locality (Chaney, 1932; Downs, 1956).

Petrology

The Picture Gorge Basalt flows range from dominantly porphyritic rocks in the Suplee area to primarily nonporphyritic or microporphyritic rocks in the Izee area. Groundmass textures are chiefly intergranular and intersertal, in many cases ranging from the one to the other within the space of a single thin section, for the distribution of amorphous materials is commonly uneven. Some rocks are ophitic. The preponderant minerals are labradorite and clinopyroxene. Olivine is decidedly subordinate, forming less than 5 percent of most flows, and is commonly partly altered to reddish iddingsite or greenish saponite (?). Granular ore makes up as much as 5 percent of typical rocks. Interstitial amorphous materials include both glass and chlorophaeite. Pale brown siliceous glass (R.I.=1.50 to 1.52), which occupies as much as 20 percent of some intersertal rocks, is heavily charged with tiny elongate clinopyroxene prisms, feldspar microlites, branching columnar ore crystals (ilmenite?), or clouds of minute granular ore dust (magnetite?). Pale green, yellow, or red-orange chlorophaeite (R.I. near 1.55) occurs as interstitial pools in intersertal fashion and in vesicles in amounts as high as 5 percent. Chabazite occurs in vesicles in some areas. Judging from the examination of 20 thin sections, four intercalated petrologic types can be distinguished within the sequence, although the stratigraphic distribution of the types is unknown in detail:

(1) Porphyritic olivine-bearing basalts: 10 to 25 percent labradorite (chiefly) and augite phenocrysts, 1 to 5 percent olivine microphenocrysts, dominantly intergranular but in part intersertal groundmass.

(2) Equigranular olivine-bearing basalts: dominantly intergranular with only minor glass but locally intersertal where chlorophaeite abundant, 1 to 2 percent equant olivine, plagioclase and clinopyroxene locally subophitic.

(3) Olivine basalts: nonporphyritic, glossy black appearance, 15 percent olivine in tiny equant grains which partly envelop edges of plagioclase laths in some places, clinopyroxene in sheaves of elongate ore-charged prisms in areas interstitial to plagioclase laths.

(4) Olivine-free basalts: microporphyritic with labradorite and augite microphenocrysts in cumulophyric clots, intersertal groundmass.

Of these types (1) and (2) are most abundant; types (3) and (4) appear to be rare.

In the vicinity of Indian and Peewee Creeks in the northern part of the area, fluvial gravels are intercalated with the lava flows.

TABLE 11. Composition of dolerite feeder dikes for Picture Gorge Basalt flows. (Petrography by Dickinson)

Percent	Constituent
40-45	Labradorite near An_{60} in laths 0.5 mm across.
25-30	Augite granules 0.1 - 0.4 mm in diameter.
12.5 - 22.5	*Chlorophaeite: orange or brown in thin-section, red or black in hand specimen, R.I.=1.52 - 1.56, locally crystallized to birefringent substances.
3-10	*Glass: tan to pale brown, charged with feldspar microlites, siliceous with R.I. near 1.50.
0-1	Olivine, commonly altered to saponite(?) pseudomorphs.

* Proportions of glass and chlorophaeite, both of which occupy interstitial areas, are complementary, such that the two total about 25 percent.

TABLE 12. Composition of diktytaxitic olivine basalt flow. (Petrography by Dickinson)

Percent*	Constituent
55-65	Labradorite, normally zoned, in large (1-5 mm.) laths.
12.5 - 17.5	Augite (2V=50), faintly pleochroic.
12.5 - 15	Olivine, magnesian, partly altered to iddingsite.
5 - 10	Glass, pale tan to brown, locally charged with columnar ore crystals (probably ilmenite) and elongate clinopyroxene prisms.
2 - 2.5	Granular ore (probably magnetite).
0 - 1	Chlorophaeite, pale green, R. I. near 1.55.
tr	Arborescent white opal (R.I. < 1.46) in vesicles.

* As much as a third of the volume of the rock may be angular vesicular voids interstitial to the plagioclase laths.

Feeders

Frozen feeders for the Picture Gorge Basalt flows are preserved as dolerite dikes and pipes with chilled margins of aphanitic basalt, some of which contain clusters of small calcite amygdules. The approximate composition of the dolerites is given in table 11. Three dike swarms occur in the area, the most extensive one in sec. 12, T. 17 S., R. 28 E., a second farther east on the divide between Lewis and Tamarack Creeks, and a small one near the head of Morgan Creek. One of the dikes of the third group can be traced to the base of a basalt flow (see plate I). Isolated dikes and pipes are widely distributed throughout the northeastern part of the mapped area. Nearly all the dikes strike northwest or north-northwest, dip steeply to the east, range from 20 to 50 feet in thickness, and have a platy structure parallel to their walls. Within 10 feet of the walls, the Mesozoic sedimentary country rocks are hardened, bleached, and partly recrystallized.

Lacustrine Beds (Tlb)

Approximately 250 feet of variegated cream, tan, and orange lacustrine tuffs and tuffaceous claystones are exposed in intricately dissected "badlands" on the south slopes of Buck Mountain in the southeastern part of the area. The unit is poorly consolidated and is well exposed only on the east slopes of Green Spring Draw. The beds rest unconformably on Lonesome Formation of Jurassic age and are overlain unconformably by welded tuff-breccia of probable Pliocene age. The lithology and stratigraphic position of the lacustrine strata suggest a tentative correlation with Mascall Formation of upper Miocene age in John Day River valley (Merriam, 1901; Merriam and others, 1925; Thayer, 1956 a, b) and in the Crooked River drainage (Chaney, 1927; Wilkinson, 1939 a; Brogan, 1952).

Diktytaxitic Olivine Basalt (Tdb)

A diktytaxitic olivine basalt flow from 50 to 100 feet thick rests unconformably on Picture Gorge Basalt and is overlain unconformably by Pliocene (?) welded tuff-breccia in the southwestern corner of the area. The best exposures are on the plateau rims overlooking the old Allison ranch in Howard Valley. The rock is gray where fresh, but weathers to reddish brown. Its mineralogic composition is given in table 12. The flow is petrologically similar to the "Pliocene-Quaternary olivine basalts" of Waters (1961, p. 605). It is petrologically different from and, judging from its stratigraphic position beneath welded tuff, is apparently older than the Plio-Pleistocene "Ochoco Lavas" (Wilkinson, 1939a) which overlie welded tuff in the Round Mountain quadrangle to the northwest. The unit is here tentatively assigned to the lower Pliocene.

Welded Soda-Rhyolite Tuff-Breccia (Twt)

The youngest consolidated rock unit exposed in the area consists of welded soda-rhyolite tuff, lapilli-tuff, and tuff-breccia. It attains a maximum thickness of nearly 100 feet, but is typically only 40 to 50 feet thick. The exposures are isolated erosional remnants, typically butte cappings and rimrocks, of a once continuous sheet or group of sheets, of ignimbrite. Mapping of the remnants was unfortunately completed on the premise that only one continuous sheet of variable lithology was represented. A subsequent field trip to the Emigrant Creek area to the south where R. L. Bateman (1961) has mapped several superposed cooling units, each of distinctive lithology, suggests by analogy that more than one discrete sheet may be present in the Suplee-Izee area.

Lithologic description

The groundmass of the rock is welded vitric and vitric-crystal tuff, locally devitrified, in which the content of crystals ranges as high as 25 percent but is less than 5 percent in most outcrops. Fresh rock is gray, hard, and brittle, with vitreous luster. Devitrified rock is softer, has a dull appearance, and ranges from gray or cream to shades of tan and pink, colors which may be due to the presence of fumarolic iron oxides. Flattened lensoid pumice lapilli and bombs, which occur sporadically in varying proportions, are preferentially oriented to define a foliation parallel to the base of the unit. Closely spaced joints and wavy color banding parallel this megascopic foliation. In thin section, the welding of the rock is clearly attested by the following features: (a) the distorted flattened shape of branching shards, (b) the draping of flattened shards around incompressible crystal fragments, and (c) the presence of attenuated collapsed pumiceous fragments, some of which are cut by perlitic cracks. In general, the finest tuffs in the unit show the least evidence of welding and contain the most crystal fragments.

Petrology

Fresh glass shards have a refractive index of 1.496 to 1.498, as determined in oils. These values suggest the glass is rhyolitic, with a silica content on the order of 70 to 75 percent (George, 1924; Williams, 1955). In many exposures, much of the glass has devitrified wholly or partly to microcrystalline spherulitic aggregates of quartz and a zeolite (heulandite ?) with refractive index near 1.500. The most abundant crystal fragments are sanidine. Quartz is also common and oligoclase-andesine is seen occasionally in thin section. The only mafic crystals observed, and they are rare, were aegirine, glaucophane, and riebeckite. Their presence constitutes evidence that the rock is an alumina-poor soda-rhyolite, to our knowledge the first indication that the welded Tertiary pyroclastics of central Oregon are alkalic rocks, at least in part. Accidental lithic fragments of sandstone, siltstone, felsite, pilotaxitic and hyalopilitic andesite, and intergranular and intersertal basalt indicate that the source vents, which were not seen, traversed a column of rock similar to that which underlies the Suplee-Izee area, hence may not be far distant. The widespread extent of the remarkably tabular unit argues for eruption from a fissure system rather than from centralized volcanic vents.

Age and correlation

The mapping of Thayer (1956a) and Wallace and Calkins (1956) has shown that the welded rhyolitic pyroclastics of the Suplee-Izee area can be traced to the north into the welded tuff member (Wilkinson, 1950) of the type Rattlesnake Formation (Merriam, 1901; Merriam and others, 1925) of Pliocene age in the John Day River valley. Campbell and others (1958) have shown further that the unit can also be traced to the south into the upper Danforth Formation (Piper and others, 1939) of Pliocene age in Harney Basin. Accordingly, the welded soda-rhyolite pyroclastic rocks of the Suplee-Izee area are provisionally assigned to the Pliocene also. We forego the use of a formal stratigraphic name pending a more certain determination of the stratigraphic relations.

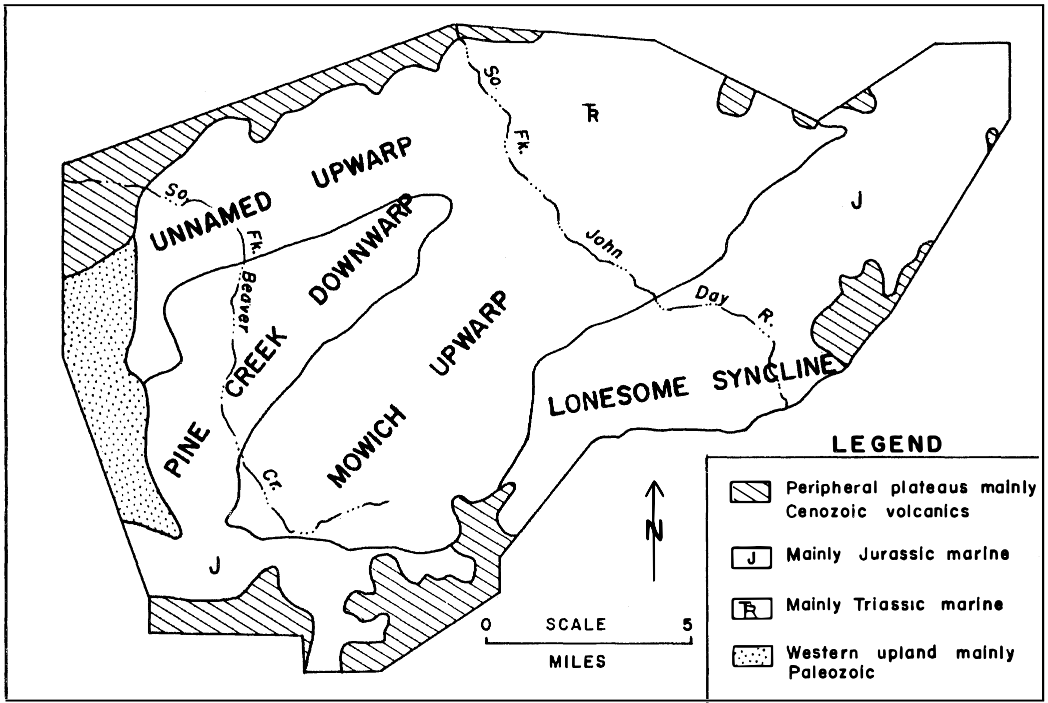
QUATERNARY DEPOSITS

Alluvium (Qal)

Most stream courses are alluviated and outcrops are few in canyon bottoms. The margins of the alluvium were mapped with considerable care, largely from aerial photographs. These contacts should prove an invaluable aid to the visitor trying to locate points on our planimetric map in the field. The contacts of alluvium with bedrock lie typically along abrupt changes in slope declivity. It should be noted that no distinction is made on the map between canyon bottom "floodplains" and the contiguous alluvial fans of side draws.

Landslides (Qls)

Slumps, block glides, debris flows, talus slopes, and rock-creep aprons are grouped as "landslides" on the map. Only features large enough to interfere with field interpretations are shown. It will be noted that most landslides mapped lie downslope from rimrocks of Tertiary basalt or welded tuff-breccia. With few exceptions, the landslides themselves are composed of these materials.



Major structural divisions of the Suplee-Izee area
(figure 6 repeated from page 12)

The western Paleozoic upland is a belt of up-faulted Paleozoic rocks along the western edge of the area.

Pine Creek downwarp is a synclinorium of down-folded Jurassic strata lying mainly east of the western Paleozoic upland and flanked on the northwest and southeast by exposures of Upper Triassic rocks.

Mowich upwarp is an anticlinorium, cored by Upper Triassic rocks and flanked by Jurassic strata, that trends from southwest to northeast across the heart of the area, and is thus the dominant structural feature of the area. An unnamed companion upwarp of folded Triassic rocks lies along the northwestern edge of the area.

Lonesome syncline is a deep structural trough of Jurassic strata lying southeast of Mowich upwarp along the southeastern edge of the area.

The peripheral lava plateaus are discontinuous uplands of gently dipping Tertiary basalt and tuff that ring the area on the north, east, and south.

PART TWO

STRUCTURAL GEOLOGY AND TECTONIC HISTORY

In this section of the report, information is assembled on the geologic structures of the area, their evolution through geologic history, and their relation to inferred tectonic conditions. Reference to plate III, "Geologic History of the Suplee-Izee District," will clarify the position occupied by the various rock units with respect to the structural elements and tectonic events of the area. Plate II includes several cross sections within the area. In the following, structural features are described, insofar as is possible, in chronologic order of development. As the area is one of complex structure, no attempt is made here to describe every fold and fault; rather, genetic groupings are emphasized and their general features discussed. For sake of convenience, figure 6, "Major structural divisions of Suplee-Izee area," is repeated on page 76.

GENERAL STRUCTURE and TECTONICS

In terms of structural style, the rocks of the Suplee-Izee area can be assigned to three major superposed structural units: (1) An upper unit, composed of Cretaceous marine strata and continental Cenozoic volcanic rocks, which is mildly warped and offset by normal faults; (2) a middle unit, composed of Triassic and Jurassic marine strata that are strongly folded and offset by both normal and reverse faults; and (3) a lower unit, the basal substrate of indurated, intruded, and mildly metamorphosed Paleozoic rocks. The middle unit of strongly folded Mesozoic strata can be further subdivided into (a) a dominantly Jurassic sequence whose folds stem from one principal diastrophic episode, and (b) a dominantly Triassic sequence in which superposed folding has resulted in flexures of complex geometric configuration.

In terms of tectonic history, three major periods of tectonic deformation can be discerned and correlated with the three major structural units: (1) A little-known period of Upper Paleozoic marine sedimentation and volcanism terminated by Permian-Triassic orogeny and igneous intrusion; (2) a Triassic-Jurassic period of marine sedimentation and volcanism punctuated by intermittent diastrophism recorded both by lithologic types and by angular unconformities; and (3) following late Mesozoic orogenesis, a Cretaceous-Cenozoic period of shallow marine sedimentation and continental volcanism punctuated by intermittent warping, faulting, uplift, and erosion.

As with the middle structural unit, the middle tectonic period can be divided, in analogous fashion, into two halves separated by an Early Jurassic diastrophic climax here termed Ochoco Orogeny, a name first suggested by S. W. Muller (oral communication, 1956). The mainly Triassic part (a) of the middle period was characterized by the rapid deposition of clastic detritus eroded from contemporaneous tectonic highlands and deposited in adjacent basins of probable tectonic origin; contemporaneous volcanism was subordinate. The mainly Jurassic part (b) of the middle period was characterized by the rapid deposition of contemporaneous volcaniclastic debris with subordinate contributions from older sources.

PERMIAN-TRIASSIC OROGENY

Sub-Begg Formation Unconformity

Begg Formation is in contact with Paleozoic rocks on Frenchy Butte in the northeastern part of the area and at several places in the hills southwest of Suplee along the western edge of the area. On Frenchy Butte, the contact is clearly an angular unconformity: conglomerate beds of Begg Formation lie parallel to the unconformity and contain reworked cobbles of the underlying greenstone and serpentine, whereas an intrusive contact between Permian (?) greenstones and serpentine is truncated by the unconformity. Southwest of Suplee the relations are not as clear, but the truncation of Permian beds by the contact and the parallelism of beds of Begg Formation to the contact are again suggested. Since no fusulinid collections younger than mid-Permian have been found in the Paleozoic rocks, and since Begg Formation probably belongs entirely to Karnian Stage of the Upper Triassic, approximately half of the Permian and half of the Triassic are apparently represented by the unconformity.

Geologic Structures

Examination of the limited exposures of Paleozoic rocks within the area suggests that they are less intensely crumpled than the less competent overlying Triassic strata, but that they are more severely brecciated. Mapping by Merriam and Berthiaume (1943) and by Thayer (1956 a,b,c) in more extensive exposures to the west and to the northeast indicates, however, that the Paleozoic rocks are also strongly deformed. The intrusion of ultramafic rocks, such as the serpentine on Frenchy Butte, prior to the deposition of Begg Formation suggests, moreover, that the Permian-Triassic diastrophism in the area was of orogenic magnitude. This judgment is strengthened by the presence of schistose metavolcanic rocks and phyllitic metapelites in the Paleozoic exposures studied by Thayer (1956 a,b,c).

Regional Relations

Dott (1961) has recently assembled the evidence suggesting "that the latest Permian-earlier Triassic interval was one of complex diastrophism, plutonism, volcanism, and elevation of lands in much of the western Cordilleran belt" (Dott, 1961, p. 561). The Permian-Triassic unconformity in the Suplee-Izee area appears to be but a local record of the crustal unrest noted by Dott within the entire mobile belt along the continental margin, and thus lends support to his interpretations.

UPPER TRIASSIC DIASTROPHISM

Three convergent lines of evidence point to extensive local diastrophism contemporaneous with the deposition of the Upper Triassic marine strata in the area. The evidence includes: (a) the lithology of the sedimentary breccias in Begg Formation, (b) stratigraphic unconformity within the sequence, and (c) thickness relations of facies equivalents in nearby areas strongly suggestive of local tectonic basins.

Sedimentary Breccias

The polymictic conglomerates and breccias have already been described. Four salient features may now be recalled: (1) They are composed dominantly of detritus apparently derived from Paleozoic rocks like those exposed within the area; (2) they were apparently emplaced by some type of submarine mass movement; (3) they are most abundant in the more northwesterly exposures, especially in the area northwest of Pine Creek downwarp; and (4) they locally contain indurated limestone blocks which themselves contain Upper Triassic fossils. The angularity of the coarse debris and the chemical instability of some of the coarse rock fragments under present surface conditions strongly suggest derivation from a nearby source of high relief undergoing rapid erosion. As the breccias are stratigraphically distributed through several thousand feet of strata, this suggestion implies continuing or intermittent diastrophic uplift of the nearby source during deposition. The source, lithology, and distribution of the breccias suggest derivation from a high block along or beyond the northwestern edge of the area mapped. We advance the hypothesis that the Camp Creek fault, described more fully in the next section of the report dealing with Ochoco Orogeny, may have become active as early as Karnian time to form a tectonic northwestern margin to the basin of Late Triassic deposition. Attendant fault scarps, perhaps in part submarine, may have been a source for the sedimentary breccias.

Unconformity

Rail Cabin Argillite of Norian age rests with angular unconformity on Brisbois Formation of latest Karnian age. In the synclinorium beneath Morgan Mountain, where the two units are involved in the same folds, the strata of Brisbois Formation are appreciably more appressed than those in the Rail Cabin Argillite. The angular discordance there is on the order of 10° to 30°, indicating folding and erosion during the Late Triassic.

Tectonic Basins

In studying the Triassic rocks of the Aldrich Mountains to the northeast, Thayer and Brown (1960) have developed a picture of Norian deposition in tectonically defined basins whereby successive members of a thick Norian sequence rest unconformably upon older members and change thickness drastically where they cross folds and faults in older members. Materials transported by mass movement and reworked Upper Triassic debris suggest unstable basin margins in a fashion analogous to the Karnian sedimentary breccias of the Suplee-Izee area. Each member of the Norian sequence they describe is apparently a great clastic wedge; one such wedge thickens at the rate of 1,000 feet per mile from west to east across about 10 miles of country. Each such wedge overlaps strata of the subjacent wedge along an angular unconformity. It is our suggestion that the conformable Begg and Brisbois Formations of the Suplee-Izee area together represent such a clastic wedge of slightly older (Karnian) age, a wedge that was somewhat deformed, uplifted, and eroded before or while some of the more easterly Norian wedges were deposited. This hypothesis implies that each wedge filled or partly filled one of a related sequence of tectonic basins formed by contemporaneous diastrophism.

OCHOCO OROGENY

The basal contact of Mowich Group of late Early Jurassic age is an angular unconformity. The group rests in turn on each of the older Mesozoic units in the area, and the structures above and below the unconformity are markedly discordant in many places (see plate II). The name "Ochoco Orogeny" is here applied to the diastrophism which gave rise to this widespread surface of unconformity. Inasmuch as the youngest strata beneath Mowich Group are the Hettangian beds of Graylock Formation and some probable Sinemurian strata of the Caps Creek beds, and considering that the oldest strata of Mowich Group are likely Pliensbachian, and certainly no younger than Toarcian, it is tempting to assign the Ochoco Orogeny, with all its attendant diastrophism and erosion, to some portion of the Sinemurian and Pliensbachian Ages of the Early Jurassic. In a sense this may be a valid conclusion, but the evidence of closely preceding Late Triassic diastrophism suggests the clear possibility that the unconformity beneath Mowich Group may be a surface compounded of the effects of long-continued deformation and erosion. Some of the structures in the oldest strata beneath the unconformity may have begun forming even before the youngest strata beneath the unconformity had been deposited; indeed, so far as direct evidence can be applied, there is no way to refute the supposition that some of the older rocks beneath the unconformity may have been undergoing erosion throughout the time some of the younger rocks beneath the unconformity were deposited. Despite these uncertainties, there are related pre-Mowich Group structures that can be treated as the results of an integrated episode of orogenic deformation, and it is to this diastrophism of integrated style and effect that the name Ochoco Orogeny is applied. The Ochoco Orogeny had certainly terminated as Mowich Group was deposited, but its earliest antecedents cannot be dated with certainty; the Late Triassic diastrophism described above may well have been an inseparable precursor.

Sub-Mowich Group Unconformity

West of Big Flat, Mowich Group rests with marked angular discordance on Karnian or older strata of Begg and Brisbois Formations, and chiefly upon the Begg, which is the older of the two. In places, as near Freeman Creek, the angular discordance is essentially 90° where Mowich Group lies across the bevelled limbs of nearly isoclinal folds in the underlying strata. Between Big Flat and South Fork of John Day River, Mowich Group also rests on Karnian strata, but only on Brisbois Formation, and the discordance is less. Still farther east, Mowich Group rests with comparatively slight angular discordance on Norian and Hettangian strata of Rail Cabin Argillite and Graylock Formation in Vester Creek syncline, and upon strata of the Caps Creek beds apparently as young as Sinemurian near the eastern extremity of the area.

There is thus a progressive decrease in the angular discordance and the stratigraphic hiatus at the unconformity from west to east. This fact is indicative of one of two alternative interpretations, or of some blend of the two: (1) Ochoco Orogeny was synchronous and short-lived throughout the area, but deformation was more intense and erosion deeper toward the west; or (2) Ochoco Orogeny spanned an appreciable part of Late Triassic and Early Jurassic time, with deformation beginning earlier and continuing longer toward the west, where the degree of deformation and depth of erosion were thus ultimately greatest owing to cumulative effects.

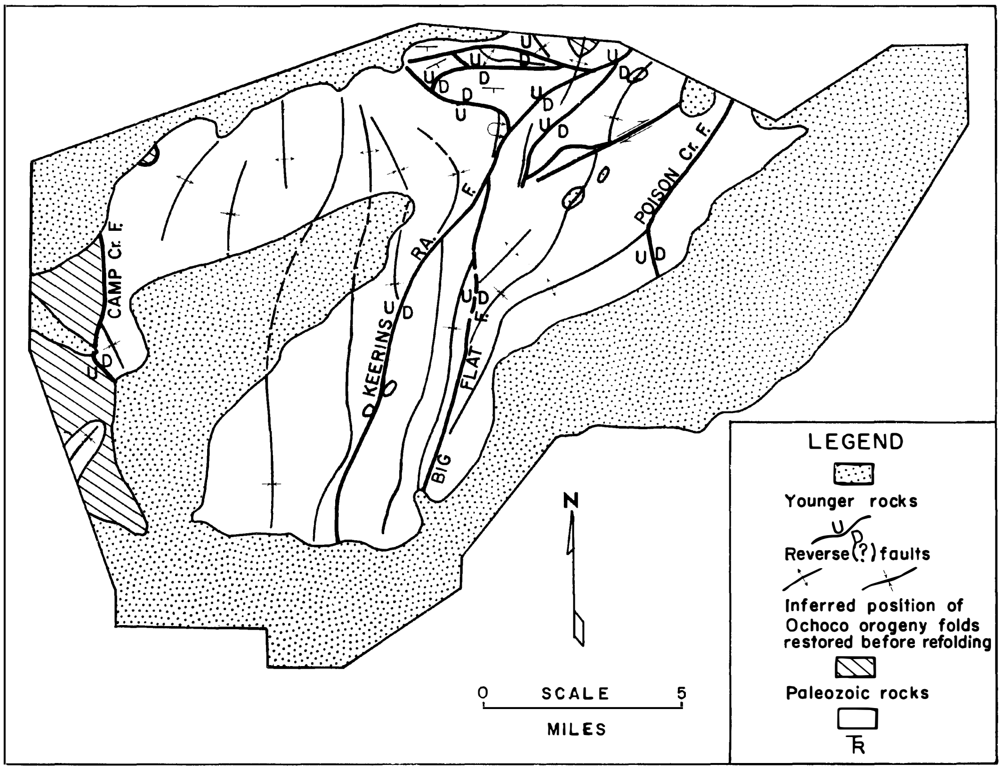


Figure 29. Structures of Ochoco Orogeny.

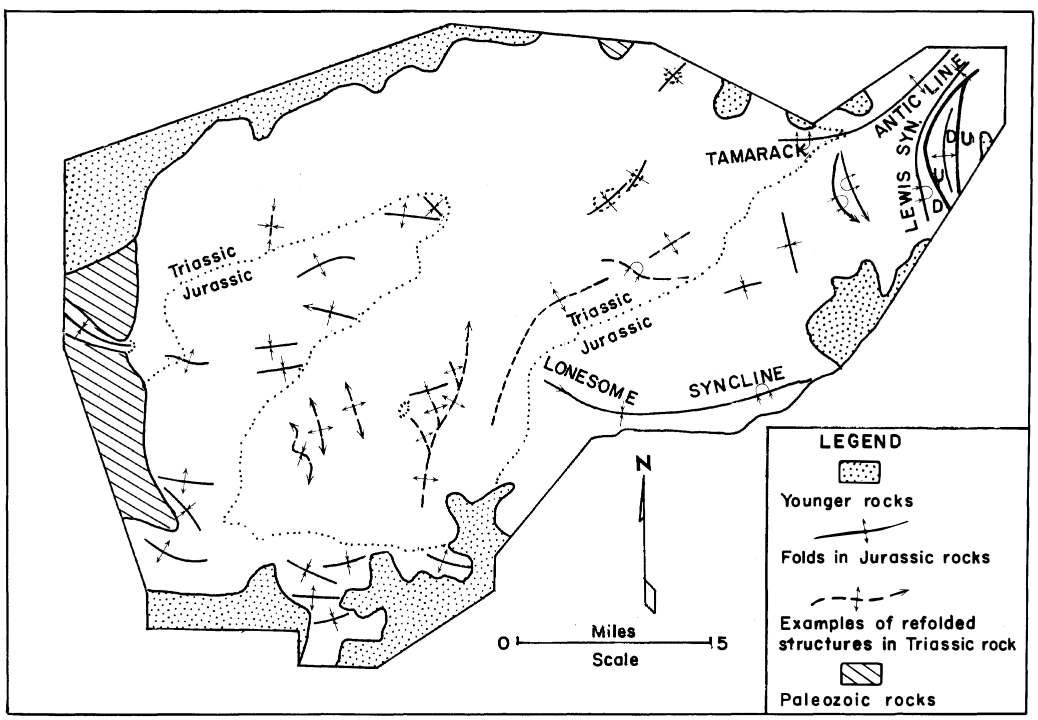


Figure 30. Structures of Jurassic-Cretaceous orogeny.

Folds

The folds formed by Ochoco Orogeny have been strongly modified by refolding during a Jurassic-Cretaceous orogeny. They are described here as they existed before the refolding (figure 29). The reader who would gain a clear picture of their present configuration must also read the section dealing with the later deformation.

West of long 119°30', Upper Triassic (Karnian) strata of Begg and Brisbois Formations were thrown into tightly appressed upright or slightly overturned folds with northerly trends prior to the deposition of Mowich Group, which was later folded about axes markedly divergent to the axes of the older folds. Along Mowich upwarp in the southern part of the tract, the folds in the Upper Triassic strata strike nearly due north and are uniformly isoclinal or nearly so; for example, Divide anticline, Fordham anticline, etc., on plate I. North of Pine Creek downwarp, in the northern part of the tract, the folds are more open and have more variable northerly trends; for example, Little Bear anticline, Jackass Creek syncline, etc., on plate I; dips less than 50° are common.

East of long 119°30', the folds of Ochoco Orogeny swing about to a northeasterly trend. As they do so, the divergence between their axes and those of younger folds in Jurassic strata decreases, just as the angular discordance at the base of Mowich Group decreases. These relations suggest that the tightly appressed folds to the west tailed off into more open folds to the northeast, where the intensity of the orogeny was less.

The geometry of the tightly appressed, closely spaced folds in Upper Triassic strata suggests that the comparatively rigid Paleozoic substrate at depth did not fully participate in the folding. The inferred difference in competency suggests the likelihood of a décollement sole at the base of the Ochoco Orogeny folds.

It is interesting to note the depth at which the folds must have formed. In the Izee district, so little stratigraphic hiatus is present at the base of Mowich Group that no great thickness of strata could have once been present before folding and erosion. If this observation is valid, the oldest beds of Begg Formation involved in the folds could not have been at depths greater than about 15,000 feet. Younger beds must have been at proportionately shallower depths.

Faults

A crudely coparallel set of north-northeasterly trending reverse (?) faults was apparently active during Ochoco Orogeny. There are three major faults in the set, spaced at intervals of about 6 miles (figure 29). The three can be dated as follows on the basis of the youngest rocks offset and the oldest rocks which lie unconformably across their traces without offset: (1) Camp Creek fault, post-Brisbois Formation (Karnian, Upper Triassic), pre-Weberg Member of Snowshoe Formation (Bajocian, Middle Jurassic); (2) Keerins ranch fault (and its subsidiary, Big Flat fault), post-Brisbois Formation, pre-Mowich Group (Pliensbachian or Toarcian, Lower Jurassic); and (3) Poison Creek fault, post-Caps Creek beds (Sinemurian? , Lower Jurassic), pre-Mowich Group. Each of the three faults, as can be noted on the map, brings together rocks of greatly different age and structure. With few exceptions, structures on opposite sides of the faults cannot be matched with confidence, hence their displacements cannot be closely estimated, although they doubtless total thousands of feet in each case. On each fault, older rocks on the west side have been brought against younger rocks on the east side. The interpretation as reverse faults is based upon two lines of evidence: (1) In a number of places, the stratigraphic thickness of fold limbs has been apparently reduced where the faults pass along them, suggesting foreshortening rather than the repetition of beds expected from normal faulting; and (2) in a few instances where the faults pass through areas of fairly rugged topography, the fault traces indicate that the fault planes dip to the west and hence have reverse movement. Camp Creek fault passes northward into a gently dipping thrust, and several klippe of Paleozoic rocks of the upper plate lie on Begg Formation in the northwestern corner of the area.

The structural discordance along the reverse faults could be due simply to great displacement. It is likely, however, that the circumstance of faulting during folding led in part to the growth of different structures on either side of the faults, such that few structures were ever truly continuous across them. The continuity of the faults in such a complexly folded terrane and their wide spacing relative to the wave length (about 1 mile) of the Ochoco Orogeny folds suggest that their positioning may arise from conditions in the underlying Paleozoic substrate beneath the postulated decollement surface. It is also possible that they first became active, as has been suggested for the Camp Creek fault, during the diastrophism contemporaneous with Late Triassic sedimentation. If so, the faults may actually be somewhat older structures than the folds which they transect and may have helped delineate the tectonic basins in which were deposited the Triassic strata they later offset at higher levels.

Frenchy Butte Buttress

In the northern part of the area, folds and faults cutting Upper Triassic strata diverge around a buttress of intruded Paleozoic rocks exposed on Frenchy Butte and in the ground to the north outside the mapped area (Wallace and Calkins, 1956). Both folds and reverse faults thus locally adopt east-west trends at a high angle to the structures of Ochoco Orogeny to the south. There is no positive evidence of their pre-Mowich Group age, but these anomalously trending structures appear to be continuous with northerly trending structures in Upper Triassic rocks to the south and probably also formed during Ochoco Orogeny. Their anomalous trend is attributed to the uparched pre-Late Triassic "basement" complex of Frenchy Butte, our thought being that its presence at an unusually high structural level caused the folds of Ochoco Orogeny to be draped semiconcordantly about it as a nucleus (see figure 29).

JURASSIC DIASTROPHISM

In Middle Jurassic time, after the regime of volcaniclastic sedimentation which followed Ochoco Orogeny was well established, mild warping and local erosion gave rise to angular unconformities within the Jurassic sequence.

Sub-Weberg Member Unconformity

Late in Early Jurassic or early in Middle Jurassic time, upwarping of the western part of the area was accompanied by erosional removal of Mowich Group from the area northwest of the axis of Pine Creek downwarp. The warping established the raised "Suplee platform" as distinct from the "Izee basin" to the east, a local tectonic distinction with important implications for the sedimentation of Snowshoe Formation. The possible indications of the early onset of Ochoco Orogeny in the west, the restriction of plicatostylid reefs in Mowich Group to the western part of the area, and the thinning of Hyde Formation of Mowich Group toward the west all suggest that the Middle Jurassic positive structural feature termed the "Suplee platform" may actually have had older antecedents.

Weberg Member of Snowshoe Formation was deposited on the bevelled edges of Mowich Group, overlapping to the west onto Triassic and Paleozoic rocks and passing to the east into a conformable sequence of dark lutite on Big Flat. Around the plunging nose of Mowich upwarp between Mowich Mountain on the east and the Ammonite Hills on the west, Weberg Member truncates approximately 1,000 feet of Mowich Group in a distance of about 3 miles. Assuming the bevelled surface of unconformity was flat as Weberg Formation was deposited, the eastward dip of Mowich Group as a result of the warping was on the order of $3\frac{1}{2}°$ to $4°$. The stratigraphic hiatus along the unconformity probably includes two ammonite zones:

the Lytoceras jurense Zone (Toarcian, Lower Jurassic) and the Leioceras opalinum Zone (Bajocian, Middle Jurassic).

Sub-Trowbridge Formation Unconformity

In the drainage of South Fork of John Day River, Trowbridge Formation rests unconformably on Snowshoe Formation, progressively overlapping that unit as far west as Big Flat. In the type locality of Snowshoe Formation near Izee, the lower or Rosebud Member of Trowbridge Formation rests upon approximately 1,250 feet of the upper member of Snowshoe Formation. Six miles to the west, the middle or Officer Member of Trowbridge Formation has onlapped 400 feet of the Rosebud Member. In this distance, the Trowbridge Formation also overlaps 1,250 feet of Snowshoe Formation so that the Officer Member at Flat Creek rests directly on the middle member of Snowshoe Formation. Six miles east of Izee, as much as 2,000 feet of the upper member of Snowshoe Formation may be present beneath the unconformity in exposures of tightly folded strata near Lewis Creek. These data suggest warping of Snowshoe Formation to eastward dips on the order of 2° to 2½° and local erosional removal of more than 1,000 feet of section prior to the deposition of Trowbridge Formation. Because ammonites of Callovian Stage (Upper Jurassic) have been found above and below the unconformity, these events apparently occurred within the span of Callovian time.

Tectonic Basin

After the Callovian warping but, judging from meager but apparently definitive ammonite collections, still within the Callovian Age, at least 12,500 feet of strata were deposited in conformable succession to form Trowbridge and Lonesome Formations. The rapidity of sedimentation of marine strata, chiefly volcanic sandstone and dark mudstone, is evidence of downwarping of major proportions. Since many of the strata are interpreted as turbidity current deposits, a major tectonic trough of regional extent is suggested.

JURASSIC-CRETACEOUS OROGENY

During Late Jurassic (post-Callovian) and/or Early Cretaceous time, orogenic deformation and intense diagenetic alteration of the Jurassic strata in the area occurred prior to deposition of the Cenomanian (Upper Cretaceous) Bernard Formation.

Sub-Bernard Formation Unconformity

In the northwestern corner of the area, a northwesterly dipping homocline of Bernard Formation rests with angular unconformity on folded Paleozoic, Upper Triassic, and Middle Jurassic strata and affords clear evidence of post-Bajocian, pre-Cenomanian deformation of orogenic magnitude. The structural accordance of Bajocian and Callovian rocks farther east near Izee suggests that the diastrophism was entirely post-Callovian. The possibility of somewhat older deformation in the west cannot, however, be entirely dismissed on any direct evidence.

Folds in Jurassic Strata

West of long 119°30' in the "Suplee platform" area, where the Jurassic sequence has a thickness of 4,000 feet or less and belongs mainly to the Middle Jurassic Series, the folds in Jurassic rocks are comparatively gentle, open structures with easterly or southeasterly trends (figure 30). Dips in the limbs of the folds are commonly less than 45° and most fold amplitudes are less than 2,500 feet, for example, Wilson Creek anticline, Smith Basin syncline, etc. on plate I.

In the "Izee basin" area to the southeast, the Jurassic sequence is 17,500 feet thick and has been arched downward into the easterly trending Lonesome syncline, a tremendous downfold with many thousands of feet of structural relief. Minor folds in this area are rare and are confined to wrinkles on the limbs of the great syncline. Dips throughout the sequence are commonly in excess of 45° and the beds in the upper part of Lonesome Formation are steeply overturned, dipping to the north.

In the northeastern part of the area, the folds in Jurassic strata swing to northeasterly trends and are tightly appressed, locally isoclinal, upright or slightly overturned structures. In this area, a pattern of divergent folds presents a major puzzle: Tamarack anticline of east-northeasterly trend lies athwart the strike of the Lewis syncline and associated structures (figure 30), which have a more northerly trend in this vicinity. To the northeast, the two divergent sets of folds swing into alignment with common northeasterly trends. To the west, however, along upper Rosebud Creek, nearly isoclinal folds with northerly trends and easterly dipping axial planes appear to plunge down the south flank of Tamarack anticline. In discussion of the map, T. D. Barrow of Humble Oil & Refining Co. made the suggestion, by analogy with the experimental results of W. H. Bucher (1956) that the anomalous northerly trending folds may have originated by westward gravitational crumpling of part of the Jurassic sequence prior to folding about axes with easterly trends. We believe the suggestion has merit, for the anomalous folding bears a similarity to "soft sediment slumping," in that it is largely confined to a particular package of incompetent strata of Snowshoe and Trowbridge Formations. The underlying and overlying strata of Hyde and Lonesome Formations are not appreciably affected.

Folds in Triassic Strata

The Upper Triassic strata folded during Ochoco Orogeny were refolded during the Jurassic-Cretaceous orogeny. The effects of refolding fall into three general categories, depending upon the intensity of the earlier folding and upon the angle between the trends of the two ages of folds.

West of long 119°30' the Ochoco Orogeny folds were northerly trending structures and had steep, locally isoclinal limbs, upon the bevelled edges of which the Jurassic strata were deposited. The folds in Jurassic strata trend easterly, nearly at right angles to the axes of the older folds. In this area, refolding produced three marked effects, all of which can be deduced from a study of the geologic map (plate I): (1) Some earlier northerly trending folds buckled longitudinally, developing a train of alternating culminations and depressions along their course. Such longitudinal buckling of anticlines formed trains of alternating domes and transverse synclinal saddles, whereas longitudinal buckling of synclines formed trains of alternating basins and transverse anticlinal saddles; (2) other northerly trending folds buckled laterally, forming sinuous crests or troughs, or forming steeply plunging subsidiary folds on their flanks, for example, Fordham anticline; (3) numerous small hinge faults developed to take up, in minor shear displacements, some of the strain necessary for the refolding to proceed. In net, the re-orientation of bedding caused by the refolding has changed the statistical fold axis from a horizontal position, with northerly strike, to a vertical position where the original folds were isoclinal and to a nearly random position where the original folds were more open.

In the northeastern part of the area, where the earlier folds were more open and the folds in Jurassic strata have a northeasterly trend more or less parallel to the earlier folds, the effects of refolding are slight. Attitudes in Triassic beds are somewhat steeper than in Jurassic beds, but strikes are not divergent.

Near South Fork of John Day River, where a slight divergence of trend is noticeable, minor oblique buckling of the older folds can be seen locally. Most apparent is the separation of Roba and Abbott-Walker anticlines by the obliquely transverse Dry Soda syncline. Also noticeable is the oblique crenulation of the trough of Vester Creek synclinorium around Morgan Mountain.

Faults

Only in the northeastern part of the area can any but minor faults be tied to the Jurassic-Cretaceous orogenic folding. Near the east edge of the area, eastward dipping longitudinal reverse faults break and foreshorten the limbs of Johnie anticline and associated structures of the anomalous northerly trending set of folds south of Tamarack anticline.

Depth of Deformation

Judging directly from the 17,500 feet of Jurassic strata present along South Fork of John Day River, the refolding of the Ochoco Orogeny folds in the Upper Triassic strata took place at depths definitely in excess of 3 miles. Judging indirectly from the widespread zeolitization and albitization of the entire Jurassic sequence, even the youngest Jurassic strata now exposed were once depressed to depths probably in excess of 3 miles. If so, the Upper Triassic strata beneath the Jurassic sequence may have lain at depths in excess of 6 miles and some parts of the Triassic terrane may have been at depths approaching 10 miles.

MOWICH UPWARP and PINE CREEK DOWNWARP

In terms of gross dimensions, the major structural features within the Suplee-Izee area are three: (1) Lonesome syncline, the easterly trending fold in the southeast initiated during the Jurassic-Cretaceous orogeny and described briefly in the preceding section; (2) Mowich upwarp, a broad anticlinorium which trends northeasterly through the center of the area; and (3) Pine Creek downwarp, a broad synclinorium lying parallel to Mowich upwarp on the northwest near Suplee. Lonesome syncline is composed of Jurassic strata that dip more steeply in the north limb (50° to 90°) than in the south limb (20° to 60°). Mowich upwarp is a southwesterly plunging elongate welt with complexly folded Triassic strata comprising most of the core and Jurassic strata on its flanks. Pine Creek downwarp is a doubly plunging spoon of folded Jurassic strata, flanked by Mowich upwarp on the southeast and by an unnamed companion upwarp of folded Triassic rocks along the northwestern edge of the area. The flanks of Pine Creek downwarp dip inward at angles of 10° to 30°, although structural relationships are complicated by smaller transverse and oblique folds produced in the Jurassic strata by the earlier (?) Jurassic-Cretaceous orogeny.

On the twin bases of divergent trend and contrasting style of deformation, Mowich upwarp and Pine Creek downwarp appear to have been formed by diastrophism divorced in time from the Jurassic-Cretaceous orogeny described in the preceding section. On the plunging nose of Mowich upwarp, a complex system of radial and transverse faults resembles patterns described by Wisser (1960) for vertically uplifted domal warps and noses; the faults of this system transect folds in Jurassic strata in an unsystematic manner, suggesting that the folds are older than Mowich upwarp. If so, the upwarp and the Pine Creek downwarp apparently post-date the Jurassic-Cretaceous orogenic folding of the Jurassic sequence. In either case, the broad warps were apparently outlined by mid-Cretaceous time, for Bernard Formation rests on Upper Triassic beds in the eroded core of the unnamed upwarp lying along the northwestern edge of the area.

CENOZOIC DIASTROPHISM

Early Tertiary Diastrophism

In the northwestern part of the area, Picture Gorge Basalt of the Miocene Columbia River Basalt Group rests with slight angular unconformity on Upper Cretaceous marine strata of Bernard Formation. The relationship is evidence of uplift and erosion during latest Cretaceous or early Tertiary time. Indirect corroborating evidence of early Tertiary highlands in the area is afforded by the absence, owing to non-deposition or erosion, of the widespread Clarno and John Day Formations of Eocene and Oligocene age, respectively.

The Picture Gorge Basalt sequence rests upon an erosion surface with appreciable local relief. Between Big Flat and Snow Mountain, the flows appear to be banked against a long slope that descended to the north about 500 feet on a 5-percent grade. To the north and to the southwest of Keerins ranch at the mouth of Pine Creek, basalt exposures occur at unusually low elevations. The exposures between Keerins ranch and Indian Creek clearly represent the eroded fill of a canyon which had several hundred feet of relief. The flat-lying flows and intercalated stream gravels occupy a V-shaped wedge which is in steep contact with Triassic rocks.

Miocene-Pliocene Diastrophism

The Miocene flows of Picture Gorge Basalt were warped and deeply eroded prior to the eruption of the Pliocene diktytaxitic basalt and welded soda-rhyolite tuff-breccia. The diktytaxitic basalt flowed northward over a steep rim of Picture Gorge Basalt and down into a valley or basin with a floor some 500 feet below the rim and near the present valley of South Fork of Beaver Creek. The welded pyroclastic rocks lie on Picture Gorge Basalt around the periphery of the area, but rest on Mesozoic rocks in the interior of it. The deformation and erosion of the Miocene lavas is a local record of the extensive Miocene-Pliocene diastrophism discussed by Thayer (1957). From his work, it is apparent that the Picture Gorge Basalt of the Suplee-Izee area lies on the warped, gently dipping south limb of the asymmetric Aldrich anticline, a regional structure with its crestal area just south of the main fork of the John Day River north of the area and its southerly flank extending to Harney Basin south of the area.

Pliocene-Pleistocene Diastrophism

Dips as high as 20° in Pliocene welded pyroclastic rocks and deep Quaternary erosion attest to significant deformation and uplift in Pliocene-Pleistocene time.

APPENDIX

MEASURED STRATIGRAPHIC SECTIONS OF JURASSIC UNITS

CONTENTS OF APPENDIX:

MEASURED STRATIGRAPHIC SECTIONS OF JURASSIC UNITS.

A. Section of Mowich Group and part of Snowshoe Formation on "Robertson Ridge" in SE$\frac{1}{4}$ sec. 28, T. 18 S., R. 26 E.; within type locality of Mowich Group; direction of up-section traverse is north to south; exposures rare on rounded, sage-covered slopes; the section is a critical one, for the superpositional juxtaposition of units representing the "Suplee platform" facies and the "Izee basin" facies is a unique key to stratigraphic relations between the two facies:

Basey Mem. of Snowshoe Fm.	500+ ft.	Andesitic tuff and volcanic graywacke: hard, tough, blue gray, weathers brown and spheroidal, bedding massive and indistinct, yielded one stephanoceratid ammonite about 10 ft. from base.
	200 ft.	Fine-grained andesitic tuff and tuffaceous silty argillite: hard, pale green to black, laminated, blocky weathering, mainly non-calcareous.

Conformable, gradational contact.

Warm Springs Mem. of Snowshoe Fm.	200 ft.	Siltstone and mudstone: soft, dark gray to black, thin-bedded, blocky to platy, calcareous in part.

Conformable, gradational contact.

Weberg Mem. of Snowshoe Fm.	150 ft.	Fine-grained calcareous sandstone and sandy limestone: gray, weathers buff, abundant pelecypods, locally contains ammonites *Tmetoceras scissum* (Benecke) and *Docidoceras* cf. *D. planulatum* Buckman.

Unconformable contact, angularity demonstrated by progressive westward overlap of alternating sandstone and mudstone-siltstone sequences in underlying Hyde Formation by overlying transgressive Weberg Member.

Hyde Fm. of Mowich Group	100 ft.	Mudstone and siltstone: dark gray, massive.
	175 ft.	Andesitic graywacke: gray-green but weathers brown, poorly sorted, mottled with buff to cream laumontite, thick-bedded.

Conformable, sharp contact.

Nicely Fm. of Mowich Group	75 ft.	Shale: dark gray to black, fissile, calcareous, sporadic 2-inch interbeds of fine-grained yellowish brown sandstone, hildoceratid ammonites collected by Lupher (1941 and locality "L", this report).

Conformable, sharp contact.

Suplee Fm. of Mowich Group	30-35 ft.	Volcanic sandstone: gray but weathers buff or green-brown, calcareous, abundant *Weyla* and other pelecypods, massive, locally pebbly.

Conformable, gradational contact.

Robertson Fm. of Mowich Group (total about 210 ft.)	40 ft.	Interbedded (in 5 to 10 ft. massive layers) chert-pebble conglomerate and andesitic sandstone, locally mixed; green, weathers brownish; contains Nerinea near base.
	45-50 ft.	Andesitic sandstone: fine- to medium-grained, gray-green, weathers brown, massive, contains Nerinea near top.
	5 ft.	Limestone: gray, sandy, bioclastic, abundant Plicatostylus shells lie parallel to bedding; in two beds, each with green-brown calcareous volcanic sandstone near base.
	40 ft.	Andesitic sandstone: medium-grained, gray-green, weathers brown with spheroidal or nodular surface, massive beds 1 to 5 feet thick with thin intercalations of dark siltstone between.
	5 ft.	Hard, brown, calcareous siltstone and olive-green to yellowish mudstone.
	10 ft.	Andesitic sandstone: fine-grained, soft, green.
	60-65 ft.	Sandy pebble and cobble conglomerate: crudely stratified in layers 2 to 4 feet thick, chert and felsite pebbles most abundant, subrounded.

Unconformable contact with Upper Triassic Begg Formation, angular discordance slight locally.

B. Section of Robertson Formation of Mowich Group near the old Harris place in SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 26, T. 17 S., R. 26 E., where the formation is thickest (total 335 ft.) and has the most (5) limestone horizons:

Disconformable contact with overlying Weberg Member of Snowshoe Formation.

15 ft.	Plicatostylid limestone: light gray.
40 ft.	Chert-grain sandstone: gray to buff, calcareous with Ostrea and Pinna.
3 ft.	Plicatostylid limestone: light gray.
40 ft.	Volcanic sandstone: fine-grained, greenish to yellowish gray, mottled, weathered surface spheroidal.
3 ft.	Plicatostylid limestone: gray, weathers yellow.
35 ft.	Sandstone: gray to brown, three 1-ft. to 2-ft. interbeds of light gray limestone with Nerinea and Plicatostylus.
19 ft.	Calcareous volcanic sandstone: dark gray, weathers brown, contains sparse plicatostylid valves.
15 ft.	Limestone: light gray-brown, aphanitic, contains sparse plicatostylid valves.
45 ft.	Sandstone: calcareous in part, brown, contains chert pebbles and Nerinea.

20 ft. Limestone: gray-brown, brecciated, abundant plicatostylid valves.

100 ft. Conglomerate: sandy with chert, felsite, and limestone pebbles, cobbles, and boulders.

Unconformable contact with underlying Begg Formation.

C. Section of Robertson Formation of Mowich Group east of Cow Creek in north part of sec. 17, T. 17 S., R. 27 E., where the formation is most fossiliferous and totals about 220 feet:

Disconformable contact with overlying Warm Springs Member of Snowshoe Formation; sharp but concordant.

4 ft. Limestone: gray, weathers brown, coarse sandy; possibly basal Snowshoe Formation.

5 ft. Limestone: gray, coarse fragmental; locally biostromal with plicatostylid valves in upright growth position, but grades laterally to massive, coarse-grained sandstone.

15-20 ft. Volcanic sandstone: green, locally gray and calcareous, locally mottled, abundant *Pinna* fragments.

25 ft. Limestone: biostromal limestone composed of plicatostylid valves in upright growth position; sharp basal contact with 1 to 2 ft. of erosional(?) relief.

75 ft. Volcanic sandstone: medium- to coarse-grained, mainly green mottled with pale patches but in part calcareous, gray, and weathered brown; spheroidal weathering common; thin interbeds of dark limestone near middle; contains sporadic *Plicatostylus* near the top and *Nerinea* near base; bed 22 ft. above base contains *Isocyprina* sp., *Modiolus* sp., *Trigonia* sp., *Weyla* sp., *Nerinea* sp., terebratulid brachiopods, and fragments of *Plicatostylus gregarius*.

3 ft. Limestone: sandy, dark maroon, weathers gray; contains *Coelastarte* sp., *Modiolus* sp., *Pholadomya* sp., *Trigonia* sp.

35-40 ft. Volcanic sandstone: greenish gray, massive, contains *Astarte* sp.

8 ft. Limestone: sandy, maroon, thin-bedded; grades to fine-grained calcareous sandstone; contains *Camptonectes* sp., *Lucina* sp., *Modiolus* sp., *Pholadomya* sp., *Pleuromya* sp., *Weyla* sp.; probably correlative with 25 feet of plicatostylid limestone exposed 1 mile farther west.

20 ft. Mudstone: silty, brown with interbeds of nodular gray-brown limestone; near base contains *Astarte* sp., *Homomya* sp., *Isocyprina* sp., *Lima* sp., *Pholadomya* sp., *Weyla* sp.

25 ft. Volcanic sandstone: dark green, medium- to coarse-grained, cross-bedded; spheroidal weathered surfaces.

Unconformable contact with Upper Triassic Brisbois Formation; no angular discordance evident locally.

D. Section of Robertson Formation in erosional outlier near head of Packwood Creek in SW$\frac{1}{4}$ sec. 6, T. 18 S., R. 27 E. (total thickness 155 ft., incomplete).

Erosional top of incomplete section.

40 ft.	Andesitic sandstone: medium-grained, green.
10 ft.	Andesitic sandstone: medium-grained, calcareous, gray, weathers brown.
12 ft.	Limestone: gray, biostromal, contains plicatostylids.
25 ft.	Andesitic sandstone: fine-grained, green.
8 ft.	Limestone: gray sandy, biostromal, contains plicatostylids.
60 ft.	Interbedded green andesitic sandstone and chert-pebble conglomerate; contains *Nerinea*.

Unconformable contact with Upper Triassic Begg Formation.

E. Section of Weberg Member of Snowshoe Formation at the type section of the member in SW$\frac{1}{4}$ and SE$\frac{1}{4}$ sec. 19, T. 18 S., R. 26 E., about 1,800 ft. north of old Washburn place on the north side of a gully tributary to Warm Springs Creek at the north boundary of sec. 30 (total thickness 203 ft.).

Conformable gradational contact with overlying Warm Springs Member of gray, calcareous, platy, silty to sandy shale that weathers to dark chips and plates.

90 ft	Dominantly gray-brown silty to fine sandy limestone with intercalated layers of calcareous shale; weathers to yellowish buff or rusty yellow chips and blocks.
110 ft.	Gray calcareous sandstone; weathers rusty yellow to yellowish green; composed dominantly of quartz and chert grains; some beds contain coarse bioclastic detritus and grade to sandy limestone; pebbly near base.
3 ft.	Pebbly calcareous sandstone, crossbedded; contains *Ostrea*, *Pinna*, and rhynchonellid brachiopods.

Angular unconformity with Upper Triassic Begg Formation evident.

F. Composite section of Basey Member of Snowshoe Formation in the type locality of the member south and southwest of Windy Ridge in secs. 1, 12, and 13, T. 18 S., R. 25 E., and sec. 6, T. 18 S., R. 26 E. (approximate total thickness is 2,500 ft.).

Conformable, gradational contact with Shaw Member composed dominantly of dark gray mudstone and shale with sporadic thin interbeds of gray limestone and greenish brown sandstone.

300 ft.	Andesitic sandstone: gray-green, medium- to coarse-grained, massive beds; laminated interbeds of yellowish brown siltstone, mudstone, and shale.
1,200 ft.	Dominantly andesitic marine tuff: blue-gray to gray-green, medium- to coarse-grained, spheroidal to blocky weathered surface, massive layers from 5 to 200 feet thick; tuff grades locally to bedded sandstone; interbeds of greenish brown siltstone and mudstone.
0-90 ft.	Porphyritic andesite lava: massive, one-quarter to one-third of rock is plagioclase phenocrysts of lath-shape, pale phenocrysts set without preferred orientation in blue-gray or olive-green aphanitic groundmass; angular blocks of lava occur in immediately overlying strata. A thin andesitic conglomerate bed occupies the same horizon where the flow is absent.
750 ft.	Dominantly shale and argillite: laminated, green, slightly calcareous, tuffaceous, hard; minor brown calcareous andesitic sandstone.
10-70 ft.	Sandstone and conglomerate in layers 5 to 10 feet thick; sand fraction andesitic; gravel fraction includes rounded pebbles of limestone, chert, argillite, and quartzite as well as porphyritic andesite.
0-150 ft.	Porphyritic andesite lava: about one-quarter of rock is plagioclase phenocrysts of lath-shape; pale phenocrysts set without preferred orientation in blue-gray to gray-green aphanitic groundmass; grades locally to flow-breccia of aphanitic lava fragments in a calcareous matrix.

Conformable contact with underlying Warm Springs Member; sharp where the basal lava of the Basey is present; gradational where the flow is absent and the overlying pebbly sandstone beds rest directly on the Warm Springs.

G. Section of Silvies Member of Snowshoe Formation in the type locality of the member along Little Snowshoe Creek and Silvies River near their confluence and near the common corner of secs. 21, 22, 27, and 28, T. 16 S., R. 29 E. (approximate total thickness is 1,500 feet).

Conformable, gradational contact with overlying part of Snowshoe Formation.

125 ft.	Coarse-grained andesitic graywacke and andesitic pebble conglomerate in alternating graded layers with scoured bottoms; blue-gray to gray-green.
550 ft.	Intercalated fine- to medium-grained blue-gray to gray-green andesitic graywacke and dark siltstone.
40 ft.	Massive andesitic pebble conglomerate (basal 10 feet) and coarse-grained andesitic graywacke.
80 ft.	Intercalated andesitic graywacke and dark siltstone.
30 ft.	Massive andesitic pebble conglomerate.

40 ft.	Massive coarse-grained andesitic graywacke.
200 ft.	Intercalated andesitic graywacke and dark siltstone.
120 ft.	Coarse-grained andesitic graywacke: blue-gray and weathers brown; in beds that are 1 to 5 feet thick, graded, and laminated in upper part; scour common at base of each bed; local convolute lamination.
30 ft.	Intercalated, thin-bedded, fine-grained andesitic graywacke and dark siltstone.
80 ft.	Medium- to coarse-grained andesitic graywacke, like the 120 ft. sequence above but with some thin interbeds of laminated volcanic siltstone.
175 ft.	Intercalated, thin-bedded, fine-grained andesitic graywacke and dark siltstone.
30 ft.	Coarse-grained andesitic graywacke: blue-gray and weathers brown.

Conformable, sharp contact with underlying lower part of Snowshoe Formation.

H. Section of Officer Member of Trowbridge Formation at the type locality of the member along Cottonwood Draw, a tributary of Rosebud Creek, in NW$\frac{1}{4}$ sec. 22, T. 17 S., R. 28 E.: (approximate total thickness is 450 ft.; the lowest resistant sequence and associated strata are repeated by faulting subparallel to bedding):

Conformable, gradational contact with black mudstone of the overlying Magill Member.

25 ft.	Dark gray and green, laminated dacitic graywacke grading upward to fine-grained felsite tuff.
75 ft.	Black and green mudstone with pencil fracture.
25 ft.	Dark gray and green, laminated dacitic graywacke grading upward to fine-grained felsite tuff.
100 ft.	Black and green mudstone with pencil fracture.
50 ft.	Dark gray and green, laminated dacitic graywacke grading upward to fine-grained felsite tuff.
100 ft.	Black and green mudstone with pencil fracture.
75 ft.	Hard, green to gray felsite tuff.

Conformable, sharp contact with black mudstone of the underlying Rosebud Member.

GLOSSARY OF TECHNICAL GEOLOGIC TERMS

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Albitized: Converted in whole or in part to albite, the soda end-member of the plagioclase feldspars, by volume-for-volume replacement.

Alluvium: Unconsolidated stream deposits, whether gravel, sand, silt, or clay.

Ammonite: One of an extinct order of mollusks related to the living chambered nautilus; most ammonites had coiled, chambered shells and their fossil remains or imprints in rocks resemble coiled worms or snakes; to the paleontologist, ammonites are among the most informative fossils in the geologic record and the complex variations of their shells define sequences of evolutionary changes that are our best present guide to the time-sequence of strata deposited during the Mesozoic Era (see plate III).

Amygdule: An ovoid mineral growth formed by the filling of a gas cavity or vesicle in a volcanic rock.

Angular discordance: Lack of parallelism between contiguous strata or other geometrically linear or planar structural elements.

Aphanitic: Refers to textures of rocks in which the crystalline constituents are too small to be seen with the unaided eye or a small pocket lens.

Appressed strata: Folded strata closely and flatly pressed against one another, face-to-face or sole-to-sole.

Arenite: In the usage of Gilbert (1955), a sandstone containing less than 10 percent silt and clay impurities in the interstices between sand grains.

Argillite: Strongly indurated rock composed of silt and clay; breaks into hard, angular fragments bounded by smooth, gently curving or planar fracture surfaces.

Authigenic: Refers to minerals that formed in place within a sediment or sedimentary rock after deposition.

Belemnite guard: The tapered, cigar-shaped internal shell of one of an extinct order of mollusks; similar to the cuttlebone of modern squids.

Bioclastic: Usually refers to calcareous rocks consisting mainly of fragmental organic remains.

Biogenic: Refers to rocks formed by the physiological growth of organisms.

Biostromal rock: A massive bed formed by the growth in place of biogenic rock with which lenses of bioclastic rock may be interstratified.

Breccia: Fragmental rock whose constituent pieces are angular, and not waterworn as in conglomerate.

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* Prepared by Dickinson with help from the Department staff and the American Geological Institute's "Glossary of geology and related sciences."

Byssal threads: Hair-like appendages by means of which some bivalves attach themselves to submerged rocks or floating objects.

Calcarenite: A "lime-sandstone" in which the grains are composed of calcium carbonate of various origins; a kind of limestone.

Calcareous: Containing calcium carbonate, especially as cement in sandstone filling the void spaces between sand grains.

Calcilutite: Fine-grained fragmental limestone analogous to calcarenite (see above); a lime-mudstone or lime-shale.

Calcirudite: Coarse-grained fragmental limestone analogous to carcarenite (see above); a lime-conglomerate or lime-breccia.

Cement: The minerals, usually quartz, carbonates, or iron oxides, deposited in the spaces between grains in fragmental rocks by precipitation from solution.

Clast: General term for a single fragment in a clastic rock.

Clastic: Refers to textures of rocks composed of separate fragments of material of any origin.

Coelenterates: A phylum of invertebrates with radial body symmetry; includes corals and jellyfish.

Colluvium: Unconsolidated, surficial mass movement deposits; includes talus, rock creep aprons, slumped soil cones, etc.

Compaction: Volume reduction of sediments under the load of overlying strata accompanied by decrease in porosity and increase in density.

Conchoidal fracture: The shell-like, furrowed, curviplanar fracture surface characteristic of such hard, brittle, non-cleavable substances as quartz, chert, obsidian, window glass, etc.

Conformable: Defined as the relation that exists between beds or strata in places where each lies in unbroken sedimentary succession upon its neighbor, with bedding planes generally parallel.

Coquinite: Fragmental limestone composed of whole shells and slabby shell fragments.

Décollement: A type of deformation in which a sheet of sedimentary rock breaks loose from the underlying formations and folds independently.

Detrital: Refers to material eroded from pre-existing rocks, and to the clastic rocks formed by the deposition of such material.

Detritus: Fragmental material derived from pre-existing rocks by weathering and erosion.

Devitrified rock: Rock originally composed in whole or in part of volcanic glass, which, with the passage of time and under proper conditions, has crystallized to newly formed mineral grains of microscopic size. The process gives the rock a dull, stony appearance.

Diastrophism: The processes by which the earth's crust is deformed, and the events of the deformation.

Diagenesis: The chemical and physical changes that take place in stratified surficial rocks after deposition; in theory, not including metamorphic events.

Diktytaxitic: Refers to a net-like texture of lavas distinguished by the abundance of jagged, irregular vesicles or gas cavities bounded by crystals, some of which protrude into the cavities.

Echinoderm plates: The single-crystal calcareous plates of segmented echinoderm skeletons, as in echinoids or crinoids.

Ecology: The study of the mutual relationships between organisms and their environments.

Effusion: A pouring out or ejection at the earth's surface.

Epiclastic: Refers to rocks composed of particles derived from mechanical disaggregation of pre-existing rocks, shaped and sized by dispersal in surface waters or winds, and deposited by these agencies.

Eutaxitic: A term applied to the structure of certain welded pyroclastic rocks (see below) having a streaked appearance due to the alternation of lenses of different color, composition, or texture.

Eugeosyncline: A vast, elongate belt of the earth's crust, the surface of which subsides over long periods of time, while processes of volcanism and sedimentation concurrently fill the space thus formed with a growing prism of stratified rocks.

Euxinic: Refers to environments and sediments of poorly oxygenated basins where water circulation is restricted, bottom sediments are black, and toxic gases are liberated into the waters by the anaerobic decay of organic debris.

Facies: Any particular distinctive characteristic displayed locally by strata whose lateral equivalents are different.

Faunule: An assemblage of fossil animals found together in a particular place, usually confined to a single stratum or thin sequence of strata.

Felsophyre: Any pale-colored volcanic rock composed of a minority of visible crystals, mainly of quartz and feldspar, set in a stony groundmass whose crystalline constituents are too small to be individually visible.

Fissility: The cleavage of shales, whereby the rock can be split into arbitrarily thin plates. The breakage is controlled by the tendency for the microscopic plates of the constituent clay minerals to be aligned parallel to bedding.

Flow markings: Any of a variety of kinds of convex markings on the soles of sandstone beds formed as casts or counterparts of concave markings cut by currents moving over the underlying finer grained sediments before or as they were buried (see also: sole markings).

Flute casts: Sandstone sole features of flow-mark type; fan-shaped in plan view, with the most relief at the apex, which points in an up-current direction.

Foliation: General term for planar or layered structural elements or patterns in rocks formed by mass deformation during metamorphism, but not including sedimentary stratification.

Formation: The fundamental unit in rock-stratigraphic classification and the basic unit for the geologic mapping of stratified rocks; recognition based on its lithologic character.

Framework: Applied to the clasts of fragmental rocks, especially sandstones, in which the sand grains or other fragments constitute a mechanically firm structure capable of supporting open pore spaces, although interstices may be occupied by cement or matrix.

Graded beds: Individual beds which display a progressive decrease in mean or maximum grain size from base to top.

Graywacke: A much-debated and variously defined term for sedimentary rocks; used here in the sense of Gilbert for poorly sorted sandstones in which a dark, indurated matrix of silt and clay interstitial to the sand grains makes up more than 10 percent of the rock.

Greenstone: A general and imprecise term for slightly metamorphosed massive volcanic rocks of greenish hue.

Groove casts: Sandstone sole features of flow-mark type; narrow linear ridges, the casts of grooves scribed in the underlying finer grained rock, aligned parallel to the flow direction of the current which deposited the sandstone.

Groundmass: The fine-grained material between the coarser crystals in a porphyritic rock.

Group: Rock-stratigraphic unit composed of two or more associated and related formations.

Hackly: Refers to an irregular, jagged fracture surface.

Hyalopilitic: Refers to microscopic texture in which tiny plagioclase microlites with haphazard orientation are enclosed in volcanic glass.

Imbrication: In fragmental rocks, the current-controlled arrangement of tabular clasts in the manner of overlapping shingles inclined up-current at an angle to the bedding.

Intercalation: Interlamination of different kinds of rocks in vertical succession, as of sandstone beds in a shale succession.

Intertonguing: Lateral sedimentary intermingling of different kinds of beds, as an intertonguing of sandstone and shale facies.

Isoclinal: Refers to folds in which strata are so appressed that opposing limbs are parallel.

Keratophyre: Soda-rich analogue of andesite.

Klippe: An isolated block of rock separated from underlying rocks by a fault surface.

Lapilli-tuff: A poorly sorted pyroclastic volcanic rock composed of particles ranging in size from the finest ash to clasts about $2\frac{1}{2}$ inches in diameter.

Lithic: Refers to sedimentary or pyroclastic rocks in which rock fragments are more abundant than mineral grains.

Lithification: The conversion of unconsolidated sediment to coherent rock, commonly through the effects of compaction or cementation.

Load cast: Any of a variety of irregular convex markings on the soles of sandstone beds formed as protrusions into the underlying stratum of mud or clay.

Lutite: Any rock formed by the lithification of sediment composed mainly of clay and/or silt (thus, particles less than 0.0625 mm in diameter).

Matrix: Detrital interstitial filling of silt or clay-sized particles in a sandstone or conglomerate; also, the groundmass of porphyritic igneous rocks.

Member: Rock-stratigraphic subdivision of a formation, recognized on the basis of lithologic variations.

Mesostasis: The interstitial material, commonly glassy, between the larger mineral crystals of a volcanic rock.

Metasomatism: The processes by which one mineral or mineral aggregate is replaced by another of partly or wholly differing chemical composition owing to the introduction of material from external sources.

Mudflow: Rapid downslope flowage of heterogeneous debris including a large proportion of muddy matrix in which various objects of large size may be enclosed and transported.

Mudstone: Massive, soft rock formed by the lithification of mud, that is, mixed clay and silt; lacks fissility but may display consistent nodular or blocky fracture.

Neritic: Refers to the environment of shallow marine waters extending in depth approximately to the lower limit of effective penetration of radiant sunlight at about 100 fathoms (600 feet).

Onlap: Increasingly greater areal extension of successive sedimentary rock units; formed as a sea transgresses across an erosion surface.

Orogeny: Mountain formation, particularly the folding and faulting of eugeosynclinal prisms of rock along their belt-like trend.

Overlap: Extension of one formation beyond others by covering their erosion-bevelled edges.

Pilotaxitic: Refers to microscopic texture of volcanic rocks in which tiny, interwoven plagioclase microlites are arranged in sub-parallel alignment as a result of magma flow.

Polymictic: Refers to sedimentary rocks, especially conglomerates, composed of clasts derived from a variety of source rock types.

Pipe: A cylindrical intrusive body.

Plunging structure: Any fold whose axis of flexure is inclined to the horizontal.

Porphyro-aphanitic: Refers to the texture of a rock, usually volcanic, in which large visible crystals, called phenocrysts, are set in an aphanitic groundmass.

Porphyroblasts: Crystals of metamorphic, commonly metasomatic, origin that have grown in place in a rock to sizes greater than those of the other crystals in the rock.

Pressolution (pressure solution): Solution at the contact surfaces of grains in fragmental rock; the resulting enlargement of contact surfaces reduces pore space and tightly welds the rock.

Pyroclastic: Refers to materials forcibly expelled from volcanic vents as fragmental ejecta.

Provenance: The terrane from which the detrital material within a given set of sedimentary strata was derived by erosion; embodies concept of source rocks plus modifications produced by weathering.

Reefoid rocks: An accumulation of hard, unstratified biogenic material as a ridge of rock at or near sea level.

Rudite: Any rock formed by the lithification of sediment composed mainly of gravel (thus, particles greater than 2 mm in diameter).

Rugose: Applied to fossils with characteristic strongly and irregularly wrinkled surfaces.

Sessile: Applied to organisms that live closely attached to other objects and never or rarely move about under their own power.

Shelf: A marine bottom of gentle slope in shallow waters.

Sole markings: A general term for geometric patterns, mainly convex irregularities of surface, on the soles of sandstone beds; restricted to features that formed about the time of deposition when the sediment was unconsolidated.

Spicule: Tiny siliceous or calcareous object, commonly needle-like or branching, contained in the tissues of certain invertebrates, such as sponges.

Stage: A time-stratigraphic unit employed to classify rocks as the record of a specific interval of time without regard to lithology; recognition based on the position of its fossils in the evolutionary succession.

Substrate: A general term to denote material of type and properties different from an overlying cover.

Superposition: The order in which stratified rocks are deposited in succession one above the other.

Tectonic: Refers to geologic features and processes pertaining to or resulting from deformation of the earth's crust.

Terrigenous: In sedimentation, refers to detrital material derived from the erosion of land areas.

Tests: Small hard covering or supporting structure of some invertebrate animals, especially one-celled forms; may be enclosed within living tissue while the animal lives.

Tongue: A local rock-stratigraphic unit known to wedge out laterally between strata of different lithology and to merge in the other direction with a larger thickness of strata of like lithology, perhaps a formation of which the wedge is said to be a tongue.

Turbidite: Sediment or sedimentary rock inferred to have been deposited from a turbidity current.

Turbidity current: A turbid mass of mixed sediment and water which acts as a semi-homogeneous fluid and pours downslope beneath a body of clear, still water because of the greater density of the sediment-laden water, much as water will flow under oil; ideally conceived as turbulent flow of a muddy suspension, but probably grading in nature to submarine landslides on the one hand and to sand runs or grain-dispersion flows on the other.

Vitroclastic: Refers to rocks whose fragmental texture is dominated by the abundance ot glass shards.

Vitrophyre: Any volcanic rock composed of a minority of visible crystals set in a glassy groundmass.

Volcaniclastic: Refers to fragmental rocks, whatever the details of their history, whose constituent particles are composed of products of volcanism.

Wacke: In the usage of Gilbert, a sandstone containing more than 10 percent silt and clay impurities in the interstices between the grains.

Warping: Gentle folding of rocks in the earth's crust resulting in slight changes in elevation or bending of strata.

Welded tuff: Pyroclastic volcanic rock whose constituent glassy particles were so hot at the time of deposition that the particles welded themselves to one another; commonly the glassy material was hot enough to be plastic so that irregular shards, frothy pumice blocks, etc., are compressed by the weight of accumulating material to form characteristic banded or eutaxitic structure.

Zone: In this report synonymous with faunizone, which may be defined as a succession of beds characterized by an assemblage of organisms, such assemblage being recognized by the joint occurrence of certain forms with different, but overlapping, total ranges in the time span of the geologic column; thus a time-stratigraphic unit whose recognition is based upon the orderly evolutionary sequence of changing organisms; each stage is composed of several zones.

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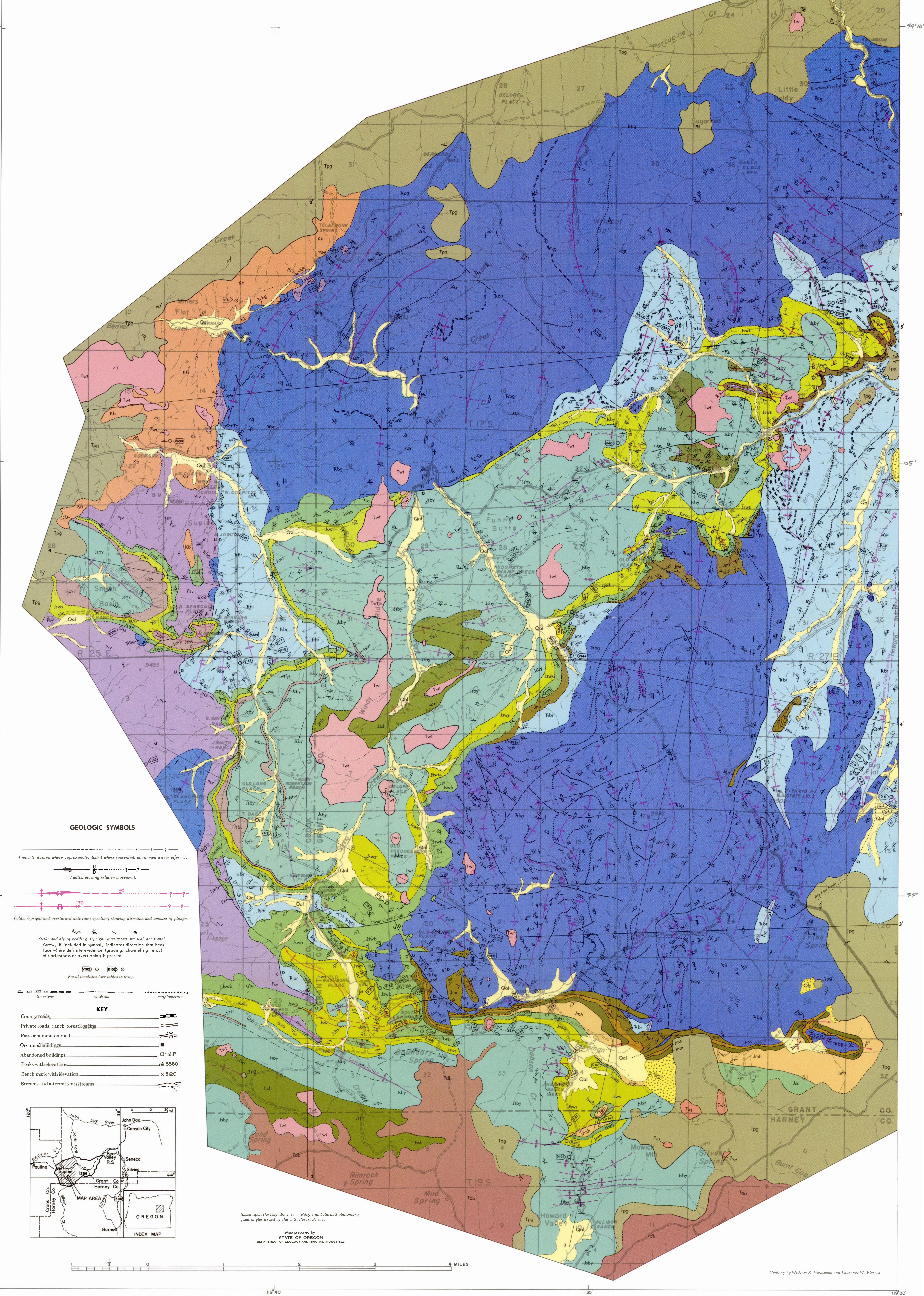
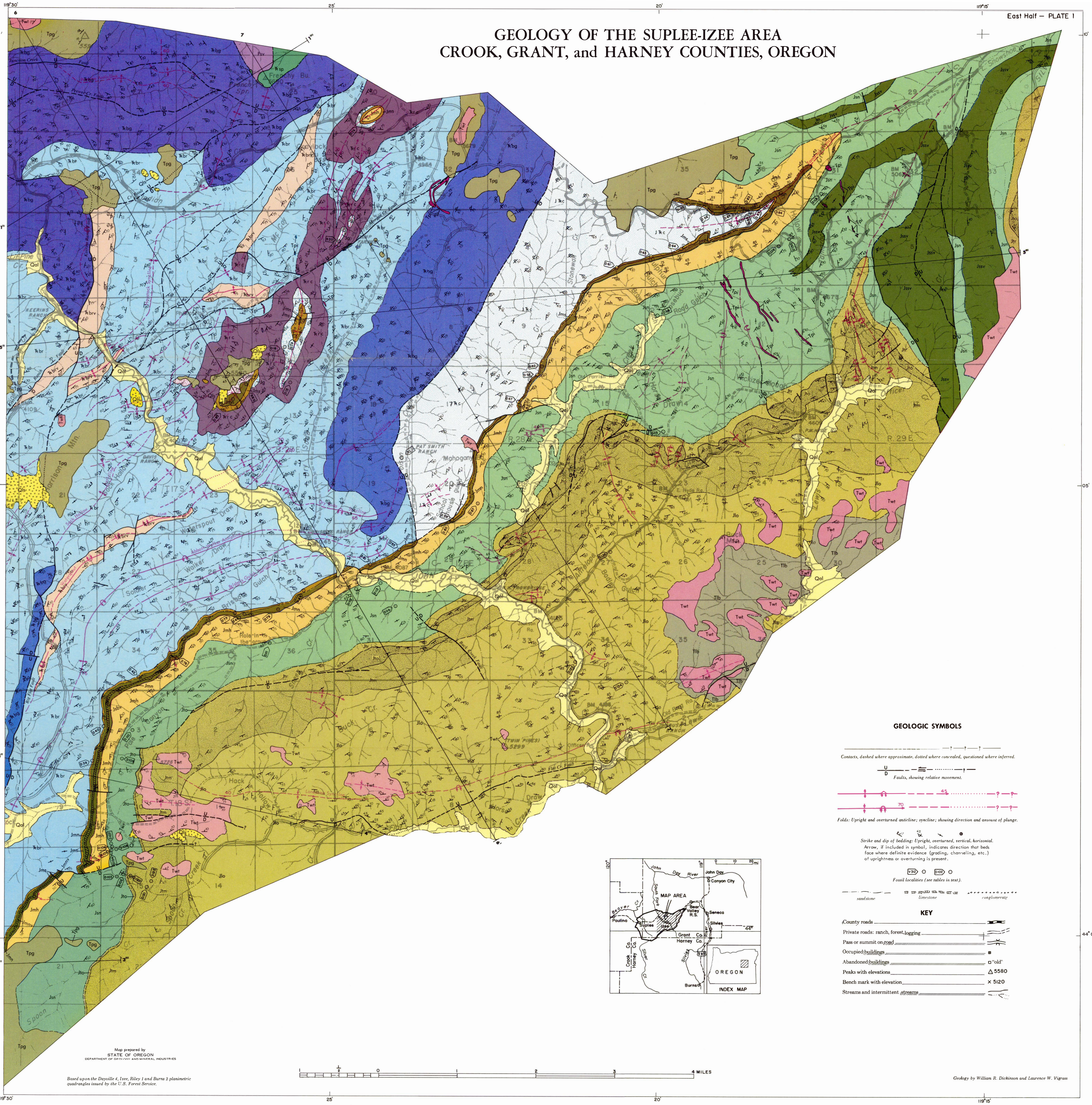
West Half — PLATE 1

GEOLOGY OF THE SUPLEE-IZEE AREA
CROOK, GRANT, and HARNEY COUNTIES, OREGON



GEOLOGY OF THE SUPLEE-IZEE AREA
CROOK, GRANT, and HARNEY COUNTIES, OREGON



Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

Based upon the Dayville 4, Izee, Riley 1 and Burns 2 planimetric quadrangles issued by the U.S. Forest Service.

Geology by William R. Dickinson and Laurence W. Vigrass

Generalized Geologic Sections

EXPLANATION

QUATERNARY

Qls
Landslides
Slumps, block glides, debris flows, talus, creep deposits masking bedrock

Qal
Alluvium
Valley flats, fans, basin fills

UNCONFORMITY

TERTIARY

PLIOCENE

Twt
Welded Soda-Rhyolite Tuff-Breccia
Includes welded tuff and lapilli tuff (=Rattlesnake Fm.?,= Danforth Fm.?)

UNCONFORMITY

Tdb
Diktytaxitic Olivine Basalt

UNCONFORMITY

MIOCENE

Tlb
Lacustrine Beds
Variegated soft tuffs and clays (=Mascall Fm.?)

UNCONFORMITY

Tpi Tpg
Picture Gorge Basalt
Black aphanitic and porphyro-aphanitic basalt Tpi, dolerite feeder dikes; includes minor gravels

UNCONFORMITY

EOCENE

Tmb
Mudflow Breccia
Includes intercalated amygdaloidal basalt

UNCONFORMITY

CRETACEOUS

CENOMANIAN

Kb
Bernard Formation
Yellowish-brown, calcareous & limonite, pebbly sandstone

UNCONFORMITY

JURASSIC

CALLOVIAN

Jlo
Lonesome Formation
Gray volcanic sandstone and black mudstone

TROWBRIDGE FORMATION

Jtm
Magill Member
Black mudstone with minor intercalated sandstone and limestone

Jto
Officer Member
Black to green mudstone with resistant volcanic sandstone and vitroclastic tuff layers

Jtr
Rosebud Member
Black to green mudstone

UNCONFORMITY

(Younger Jurassic units absent in west of area)

BAJOCIAN

(BAJOCIAN)

SNOWSHOE FORMATION IN WEST OF AREA

Jssh
Shaw Member
Gray shale with minor limestone and sandstone

Jsby Jsbv
Basey Member
Andesitic lava, tuff, and volcaniclastic rocks with minor mudstone; Jsbv: Lava flows & flow-breccias

Jsws
Warm Springs Member
Gray silty shale and mudstone

Jswb
Weberg Member
Sandy limestone and calcareous sandstone

(upper member extends into Callovian)

Jsn Jssv
SNOWSHOE FORMATION
Lower member of gray to black lutite;
middle member of same interbedded with green volcaniclastic siltstone and sandstone;
upper member of dark lutite with intercalated calcareous sand stone.
Jssv: Silvies Member
of volcaniclastic andesitic conglomerate and sandstone interbedded with lutite

(lower member extends into Toarcian)

UNCONFORMITY

TOARCIAN

MOWICH GROUP

Jmh
HYDE FORMATION
Blue-gray andesitic tuff and sandstone

Jmn Jmnv
NICELY FORMATION
Black concretionary shale with minor sandstone
Jmnv andesite lava flow

PLIENSBACHIAN?

Jms
SUPLEE FORMATION
Calcareous sandstone

Jmr
ROBERTSON FORMATION
Basal conglomerate, andesitic sandstone, plicatostylid biostromal limestone

UNCONFORMITY

HETTANGIAN

Jg
GRAYLOCK FORMATION
Gray to black siltstone with gray to black limestone in lower part

JTRc
Caps Creek beds (see text)

TRIASSIC

NORIAN-RHAETIAN

TRrc
RAIL CABIN ARGILLITE
Black to green argillite and felsitic tuff

UNCONFORMITY

KARNIAN

TRbr TRbrv
BRISBOIS FORMATION
Black, gray, and green mudstone with intercalated sandy limestone, calcareous sandstone, and tuff;
TRbrv Volcanic member of spilite and keratophyre lava, vitroclastic felsite tuff, and volcaniclastic sandstone

TRbg
BEGG FORMATION
Gray to green lutite with intercalated chert-grain ss. & chert-pebble cg., polymictic breccia & cg., volcaniclastics & minor lava, and rare bioclastic ls.

UNCONFORMITY

TRsp
SERPENTINE

PERMIAN

Psv
PALEOZOIC ROCKS
Varicolored flinty felsite, limestone, and chert

PLATE III. GEOLOGIC HISTORY OF THE SUPLEE - IZEE AREA

Age in Millions of Years	Period or Part of Period	Epoch or Age*	Stratigraphic Column: Suplee Area (West)	Stratigraphic Column: Izee Area (East)	Fauna	Sedimentation	Volcanism	Diastrophism
	QUAT.	RECENT	Alluvium (Qal) and Landslides (Qls)			Valley fills, alluvial fans.	No record	Continuing uplift(?) and erosion.
1		PLEISTOCENE				No record		Gentle folding, uplift(?), and deep erosion.
	LATE TERTIARY	PLIOCENE	Welded soda-rhyolite tuff-breccia (Twt) 50-100 ft.; diktytaxitic olivine basalt (Tdb): 0-100 ft.		None; Age relations established by superposition and by correlation with fossiliferous rocks to the north (Thayer, 1956 a, b, c; Merriam, 1901; Merriam and others, 1925), West (Chaney, 1927; Wilkinson, 1939 b); and south (Piper and others, 1939).		Pyroclastic eruption of soda-rhyolite ignimbrite sheets from nearby fissures(?). / No record / Quiet effusion of gas-charged olivine basalt from vent(s) near southwest corner of area. / No record	Continuing(?) erosion.
25		MIOCENE	Picture Gorge Basalt (Tpg) 1500 ft.	lacustrine beds (Tlb) 0-250 ft.; Picture Gorge Basalt (Tpg) 1500 ft.		Local clayey lacustrine deposits. / No record	Explosive pyroclastic eruption of silicic ash incorporated in lacustrine beds. / No record / Quiet effusion of flood basalt of Columbia River Group from fissure systems, now dike swarms, east part of area.	Gentle folding, uplift(?), and erosion. / Continuing(?) erosion.
	EARLY TERTIARY	OLIGOCENE					No record	Gentle folding, uplift, and erosion accompanied by normal faulting.
		EOCENE		mudflow breccia 0-200 ft.			Local(?) eruption of basaltic lava and mudflow breccia.	
63		PALEOCENE						
	LATE CRETACEOUS	MAESTRICHTIAN			None		No record	
		SENONIAN						
		TURONIAN						
		CENOMANIAN	Bernard Fm. (Kb) 1500 ft.		Common pelecypods, rare ammonites.	Calcareous and limonitic pebbly lithic ss. with subordinate cg. & lutite; shallow marine.		Subsidence as shallow marine shelf(?).
	EARLY CRET.	ALBIAN			None	No record		JURASSIC-CRETACEOUS OROGENY. Strong folding near Suplee; intense folding near Izee; reverse faulting east of Izee; uplift and deep erosion.
		APTIAN						
135		NEOCOMIAN						
	LATE JURASSIC	PORTLANDIAN						
		KIMMERIDGIAN						
		OXFORDIAN						
		CALLOVIAN		Lonesome Fm. (Jlo) 10,000 ft.	Rare ammonites.	Marine deposition of lithic (volcanic) graywacke, probably in deep water by turbidity currents, and intercalated dark mudstone.	Possible continuing eruption of andesitic pyroclastic debris in nearby areas.	Rapid and deep subsidence of at least 2½ miles, apparently entirely during a part of Callovian Age; time at end of subsidence and deposition unknown; probable development of deep tectonic trench, possibly linked to adjacent tectonic and volcanic island arc, and possibly of regional extent.
				TROWBRIDGE FM.: Magill Member (Jtm) 2000 ft.	Rare ammonites, pelecypods.	Marine deposition of dark mudstone with thin intercalations of volcanic sandstone; probably deep water.		
				TROWBRIDGE FM.: Officer Member (Jto) 100-500 ft.	None	Marine deposition of dark mudstone, volcanic graywacke, and vitroclastic rhyodacitic ash.	Explosive pyroclastic eruption of rhyodacitic ash.	
				TROWBRIDGE FM.: Rosebud Member (Jtr) 0-500 ft.		Marine deposition of dark mudstone; probably in shallow water.	Probably no active volcanism; andesitic detritus common in rock sequence.	
				- ? - ? - ? - ? - ? - ? -		No record		Warping, uplift, and erosion.
				SNOWSHOE FORMATION: upper member 2000 (?) ft.	Rare ammonites, pelecypods.	Marine deposition of laminated dark lutite with intercalated thin sandstone and limestone beds; probably at shallow to moderate depths.		Moderate subsidence, probably somewhat greater in "Izee basin" in the east than on "Suplee platform" in the west; active andesitic volcanism suggests likelihood of diastrophism in nearby areas.
	MIDDLE JURASSIC	BATHONIAN			None, possibly undetected hiatus.			
		BAJOCIAN	SNOWSHOE FORMATION: Shaw Member (Jssh) 750 ft.		Rare ammonites and pelecypods, probably of Otoites sauzei Zone, in Shaw Member.			
			Basey Member (Jsby) 0-2500 ft.	middle member 1000 ft.; Silvies Member (Jssv) 0-1500 ft.	Common ammonites, probably of Otoites sauzei Zone, and Posidonia in Basey Member and middle member.	Middle member of basinal interlaminated dark lutite and graded volcaniclastic siltstone at Izee; grades east to graded andesitic ss. & cg. of Silvies Member and grades west to shallow (?) water volcaniclastic rocks and minor lava of Basey Member at Suplee.	Contemporaneous eruptions, dominantly pyroclastic, of augite andesite supplied nearly all detritus in rock sequence; two thin lava flows near Suplee.	
			Warm Springs Mem. (Jsws) 200-300 ft.; Weberg Member (Jswb) 0-200 ft.	lower member 500-750 ft.	Lower to middle Bajocian ammonites and pelecypods; abundant in Weberg and Warm Springs Members; common in lower member; abundant Posidonia. Common ammonites of Lytoceras jurense Zone in lower 100 ft. of lower member.	Laminated dark lutite of lower member at Izee and eastward probably deposited at moderate depth; passes westward to dark lutite tongue of Warm Springs Member, transgressive shallow marine sandstone of Weberg Member, and hiatus at unconformity.	Probably no active volcanism; andesitic detritus abundant in rock sequence.	Warping, uplift, and erosion near Suplee, unbroken sedimentation near Izee.
	EARLY JURASSIC	TOARCIAN	MOWICH GROUP: Hyde Fm. (Jmh), 700 - 1500 ft.		None diagnostic.	Marine deposition of andesitic tuff and volcanic sandstone at shallow to moderate depths.	Pyroclastic eruptions of augite andesite supplied all detritus to basin.	Subsidence of shelf formed by inundation of erosion surface.
			Nicely Fm. (Jmn), 75 - 350 ft.		Common lower to middle Toarcian ammonites.	Marine deposition of black shale.	Augite andesite lava flow (50 ft.) at Big Flat.	
			Suplee Fm. (Jms), 25 - 75 ft.		Abundant pelecypods; common ammonites.	Marine deposition of shallow water sandstone with minor limestone and conglomerate.	Pyroclastic eruptions of augite andesite supplied most detritus.	
		PLIENSBACHIAN	Robertson Fm. (Jmr), 0-335 ft.		None diagnostic.			
					None	No record	No record	OCHOCO OROGENY; intense folding near Suplee declining to the east; reverse faulting.
		SINEMURIAN		? - ? - ? - ? - ? - ? - ? Caps Creek beds (JTR C) ? - ? - ?	Ammonites collected by Thayer (written communication, 1961).	Marine deposition of mainly lutite.	- ? - ? - ? - ? - ? - Record uncertain; possible eruption of andesitic pyroclastics.	- ? - ? - ? - ? - ? - Details unknown owing to uncertainty regarding age of Caps Creek beds.
180		HETTANGIAN		Graylock Fm. (Jg) 500 ft.	Common ammonites in Graylock Fm.	Marine deposition of volcanic siltstone and calcarenite.		
	LATE TRIASSIC	RHAETIAN		Rail Cabin Argillite (TRrc) 2000 ft.	None	Marine deposition of dark argillite with intercalated felsitic tuff and minor fragmental limestone.	Explosive pyroclastic eruption of silicic ash.	Subsidence of shelf(?), probably marginal to rapidly subsiding tectonic basins to the NE (see Thayer and Brown, 1961).
		NORIAN			Rare ammonites.	No record	No record	Gentle folding, uplift, and erosion.
		KARNIAN	Brisbois Formation (TRbr) 5000 ft.		Common ammonites and pelecypods of Tropites subbullatus Zone.	Marine deposition of lutite with intercalated calcareous ss. and sandy ls.	Subordinate subaerial and submarine eruption of silicic ash, dacitic to andesitic ash, dacitic to andesitic lava, and spilitic lava.	Rapid and deep subsidence of at least 2½ miles, apparently entirely during Karnian Age; probably in local tectonic basin adjacent to tectonic highland of rugged relief.
			Begg Formation (TRbg) 7500 ft.		Rare pelecypods and coelenterates of probable Karnian Age.	Marine deposition of lutite with intercalated ss., cg., breccia, and volcaniclastic rocks.		
	E & M TRIASSIC	LADINIAN			None	No record	No record	PERMIAN-TRIASSIC OROGENY Moderate to strong folding, rock alteration, intrusion of serpentine, and deep erosion.
		ANISIAN						
230		SCYTHIAN						
	PERMIAN	OCHOAN						
		GUADALUPIAN						
		LEONARDIAN	Paleozoic rocks (Psv)		Rare lower Permian fusulinid.	Shallow marine deposition of felsite lava and tuff, chert, and limestone.	Eruption, largely pyroclastic, of silicic volcanic rock, largely dacite.	Subsidence.
280		WOLFCAMPIAN						

* Note: Spacing of age boundaries is not proportioned to their duration.

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