Bedrock Geology of The Mitchell Quadrangle, Wheeler County, Oregon

BULLETIN 72

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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FOREWORD

The Mitchell area of central Oregon has been well known, both to geologists and paleontologists, for more than 100 years. Dr. Thomas Condon, the first state geologist, collected fossil remains from the Cretaceous marine sedimentary rocks back in the 1860's. In more recent years students and professors from Oregon State University have used this region as an outdoor classroom in geology because of the wide variety of geologic features that can be studied here at first hand. This report is the culmination of more than ten years field work by the authors while instructing at the summer geology field camp.

The information contained in the bulletin will be of particular interest to the petroleum industry because of the excellent descriptions of the Cretaceous sediments that form a broad northeast-trending belt through the center of the quadrangle. The late Mesozoic sedimentary section of central Oregon should be a major target for oil exploration because of the environmental conditions under which it was deposited.

This part of Oregon also has great scenic beauty, due in no small part to the varicolored volcanic formations that cover much of the land. Painted Hills State Park lies along Bridge Creek in the western edge of the Mitchell quadrangle, and the famous John Day fossil beds are a few miles beyond the eastern border.

The professional geologist or paleontologist will find this comprehensive report is a valuable source of basic information on the stratigraphy and structure of central Oregon. The interested layman and recreationist will be able to learn more about the earth history of this region and the geologic development of the present topographic features.

R. E. Corcoran
Oregon State Geologist

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BEDROCK GEOLOGY OF THE MITCHELL QUADRANGLE, WHEELER COUNTY, OREGON

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INTRODUCTION

LOCATION, GENERAL DISCUSSION AND SIGNIFICANCE OF THE AREA

The Mitchell quadrangle of Wheeler County, Oregon lies on the north flank of the east-west-trending Ochoco Mountains. Thornbury (1965) classified this area as lying within the Blue Mountains section, Central Highlands Subprovince, of the Columbia Intermontane Province. The quadrangle, comprising approximately 215 square miles, is one of great geologic interest, possessing a greater variety of rock types and ages than most areas of similar size within the state of Oregon. The Permian, Cretaceous Tertiary, and Quaternary systems are represented; marine and continental sedimentary rocks of many types are present; metamorphic rocks crop out in the core of the area; pistons, sills, dikes, and irregular intrusions are records of plutonic activity; lava flows and tuffs record volcanic episodes. Major folds, faults, and unconformities delineate recurring tectonic events.

The quadrangle encompasses a major topographic basin draining toward the northwest with most streams flowing into Bridge Creek (Figure 1), a major tributary of the John Day River, or directly into the John Day River at the northern border. This basin is flanked by the Ochoco Mountains escarpment on the south, the Keyes Mountain complex on the southeast, and the huge syncline of Sutton and Horse Mountains, which dominates the topography on the north. In the central, basinal parts of the quadrangle vast pediments, carved from a variety of less resistant rock types, sweep down from retreating escarpments of resistant rock. Farther south linear ridges of resistant rock form giant cuestas and hogbacks. High, conical mountain masses surmount both pediments and ridge-formers. In part volcano-shaped, these mainly are huge piston intrusions or sills; however, an exception is Keyes Mountain (Figure 2), the exhumed remnant of an Upper Clarno Volcano.

Prominent among the high isolated peaks are Keyes Mountain (elev. 5704), the highest point in the quadrangle; White Butte (elev. 5664), the largest of the piston intrusions; Tony Butte (elev. 5106); and Marshall Butte (elev. 4538). The lowest elevation, in the northwesternmost corner of the quadrangle, is approximately 1600 feet along the John Day River. Thus, in this deeply dissected semiarid terrain there is over 4000 feet of relief.

U.S. Highway 26 traverses the southern half of the quadrangle. State Highway 207, from Fossil, joins U.S. 26 at the village of Mitchell. In addition to these two paved highways there is an improved road down Bridge Creek which leads to the Painted Hills State Park, an improved road down Girds Creek which reaches the John Day River, and a number of ranch roads which permit vehicular access to most parts of the quadrangle.

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[1] Part of the research which contributed data to this project was funded by National Science Foundation Grants GA 1155 and GA 1163.

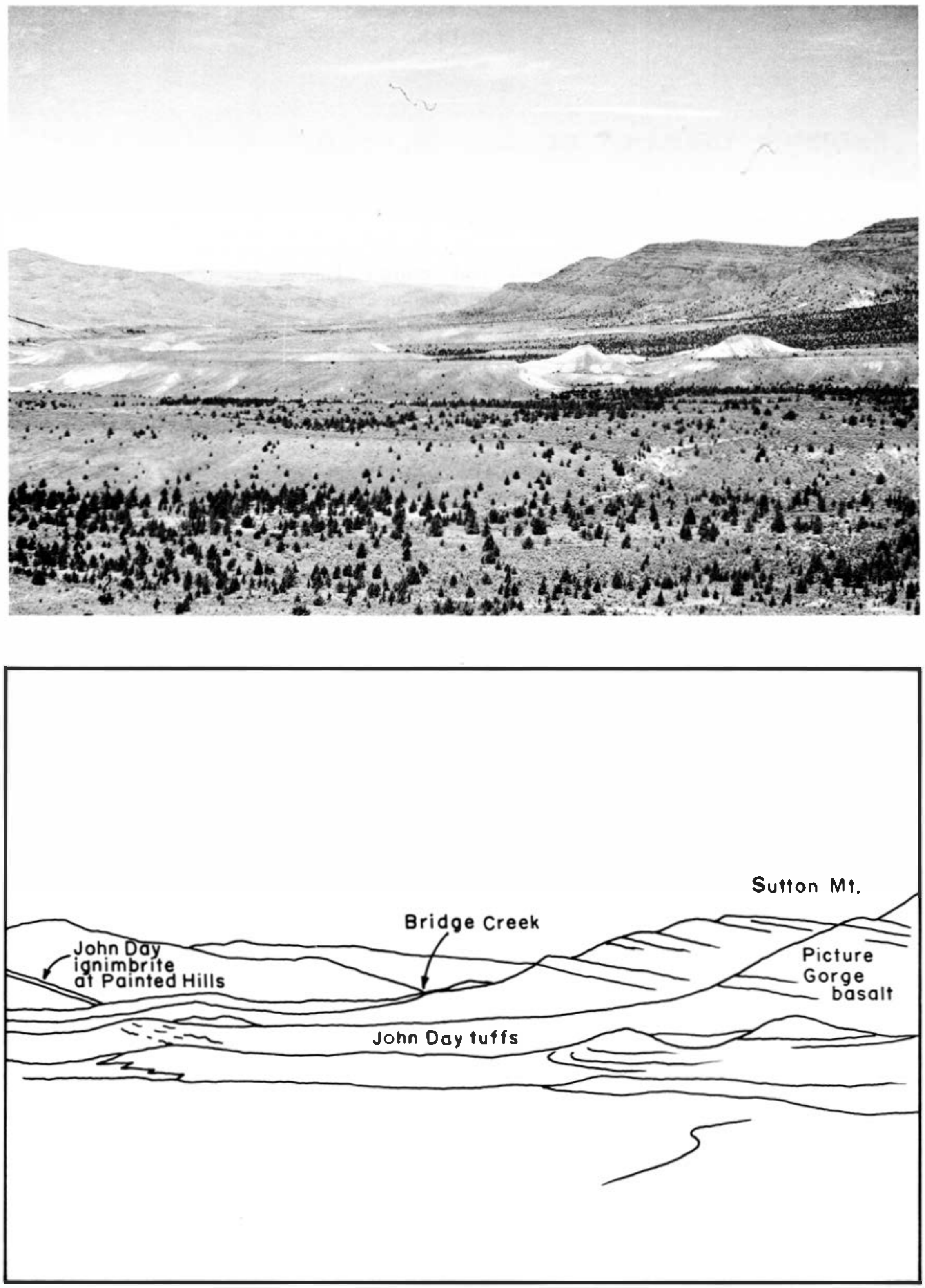


Figure 1. Panorama of Picture Gorge basalts of Sutton Mountain with sweeping pediments, developed on John Day tuffs, descending to Bridge Creek.

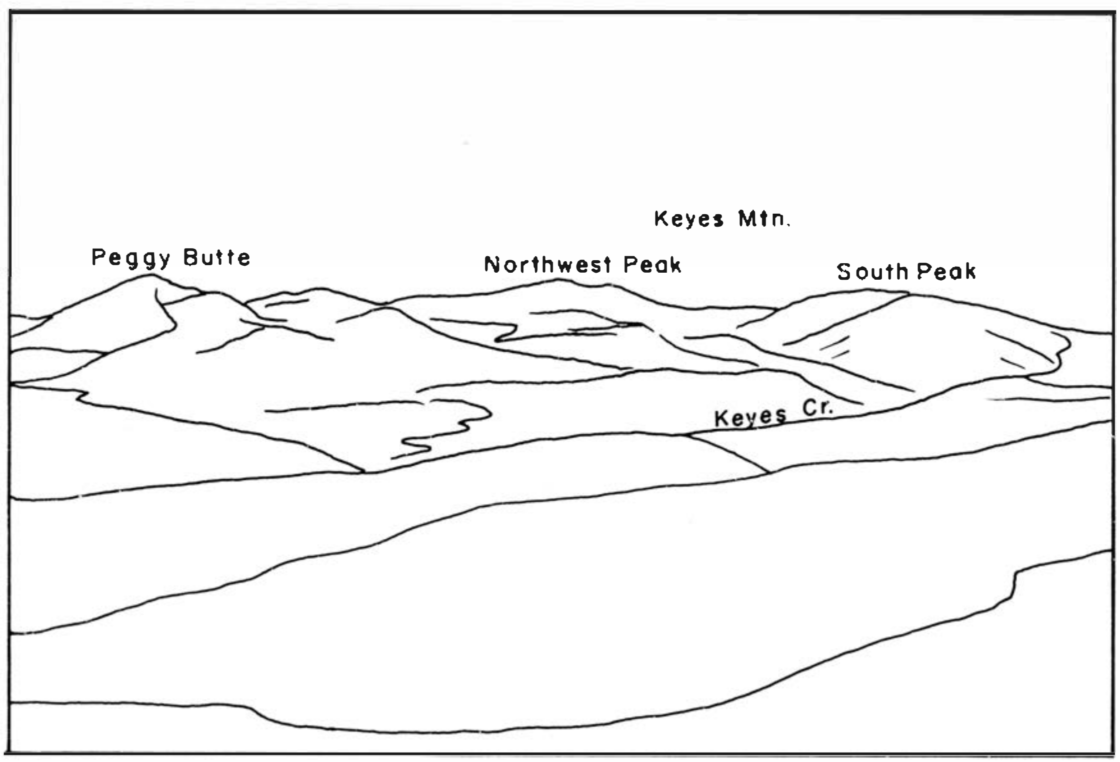


Figure 2. Keyes Creek Valley and the summits of Keyes Mountain, on Upper Clarno volcano. The prominence on the left is Peggy Butte, on upfaulted block capped by Keyes Mountain andesite flows.

The quadrangle supplies interest to many. The sweeping vistas of varicolored rocks and the variety of rock types and ages and landforms appeal both aesthetically and geologically; the local occurrences of petrified wood, varieties of chalcedony, and numerous zeolites attract the rockhound; the rock sequence with its complex depositional and deformational history discloses the paleogeographic history of central Oregon; and the mixed marine and continental sedimentary rocks of Cretaceous age are both a laboratory for the study of paleoenvironments and a key to possible petroleum exploration in Oregon.

PREVIOUS WORK

More than a century ago Dr. Thomas Condon, a pioneer geologist and Christian missionary, collected fossils from rocks in central Oregon which later were identified as being of Cretaceous age. Some of the grandest exposures of these old rocks lie within the Mitchell quadrangle. Merriam (1901) described the geology of the John Day Basin and also mentioned the presence of marine Cretaceous rock in the southern part of this basin. Merriam also first described the Clarno Formation, rocks of which are widespread and well-exposed in the Mitchell quadrangle. The Cretaceous sequence of rocks, over 9000 feet thick and the most extensive in central Oregon, has been described by Wilkinson and Oles (1968).

METHODS OF STUDY

The present report is the culmination of nine years of study of the quadrangle, and the map is a joint effort by Wilkinson and Oles from 1962 through 1967, and by Oles and Enlows from 1968 through 1971. Mapping was accomplished with the aid of stereoscopic pairs of high-altitude (scale 1:60,000) aerial photographs obtained from the U. S. Geological Survey. Part of the mapping was by photo-interpretation; the major part was accomplished in the field. From the aerial photographs a base map was prepared to a scale of 1:24,000 on advance sheets of the Mitchell 4 quadrangle of the U. S. Geological Survey. The result is a detailed map of an area in excess of 200 square miles. More detailed lithic descriptions have been accomplished by thin-section analyses, by X-ray diffractometer methods, and by chemical analyses.

ACKNOWLEDGMENTS AND DEDICATION

The authors gratefully acknowledge the many courtesies, extended through many years, of the inhabitants of Mitchell, the "logistical" base. Additionally, we thank the ranchers of the Mitchell quadrangle whose courtesy and forebearance permitted us to trespass at will. To Drs. Edward M. Taylor and William H. Taubeneck, Department of Geology, Oregon State University, we are indebted for stimulating discussions and field assistance, especially with rocks of the Clarno Formation. Moreover, Dr. Taylor was of signal assistance in providing chemical analyses of Clarno rocks by means of X-ray fluorescence spectroscopy. To Dr. David A. Bostwick, of the same department, our thanks for paleontological data on the Permian rocks, and to Clara Jarman our thanks for mineralogical information on the Hudspeth mudstones. Additionally, we are grateful to Dr. J. G. Johnson for critical reading of the manuscript. We wish to thank the State Department of Geology and Mineral Industries, R. E. Corcoran, State Geologist, for making possible this color map of a critical area. We also wish to thank Steven R. Renoud for the geological drafting of the final map. To Lee Oles we are indebted for the line drawings accompanying certain of the illustrations.

Finally the writers honor the field companionship and consummate field skills of Dr. W. D. Wilkinson, who unfortunately passed away on January 3, 1969. We dedicate this map and report to him.

STRATIGRAPHY

Exposed rocks of the quadrangle, comprising 37 mapped bedrock units and three surficial units, fall into four systems: Permian, Cretaceous, Tertiary, and Quaternary. The total stratigraphic sequence involves more than 19,000 feet of marine and continental sedimentary rocks, lava flows, and Quaternary deposits (Table 1).

PERMIAN METASEDIMENTS (Pms)

The oldest rocks, the basement, of the Mitchell quadrangle are metasedimentary. They are exposed mainly at two localities. The smaller of the outcrop areas, and the best exposed because of deep stream dissection, is in the vicinity of Meyers Canyon, SW 1/4, sec. 13, and NE 1/4, sec. 23, T. 11 S., R. 21 E. Here, in the steep walls of Meyers Canyon and a parallel tributary immediately south, there are exposed about 60 acres of phyllites and subordinate crystalline limestones. The metamorphic rocks stand nearly vertically, are intensely deformed, and have numerous small-scale isoclinal and subisoclinal folds; quartz boudins are common to the crestal areas of the folds. The crystalline limestones are found in pods and lenticular masses up to 50 feet in length or in long stringers within the enclosing phyllite. The pods appear to be tectonically dislocated lenses of former limestone beds. Fusulinids, too poorly preserved to permit of generic identification, have been collected from the limestones by Dr. David A. Bostwick. The sizes and shapes of the fusulinids indicate a Permian age and they resemble those Early Permian forms found in the Coyote Butte Formation of the Grindstone Creek area 45 miles to the southeast.

The larger of the basement outcrop areas is farther to the northeast in the vicinity of Tony Butte. About two square miles of these older rocks are exposed in parts of secs. 34, 35, and 36, T. 10 S., R. 22 E., secs. 1, 2, 3, and 12, T. 11 S., R. 22 E., and secs. 6 and 7, T. 11 S., R. 23 E. The major lithic types here are phyllites, crystalline limestone, and chert.

CRETACEOUS ROCKS (K)

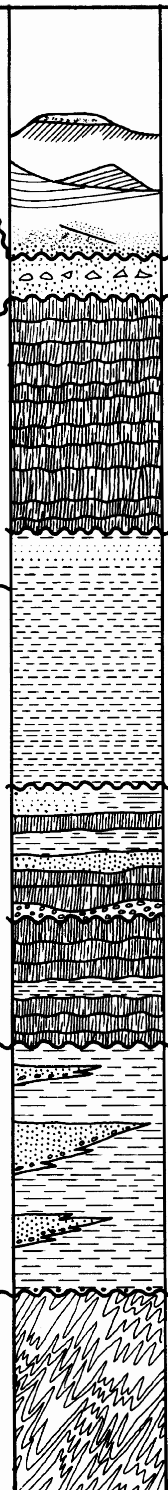
Hudspeth and Gable Creek Formations (Kh and Kgc)

All Cretaceous rocks in the Mitchell quadrangle are divided into two formations. One, in part the older unit, is a widespread and thick sequence of marine mudstones having subordinate siltstones and sandstones (Figure 3). This is the Hudspeth Formation (Kh). A series of conglomerate and sandstone beds (Figure 4) intertongues intricately with the Hudspeth Formation. These rocks, predominantly of fluvial and deltaic origin, are the Gable Creek Formation (Kgc). The complex intertonguing of the two formations is depicted on the areal geologic map and is represented schematically in Figure 5. The tongues of the Hudspeth Formation are numbered in ascending order from 1 through 12, and those of the Gable Creek Formation from 1 through 11.

The total sequence is described in the following generalized terms. First, the Basal Member (Khb) of the Hudspeth Formation, a thin sandstone and pebbly sandstone unit, lies with profound angular unconformity on the metasedimentary rocks of Permian age. This unit, 76 feet thick, is well-exposed in steeply dipping strata in the tributary to Meyers Canyon located in the S 1/2, sec. 13, T. 11 S., R. 21 E. A similar thickness of the basal unit intertongues with Hudspeth Formation mudstones on the southwest flank of Tony Butte, where the rocks also overlie the metasedimentary sequence. The latter locality has its best exposures of the Basal Member in the NE 1/4 NE 1/4, sec. 3, T. 11 S., R. 22 E. in Green Hollow.

The thick mudstone and siltstone unit, one of the dominant valley- and pediment-forming rock units of the southern half of the quadrangle, which overlies the Basal Member is the Main Mudstone Member (Kh1) of the Hudspeth Formation. Eleven tongues of each formation overlie the Main Mudstone Member. Within this sequence seven tongues of the Gable Creek Formation (tongues 1, 2, 4, 5, 7, 8, and 10) wedge out southward into the marine facies of the Hudspeth Formation. The other four Gable Creek tongues thin markedly and become finer grained to the south. In obverse manner, three tongues of the Hudspeth

Table 1. Stratigraphic sequence in the Mitchell quadrangle



QUATERNARY	Pleistocene	Quaternary deposits	Qal Qls Qfg	Variable	Valley fill and floodplain deposits; extensive landslide areas; remnants of high, older fans.
TERTIARY	Pliocene	Rattlesnake Formation	Tr	<25'	Isolated remnants of ignimbrite preserved in topographic lows.
TERTIARY	Miocene	Columbia River Group	Tcr	<1,000'	Thick basalt flows, most probably correlative to the Picture Gorge Formation. Tib: intrusions of basalt, melabasalt, and diabase; may pre-date Miocene.
TERTIARY	? Eocene – Oligocene	John Day Formation	Tjd	0 – 3,500'	Varicolored fluvial and lacustrine tuffs, sands, and gravels; locally an ignimbrite member (—i—). Tir, Tid: various leucorhyolite and dacite intrusions.
TERTIARY	Eocene – Oligocene	Clarno Group: Upper	Tct_2 Tcmf Tcf_2 Tcva	2,000'±	Andesite flows, mudflows, lacustrine and fluvial tuffaceous sediments, mainly derived from Keyes Mt., an exhumed volcano; local vent agglomerate.
TERTIARY	Eocene – Oligocene	Clarno Group: Lower	Tcf_1 Tct_1 Tcvb	4,000'±	Thick andesite flows with intercalated varicolored tuffaceous sediments; local volcanic breccias. Tia: White Butte and other andesite intrusions.
CRETACEOUS	Albian – Cenomanian	Gable Creek and Hudspeth Formations	Kgc Kh	9,000'+	Fluvial-deltaic Gable Creek Sandstones and conglomerates (11 members) intricately intertongued with marine Hudspeth mudstones, siltstones, thin sandstones (12 members plus a basal unit - Khb)
PERMIAN	Wolfcampian(?)	Metasediments	Pms	?	Phyllites, cherts, and crystalline limestones - metamorphosed marine sedimentary rocks.

Figure 3. Typical Hudspeth mudstones interbedded with thin, resistant sandstones.

Figure 4. Cliff-forming member of Gable Creek tongue 3 at Mitchell. Note lensing channel sands (lighter tones) within conglomerates.

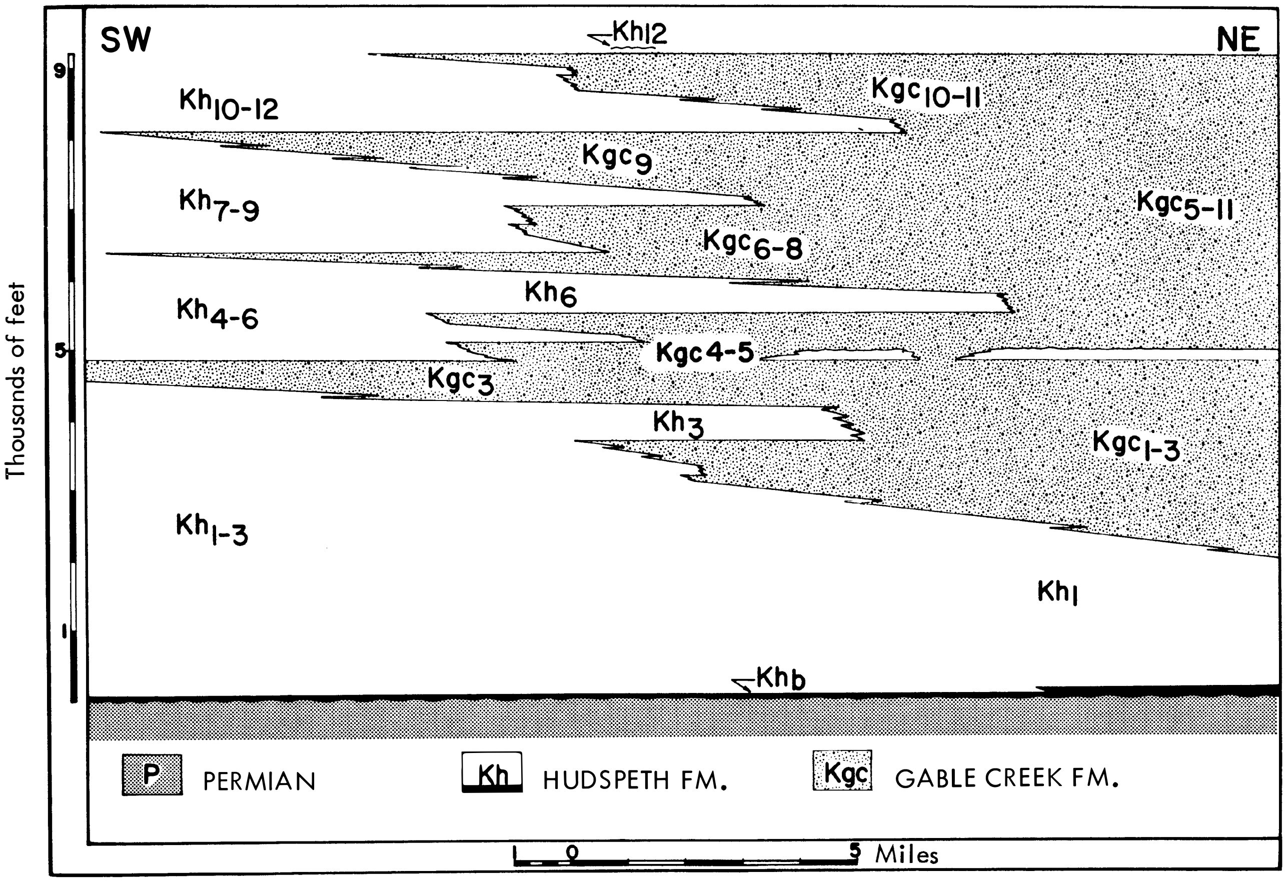


Figure 5. Schematic diagram of intertonguing Hudspeth and Gable Creek Formations.

Formation (2, 3, and 8) wedge out northward into the Gable Creek Formation. Despite the fact that much of the two formations is exposed only south of the Mitchell fault, and only the lower, older tongues can be seen north of the fault, most of the Hudspeth members appear to thin markedly to the north. The youngest Cretaceous rocks exposed in the quadrangle belong to Hudspeth tongue 12 (Kh_{12}), and are exposed only in sections 5, 6, 7, and 8, T. 12 S., R. 22 E., where they are overlain unconformably by the Tertiary Clarno Formation.

Outcrop area

The outcrop area of Cretaceous rocks in the Mitchell quadrangle is elongate, more than 22 miles along strike in a northeast-southwest direction. North of the Mitchell fault the maximum outcrop width is about five miles; south of the fault the greatest outcrop width is about 12 miles. The detailed description of the Cretaceous units may be found in the 1968 paper by Wilkinson and Oles. A paleogeographic synthesis of the two Cretaceous formations is described more fully in the section on Geologic History.

The less resistant mudstones and siltstones of the Hudspeth Formation generally crop out in sweeping pediments or in narrow strike valleys (Figure 6). The more resistant sandstones and conglomerates of the Gable Creek Formation form striking cliffs and giant cuestas. The result of two such units, one less resistant and one more resistant to weathering and erosion, intertonguing intricately is a landscape north and south of the Mitchell fault which can be described as a giant staircase of Hudspeth valleys and Gable Creek ridges. It is of interest that in this area the mudstone and siltstone valley-formers of the Hudspeth Formation are arable, and it is along these elongate strips that much of the farming of forage crops is accomplished.

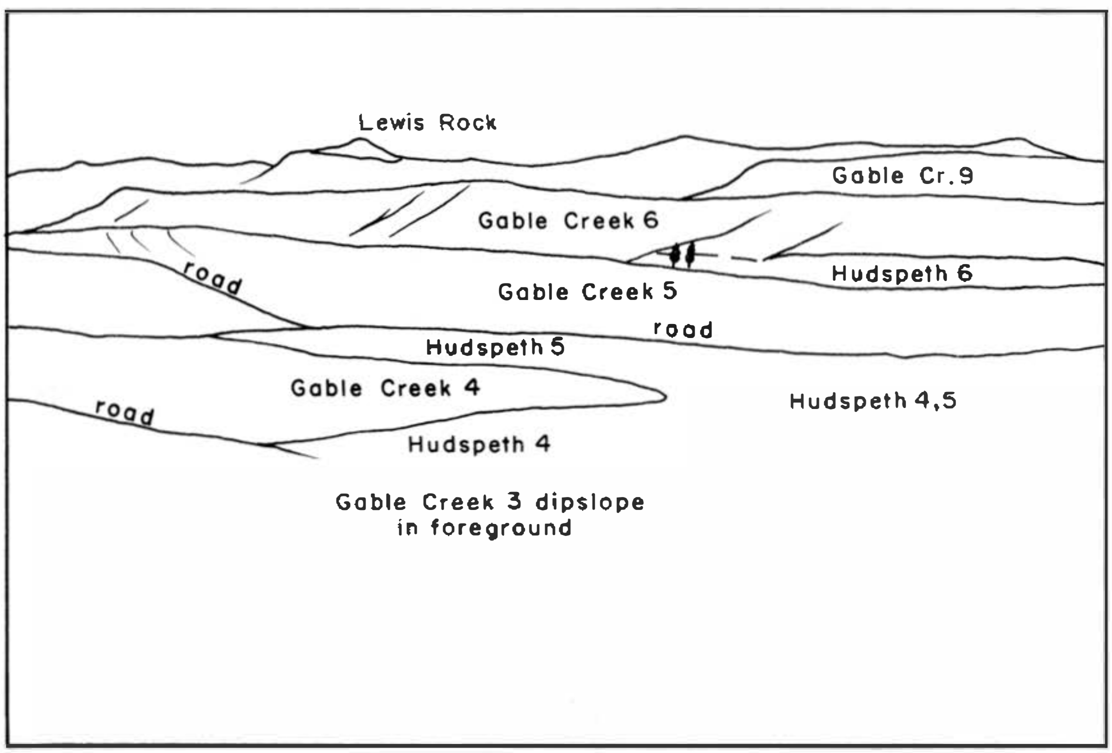


Figure 6. Looking southeast across Goble Creek valley at staircase of southeast-dipping Goble Creek cuestas and intervening Hudspeth valleys. Goble Creek tongue 4 wedges out southwest into Hudspeth mudstones in foreground.

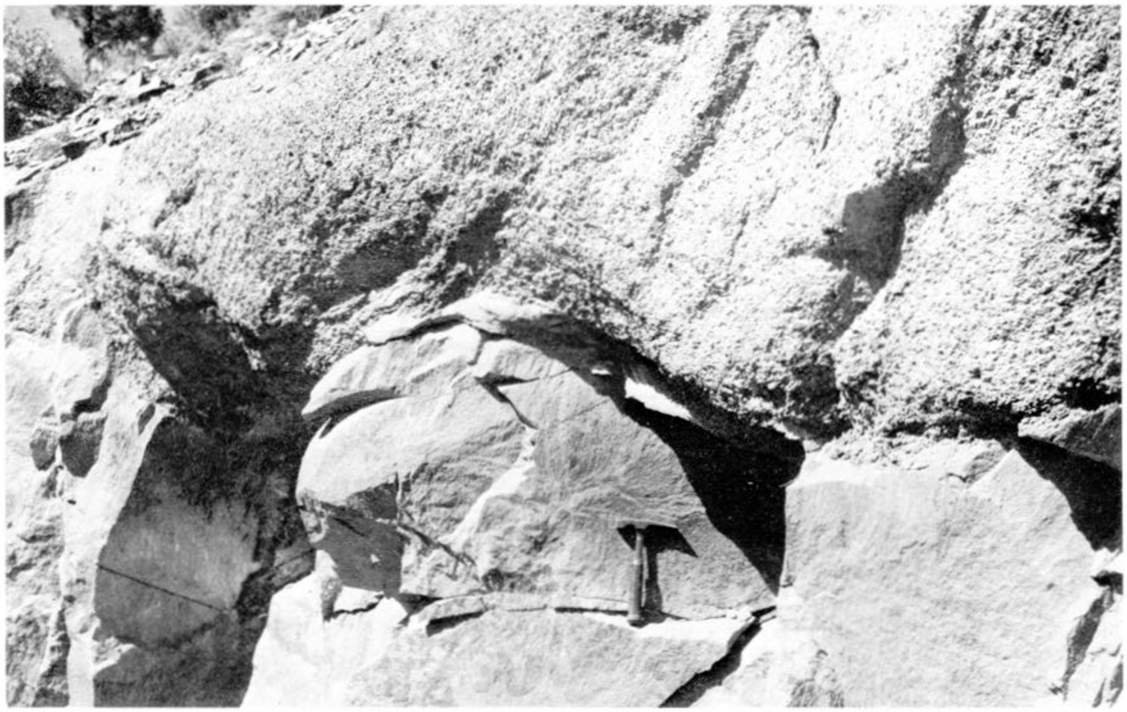


Figure 7. Sharp contact between Goble Creek pebble conglomerate above and sandstone below. The deeply undulating contact is partly the result of scour-and-fill, partly load deformation of hydroplastic sediments. Upper Bridge Creek road, near confluence with Johnson Creek.

Figure 8. Typical Goble Creek conglomerate and pebbly sandstone.

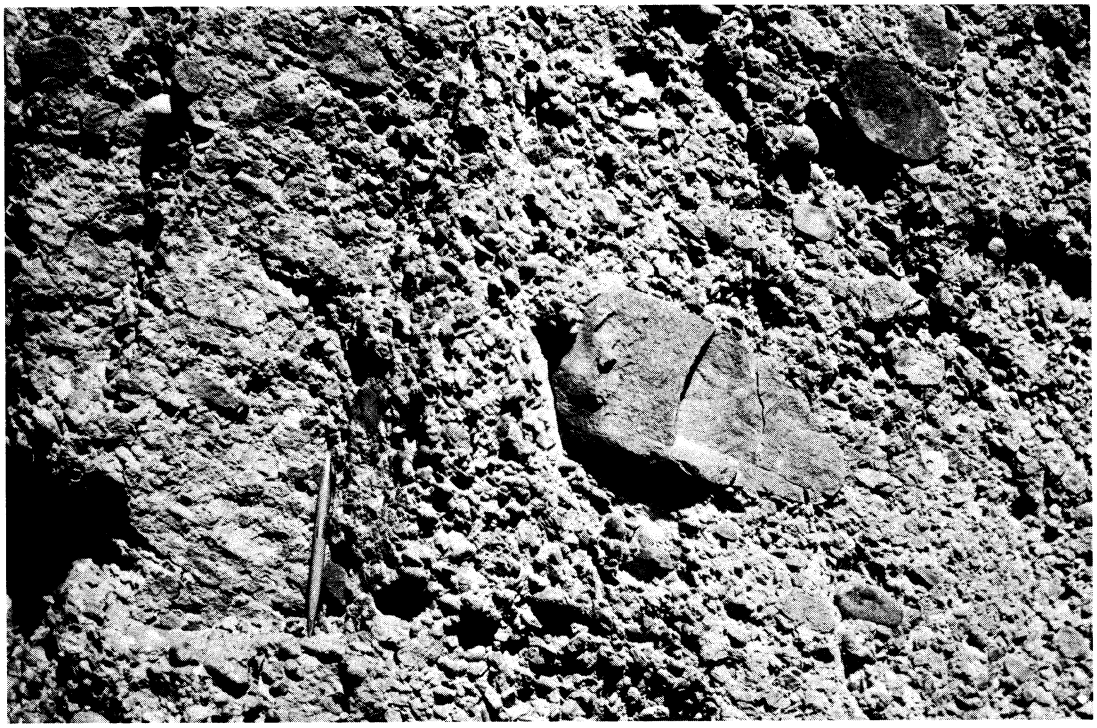


Figure 9. Poor sorting typical of many Gable Creek conglomerate units.

Petrography

Conglomerates (Figures 7, 8, 9): The clasts are rounded to subrounded, ranging in size from small pebbles to boulders. Chert, quartzite, and granitic rocks are the most common clasts with vein quartz, phyllite, greenstone, mafic volcanics, and sandstone present in minor amounts. The matrix is similar to the Gable Creek sandstones and cement is calcite.

Sandstones: The sandstones are best termed lithic arenites. They are characterized by poorly sorted, angular to subangular grains of mafic volcanics, devitrified volcanic glass, phyllite, chert, quartz, and feldspar. The matrix is chiefly smectite and the cement calcite. An average sandstone would consist of 77 percent framework, 10 percent matrix, 8 percent cement, and 5 percent void.

Mudstones: The mudstones consist largely of smectite with minor chlorite, illite, and kaolinite, and more or less admixed silt-sized grains of quartz and minor plagioclase.

Age of Cretaceous rocks

The Cretaceous strata of the Mitchell area range in age from early Albian to Cenomanian. These dates are based on collections of faunal suites of ammonites and pelecypods. Fossil determinations have been made by Anderson (1938, 1958), Jones (1965) and Packard (1928, 1929, written communications 1969, 1970). Since publication of the detailed description of the Cretaceous rocks of the Mitchell quadrangle by Wilkinson and Oles (1968), younger Cretaceous fossils have been found. These, represented by *Trigonia* sp., were collected in the Johnson Creek valley from Gable Creek tongue 11 and are correlative to Cenomanian forms described by Packard from the Antone locality farther southeast.

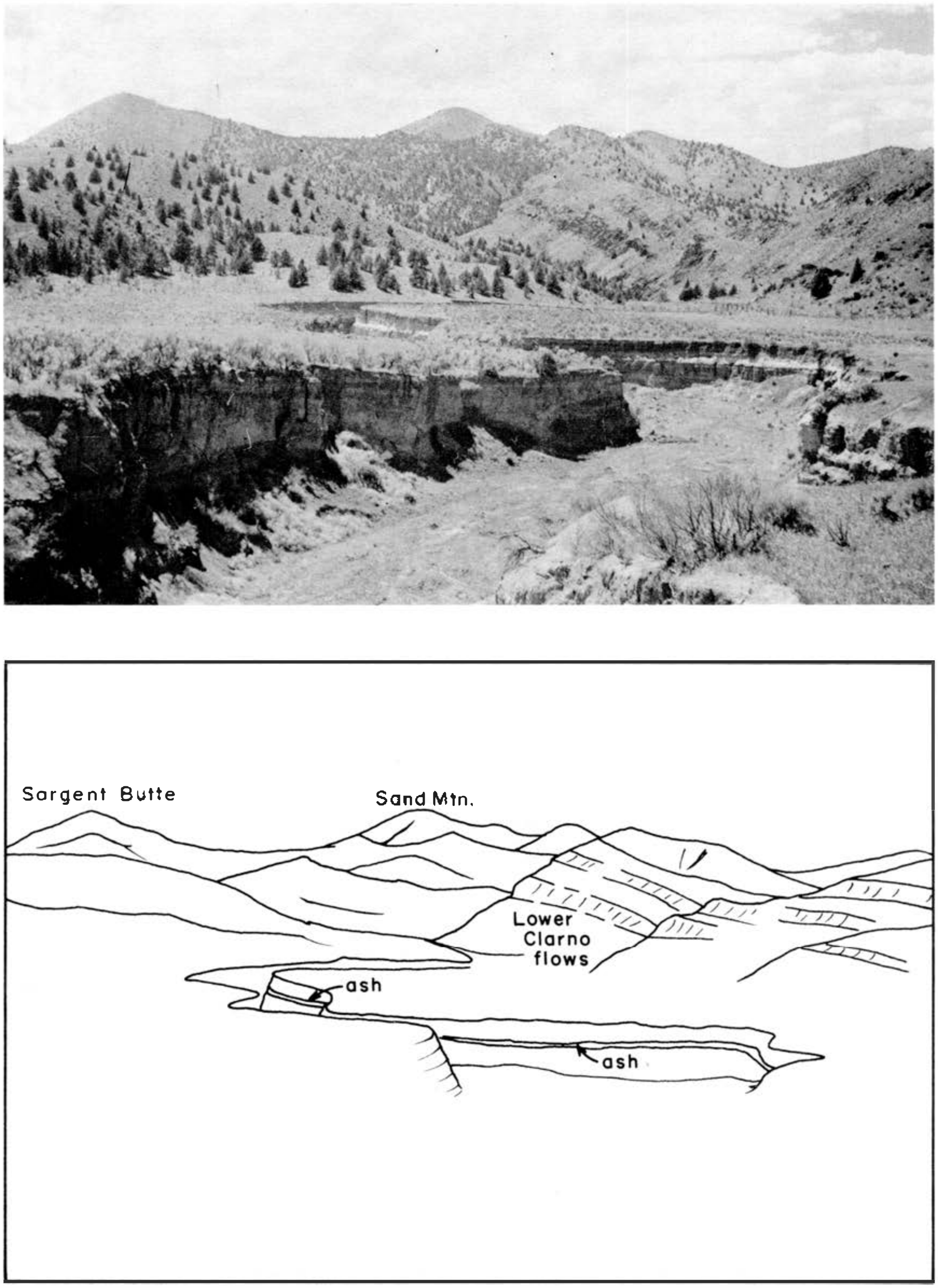


Figure 10. White Mazama ash layer exposed in dissected older alluvium of Meyers Canyon. Steeply northwest-dipping Lower Clarno andesite flows in middle distance. Sargent Butte and Sand Mountain, rhyolite intrusions, on skyline.

TERTIARY ROCKS (T)

The Tertiary rocks of the Mitchell quadrangle include the Clarno Group, the John Day Formation, the Columbia River Group, and the Rattlesnake Formation. Although the Tertiary sequence is incomplete --a more complete section of later Tertiary rocks is exposed farther east in the Picture Gorge-Dayville area--there are rocks representing the epochs Eocene through Pliocene. Each of the major Tertiary units rests with angular unconformity on the rocks below and is in turn overlain with angular unconformity by the succeeding unit. This is testimony to the recurrent instability from a tectonic standpoint and the episodic nature of the orogeny that has so profoundly deformed this region.

Clarno Group (Tc)

The Clarno Formation was named by Merriam (1901) for rocks in the vicinity of Clarno Ferry on the John Day River. At that locality the suite of rocks includes lava flows, breccias, and tuffs. The rocks overlying the Cretaceous and underlying the John Day Formation in the Mitchell quadrangle have been correlated to the Clarno Formation. However, the authors of the present paper will refer to the Clarno rocks as a "group" rather than a formation. The necessity for employing the term "group" is based on the fact that two dissimilar sequences of rocks, each ascribed to the Clarno in the Mitchell quadrangle, are separated by an angular unconformity. It is planned at a future date to describe formally two formations and to designate type sections with detailed descriptions. At the present time, however, we will refer to the two formations in an informal way, writing of the older Clarno rocks as the Lower Clarno, and the younger as Upper Clarno.

Lower Clarno Formation ($Tcvb$, Tcf_1, Tct_1)

The Lower Clarno rocks, best exposed north of the Mitchell fault, consist of volcanic breccias, andesite flows, and varicolored tuffaceous sediments. The total thickness is unknown, and multiple faulting makes a determination difficult, but the thickness probably exceeds 4000 feet. Additionally, at least one major intrusion, White Butte, is of early Clarno age.

Lower Clarno flows (Tcf_1): In the vicinity of the intersection of U. S. Highway 26 and the Painted Hills road (sec. 21, T 11 S., R. 21 E.), there are steeply dipping, hogback-forming andesite flows (Figure 10) and intercalated varicolored tuffaceous sediments (Tct_1). These rocks, which participated in the major orogenic episode which also folded the older Cretaceous sequence, lie with slight angular discordance on an erosional surface on the Cretaceous rocks. In sec. 21, along Bridge Creek and U. S. Highway 26, the contact is well-exposed and is marked by a zone, up to 30 feet thick, of deeply weathered red to reddish brown Gable Creek conglomerate. This ancient regolith contains clayey materials and abundant iron-stained pebbles derived from the underlying conglomerate. Best exposed here along Bridge Creek, the ancient regolith also is exposed elsewhere in the quadrangle, and observations along strike indicate that the erosional and weathering surface developed on the Cretaceous rocks had a topographic relief of several hundred feet. Andesite flows emplaced against and on that eroded surface record initial Clarno deposition in this area.

The Lower Clarno flows characteristically are resistant, and stand up above adjacent, less resistant, units as prominent ridge-formers, many rising more than 500 feet above the enclosing rocks. Columnar jointing is rare; irregular and curved joints are common. Closely spaced platy jointing is very common and generally is parallel to the tops and bottoms of the flows. As such, it probably is a response to original flow banding. Dusky red or dark reddish brown in overall hue, the flows are notably stained a reddish color along joints. In addition, the porphyritic rocks have feldspar phenocrysts commonly stained a dusky red.

Lower Clarno tuffaceous sediments (Tct_1): The sequence of Lower Clarno flows, many of which can be differentiated from each other by intervening baked zones, is interrupted by a pronounced tuffaceous unit (Figure 11). Some of the best exposures of these tuffaceous rocks lie north of Meyers Canyon at the common corner of secs. 10, 11, 14, and 15, T. 10 S., R. 21 E. Here, in a colorful southeast-facing slope, in part smoothly rounded and in part deeply gullied, these rocks crop out between underlying and overlying andesite flows. The basal tuffaceous unit, about 100 feet thick, weathers light brownish gray and dark reddish brown to dusky red. Overlying this unit are 10 feet of grayish orange to dark yellowish orange beds. Above this about 40 feet of tuffaceous strata are characterized by a basal zone, up to 20 feet thick, which is conglomeratic, with boulders up to four feet in diameter. This conglomerate, with subangular to rounded pebbles, cobbles, and boulders of andesite in a tuffaceous matrix, is partly torrentially bedded and probably was a fan deposit. The succeeding zone, resembling the basal unit, is 10 feet thick. This in turn is overlain by a four-foot band of pale yellow brown and grayish red tuffaceous rock. This unit is overlain by 40 feet of very pale orange rock. The tuffs range from dominant mudstones and siltstones to rare sandstones and conglomerates. Some show obvious fluvial deposition; others may have been lacustrine. The unit, 204 feet thick at this locality, is overlain by a typical Lower Clarno flow, the base of the flow being nearly glassy at the contact with the underlying sedimentary rocks.

The Lower Clarno tuffaceous rocks in some ways strikingly resemble tuffs and tuffaceous claystones of the younger John Day Formation. However, the Lower Clarno rocks can be differentiated in that they are thinner, are intercalated in Lower Clarno flows, and generally are steeply dipping, having participated with the Lower Clarno flows in the main orogenic episode that folded the Cretaceous rocks.

Figure 11. Varicolored Lower Clarno tuffaceous sediments capped by Lower Clarno lava flows. North rim, Meyers Canyon.

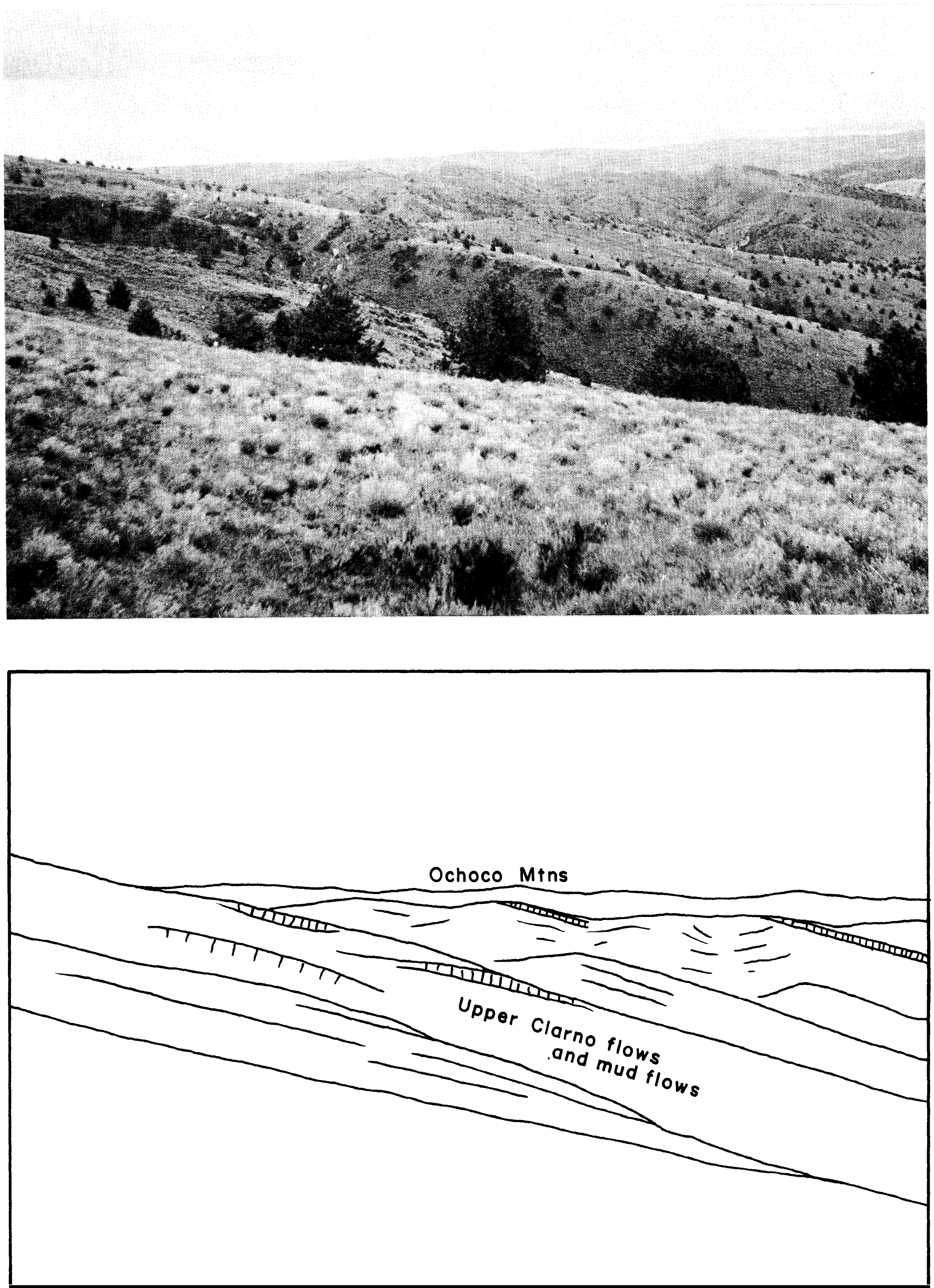


Figure 12. Upper Clarno lava flows and mudflows dipping west off Keyes Mountain. Ochoco Mountains front on skyline to south. Peggy Butte area.

At the Meyers Canyon localities, and also farther southwest in the Sand Mountain–Sargent Butte area (secs. 17, 19, 20, T. 11 S., R. 21 E.), these volcaniclastic rocks are characterized by the conglomerate zone; by rounded grains of zeolite, quartz, and dark lithic fragments; and by striking irregular polygonal mud cracks up to five inches long and two inches deep on the weathered surfaces of finer grained units. Throughout the unit there are slickensided plates of selenite and fibrous calcite.

Lower Clarno volcanic breccia (Tcvb): The unit designated as Lower Clarno volcanic breccia crops out only on the south flank of White Butte in parts of secs. 20, 21, 28, and 29, T. 12 S., R. 21 E. These rocks lie, with slight angular discordance, on Cretaceous rocks of Hudspeth tongues 7–9 and Gable Creek tongue 9. The Cretaceous rocks have been shouldered aside and steeply tilted by the forcible intrusion of

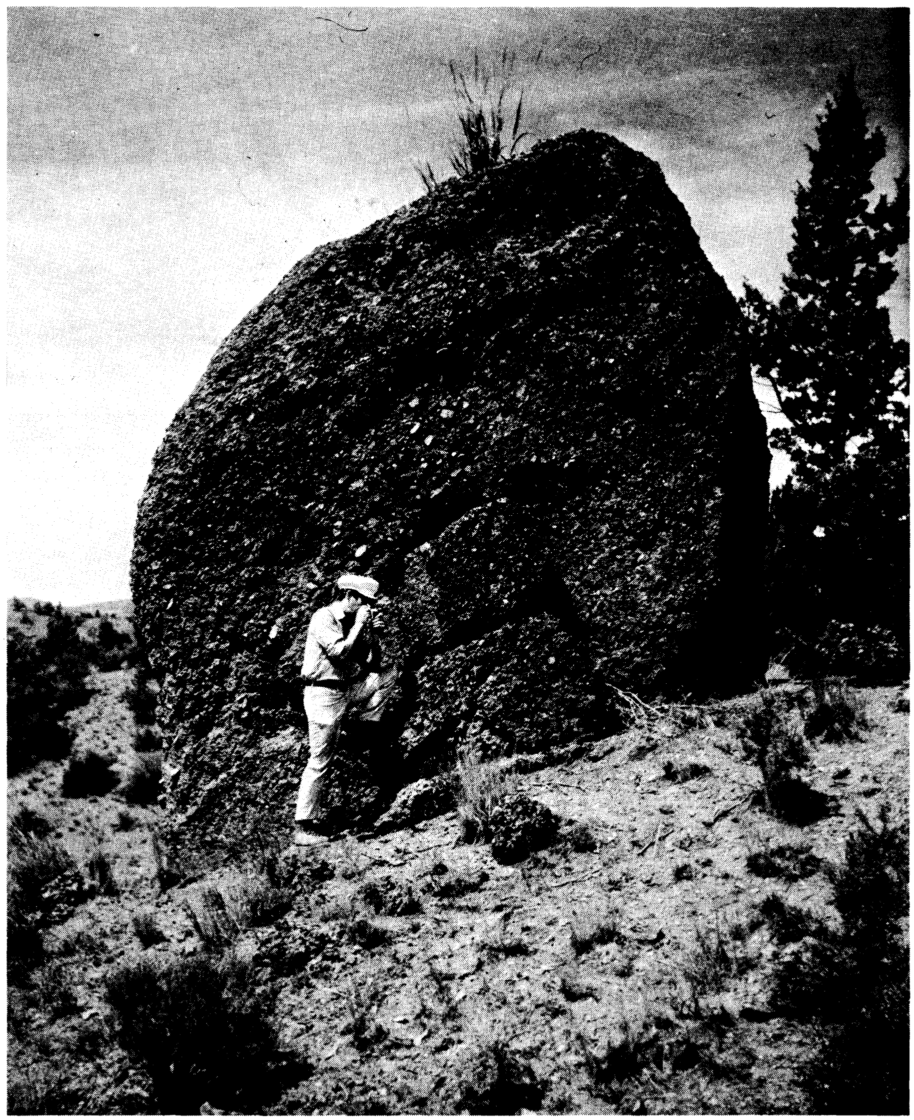


Figure 13. Huge boulder of Cretaceous conglomerate carried by an Upper Clarno mudflow. Half a mile northeast of Mitchell.

White Butte, and the Lower Clarno volcanic breccia has participated in this deformation. The breccia is unconformably overlain by Upper Clarno mudflows which lie almost horizontally on the steeply dipping older rocks.

The breccias are cliff- and hoodoo-formers. The clasts range from angular fragments two inches in diameter to subrounded to angular blocks up to 18 inches. The larger fragments are porphyritic andesite isolated in a matrix of sand-sized lithic debris. Near the top of the sequence there are thinly laminated, fine- to medium-grained sandstones.

The matrix of the volcanic breccia is best described as a pebbly volcanic wacke. The lithic fragments consist of mafic volcanics up to 5 mm in diameter which have been severely altered. Plagioclase laths "float" in a red-stained opaque matrix. There are some fresh, Lower Clarno-type volcanic rocks represented. These are porphyritic with clinopyroxene, plagioclase, and hornblende in a fine-grained holocrystalline matrix. The sand-sized mineral grains consist of hornblende, plagioclase, clinopyroxene, and magnetite, all of which are angular to subangular. The finest materials of the matrix are green smectite and kaolinite(?) of silt or clay size.

The source of both the framework and matrix of this rock is apparently the Lower Clarno volcanics. The volcanic breccias rest on Cretaceous rocks and are overlain with profound angular unconformity by Upper Clarno mudflows, but their position in sequence is imperfectly known. Because they have participated in the tilting caused by the White Butte intrusion, and have obvious Lower Clarno lithic affinities, it is conceivable that these breccias occupy a stratigraphic position correlative to the tuffaceous unit so well exposed farther north near Sand Mountain, Sargent Butte, and Meyers Canyon.

Upper Clarno Formation (Tcva, Tcf_2, Tcmf, Tct_2)

Rocks referred to the Upper Clarno are found only in the southern, southeastern, and eastern parts of the quadrangle. Structural attitudes, thicknesses and directional properties indicate that the majority had as a source the plexus of Keyes Mountain. This mountain mass (Figure 2), with the south peak being the highest point (elev. 5704) in the quadrangle, consists of three major peaks--the northwest, the south, and the east--and several subordinate high points. The northwest and south peaks are separated from the east peak (Flock Mtn.) by south-flowing Marshall Creek. Quaquaversal dips from the Keyes Mountain complex indicate that it is an exhumed Eocene or Oligocene volcano. A sequence of lava flows and mudflows spreads in all directions from Keyes Mountain (Figure 12), forming the most widespread outcrops of this part of the quadrangle.

The rocks derived from Keyes Mountain rest on a diversity of older rock types, and certain general observations may be made. First, when Keyes Mountain commenced its eruptive history there was a surface of considerable relief and dissection; well over 400 feet of relief can be demonstrated. The old eroded surface, whether developed on the Permian basement rocks, a variety of Cretaceous rocks, or Lower Clarno rocks, was deeply weathered; and everywhere a regolith, usually marked by a 10-20 foot thick maroon zone, is present. Locally, where Gable Creek conglomerates cropped out, giant residual boulders up to 15 feet in diameter (Figure 13) lay on the surface. These were overrun by flows or mudflows from Keyes Mountain and were incorporated in the basal parts of the younger units. Not only is the deeply weathered ancient regolith visible, but the ancient relief is well displayed at many localities where deep channels, presumably formed by stream action, have been back-filled by flows or mudflows. As a high volcano surmounting a platform of older rocks, Keyes Mountain furnished a vast number of flows and mudflows (Figures 14, 15) which are either intracanyon to the older rocks, intracanyon to each other, or lap against the paleotopography developed on the older rocks. It is of interest to note that the rocks derived from Keyes Mountain, although moderately tilted to south and to west, have not participated in those stronger orogenic episodes that earlier deformed the Permian, Cretaceous, and Lower Clarno rocks. As a consequence, the entire Upper Clarno sequence lies with angular unconformity on older rocks. In a terrain of dissection and relief, developed prior to the Upper Clarno events, and with flows and mudflows spilling down across a variety of older rock types, it is extremely difficult to establish a coherent stratigraphic sequence for the Upper Clarno.

Upper Clarno mudflows (Tcmf): At many localities where Upper Clarno rocks are areally extensive, mudflows are the oldest rocks representative of the sequence. Lying on a deeply weathered surface with

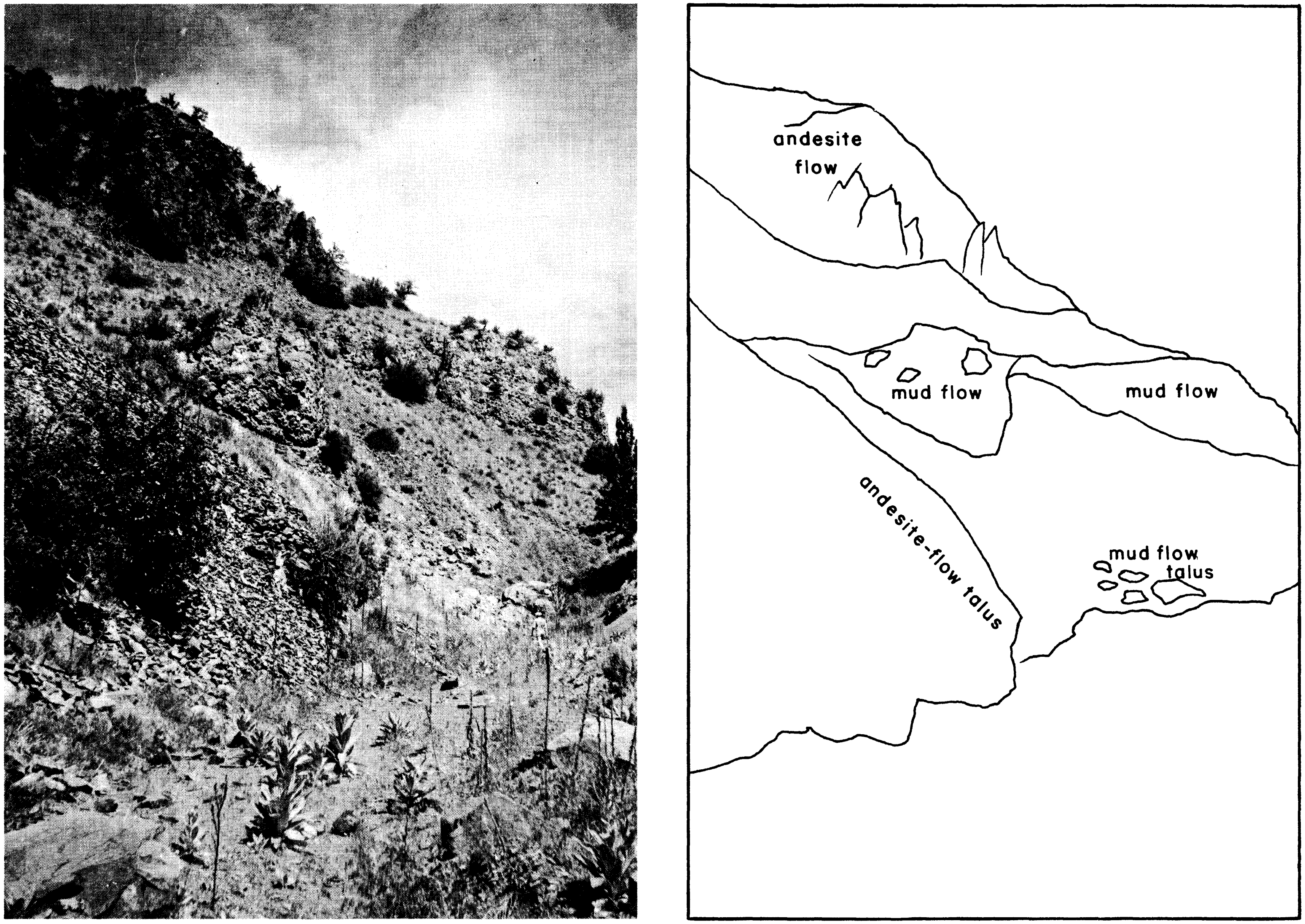


Figure 14. Upper Clarno topography. A cliff-forming andesite flow overlies a bench- and ledge-forming mudflow unit. Dry wash a quarter of a mile east of Mitchell.

relief locally exceeding 400 feet, the Upper Clarno mudflows variously overlie with angular unconformity Permian, Cretaceous, and Lower Clarno rocks. Close to Keyes Mountain, the source, the mudflows appear to be intercalated with lava flows, but the stratigraphic succession is not simple. Mudflows are, in some places, intercalated with lava flows, but a false sense of the succession often is gained because lava flows lie juxtaposed, intracanyon to mudflows; the reverse is also true. Rather than having simply older mudflows overlain by lava flows, there are many places on the flanks of Keyes Mountain where mudflows and lava flows are intercalated, lap each other, or are intracanyon in a bewildering succession. At least 21 discrete lava flows have been mapped, many of which are separated by, or lie intracanyon to, mudflows. It is apparent that the construction of Keyes Mountain was episodic, and that long intervals of weathering and erosion separated volcanic events. During such erosive intervals valleys, probably carved by stream erosion, became channels for later mudflows and lava flows, thus furnishing new paths for both rock types during succeeding eruptive events.

Nowhere north of the Mitchell fault are mudflows found that form more than 400 feet of uninterrupted sequence. However, south of the Mitchell fault mudflows up to a thousand feet in thickness are piled up in the Johnson Creek valley. These are overlain by Upper Clarno lava flows at Lewis Rock (secs. 20, 21, T. 12 S., R. 22 E.). At many places the mudflows form bold escarpments, some being nearly vertical, and joint-controlled hoodoos are prominent. At other places the mudflows are far less resistant to weathering and erosion and underlie gentle slopes and valleys.

North of Keyes Mountain and south of Tony Butte the older rocks are Hudspeth mudstones. These have been deeply weathered and are overlain by an ancient, maroon-colored regolith. The upper part of the mudstones is jumbled, bedding is indistinct, and there is ample evidence for gravitative downslope movement on the ancient topography. Cut into this regolith and the more typical mudstones is a deep and wide channel which is filled by mudflow. The mudflow ranges from the finest clay-sized materials to boulders five feet in diameter. At this locality the boulders are of extraordinary interest. They include not only the expectable porphyritic andesites from Keyes Mountain, but there are phyllites, silicified limestones, chert, quartzite, and jasper. It is apparent that the mudflow, eventually emplaced on Cretaceous mudstones, swept down and across a terrain dominated by Permian metasediments. Above Limekiln Creek, southeast of Tony Butte, the Permian metasediments are directly overlain by mudflows, and here, too, there is a well-defined dusky red regolith at the contact, which facilitates mapping.

In the more typical exposures of mudflow, the common outcrop colors are tan and gray with a greenish cast, and large rounded to subangular boulders and cobbles protrude (Figure 16) as more resistant knobs from a finer, less-resistant matrix. With the exception of the exotic older rocks, both the larger clasts and matrix of the mudflows are formed from porphyritic andesite.

The sizes and number of the boulders decrease markedly away from Keyes Mountain. Within three miles of Keyes Mountain boulders up to 15 feet in diameter are not uncommon, but five miles from Keyes Mountain the largest boulders rarely exceed two feet in diameter. Most of the larger clasts are matrix-supported; locally there are mudflow units with more boulders than matrix. The matrix ranges from clay to sand size. Discernible constituents are pyroxene crystals, feldspar laths, a few quartz crystals, and broken fragments of porphyritic andesite. Where the sand size is dominant the sands commonly are medium to coarse grained, angular, and extremely poorly sorted. From a textural standpoint, the mudflow units generally are poorly sorted. Bedding is not obvious at many localities, but there is rude stratification, mainly delineated by a crude sorting, grading, and differential weathering. At some places, units are far better sorted and resemble normal fluvial deposits, but the majority are so poorly sorted and stratified that they appear to have been emplaced as mudflow slurries. The bedding in the mudflows, ranging from massive and indiscernible to that which is thin and well defined, is similar to the structures encountered in modern fan deposits.

Farther from Keyes Mountain--off the flanks and in piedmont positions where the mudflows are finer grained, boulders are uncommon, and cobbles and pebbles are the largest clasts--lenses and channel fillings of sand- and silt-sized materials become common. Within these lenses and channels there are pebbly conglomerates, pebbly sandstones, and sandstones, some of which are thinly laminated. At a few localities cross-bedding or cross-lamination is present. Throughout the mudflows scour-and-fill channels and abrupt lateral variations indicate that water was the transporting medium. Farthest from the mountain, where a piedmont terrain must have existed, there are well-defined zones of claystones and fine-grained sandstones. The bedding is usually good, commonly is laminated, and at many places is

Figure 15. Stream-dissected Upper Clarno mudflow. Dry wash a quarter of a mile east of Mitchell.

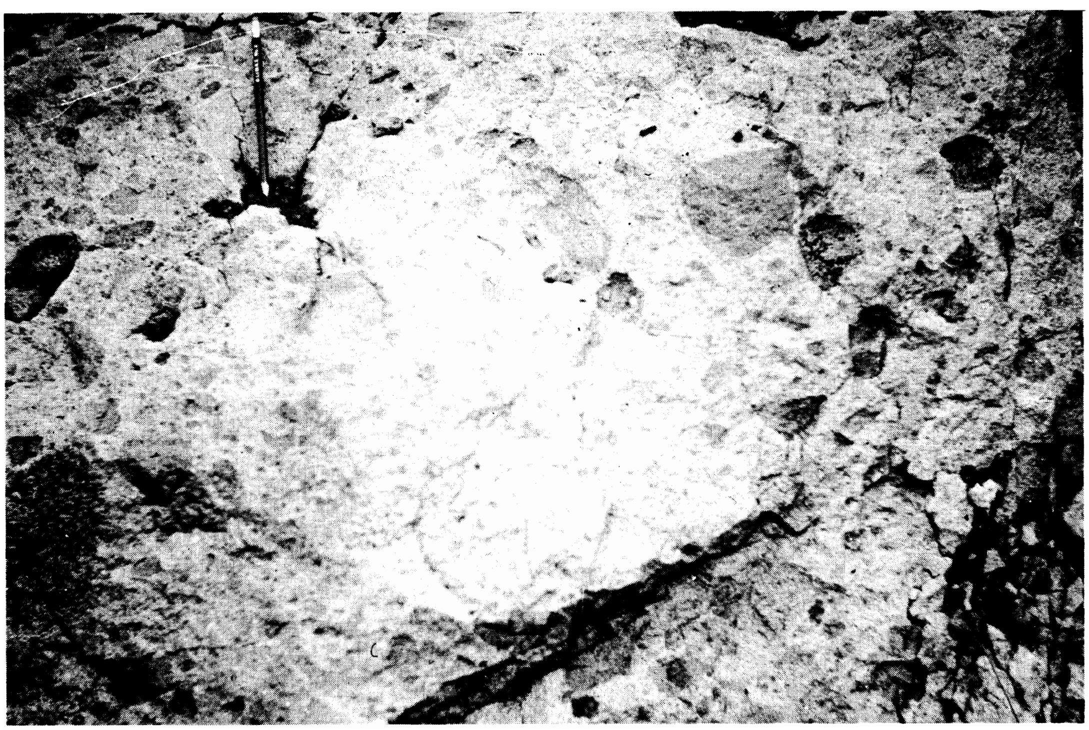


Figure 16. Detail of angular to subrounded andesite clasts embedded in a finer-grained andesite matrix. Upper Clarno mudflow.

cross-laminated or cross-bedded. These tuff-like rocks contain numerous leaves and twigs, and the rocks presumably were deposited in fluvial, deltaic, and lacustrine environments distant from the sediment source of Keyes Mountain. Most of these finer grained equivalents of the mudflows lap against or lie intracanyon to mudflow units and are mapped as Upper Clarno tuffaceous sediments (Tct_2).

Near Keyes Mountain the mudflows and the associated lava flows dip away from the mountain with quaquaversal dips (Figure 12). Farther from the mountain the mudflow units decrease in dip and five miles from the source the mudflows are essentially flat-lying and overlie or lap against older rocks. It is apparent from the distribution of rock units that the mudflows spread farther from Keyes Mountain than did the lava flows and formed fan and piedmont deposits. Some of the mudflow units, in particular those lying south and above the Hudspeth hauling road, are characterized by an abundance of woody material. This broken up and silica-replaced wood apparently was overrun by the mudflows. Locally there are twigs and reeds, dominantly preserved as carbon residues, and small logs. At one locality tree trunks, apparently in growth position, occur at the base of a mudflow. These trees, once growing in the regolith developed on the Cretaceous rocks, were obviously overrun by the mudflow.

The mudflow matrix and associated tuffaceous sediments are generally light olive gray, yellowish gray, or greenish gray. All are classified as volcanic wackes (Figure 17) rich in volcanic rock fragments and plagioclase. In most of these poorly sorted rocks the framework consists of finely crystalline, holocrystalline volcanic clasts of Clarno andesite, and smaller grains of plagioclase, magnetite, clinopyroxene, hypersthene, hornblende, and very subordinate quartz, quartzite, and chert. The matrix has the same composition but is generally silt sized and additionally has kaolinite, green smectite and red to brown iron oxide. Much of the green smectite is authigenic and cements the mudflow units into coherent rock masses. Some of the observed authigenic changes include plagioclase changing to laumontite, and pore spaces lined with coarsely crystalline olive-green smectite.

Upper Clarno tuffaceous sediments (Tct_2): Those facies of the mudflows which are mapped as Upper Clarno tuffaceous sediments are generally found more than two miles from Keyes Mountain and best developed eight to ten miles from it. These finer grained clastic rocks are intercalated in the Upper Clarno mudflows, lie intracanyon to the mudflows as channel fills, or form extensive, possibly lacustrine, deposits which lap against Upper Clarno mudflows or older rocks. These tuffaceous sediments are lithologically distinct from those of the Lower Clarno. They are monotonously the same in color, weathering to a greenish gray. Some are claystones; many are medium brown siltstones, the brown color probably being derived from abundant plant fragments including resinous translucent debris; and many are fine- to medium-grained sandstones. At various places the tuffaceous sediments contain abundant reeds, leaves and twigs. At one locality a hard resistant ledge-former is partly crystalline limestone, partly a dark gray chert, suggesting a lacustrine deposit. At some localities cross-bedding and repeatedly truncated foresets are typical of fluvial and deltaic deposition. At a few outcrops there are pebbly sandstones up to four feet thick; pebbles dominate, but there also are isolated boulders and cobbles. These subangular to subrounded larger clasts typically are matrix-supported, with volume of the matrix exceeding that of the larger clasts. This is a distinct difference from the more tightly packed Cretaceous conglomerates. The larger clasts are dominantly andesite with subordinate siltstone and mudstone pebbles.

Most of the Upper Clarno tuffaceous sediments are slope- and valley-formers, being far less resistant toweathering and erosion than adjacent rocks. However, southwest of Sargent Butte in sec. 20, T. 11 S., R. 21 E., the sediments crop out in a series of low hills which stand up protected by a cap rock. The cap rock is a cliff-forming ignimbrite up to 35 feet thick, which surmounts the sedimentary sequence. The base of the ignimbrite rests on the tuffaceous sediments at an undulating contact, and is marked by a discontinuous, dark yellowish orange (10YR 6/6), deeply altered, basal, ash-fall pumice one to three inches thick. This ignimbrite cap rock is probably the youngest Clarno rock present in the area.

In this section the oldest strata in the unit are fine pebble breccias and conglomerates, and the sandstone matrix has abundant angular plagioclase. The sandstones in the sequence have angular to subangular plagioclase dominant; jasper is a constituent common to many of the sandstones. The finer-grained sandstones are laminated and cross-laminated, with scour-and-fill channels very common. The unidirectional sedimentary structures suggest fluvial and deltaic deposits; the parallel laminae suggest lacustrine deposits, the results of stream transport from Keyes Mountain to piedmont positions which contained ancient lakes and ponds of limited size.

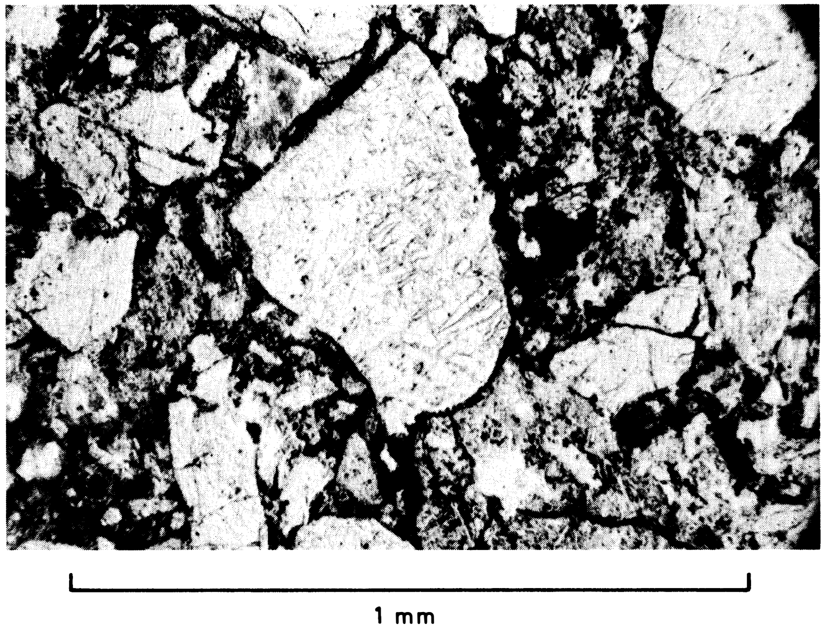


Figure 17. Upper Clarno volcanic wacke: large central grain of plagioclase altering to laumontite. Additional grains of plagioclase and lithic grains composed of mafic volcanics. Matrix of smectite and small grains of feldspar, augite and mafic volcanics. Nicols parallel.

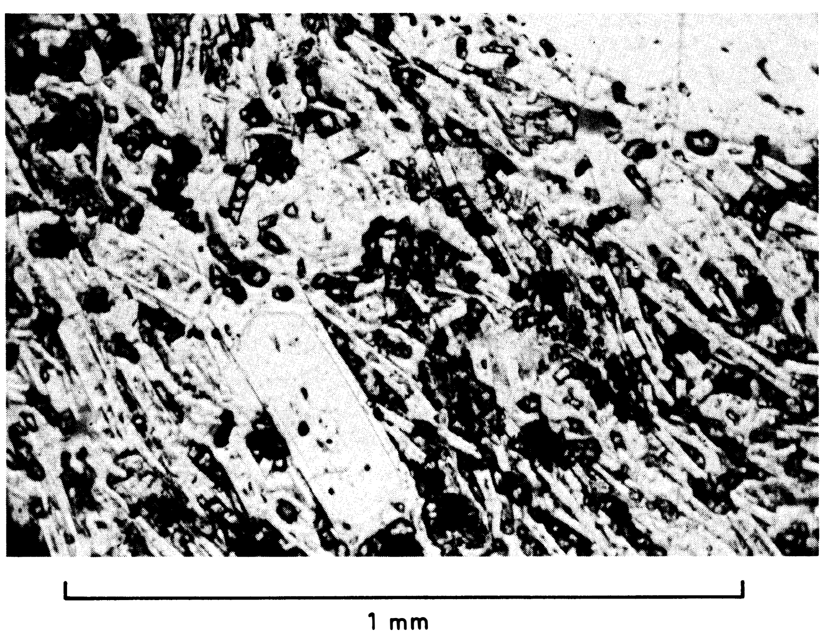


Figure 18. Lower Clarno flow: labradorite phenocrysts in a pilotaxitic groundmass of smaller laths and anhedral masses of andesine, small augite grains and magnetite. Parallel nicols.

The maximum thickness of these Upper Clarno rocks on outcrop occurs southwest of Sargent Butte where at least 350 feet are exposed.

Clasts of the coarser sediments are angular to subangular and consist largely of Clarno andesite lithics or plagioclase, clinopyroxene, hypersthene, hornblende, and magnetite weathered from the Clarno andesites. Bipyramids of quartz are rare but widespread, especially in the finer sediments, indicating contributions from a more acid source. The abundant matrix consists of silt-sized fragments of the above minerals, green smectite, ferric oxide, and minor kaolinite. The sparse cement is calcite. These coarser clastics are best classified as volcanic wackes.

The finer clastic sediments consist largely of green smectite and ferric oxide, silt-sized fragments of the mineral clasts mentioned above, minor kaolinite, and finely divided organic material. They variously are siltstones, mudstones, or claystones.

Upper Clarno flows (Tcf_2): Upper Clarno lava flows, derived from Keyes Mountain, are conspicuous ridge-, cliff-, and dipslope-formers in the southeast part of the Mitchell quadrangle. Most numerous and topographically significant on the flanks of Keyes Mountain, discrete flows are present as much as six miles from the source. An example of thick flows relatively distant from the mountain is that of Lewis Rock, where flows totalling over 400 feet in thickness make up the bold north-facing escarpment in sec. 20, T. 12 S., R. 22 E. and overlie the thickest sequence of Upper Clarno mudflows. But the simple stratigraphic relationship of Lewis Rock, with lava flows surmounting mudflows, is not present on the flanks of Keyes Mountain, where there is a complex of lava flows intracanyon to mudflows and vice versa.

The number and thickness of Upper Clarno lava flows decrease markedly away from Keyes Mountain. At the summit and on the flanks of the mountain 21 discrete flows have been identified, some of which exceed 150 feet in thickness. Farther from the mountain the flows decrease in number and thickness and, in the vicinity of Mitchell, only one flow remains as thin, isolated, erosional remnants capping knolls underlain by a mudflow.

At and immediately adjacent to Keyes Mountain the lava flows lie on or against mudflow units and at the mountain the base of the sequence is not visible. Farther away from the mountain lava flows generally lie intracanyon to mudflows. However, in the Marshall Butte area a lava flow derived from Keyes Mountain directly overlies Cretaceous conglomerates.

Certain features are characteristic of most of the lava flows. Topographically they are ridge-, cuesta-, dipslope-, and cliff-formers. Steep-sided and cliffy, the flows have a pervasive dark tone, dusky yellow brown to moderate brown being the dominant colors. These dark tones are in marked contrast to the lighter greenish grays of the adjacent mudflow units. Viewed more closely the flows, unlike the basalts of the much younger Columbia River Group, rarely show good columnar jointing. On the contrary, there are irregular, often widely spaced joints transecting the flows approximately at right angles to the flow surfaces. What is most prominent is a well-developed platyness which apparently is a reflection of flow structure. The platyness is not only apparent in talus at the foot of cliffs but is accentuated on faces by etching produced by weathering. The result is a closely spaced (usually less than two inches) ribbing on cliffs which is parallel to the tops and bottoms of flows and at right angles to the rude columnar jointing which is locally developed. The platyness can be used with confidence in obtaining attitudes on the flows. At a few places where the bottom of a flow is well exposed and channeling of the underlying mudflows can be seen, the platyness and etched ribbing form a series of curves roughly parallel to the channel bottom.

Close to an outcrop of Upper Clarno lava flows a red iron-oxide staining is characteristic. The red, which one is tempted to describe with the artist's term magenta, is dusky red (5 R 3/4). This red staining is notable along joints, stains plagioclase phenocrysts, and locally forms swirling or concentric banding reminiscent of liesegang bands.

These flows are generally porphyritic with plagioclase phenocrysts, up to 3/4 inch in length, in a more finely crystalline matrix. The matrix is dense, dark gray or dark grayish green and, in addition to the plagioclase, locally contains either pyroxene or hornblende phenocrysts. The marked flow structure which controls the platy jointing is also accentuated by a sub-parallel orientation of the plagioclase phenocrysts. All phenocrysts are subhedral to euhedral. Many specimens have abundant green smectite in the matrix.

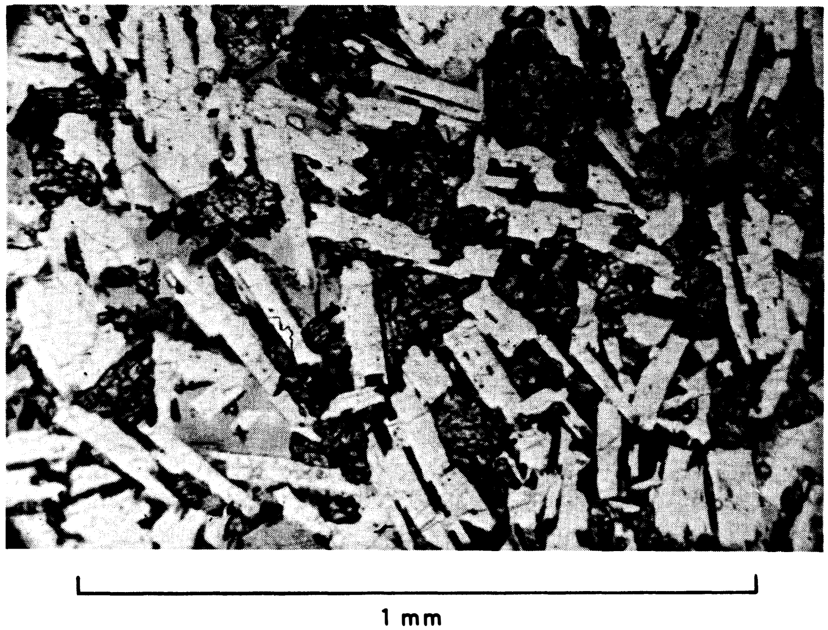


Figure 19a. Lower Clarno flow: labradorite, augite, magnetite and a little brown glass in a diabasic texture. Nicols parallel.

Figure 19b. Same as Figure 19a but with nicols crossed.

Upper Clarno vent agglomerate (Tcva): Marshall Creek heads in an amphitheater--a central depression in reference to the three main peaks of Keyes Mountain--and from this depression the lava flows and accompanying mudflow units dip away in all directions. Although exposures within the basin are poor because of forest and other vegetal cover, deep cuts on the road which leads to the Bell System microwave station on the east peak provide good outcrops of what is interpreted as vent agglomerate. A vent agglomerate is considered to be that pyroclastic deposit within and immediately adjacent to the vent of a volcano. It consists of poorly sorted volcanic debris ranging from large blocks to the finest materials. Rocks fitting this description are exposed in the road cuts. There are blocks of angular to subrounded porphyritic andesite--the sizes range from large boulders down to pebbles--lying in a medium- to coarse-grained matrix of plagioclase laths, fine lithic fragments, and much green smectite. In overall appearance the rocks should be described as a breccia. Bedding is lacking, a characteristic strikingly different from the crude but recognizable layering of the mudflows in the vicinity. The larger fragments of porphyritic andesite have excellent examples of subhedral to euhedral crystals of plagioclase and pyroxene; these crystals also form a significant part of the matrix.

Because of the isolated and limited outcrops, nowhere is the unit seen in contact with rocks, either older or younger. Thus the contacts displayed on the map are concealed, and have been delineated on topographic breaks in slope and lithologies topographically higher than the vent agglomerates of the basin. The interpreted contacts suggest that the vent agglomerate was a depression-infilling unit and that somewhere in the forested basin of today there once was the main vent of the volcano. Erosion of the non-resistant vent agglomerate presumably is the direct reason for the bowl-shaped depression in the summit area of Keyes Mountain.

Petrography of the Clarno flows

Classification: A classification based upon modal analyses of the finely crystalline Clarno flows is considered impractical. Plagioclase exists as microlites, interstitial anhedral masses, and both large and small phenocrysts, often all in the same rock (Figures 18, 19a, 19b). The larger phenocrysts are labradorite, averaging about An_{63}, but the groundmass feldspar is commonly andesine with the microlites more sodic than larger anhedral masses. Smaller phenocrysts are either labradorite or andesine.

All Clarno flows are classified as andesites. This determination relies on color index, chemical analyses, and normative analyses. However, the presence of groundmass andesine and minor quartz with phenocrysts of augite, hypersthene, and hornblende along with the laboradorite is also considered diagnostic. Although separated by an angular unconformity and mapped as an upper and lower sequence, the lithology, petrography, and chemistry are so similar that all Clarno flows are included in the following general description.

Texture and mineralogy: The fresh flow rocks are most commonly olive gray (5Y 4/1) but some are as dark as dark gray (N3) or dark greenish gray (5GY 4/1), or as light as light olive gray (5Y 6/1). The green tint is caused by green smectite, which is nearly always present even in apparently fresh rocks. The flows weather to dark yellowish brown (10YR 4/2) or grayish to dusky red (10R 4/2).

Although predominantly porphyritic with a pilotaxitic groundmass, variations include simple pilotaxitic, diabasic, or porphyritic with a granular or diabasic groundmass (Figures 20, 21, 22a, 22b). Phenocrysts are commonly 1-2 mm long, but thick flows locally contain phenocrysts 3-5 mm long and sizes up to 1 cm are reached. Phenocrysts consist of euhedral to subhedral plagioclase, clinopyroxene (augite), hypersthene, hornblende, and magnetite.

Modal analyses were made on eight Lower Clarno flows and 21 Upper Clarno flows.

Of the eight Lower Clarno flows:

(1) all contain plagioclase, augite, hypersthene, quartz, and magnetite;
(2) four contain hornblende or pseudomorphs from resorbed hornblende now composed of pyroxene, feldspar, and magnetite;
(3) two contain traces of interstitial glass.

Of the 21 Upper Clarno flows:

(1) all contain plagioclase, clinopyroxene, and magnetite;
(2) 17 contain hypersthene;

1 mm

Figure 20. Upper Clarno andesite flow from Keyes Mountain: labradorite and augite phenocrysts in a pilotaxitic groundmass of andesine and augite microlites, magnetite, and minor brown glass. Nicols parallel.

1 mm

Figure 21. Upper Clarno andesite flow from Keyes Mountain: phenocrysts of labradorite, augite and hornblende now largely altered to magnetite and a rim of augite. The pilotaxitic groundmass consists of andesine and augite microlites with magnetite and minor brown glass. Nicols parallel.

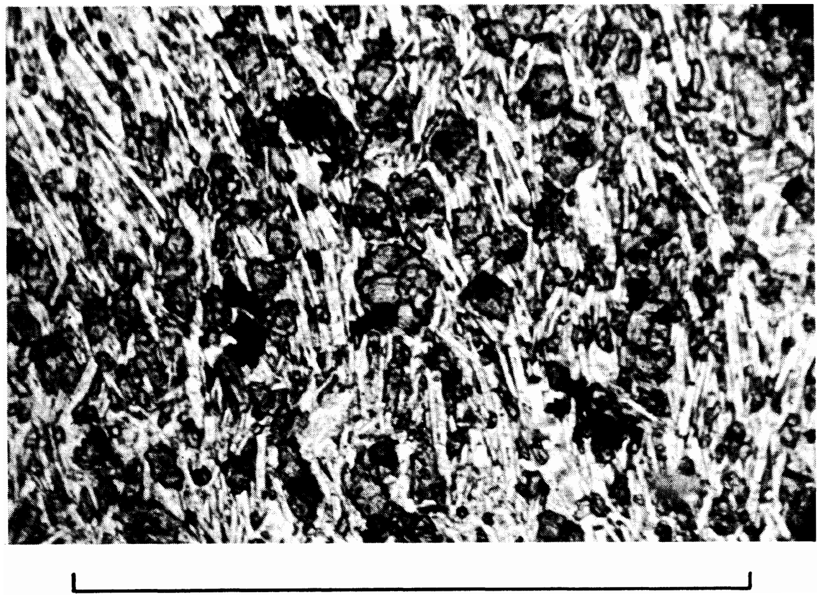


Figure 22a. Upper Clarno of Keyes Mountain: pilotaxitic texture, andesine and augite microlites with magnetite. Nicols parallel.

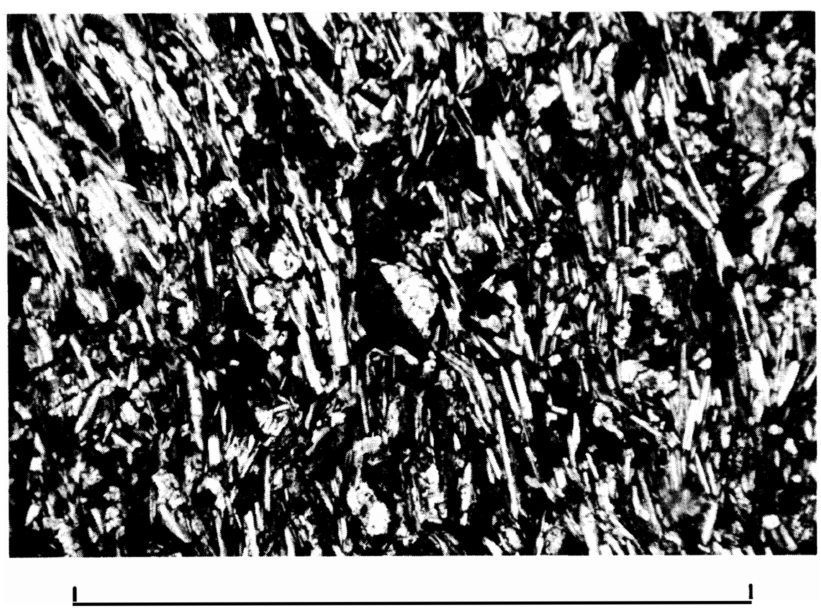


Figure 22b. Same as Figure 22a but with nicols crossed.

(3) 14 contain quartz;
(4) seven contain hornblende or pseudomorphs;
(5) four contain traces of interstitial glass.

An average mode is shown in Table 2:

Table 2. Average modal analyses from 8 Lower Clarno flows and 21 Upper Clarno flows

Mineral	Lower Clarno flows	Upper Clarno flows
	percent	percent
Plagioclase	74	80
Augite	20	12
Magnetite	4	6
Hypersthene	1	2
Quartz	1	Tr
Hornblende	Tr	Tr
Glass	Tr	Tr

Hornblende may be green or brown and is commonly bordered by masses of magnetite, or it may be completely resorbed, leaving a mass of magnetite, pyroxene, and feldspar. Green smectite is common, filling interstices and replacing primary minerals. Red ferric oxide from altering magnetite or ferro-magnesian minerals is common and calcite replacement of plagioclase is less common.

Chemical analyses were made of seven of the freshest flow rocks, three Upper Clarno and four Lower Clarno. Averages of these analyses along with the average normative analyses derived from them are given in Table 3 with Nockolds' (1954) average andesite and McBirney's (1969) average of 29 calc-alkaline andesites from continental margins.

Petrography of the Clarno ignimbrite

The Upper Clarno ignimbrite is very pale orange (10YR 8/2) to yellowish-gray (5Y 8/1), porphyritic, and contains feldspar phenocrysts, flattened pumice fragments (Figures 23a, 23b) up to 3 cm long, and lithic fragments up to 2 cm in diameter bound in a firmly welded, aphanitic, vitroclastic matrix which exhibits good eutaxitic texture.

Sanidine (Figures 24, 25), now partly altered to calcite, occurs in euhedral to subhedral laths up to 2.5 mm long. The matrix, once composed of glass shards, bubble walls, dust, and pumice fragments is now extensively devitrified exhibiting spherulites, axiolites, and anhedral masses of quartz and alkali feldspar up to 0.1 mm in diameter. The flattened pumice develops particularly good axiolites. Lithic inclusions consist chiefly of strongly altered mafic volcanics which yield brown to red iron oxide that tints the rock. The following interesting lithic types are worth listing:

(1) Clarno andesites with pilotaxitic texture;
(2) Devitrified mafic volcanics with plagioclase phenocrysts;
(3) Rhyolite with flow texture and sanidine phenocrysts;
(4) Light colored masses of devitrified glass (obsidian?);
(5) Volcanic wacke, one fragment 8 mm in diameter (probably Clarno);
(6) Micritic limestone (caliche?).

An average mode gained from point counts on four separate samples is:

Groundmass of glass fragments and pumice	81.3 percent
Sanidine phenocrysts	9.4
Lithics	9.3
	100.0 percent

Two chemical analyses and the normative minerals derived from them are given in Table 4. Because of the firmly welded nature of the rock it was impractical to remove the lithics, hence the analyses are not completely representative of the original magma of the ash flow.

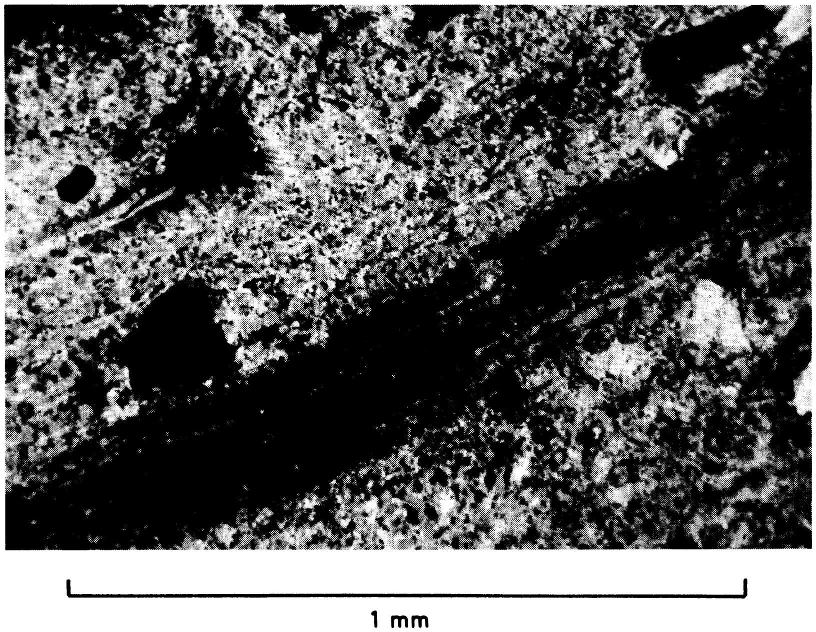


Figure 23a. Clarno ignimbrite: a flattened pumice fragment in a vitroclastic matrix of glass shards and bubble walls. Nicols parallel.

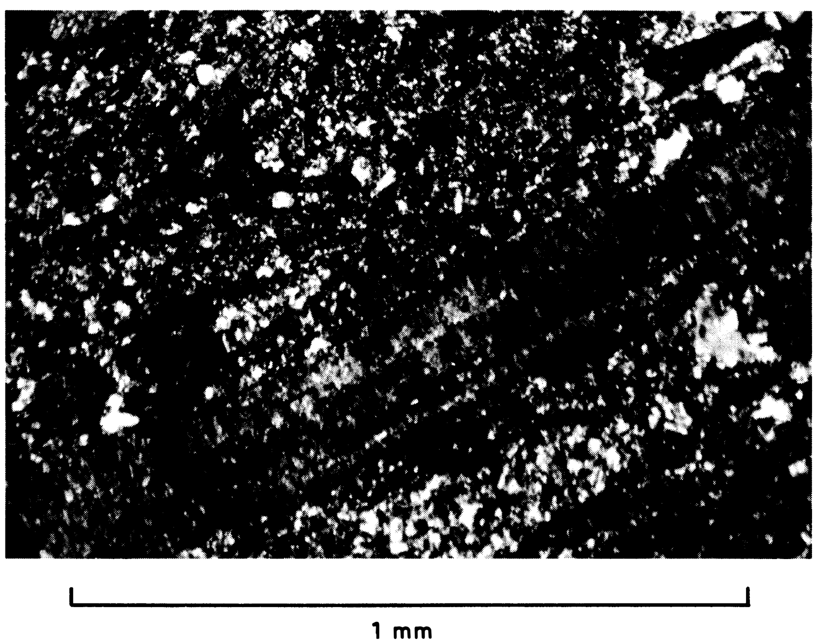


Figure 23b. Same as Figure 23a but nicols crossed. Note extensive devitrification in matrix and the axiolitic texture in the flattened pumice.

Table 3. Chemical analyses and derived normative compositions for Clarno flows, Nockolds' average andesite and McBirney's average of 29 calc-alkaline andesites from continental margins

Component	Upper Clarno (3 analyses)	Lower Clarno (4 analyses)	Av. Clarno (7 analyses)	Nockolds (49 analyses)	McBirney (29 analyses)
SiO_2	58.03	57.25	57.57	54.91	59.30
TiO_2	1.17	1.31	1.23	1.33	.80
Al_2O_3	17.37	18.10	17.79	17.39	17.62
Fe_2O_3	1.64	1.75	1.70	3.53	3.25
FeO	4.89	5.26	5.10	5.56	3.52
MgO	3.57	3.33	3.43	4.42	3.32
CaO	6.97	7.33	7.17	8.02	6.33
Na_2O	4.92	4.38	4.61	3.72	3.86
K_2O	1.09	1.22	1.16	1.12	2.01
		Normative Composition			
Qz	5.16	5.34	5.82	5.70	10.27
Or	6.67	7.23	6.67	6.70	11.88
Ab	41.40	37.20	38.78	30.90	34.65
An	21.96	28.08	24.47	27.20	24.80
Di	10.2	6.83	8.99	20.4	4.31
Di Wo	5.22	3.48	4.64	4.20	
Di En	3.00	1.90	2.90	10.90	
Di Fs	1.98	1.45	1.45	5.30	
Hy	9.6	11.02	8.34		9.22
Hy En	5.90	6.40	5.70	-	
Hy Fs	3.70	4.62	2.64	-	
Mt	2.32	2.55	2.55	5.1	3.39
Il	1.28	2.43	2.28	2.4	1.11

In a rock composed overwhelmingly of glass, or devitrified glass, it is often informative to treat the norm as the mode and classify the rock on this basis. Because of the anomalous high lime and low soda, the Johannsen (1939) classification, if used, would place this rock in Class 1, Order 3, Family 3 for which there is no name. However, in view of the high normative orthoclase and quartz and the extremely low ferromagnesian content, the rock might best be termed a leucorhyolite.

The Clarno ignimbrite caps a Clarno sequence but is not in turn overlain by Clarno rocks, hence it might be interpreted as a valley-filling tuff younger in age than the Clarno, perhaps John Day. The texture, mineralogy, and chemistry of this ignimbrite were compared with all known ignimbrite units younger than Clarno which have been found in central Oregon and none were found to be similar. On this evidence, as well as on the stratigraphic evidence given earlier, it was decided to include this ignimbrite within the Clarno Formation.

The basal John Day ignimbrite mentioned by Peck (1964) in the Antelope-Ashwood area and by Swanson and Robinson (1968) in the Horse Heaven District differs markedly from the Clarno ignimbrite both as to texture and mineralogy. The basal John Day ignimbrite contains only 1 percent lithics and 5 percent phenocrysts consisting of quartz, soda-rich sanidine with a 2V of 38-48°, oligoclase and sparse but commonly present hornblende. This contrasts with the Clarno ignimbrite which contains 9 percent lithics, 9 percent potassium-rich sanidine with 2V of 10° or less and no quartz, plagioclase or hornblende phenocrysts. The chemical contrast can be seen in Table 4.

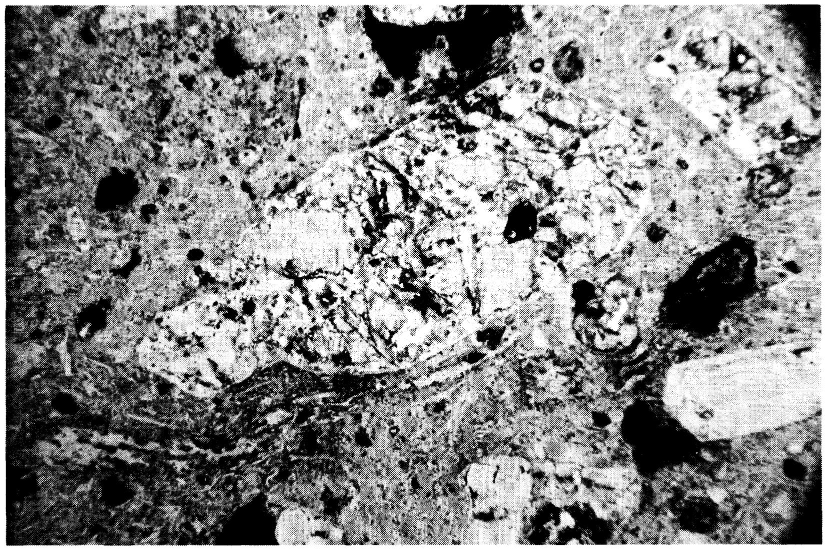


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Figure 24. Clarno ignimbrite: sanidine phenocrysts and lithic inclusions in a vitroclastic matrix exhibiting good eutaxitic texture. The large sanidine phenocryst is partially replaced by calcite. Nicols parallel.

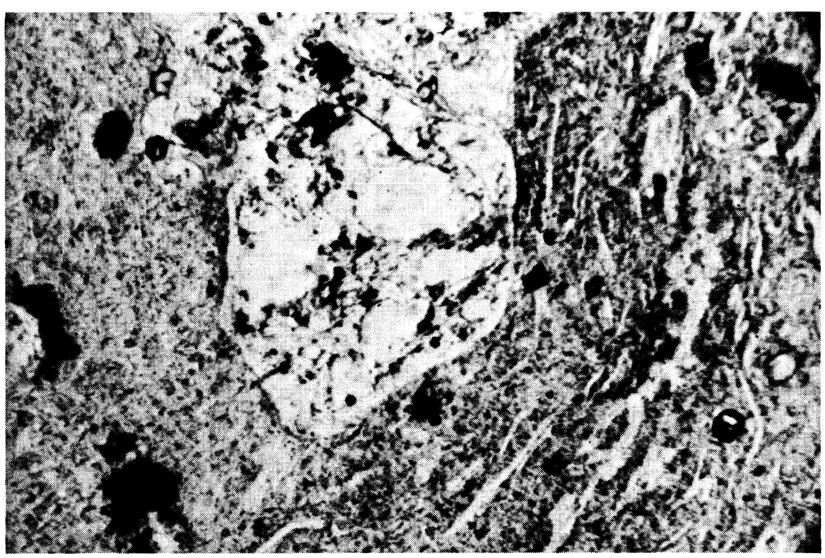

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Figure 25. Clarno ignimbrite: a sanidine phenocryst partially replaced by calcite in a vitroclastic matrix exhibiting good eutaxitic texture. Nicols parallel.

Table 4. Chemical analyses and normative compositions of some central Oregon ignimbrites

	Clarno Sample #1	Clarno Sample #2		Basal[1/] John Day	Basal[2/] John Day	Middle[2/] John Day #2	Middle[2/] John Day #3	Middle[3/] John Day	Middle John Day Mitchell Sample #1	Mascall[4/]	Rattle-snake Mitchell
SiO_2	73.10	72.20		74.21	75.94	77.56	76.10	75.12	71.00	74.56	78.80
TiO_2	.42	.17		.53	.17	.19	.17	.38	.48	.23	.21
Al_2O_3	12.80	12.90		13.64	13.75	11.98	12.02	13.05	13.40	13.13	11.71
Fe_2O_3	.60	.56		1.02	1.37	1.79	1.48	2.11	2.20	.80	.37
FeO	.40	.44		.24	.27	.89	.70	.09	2.80	1.70	
MgO	.20	.20		.20	.13	.11	.35	.24	.30	.27	.21
CaO	2.80	2.40		1.02	1.03	.82	.65	.67	1.50	.75	.13
Na_2O	.85	.90		2.54	2.43	2.31	3.06	3.97	4.35	3.71	4.21
K_2O	8.80	9.30		5.60	5.29	5.04	3.58	3.94	3.96	4.45	4.21
P_2O_5	-	-		.12	.01	.02	.01	.10	-	.06	.01
MnO	-	-		.06	.03	.05	.09	-	-	-	.01
Total	99.97	99.07		99.18	100.42	100.76	98.21	99.67	99.99	100.66	99.87
Qz	26	25		36	39	43	43	35	26	33	36
Or	49	52		34	31	30	21	23	23	26	26
Ab	6.9	7		22	20	19	26	34	36	31	36
An	13.0	11.0		5.1	5.0	4.2	3.3	3.3	5.2	3.4	.5
C	3.4	2.9		1.5	2.2	1.1	1.9	1.0	-	.9	-
Wo	-	-		-	-	-	-	-	2.2	-	-
En	.5	.5		.5	.3	.3	.9	.6	.8	.7	.5
Fs	-	-		-	-	-	-	-	2.5	2.1	-
Mt	.2	.9		-	.5	2.3	1.9	-	3.2	1.2	.2
Hm	.4	-		1.0		.2	.2	2.1	-	-	-
Il	.7	.3		.5	.3	.3	.3	-	.9	.5	-
Rt	-	-		.3	-	-	-	.4	-	-	-
Total	100.1	99.6		100.9	98.3	100.4	98.5	99.4	99.8	98.8	99.0

1/ Swanson and Robinson (1968) recalculated to dry wt.

2/ Peck (1961) recalculated to dry wt.

3/ Hay (1962) recalculated to dry wt.

4/ Davenport (1971) average of three analyses.

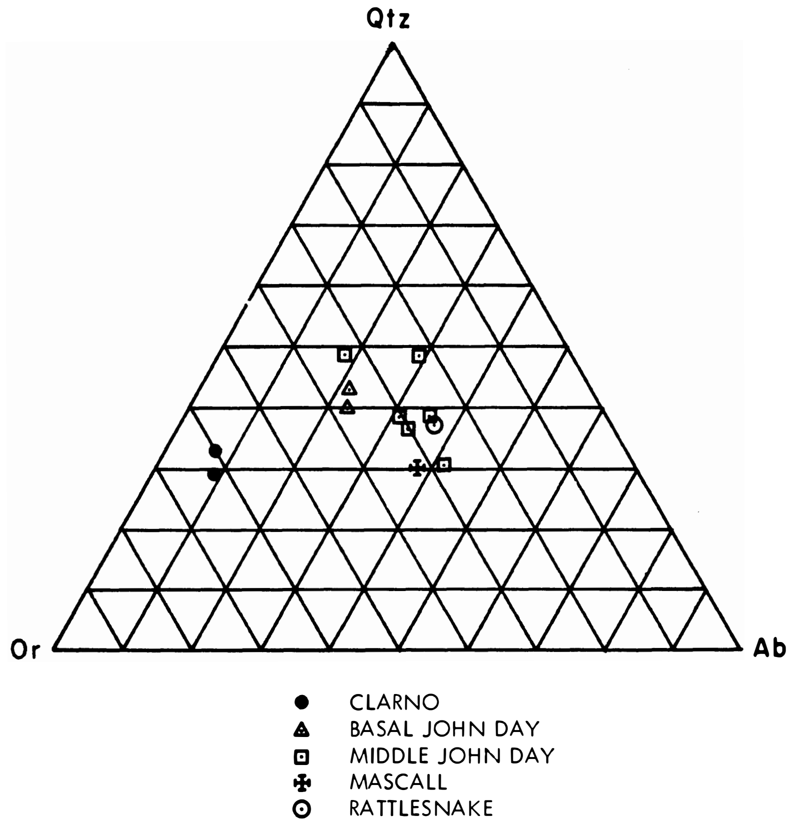


Figure 26. Plot of normative quartz, orthoclase and albite for central Oregon ignimbrites taken from Table 4 and recalculated to 100%.

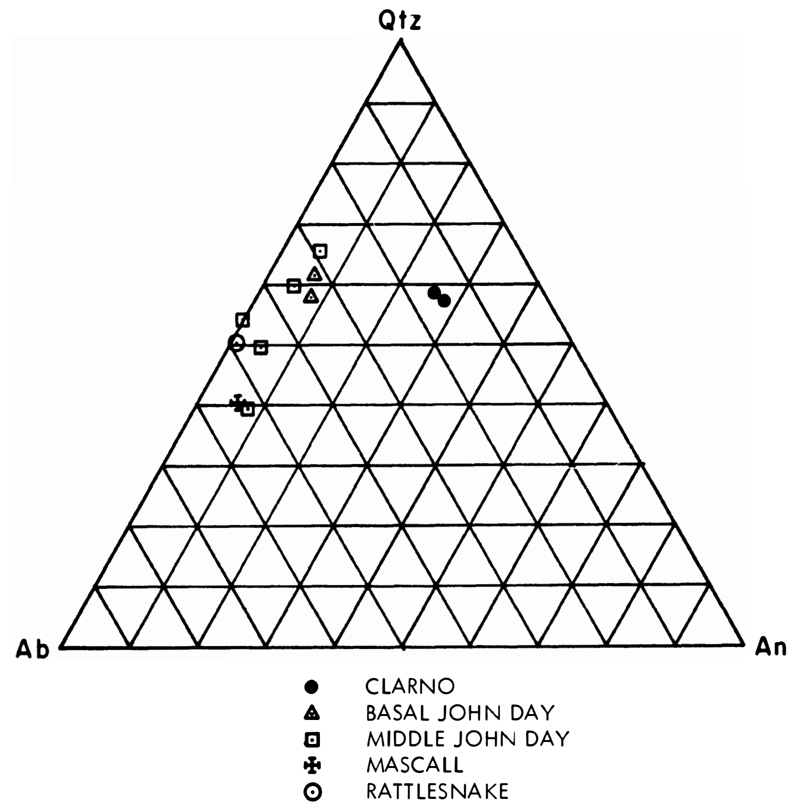


Figure 27. Plot of normative quartz, albite and anorthite for central Oregon ignimbrites taken from Table 4 and recalculated to 100%.

Peck (1961) describes three ash flow tuffs in the Ashwood and Willowdale area of north-central Oregon which are found near the middle of the John Day sequence. All contain oligoclase, quartz, and anorthoclase ($Or_{30}Ab_{70}$). Chemical analyses and norms are given in Table 4. Middle John Day ash flow tuffs are found in the Painted Hills a short distance to the north of the Clarno outcrop. According to Hay (1962) they contain but 0.5 percent lithics, 0.7 percent plagioclase (An_{10-12}) and 1.1 percent altered pyroxene. The predominant groundmass is altered to alpha cristobalite and alkali feldspar. For chemical contrast see Table 4. The middle John Day ignimbrite found in the Mitchell quadrangle is described on page 37.

The Mascall ignimbrite member described by Davenport (1971) in the Paulina Basin and adjacent areas consists of:

92.7 percent glass shards, bubble walls, pumice and dust;
2.74 percent obsidian chunks up to 1 cm in diameter with an odd texture as if inflated, then collapsed in the welding process;
1.74 percent phenocrysts, largely anorthoclase ($Or_{10}Ab_{90}$), sparse quartz, zircon, magnetite, and clinopyroxene;
2.82 percent lithic fragments.
100.00 percent

A chemical analysis of the Mascall ignimbrite member is shown in Table 4.

The Rattlesnake ignimbrite in the Mitchell quadrangle is described on page 43 and the chemical analysis is included in Table 4.

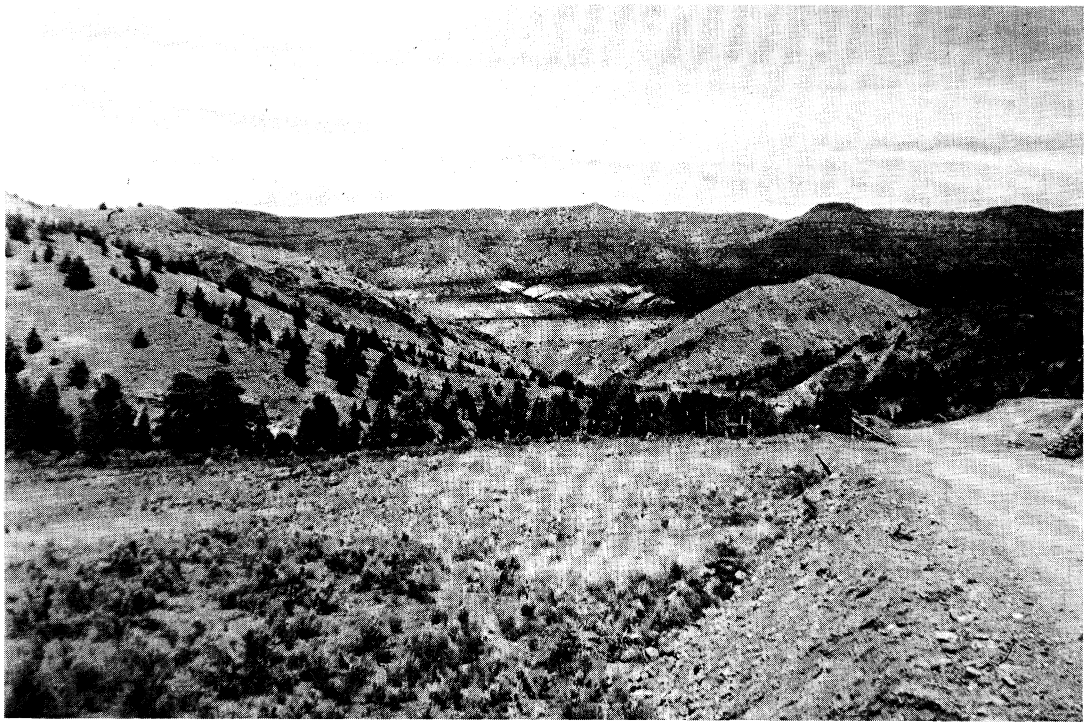
The disparity in composition between the Clarno ignimbrite and other central Oregon ignimbrites is well shown in Figures 26 and 27, triangular diagrams illustrating the quartz-orthoclase-albite and the quartz-albite-anorthite ratios obtained from the normative analyses of Table 4.

John Day Formation (Tjd)

The most colorful and one of the most widespread of the Tertiary units in the Mitchell quadrangle is the John Day Formation (Figure 28) of Oligocene-Miocene age. Less resistant than the underlying and overlying formations, the John Day rocks crop out mainly in an arcuate belt below the cliff-forming basalt flows of the Columbia River Group preserved in the Sutton Mountain syncline. As a less resistant unit the John Day Formation is a slope-, pediment-, and valley-former at most localities. In addition to the extensive outcrops in the lower Bridge Creek valley, along the John Day River, and flanking the Sutton Mountain syncline, there also is a thin section of John Day sediments underlying the Thorn Hollow syncline in the southeasternmost part of the quadrangle.

At most places the John Day rocks rest with angular discordance on a much-weathered, regolith-mantled, older terrain of Lower Clarno lava flows. The colorful, dusky red, ancient regolith developed on the older lava flows is generally overlain by a moderate reddish brown to dark reddish brown tuffaceous claystone and siltstone unit of the John Day. Because of the similarities in color of the regolith and the overlying John Day rocks the contact between the two is difficult to define precisely; it is best drawn on an abrupt topographic break in slope between the older more resistant lava flows and the overlying soft sediments. Elsewhere, Lower Clarno rocks which once were hilltops or mountains can be seen lapped and enclosed by John Day sediments. Recent uplift and exposure of these topographic highs leave the older rocks as isolated knobs completely enclosed in John Day rocks. This is particularly true along Bridge Creek in secs. 8 and 9, T. 11 S., R. 21 E.

In addition to the ancient regolith, which represents an interval of deep weathering of Lower Clarno rocks, a hilly to mountainous topography developed on the Clarno rocks with a relief which might have exceeded 3000 feet. Observation of the map and of the outcrop pattern emphasizes this relief. From the wide outcrop areas of John Day rocks in the northwest along the John Day River and Bridge Creek, the outcrop width slims markedly to a very narrow band beneath the southeasternmost peak of Sutton Mountain in sec. 1, T. 11 S., R. 21 E. This narrow band persists to the northeast across Girds Creek. From Girds Creek in sec. 30, T. 10 S., R. 22 E., the John Day outcrop widens appreciably to the northeast. This pinching and swelling of the John Day outcrop belt is considered to be a function neither of changing dip nor of repetition or suppression at faults. Field mapping, coupled with calculations based on outcrop width and average dip, indicates marked variations in formation thickness within the quadrangle. In the



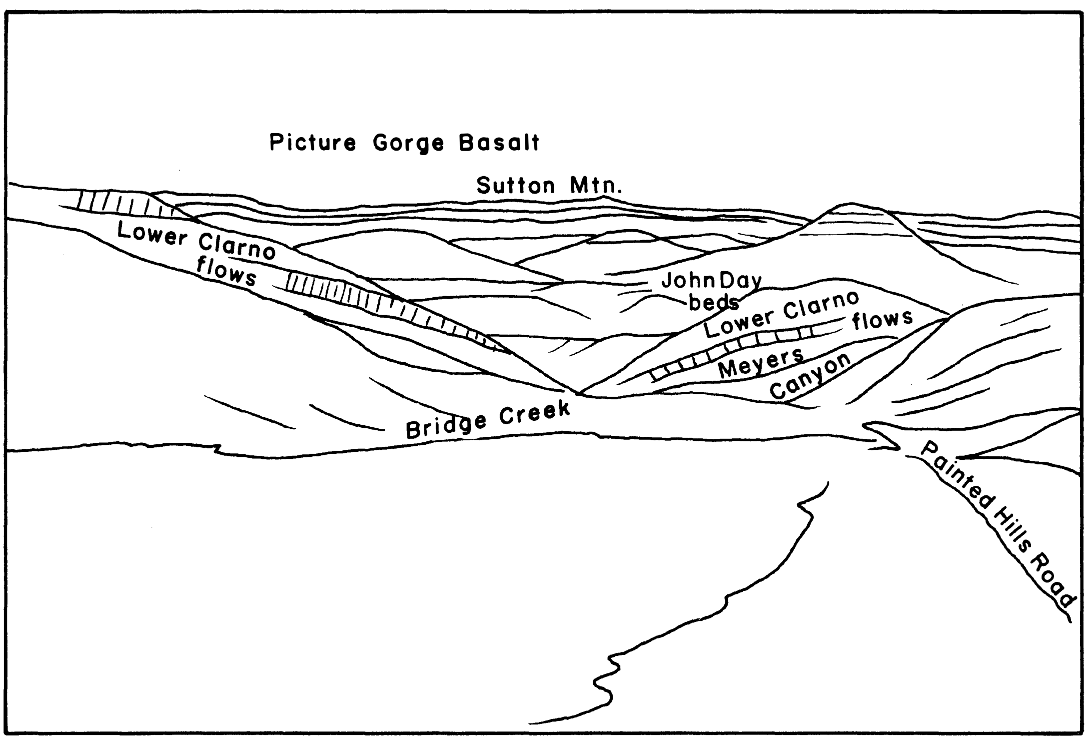


Figure 28. Sutton Mountain on skyline with bold escarpments of Picture Gorge basalt flows rising above light-toned John Day rocks truncated by pediments. Bridge Creek.

Figure 29. Lower red member, John Day tuffaceous claystones. NW$\frac{1}{4}$, sec. 9, T. 11 S., R. 21 E., immediately north of Painted Hills road.

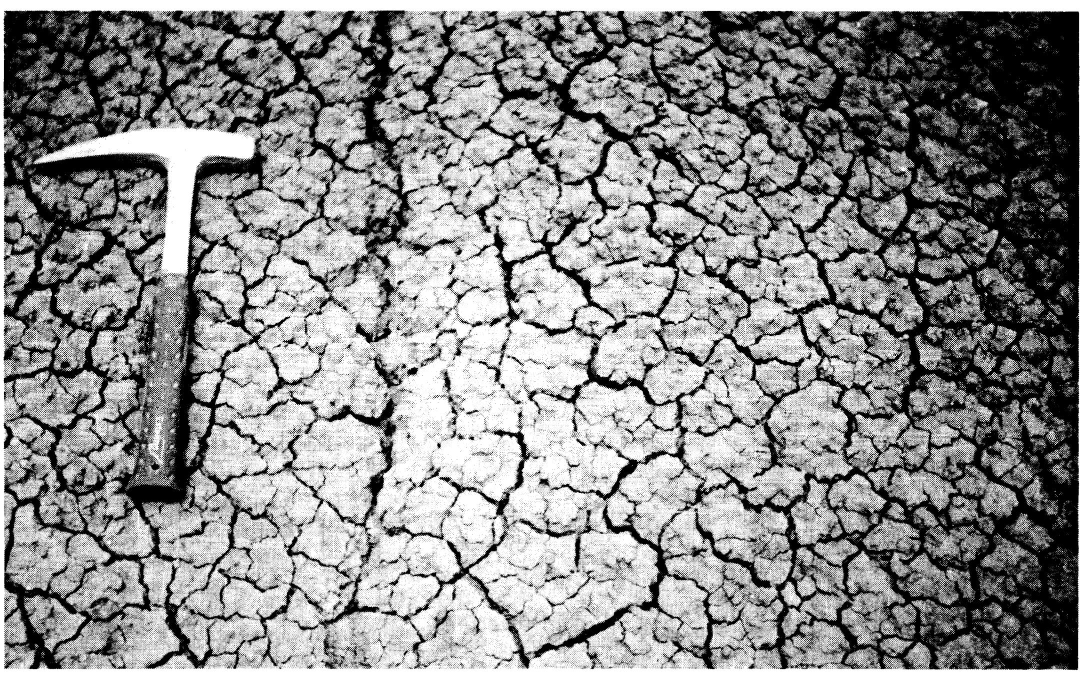


Figure 30. Mud-cracked John Day tuffaceous sediments. The surfaces when wet assume a gumbo-like consistency.

west-central part of the quadrangle, along a line of section across Bridge Creek in secs. 29 and 32, T. 10 S., and secs. 5 and 6, T. 11 S., R. 21 E., the John Day rocks exceed 3,500 feet. In the Blue Banks area to the northeast in sec. 22, T. 10 S., R. 22 E., on the southeast flank of Horse Mountain, the thickness exceeds 2,800 feet; but in sec. 1, T. 11 S., R. 21 E., directly under "The Prow" of Sutton Mountain, the thickness is probably little more than 100 feet. And in the southeast corner of sec. 7, T. 12 S., R. 23 E., overlain by a Rattlesnake ignimbrite caprock, the remnant of John Day is no more than 20 feet thick. This disparity in thicknesses can be explained in a variety of ways; the best explanation involves a combination of John Day deposition against mature topography developed on the Lower Clarno rocks, coupled with later warping and erosion of the John Day prior to Columbia River volcanism.

Although the John Day Formation can be described in broad terms as a slope- and valley-former, several things are significant about the formation. First, in the northwest quadrant of the quadrangle on the south and southwest flanks of Sutton Mountain there are developed sweeping, miles-long pediments. Although not studied in detail, at least three pediment levels are recognizable, each with expansive, concave upward surfaces which truncate the dipping John Day sediments and are mantled with sands and gravels. These pediments, now being deeply dissected and destroyed, are among the more notable geomorphic features of this part of the quadrangle.

In addition to its notable sculpture into pediments, John Day tuffaceous sediments are involved in extensive landslides. It is probable that the sediments, heavily loaded with water-expandible montmorillonite, have been the lubricating and gliding vehicle for the downslope transfer of heavier, more resistant and more competent overlying units. One major landslide area lying in secs. 7, 18, 19, and 30, T. 10 S., R. 23 E., and secs. 12, 13, and 24, T. 10 S., R. 22 E. and extending beyond into the next quadrangle, has a chaos of Columbia River basalt blocks and knobs gravitatively moving downslope intermixed with and gliding on John Day tuffaceous sediments.

A second prominent example of landsliding descends from "The Prow" of Sutton Mountain in sec. 1, T. 11 S., R. 21 E. Gravity-moved materials have swept down in sinuous tongues or lobes from the towering cliffs of the Columbia River Group, both to the southwest and to the northeast. The heavier basaltic talus and slump debris are intimately mixed with John Day tuffs and tuffaceous claystones, the apparent lubricating vehicle for this mass-wasting movement. The tongues have flowed around isolated hogbacks of Lower Clarno flows and at some places have broken through the flows, presumably following prior drainage channels, to spill out as piedmont lobes onto rocks of the John Day Formation.

Within the Mitchell quadrangle the John Day rocks consist of two mappable units. The lower and thinner unit is moderate reddish brown to dusky reddish brown tuffaceous claystones and siltstones (Figure 29). The thicker upper unit is very light gray to very pale orange tuffaceous claystones and siltstones. The green member, so prominently exposed farther east near Picture Gorge, is present only in the Blue Banks area in the northeast, where it lies between the lower red and upper pale orange units. The sediments are well-bedded with bands of varying color accentuating the bedding, as do locally more resistant layers which stand out as ribs and thin ledges. The weathered surfaces of most of the sediments have a popcorn appearance (Figure 30)--a swollen, highly porous, much mud-cracked mantle--the result of episodic wetting and swelling followed by dessication and shrinkage of the montmorillonitic clays in the tuffs. When wet, as during heavy rains, these surfaces become gumbo-like in consistency and almost impossible of traverse by either foot or vehicle.

In the northwesternmost part of the quadrangle, below the cliffs of Columbia River basalt, a key bed is mapped with dashed lines and the symbol i. This marker bed is one of the ignimbrite layers so well-exposed farther south and west out of the quadrangle in the Painted Hills (Figure 1). It is recognizable here and is mapped in the landslide blocks so common to this part of the quadrangle. This unit is correlative to Hay's (1962) ignimbrite unit of the middle member of the John Day Formation.

The ignimbrite is approximately 50 feet thick and consists chiefly of an aphanitic very light gray (N8) to very pale orange (10 YR 8/2) matrix which contains an occasional feldspar phenocryst, lithic fragment, or recognizable collapsed pumice fragment. A great many pale yellowish brown (10YR 6/2), angular to rounded, stony inclusions are found to be large axiolites or compound spherulites of alpha cristobalite and alkali feldspar which have developed in the matrix as a result of devitrification. Some of the spherulites are round (Figure 31a, 31b) and have destroyed the vitroclastic texture of the matrix in which they apparently grew; some axiolites have obviously developed from shards and bubble walls (Figure 32a, 32b). Other large (up to 7 mm in length or diameter) irregular axiolites or spherulites have

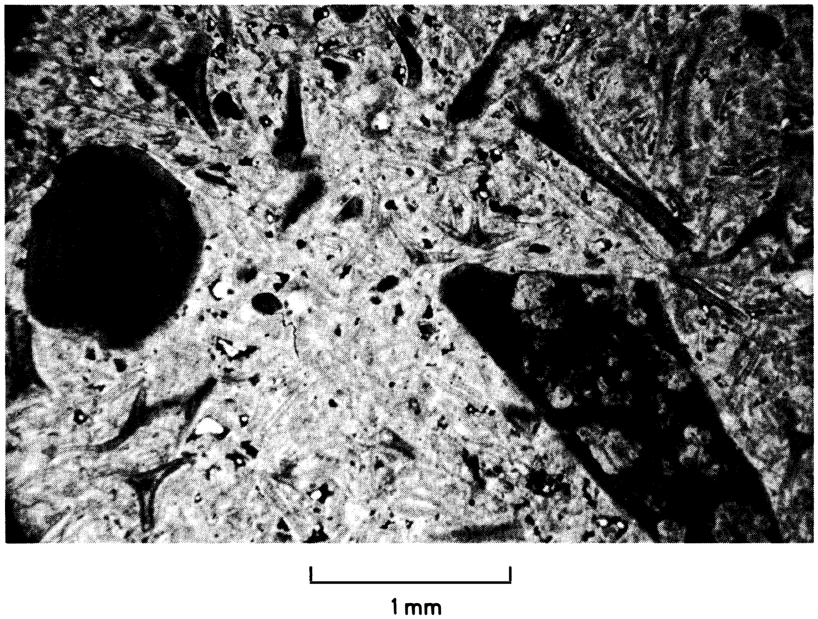


Figure 31a. Middle John Day ignimbrite: axiolites, a large simple spherulite and a compound spherulite partially replaced by calcite. Nicols parallel.

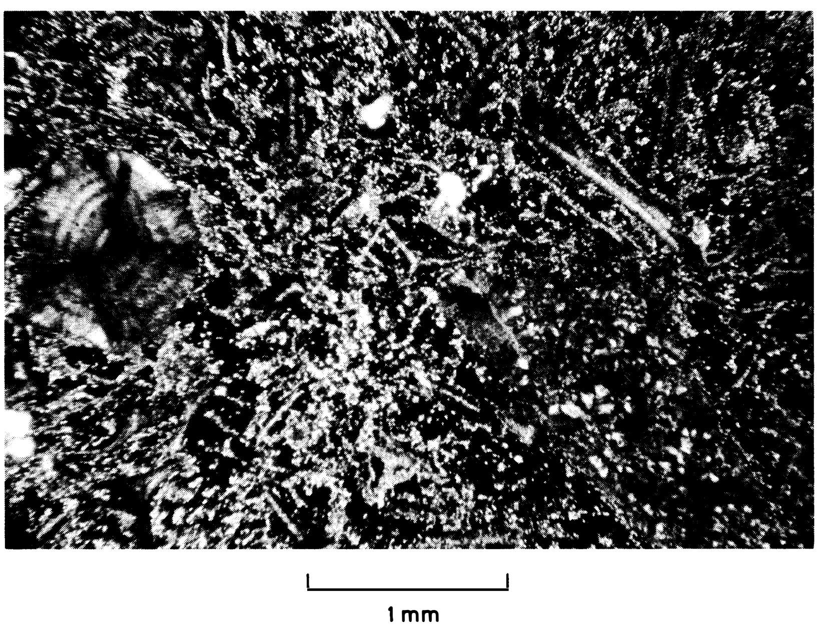


Figure 31b. Same as Figure 31a but with nicols crossed; spherulitic needles are cristobalite and sanidine, the irregular anisotropic masses are calcite.

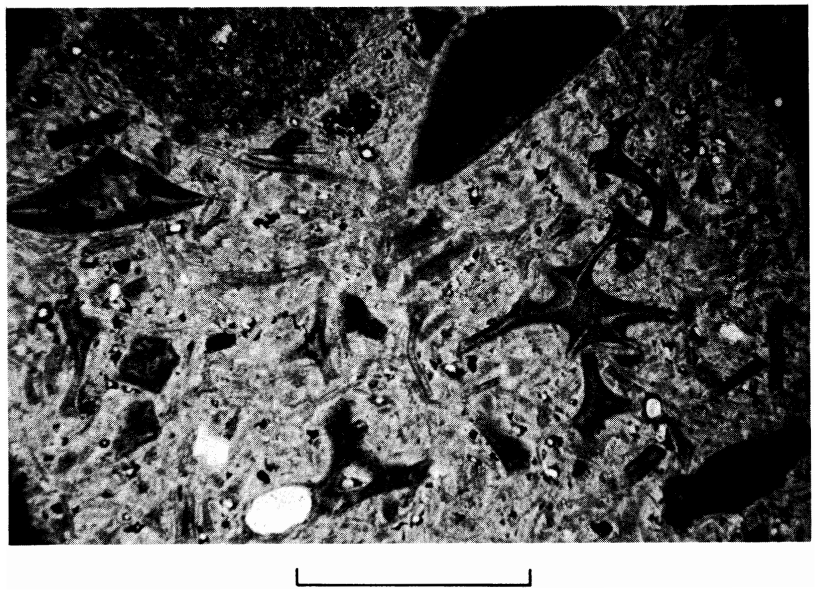


Figure 32a. Middle John Day ignimbrite: axiolites and spherulites, both compound and simple; some grow in shards and bubble walls, some have expanded into the matrix of smaller shards and dust. Nicols parallel.

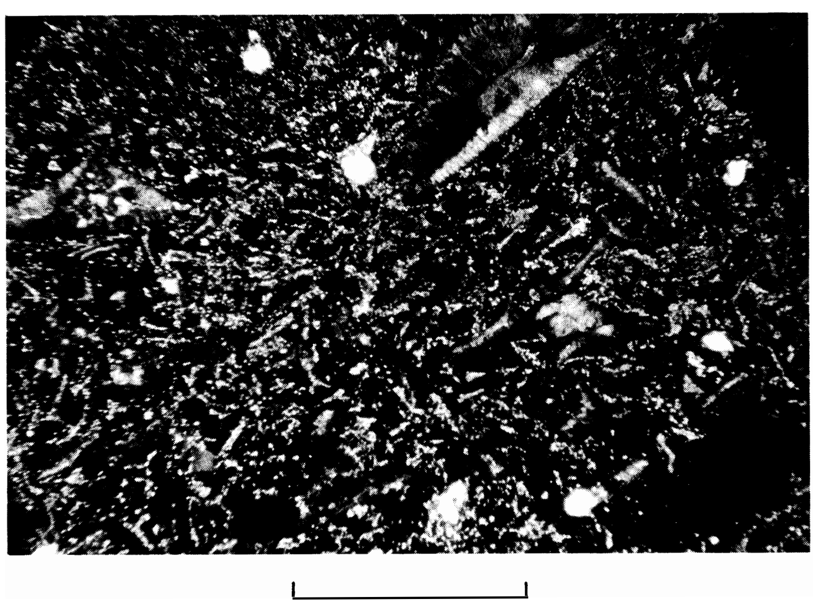


Figure 32b. Same as Figure 32a but with nicols crossed; the needles of the spherulites and axiolites are alpha cristobalite and sanidine; the small equant anisotropic patches are calcite grains replacing the glass of the matrix.

started with a shard, bubble wall or pumice fragment as a nucleus but have grown enormously (Figure 32a, 32b), expanding into the adjacent matrix of fine shards and glass dust and losing much of their original shape. A rather poor eutaxitic texture is visible in the more firmly welded parts of the rock. The matrix surrounding the axiolites and spherulites is commonly partially glassy and in part replaced by calcite. Altering mafic lithics supply the ferric oxide and hydroxide which give the rock its pale orange to yellowish brown tint.

The following is the composite of several modal analyses on the middle John Day ignimbrite:

95 percent	glassy matrix, now partially devitrified or replaced by calcite
4 percent	lithics
1 percent	oligoclase
Tr	anorthoclase
Tr	quartz
100 percent	

Chemical analyses of two samples of the middle John Day ignimbrite in the Mitchell quadrangle and the normative minerals derived therefrom are given in Table 4.

If fitted into the Johannsen classification on the basis of normative rather than modal mineral composition, the John Day ignimbrite fits best into Class 2, Order 2, Family 7 rhyodacite, or possibly Class 2, Order 1, Family 7 sodaclase rhyodacite.

High in the sequence, in section 34, T. 10 S., R. 21 E., beneath the cliffs of Columbia River basalt and at the head of an extensive pediment, the tuffaceous claystones and tuffs are succeeded by fluvial sands and gravels more than 200 feet thick. The gravels, generally not well enough indurated to be called conglomerates, are well-bedded, the bedding being emphasized by sorting, by normal grading, by sharp scour-and-fill contacts with underlying tuffs, and by local cross-bedding. The larger clasts, mainly subrounded fine pebbles to boulders, are enclosed in a matrix of tuffaceous materials and lithic and mineral fragments. Most of the larger fragments are composed of older Clarno andesite, but some light green chert suggests a contribution from an older terrain. The thin-bedded, fine- to medium-grained sandstones contain feldspar and glass fragments, grain-supported in a tuffaceous matrix. There are rare fragments of opalized bone. The beds range from laminated to 18 inches thick, but most are less than 12 inches. Within this upper fluvial sequence are two discrete layers up to 6 inches thick, full of glass shards, blebs and bubbles, some sand-sized grains of quartz, and some pumice. Whether these two thin layers are extensions of ignimbrites has not been ascertained.

The differences in thickness of the John Day Formation from place to place in the quadrangle and the overlap of older Clarno rocks by sediments indicate that high relief had developed on the older rocks and that basins, separated by intervening high areas, became loci for John Day deposition. Stratigraphic and petrographic studies by Merriam (1901), Calkins (1902), Coleman (1949), Waters (1954), Peck (1960, 1964), Fisher and Wilcox (1960), and Hay (1962), as well as by the authors, clearly indicate that the John Day Formation in the Picture Gorge, Painted Hills and Mitchell areas consists largely of acidic pyroclastic debris of air-fall origin. The original surface layers of ash were commonly moved off hills and into basins by sheetwash, running water and winds; mixed with older surface debris, largely Clarno; and reworked by roots and burrowing organisms. Accumulation appears to have been slow enough to allow weathering processes to alter much of the glass to clay (Hay 1962). Thick ash-fall deposits could survive, at least in part, if deposited in a quiet basin and occasional ash flows supplied ignimbrite marker beds to the sequence. Evidence of an occasional lake or swamp can be seen in the presence of thinly bedded claystones and lignites.

Columbia River Group (Tcr)

The major outcrop area of Columbia River basalts in the Mitchell quadrangle is in the north third of the map area where these impressive cliff- and ledge-forming lava flows form a vast pile in the core of the Sutton Mountain syncline (Figure 33). Rising above the pediments and landslides developed on the underlying John Day rocks, the lava flows form giant staircases of narrow benches and high cliffs (Figure 34), single examples of which exceed 200 feet in height. The cliffs and ledges are traversed by deep and steep gullies which, during times of rain and melting snow, display spectacular waterfalls. Even during the dry season locations of such ephemeral waterfalls are marked by vertical streaks visible from great distances, the streaks accentuated by salts and lichen.

Figure 33. Looking north down Girds Creek at Picture Gorge basalt.

At the top of the set of flows forming Sutton and Horse Mountains there are sweeping dip slopes which form a wide and long summit bowl-shaped depression, interrupted by steep-walled box canyons, the results of deep dissection. Both Girds Creek and, farther to the northeast, Shoofly Creek traverse the flows and join the John Day River farther north after descending by numerous rapids through steep-gradient canyons.

Columbia River basalt also is found in some of the major landslide areas adjacent to Sutton and Horse Mountains and farther to the east. Totally isolated from these major outcrops, in the southeastern part of the quadrangle, lies the Thorn Hollow syncline. Far smaller than the Sutton Mountain structure, this local flexure, with a sequence of the Columbia River Group about 300 feet thick preserved in its core, is surrounded by landslides composed of John Day and Clarno rocks. In the southeasternmost part of the quadrangle and also along the south border there are isolated fault blocks surmounted by Columbia River basalt.

Although mapped here as the Columbia River Group, these lava flows are probably correlative with those flows mapped farther east as the Picture Gorge Basalt.

The thickness of the formation in this quadrangle is variable. However, in the largest outcrop area, that of Sutton and Horse Mountains, the thickness is remarkably constant, ranging only between 900 and 1000 feet. The gentle dips, the high cliffs formed by individual flows, and the staircase effect all give a topographic signature of mesas, buttes, and box canyons, a topography distinctive and different from all of the older units in the quadrangle.

From a distance the pervasive colors of the stacked flows are pale red purple. Closer to the outcrops, grayish red is dominant, and many of the flows are characterized by a yellow mottling, the result of a profuse growth of a lichen. Columnar jointing is prevalent and characteristic. Giant columns, commonly well formed and ranging up to three feet in diameter, are usually present. Blocks and irregular fragments derived from the weathered columns, plus some platy basaltic debris, litter steep talus slopes beneath the cliffs. Light gray or whitish salt-streaked chutes or streaks on many of the cliffs mark intermittent streams and waterfalls. On some of the steep talus slopes there are numerous basalt streamers separated by grass- or sagebrush-covered lobes. Much of the rubble at the foot of cliffs is vesicular and some is clinker-like as in aa-type basalts.

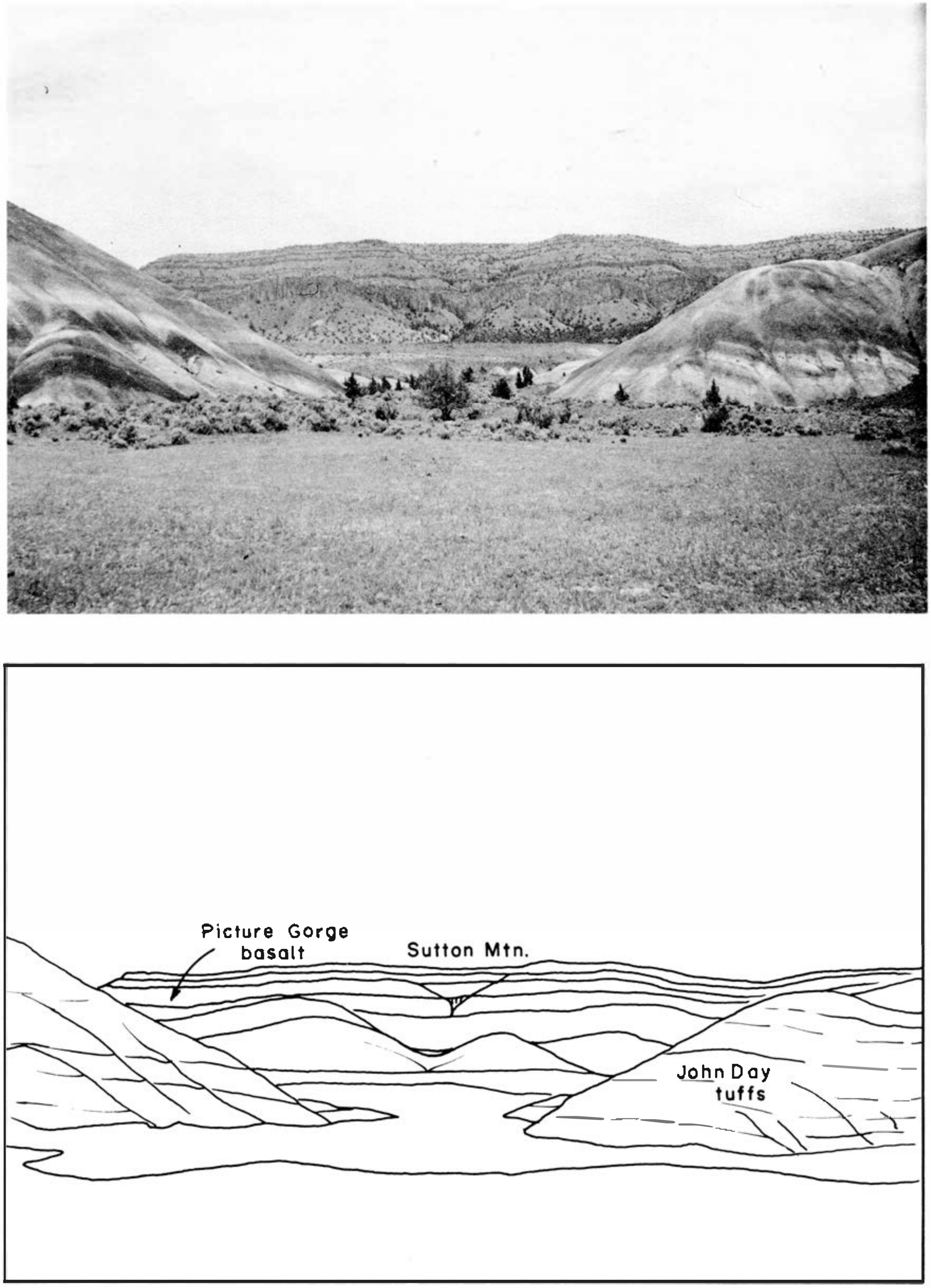


Figure 34. Picture Gorge basalt flows of Sutton Mountain rise above bedded John Day tuffs. Bridge Creek.

The thick stack of flows preserved in Sutton and Horse Mountains and the thinner sequences of the Thorn Hollow syncline and southern fault slices, coupled with the fact that the highest part of the Ochoco Range, south of the quadrangle, is surmounted by Columbia River flows, suggest strongly that at one time the entire quadrangle was covered by these flows.

Where the basal flow can be seen in contact with the underlying John Day rocks the basalt rests with angular discordance on an eroded surface; however, at most places the contact is obscured by steep talus cones of basalt rubble streaming down from the cliffs above. Mapping of the contact is best accomplished by using the pronounced break in slope between cliff-forming flow above and talus-strewn John Day below. In the north half of the quadrangle where Columbia River basalt is the dominant rock type, it is the youngest unit exposed. Only in the southeasternmost part of the map area, in secs. 13 and 24, T. 12 S., R. 22 E., and sec. 19, T. 12 S., R. 23 E. is the Columbia River Group overlain by a younger rock unit. In these sections a thin wedge edge of the Rattlesnake ignimbrite laps onto the old topography.

Petrography

Waters (1961) reported that the Picture Gorge basalts, the probable lateral correlative of the Columbia River basalts of the Mitchell quadrangle, are characterized by 5 percent olivine, the presence of saponite (green smectite) after olivine, and abundant chlorophaeite. He gave an average mode of:

Plagioclase	39.2 percent
Pyroxene	37.5
Olivine (incl. saponite)	4.7
Glass	6.3
Chlorophaeite	5.3
Opaques	6.3
Zeolites	0.6
	99.9 percent

Columbia River basalts in the mapped area closely resemble the rocks described by Waters, although glass is absent or has been completely altered. Where fresh, they have an olive black color, the texture is diabasic to ophitic, and the rock is holocrystalline. Two modal analyses of typical basalts show:

	KFO-1702	KFO-1702-b
Labradorite (An_{58-64})	51 percent	48 percent
Augite	31	39
Olivine	1	1
Magnetite	3	6
Chlorophaeite and green smectite	14	6
	100 percent	100 percent

Olivine probably should be much higher, but the crystals have been partly to totally altered to green smectite. It is probable that olivine once formed at least 5 percent of the rock. Augite also is altered, making it difficult to determine the original amount.

Rattlesnake Ignimbrite (Tr)

The Rattlesnake Formation is represented only by its ignimbrite member, which variously lies upon Clarno, John Day, and Columbia River rocks in the southeastern corner of the quadrangle. The ignimbrite is about 25 feet thick at a maximum (Figure 35). The basal two to three feet is light olive gray, poorly welded, and rich in lithic fragments picked up from the underlying regolith (Figure 36); the middle part is yellowish gray, and is firmly welded with a good eutaxitic structure; the upper part is firmly welded, is pinkish gray to pale red, and has a well-developed eutaxitic structure which results in a slabby surface. Lithic fragments can be found throughout the entire thickness, but the clasts are larger and more numerous at the base where there are cobbles up to 8 cm in diameter. The ignimbrite is made up largely of glass shards, bubble walls, and pumice fragments. The pumice fragments are generally under 2 cm in length.

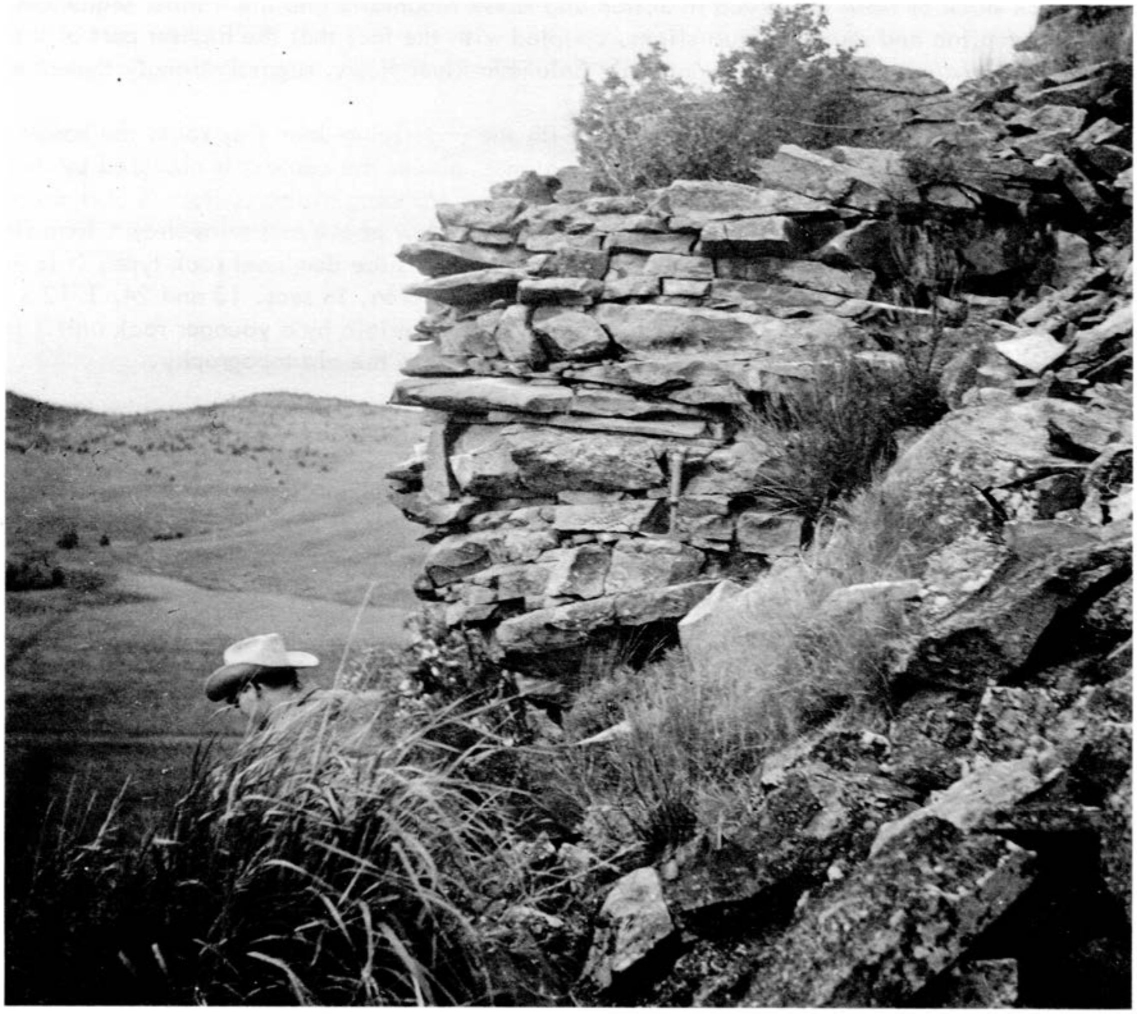


Figure 35. Rattlesnake ignimbrite ledge-former and caprock surmounting mesa east of Marshall Creek.

Petrography

The texture of the ignimbrite is vitroclastic with a fair microscopic eutaxitic structure (Figure 37). Glass, both brown and clear in about equal proportions, forms 93 percent of the rock; lithic fragments, largely clasts of mafic volcanics, form 6.25 percent; and phenocrysts of euhedral to subhedral anorthoclase, quartz, magnetite, and iron-rich augite compose the remaining 0.75 percent. The only abundant phenocrysts are anorthoclase and quartz, which occur in a ratio of 85 anorthoclase to 15 quartz. The orthoclase to albite ratio in the anorthoclase is $Or_{30}Ab_{70}$.

A chemical analysis of the ignimbrite cap rock in the SE 1/4, sec. 7, T. 12 S., R. 23 E. is shown in Table 4 along with the normative minerals. The analysis given is the dry weight percent recalculated to 100 percent. The total iron content is given as Fe_2O_3 and all lithic fragments were removed from the sample prior to analysis.

In a rock which is both chemically simple and consists of 99 percent glass it is thought advisable to treat the norm as the mode and classify the rock according to the classification of Johannsen (1931). This procedure places the rock in Class 1, Order 1, Family 7 eruptive and suggests the name leuco-sodaclase-rhyodacite.

Petrography of Major Intrusions

Several conical topographic highs in the Mitchell quadrangle are piston intrusions or plugs of compact and resistant igneous rocks. Additionally there are large irregular intrusions, sills, and dikes. Because these rock masses differ widely in their classification it is thought best to specify each major intrusive feature and name and describe the rock type. Chemical analyses and derived normative compositions for these intrusive rocks are given in Table 5.

Table 5. Chemical analyses and normative composition of the major intrusions

Component	White Butte Andesite	Tote-Goat Andesite	Marshall Butte Melabasalt	Tony Butte Dacite	Sargent Butte Leucorhyolite
SiO_2	63.00	60.40	46.30	73.00	78.20
TiO_2	.68	.90	2.00	.14	.05
Al_2O_3	18.80	18.30	12.70	16.30	14.00
Fe_2O_3	1.08	2.41	2.28	-	-
FeO	3.20	3.19	6.87	1.40	.70
MgO	1.70	2.30	10.20	.80	-
CaO	4.80	6.50	12.60	2.60	.20
Na_2O	4.40	4.33	4.90	4.05	1.70
K_2O	1.90	1.20	1.60	1.45	4.85
		Normative Composition			
Qz	15.66	13.26		36.42	48.66
Or	11.12	7.23	9.45	8.34	28.91
Ab	37.20	36.68	.55	34.06	14.15
An	23.91	26.69	8.62	12.78	1.11
C	.71			3.47	5.50
Ne			22.15		
Di		4.54	43.02		
Hy	8.00	5.95		4.24	1.32
Ol			8.76		
Mt	1.62	3.48	3.48		
Il	1.37	1.67	3.80	.30	

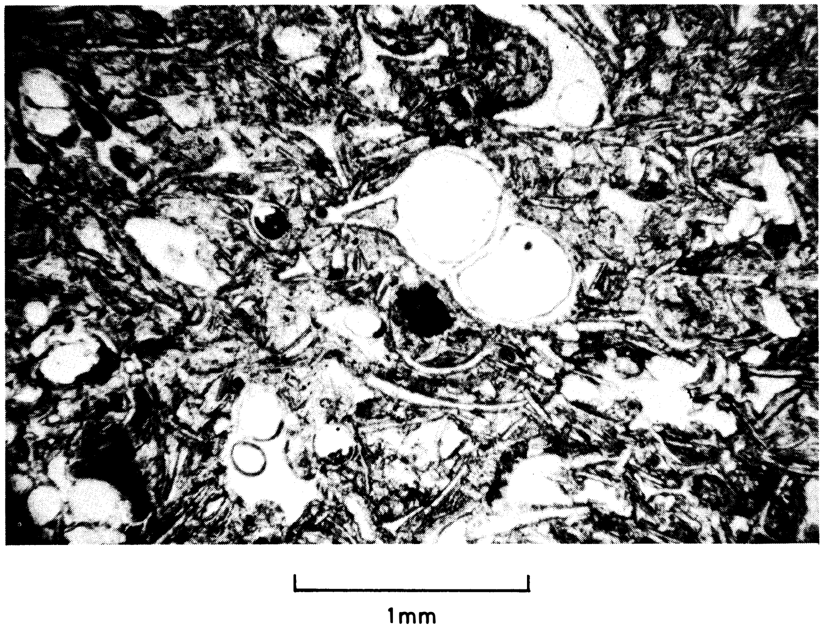


Figure 36. Rattlesnake ignimbrite from the caprock along U.S. 26 in sec. 7, T. 12 S., R. 23 E. The porous, poorly welded lower two feet of the ignimbrite sheet: glass shards and bubble walls of both clear and brown glass, interstitial brownish glass dust, a reddish opaque lithic fragment composed of altered mafic volcanic rock. Parallel nicols.

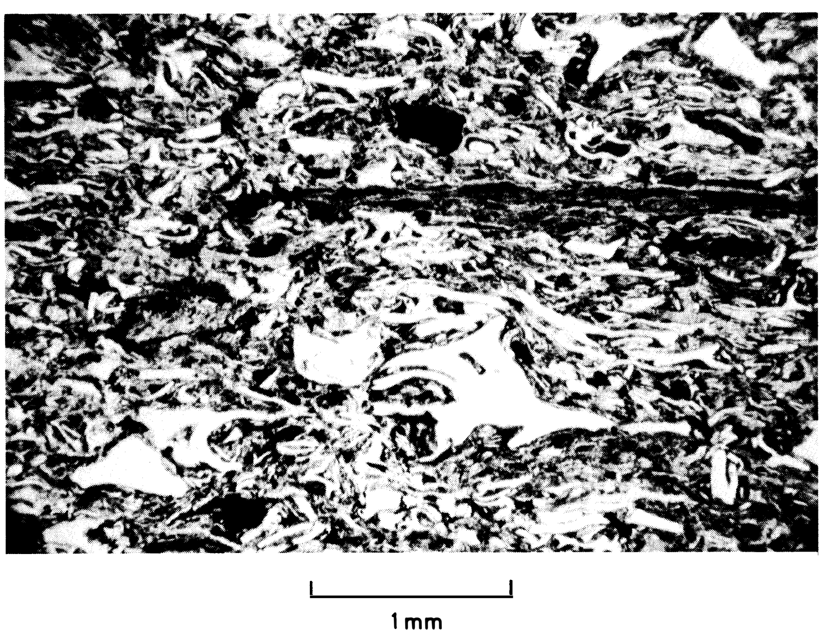
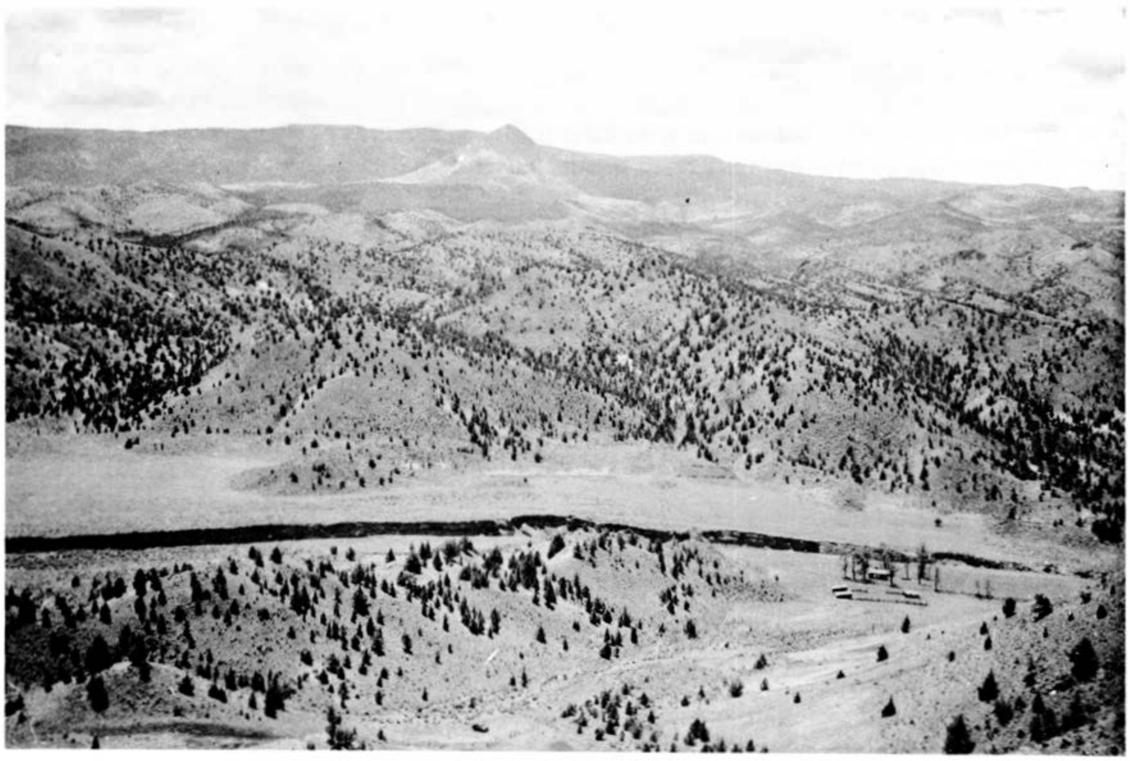


Figure 37. Rattlesnake ignimbrite, same locality as Figure 36. Firmly welded middle part of the ignimbrite sheet exhibiting good eutaxitic texture, a flattened pumice fragment, clear and brown glass shards and bubble walls, two opaque lithic fragments of altered mafic volcanics. Parallel nicols.



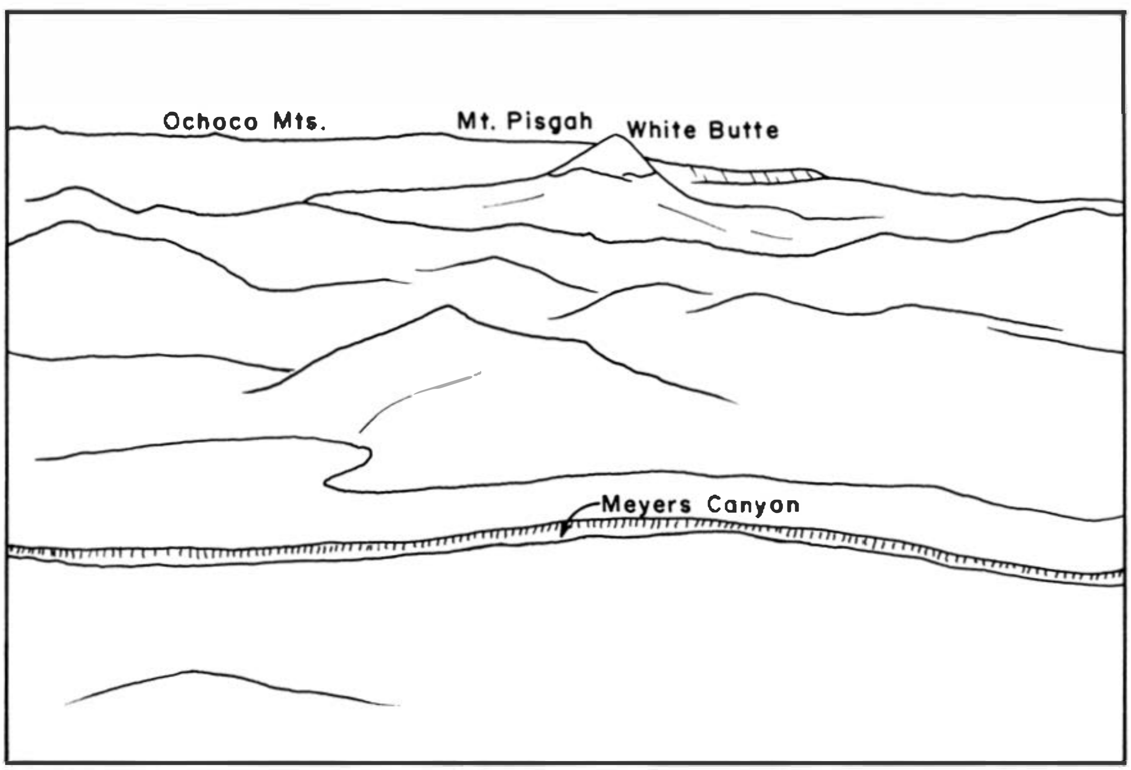


Figure 38. Meyers Canyon. Older alluvium of valley floor is being dissected, forming a deep box canyon. White Butte piston intrusion and Ochoco front in distance.

White Butte andesite (Tia)

This huge piston intrusion forms the highest and largest of the conical intrusions in the area (Figure 38). The typical White Butte andesite is light olive gray (5Y 6/1) and weathers to a dark yellowish brown (10-YR 4/2). It is porphyritic but seriate with euhedral to subhedral phenocrysts of labradorite up to 2 mm long, green hornblende up to 7 mm long, and smaller augite, in a holocrystalline granular groundmass of small andesine or labradorite laths and andesine microlites with less common augite, magnetite, quartz, and hornblende. The hornblende is commonly rimmed with dark magnetite borders and the plagioclase altered to calcite and green smectite. An average of several modal analyses yielded:

Plagioclase	82 percent
Augite	5
Hornblende	5
Magnetite	4
Quartz	4
	100 percent

Andesite dikes, sills, and irregular intrusions (Tia)

Intruding both the Cretaceous and Clarno sequences are a number of dikes (Figure 39), sills (Figure 40), and irregular intrusions (Figure 41, 42) whose texture and mineralogy are so similar to that of the Clarno flows that they are considered comagmatic. Many of these intrusions are found along the axis of the Mitchell anticline, thus gaining for them the term "axial intrusions."

The textures, colors, and mineralogy differ somewhat with the size and cooling history of the intrusive masses, but a general description of a more or less typical representative of this group can be given. Such a rock is light olive gray (5Y 6/1), porphyritic, with phenocrysts of labradorite, augite, and rare hypersthene and/or hornblende in an aphanitic pilotaxitic groundmass. The groundmass minerals consist of andesine microlites and anhedra, small grains of augite and magnetite, and traces of quartz or glass. Green smectite and calcite are common alteration products. For the holocrystalline varieties the plagioclase content ranges between 72 and 85 percent.

Tote-Goat Hill andesite (Tia)

The multiple dikes forming the backbone of this isolated hill are aphanitic but holocrystalline with a pilotaxitic texture. They commonly are dark yellowish brown (10YR 4/2), although a limited patch forming the southernmost part of the outcrop is grayish yellow green (5GY 7/2). Andesine laths up to 0.25 mm long are set in a finer matrix of feldspar microlites and anhedral grains, quartz, magnetite, and a brown smectite forming from pyroxene and probable biotite. A modest amount of calcite and kaolinite replaces feldspar, and ghosts of completely resorbed hornblende are present. The mode is:

Andesine (An_{35})	75 percent
Smectite	15
Clinopyroxene	4
Magnetite	5
Quartz	3
	102 percent

Basalt or diabase dikes (Tib)

Two major dikes, one of which has been widely offset by the Mitchell fault, are so similar in texture and mineralogy that they are considered together. The larger of the two is found in the Keyes Creek area north of the Mitchell fault and in the Nelson Creek area south of the fault. This dike variously cuts Cretaceous and Upper Clarno rocks. The second dike, immediately west of the airstrip north of Mitchell, not only cuts rocks of Cretaceous age but, as a resistant unit, holds up the sweeping pediment developed on the Main Mudstone Member of the Hudspeth Formation.

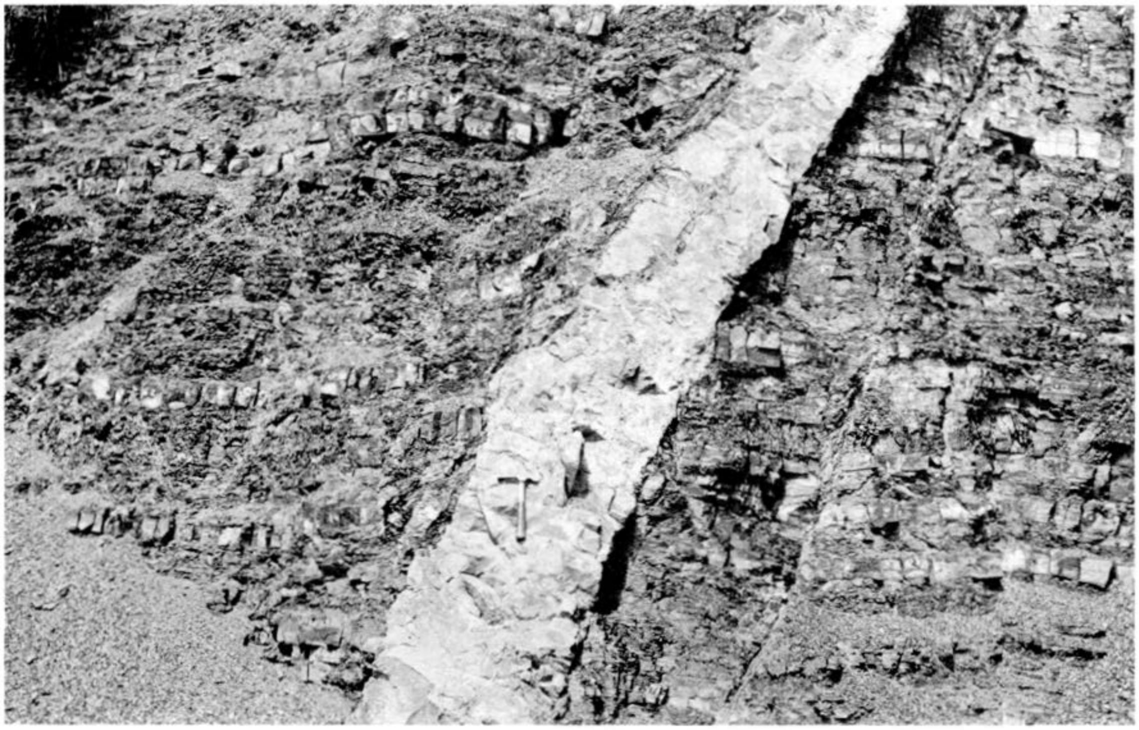


Figure 39. Small Clarno andesite dike traversing Hudspeth mudstones, siltstones, and thin sandstones. Johnson Creek Road.

Figure 40. Base of the Nelson Creek sill in sharp contact with Hudspeth mudstones.

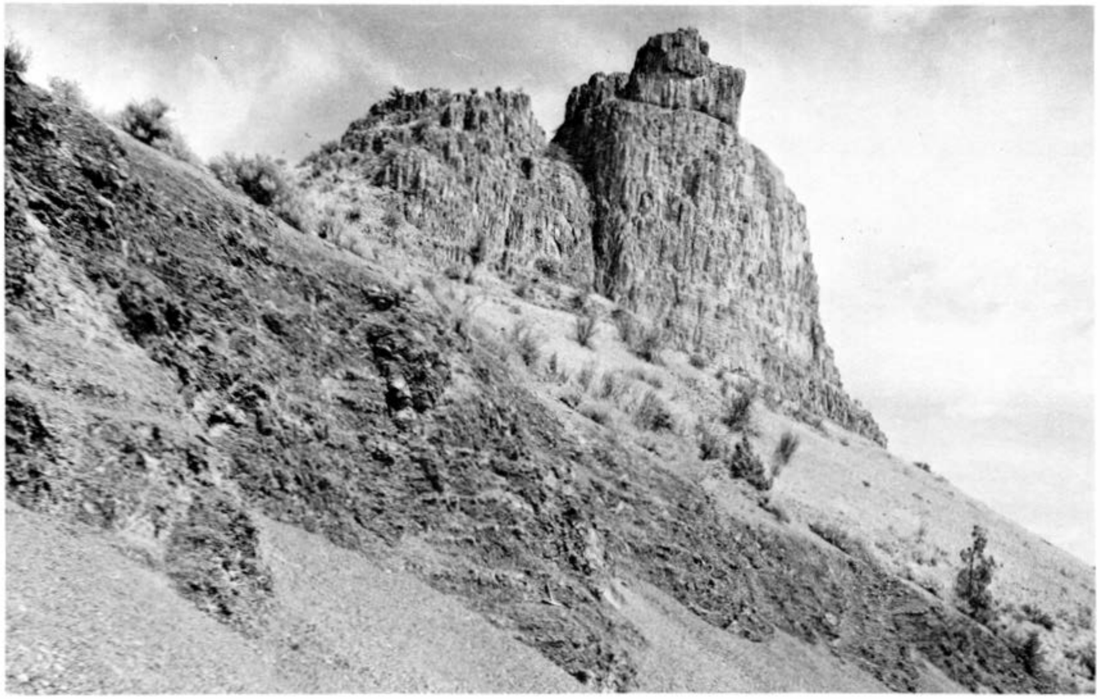


Figure 41. Mitchell Rock, an irregular intrusion of Clarno andesite into Hudspeth mudstones.

Figure 42. Irregular contact between Clarno andesite intrusion and Hudspeth mudstones. Axial intrusion, Meyers Canyon area.

These dike rocks are medium dark gray (N4) and finely crystalline. Labradorite (An_{60}) and pigeonite, in grains and laths up to 1 mm in length but averaging nearer 0.5 mm, are associated in a diabasic texture. Chlorophaeite, green smectite, olivine, opaques, and a little quartz make up the rest of the rock. Calcite is a common alteration product. The average mode is:

Labradorite (An_{60})	58 percent
Pigeonite	26
Chlorophaeite and green smectite	8
Opaques	6
Olivine	2
Quartz	Tr
	100 percent

Marshall Butte melabasalt (Tib)

The intrusive rock of this large conical mass (Figure 43) is brownish black (5YR 2/1). The rock is porphyritic (Figure 44) with phenocrysts of euhedral to subhedral augite and olivine, up to 1 mm in diameter, in a granular matrix of smaller pyroxene grains, magnetite, rare olivine, and anhedral interstitial labradorite. The olivine is partly altered to iddingsite and a green smectite, and vesicles are commonly filled with green smectite. Modal analyses yield:

Augite	71 percent
Olivine	12
Labradorite (An_{59})	9
Magnetite	8
	100 percent

Small intrusions of a similar melabasalt also have been mapped west of Marshall Butte in sec. 30, T. 11 S., R. 22 E. and in secs. 19 and 20, T. 11 S., R. 21 E. on the West Fork of Bridge Creek.

Tony Butte dacite (Tid)

This dacite plug, which transects both the Permian metasediments and Cretaceous rocks, is yellowish gray (5Y 7/2) and porphyritic with feldspar laths up to 4 mm long in an aphanitic groundmass. A few ragged biotite laths, now extensively altered to brown smectite, and rare pseudomorphs of what used to be hornblende but now are masses of magnetite, feldspar, and green chloritic material, can be found. A pilotaxitic groundmass of feldspar microlites, quartz, and anhedral interstitial feldspar is so fine as to make difficult the accurate identification of the feldspar. Sparse hypersthene and magnetite can be seen. The approximate modal analysis is:

Andesine (An_{38})	62 percent
Quartz	32
Biotite	6
Remainder	Tr
	100 percent

Sargent Butte leucorhyolite (Tir)

A distinctive pale orange (10YR 8/2) rock occurs in Sargent Butte, a conical intrusive mass, and its smaller, irregular satellites, as well as in Sand Mountain to the west and various irregular intrusions in the axial region of the Mitchell anticline and along the Mitchell fault. This aphanitic rock contains many very fine pores or vesicles and numerous minute specks of limonite. The vesicles average about 1 mm in diameter; some are empty, others are filled with chalcedony; subhedral quartz crystals extend into many vesicles. The overall texture is xenomorphic granular (Figure 45a, b) with grains 0.1 mm or less in diameter. Spherulitic masses of quartz near 1 mm in diameter are common. The major minerals are quartz and an alkali feldspar. Limonite stains and some lath-like masses of a chloritic mineral indicate the former presence of some ferromagnesian mineral and perhaps magnetite. The feldspar is in part

Figure 43. Keyes Creek Valley: sweeping pediments, mainly carved in mudflows, descend from Marshall Butte, a melabasalt intrusion.

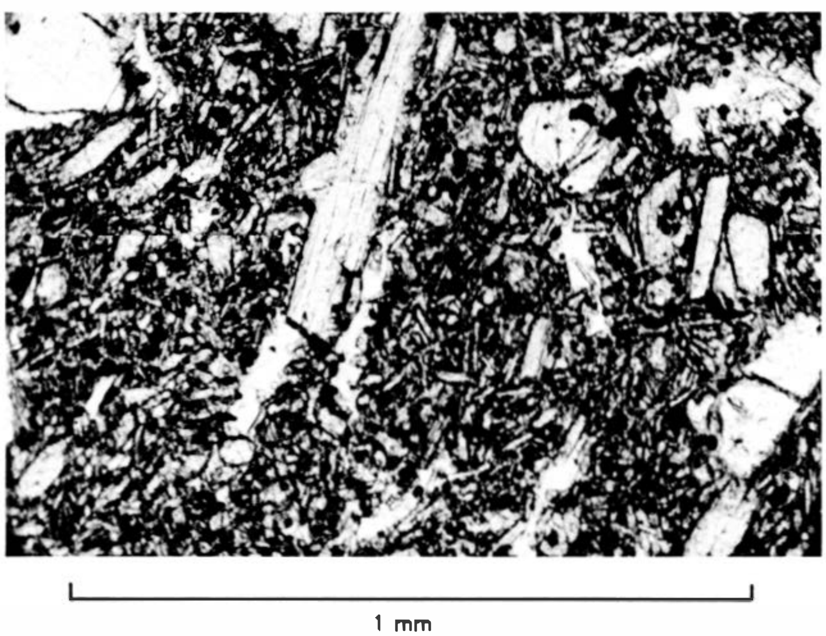
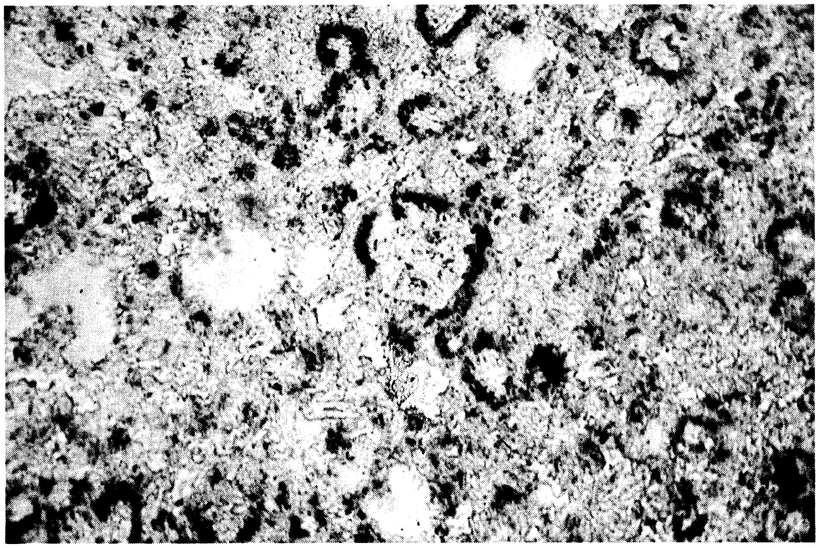
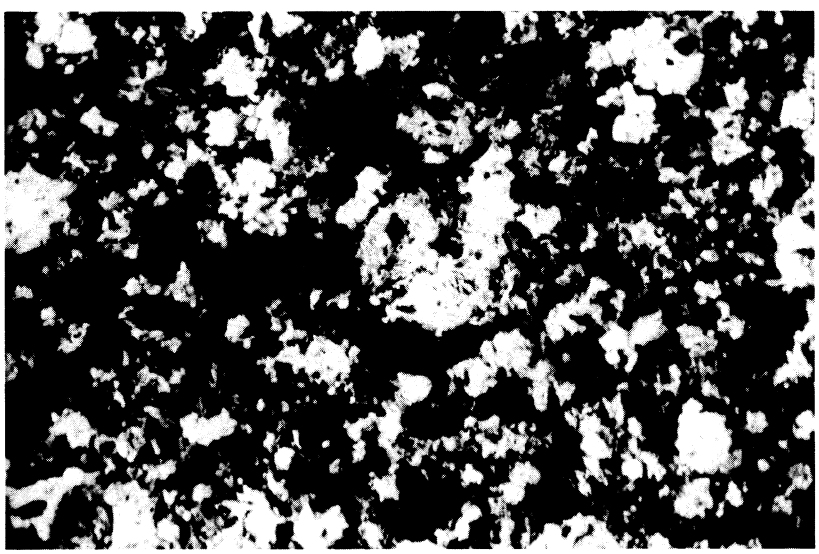


Figure 44. Marshall Butte melabasalt: phenocrysts of subhedral to euhedral olivine and augite and anhedral labradorite in a groundmass of smaller augite grains, magnetite and some anhedral labradorite. Parallel nicols.



1 mm

Figure 45a. Sargent Butte leucorhyolite: confused mass of anhedral quartz and minor anorthoclase with many vesicles. Nicols parallel.



1 mm

Figure 45b. Same as Figure 45a but with nicols crossed.

altered to kaolinite. An X-ray diffraction pattern of a polished specimen yielded peaks consistent with an identification of the feldspar as anorthoclase.

The very fine texture of this rock made it impossible to obtain a reliable modal analysis, so its classification was determined in the same fashion as the glassy rocks. Using the normative mineral composition given in Table 5 as the mode, it is best classified as a leucorhyolite.

STRUCTURE

INTRODUCTION

The Mitchell quadrangle lies on the north flank of the east-west trending Ochoco Range. Immediately south of the quadrangle a series of antithetic step faults parallel to the mountain front lifts successively higher blocks to the summit of the range. Within the quadrangle some similar but minor step faulting is found in the southernmost part. In the Mitchell quadrangle the major structural features are a pronounced northeast-southwest-strike of the formations, a giant syncline prominent in the Columbia River Group in the northern part, a smaller scale syncline in the southeast corner, and a complexly faulted and intruded anticline in the center of the quadrangle (Figure 46). The northeast-southwest trend is accentuated by the Sutton Mountain syncline on the northwest, the Mitchell anticline in the central region, and the Thorn Hollow syncline to the southeast. This simplified overview of the structure does not take into account additional faulting, tilting, and intrusions which complicate the structure.

The principal faults are the large-scale Mitchell strike-slip fault trending east-west across the south half of the quadrangle, and the northeast-trending Meyers Canyon fault. Numerous intrusions, especially in the axial regions of the Mitchell anticline, have made this region of older rocks structurally complex. The development of the major synclines, the intervening anticline, and the subordinate faults and fault-controlled intrusions will all be discussed in the sequential narrative of the section on Geologic History. The one major structural feature to be described in some detail here is the Mitchell fault.

MITCHELL FAULT

The major fracture of the quadrangle is the Mitchell fault. This prominent lineament, which shows up remarkably on aerial photographs, is defined by intrusions which sharply abut it through much of its length. The fault produces striking stratigraphic changes across its zone, and extensive right-lateral strike-slip displacement is evident in addition to pronounced vertical movement. Strangely, the rather wide crush zone of the fault is rarely a valley-former. Most commonly the fault traverses the topography of the quadrangle without regard to rock type, pre-existent structure, or topography.

On a regional basis the fault continues beyond the quadrangle to the east where it is concealed beneath the Columbia River Group in the adjacent quadrangle. A prolongation of the fault farther east is speculative. If the fault were to continue its nearly east trend it is conceivable that it would be the same fault as that at the John Day River, near Goose Rock, in T. 11 S., R. 26 E., where it has been described (Brown and Thayer, 1966) as the Middle Mountain fault. At this locality the north side is up, bringing metasediments, possibly of Permian age, against younger rocks on the south. This would be the same sense of vertical displacement as the older episodes of vertical movement of the Mitchell fault in the Mitchell quadrangle. On the other hand, if the fault were to bend to the east-southeast it well might be a continuation of the John Day fault mapped by Brown and Thayer farther east. West of the Mitchell quadrangle the fault bends from its slightly north of west trend and, swinging to a west-southwest strike, continues for at least 20 miles paralleling the strike of Lower Clarno rocks.

The displacement along the fault is imperfectly known. The prominent Keyes Creek dike on the north side of the fault, which intersects the fault in sec. 4, T. 12 S., R. 22 E., is probably matched on the south side by the Nelson Creek dike in secs. 1, 2, and 12, T. 12 S., R. 21 E. Based on petrography, alignment, and outcrop characteristics it is thought that the two are tectonically separated segments of a single major dike. The Nelson Creek dike, if prolonged through a covered and vegetated area to an intersection with the fault, would demonstrate approximately 22,000 feet of right-lateral separation.

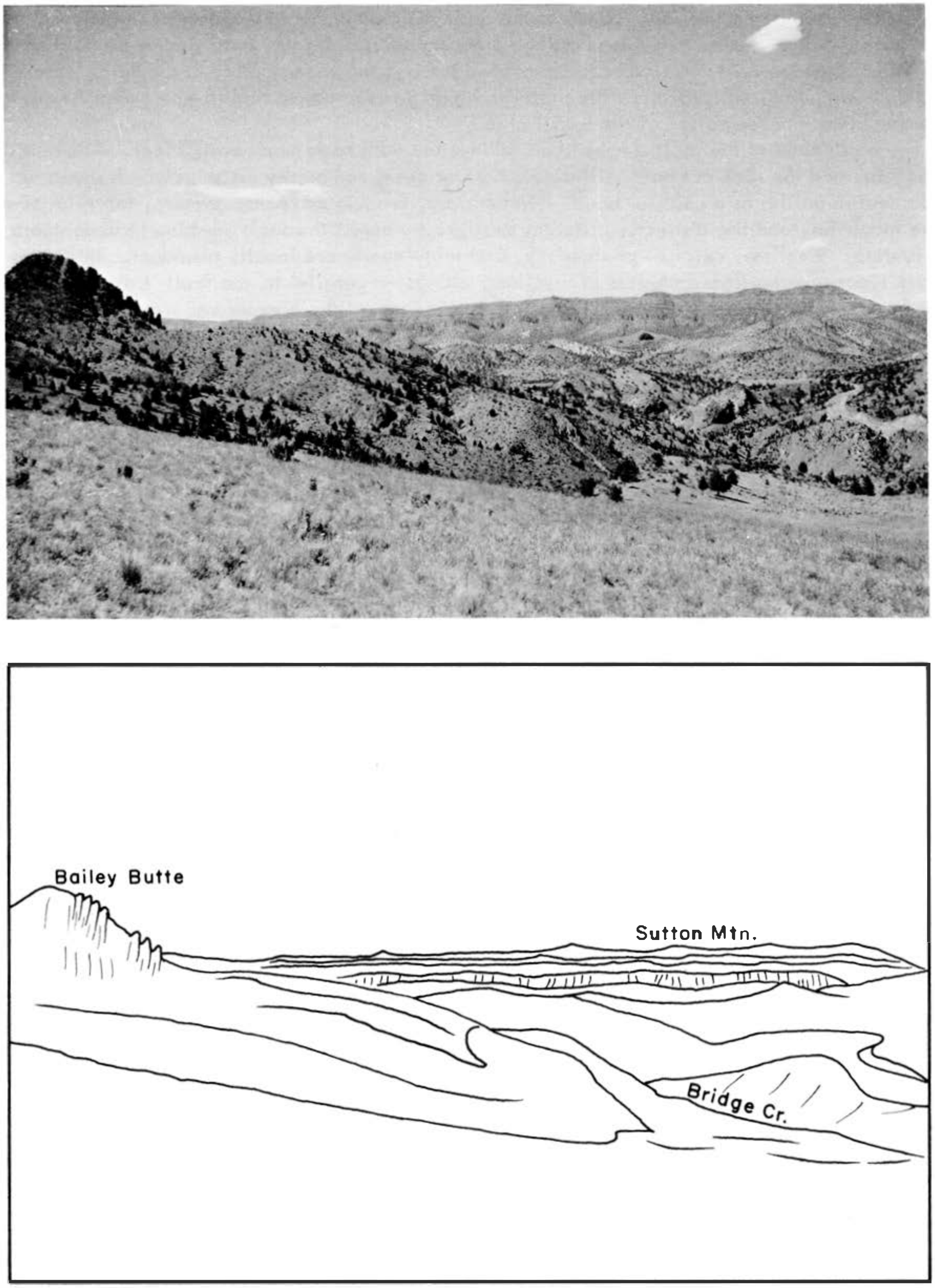


Figure 46. Panorama showing Bailey Butte sill on left, axial region of Mitchell anticline north of Mitchell fault, and Sutton Mountain on skyline.

The figure of 22,000 feet -- in excess of four miles -- is supported by the approximate offset of the axis of the Mitchell anticline. North of the fault the axis is lost in a welter of intrusions, but an approximate prolongation to the fault gives one piercing point. On the south side of the fault and west of the Mitchell quadrangle, the axis can be mapped through the west flank of Black Butte, furnishing a second piercing point. This offset of the anticlinal axis gives a lateral displacement commensurate with that derived from the separation of the basalt dike.

The crush zone of the fault ranges from 50 feet in width to as much as 500 feet. Aberrant attitudes are frequent, and the rock has been milled to a dark or dusky red earthy material which shows up on hillsides and in gullies as a colorful band. Slickensides, brecciated rocks, grooves, the lines of springs in some localities, and the distinctly different stratigraphy across the fault combine to accentuate this major feature. Zeolites, calcite, chalcedony, and drusy quartz are locally abundant. Intrusions of various rock types ranging from andesites to rhyolites, elongated parallel to the fault trace and usually bounded on one side sharply by the fault, delineate the zone. Where exposures are good, the beds immediately adjacent to the fault can be seen steeply folded, dragged, and crushed. Strata which away from the fault dip more or less gently, at the fault are pulled over into vertical or overturned dips.

The vertical displacement on the fault varies along the strike dependent upon the locale. The overall sense of vertical displacement is down on the south side, as exemplified by the younger units of the Cretaceous sequence being preserved only on the south side. Conversely, only on the north side are the oldest units of the Cretaceous exposed, and only in the axial region of the Mitchell anticline, north of the fault, are the isolated exposures of the basement crystalline rocks of Permian age found. In addition to the stratigraphic fact that the south side of the fault is down, it is only on the south side that such comparatively young rock units as the Upper Clarno Mudflows have a thick development, as if during some past interval a fault-line escarpment existed and there was basin-filling south of the fault. In the vicinity of the town of Mitchell vertical movement has juxtaposed Gable Creek tongue 3 on the north with Hudspeth tongue 10 on the south, a stratigraphic displacement of approximately 3,200 feet.

On the west beyond the quadrangle, and at several places within the quadrangle, drag of the adjacent Cretaceous or Clarno beds indicates the latest movement was down on the north side. It is probable that these latest movements were in accord with the north side down displacements of the step faults on the north flank of the Ochoco Range. This movement would then be at a very late stage in the history of the fault and would be a reversal of the vertical sense of displacement.

GEOLOGIC HISTORY

INTRODUCTION

The Mitchell quadrangle is one of considerable complexity and geologic interest from the standpoint that its rocks record a long-lived sequence of diastrophic pulses. From the crystalline basement of Permian metasedimentary rocks to the youngest rock unit in the area -- the Rattlesnake ignimbrite -- every major stratigraphic unit is separated from its neighbors by angular unconformities. Each angular unconformity is representative of an episode which resulted in folding or tilting and each records renewed weathering and erosion prior to deposition of the next unit.

The discussion of the Geologic History will be sequential, starting with the oldest unit and culminating with the modern-day events.

OLDEST OROGENY

The first event about which we can speculate is a marine domain in which muds, sands, and cherts were deposited, with intercalated limy sediments. Within these carbonates were incorporated fusulinids of Permian age. Following lithifaction and at some later date -- post-Permian but pre-Cretaceous -- an unnamed orogeny, of a severity which included progressive regional metamorphism, affected the Permian sedimentary rocks. Because elsewhere in central Oregon Triassic rocks have been metamorphosed to some degree but Jurassic rocks show little penetrative metamorphism, it is probable that this unnamed orogeny occurred sometime during the Triassic or earliest Jurassic. During this orogeny and the accompanying progressive regional metamorphism the mudstones and siltstones were converted to phyllites; the sandstones to quartzitic rocks; and the limestones, disconnected into tectonic blocks, were transformed into crystalline limestone pods. Some of the fusulinids survived the deformation and can today be used to date these rocks. Continuing horizontal compression succeeded the metamorphism, and the phyllites and quartzites were very tightly--locally isoclinally--folded along northeast-southwest trending axes. Regional uplift also presumably accompanied this episode.

As a result of the uplift, weathering and erosion attacked the rocks. Much time elapsed and a topography of considerable relief was produced on the older rocks.

CRETACEOUS DEPOSITION

As a result of regional downwarping the sea encroached on the eroded Permian metasediments, and transgressive marine sandstones and siltstones of Cretaceous (presumably Albian) age were deposited. Succeeding the transgression and the deposition of the Basal Member of the Hudspeth Formation, muds and silts were deposited which formed the Main Mudstone Member of the Hudspeth Formation. This thick member, although persistent throughout the outcrop area of Cretaceous rocks in the quadrangle, does thin markedly to the north and east. Overlying these marine sediments is Gable Creek tongue 1, a unit of fluvial and deltaic sandstones and conglomerates. And then in succession thereafter, dependent upon position within the quadrangle, Hudspeth and Gable Creek tongues succeed each other. These encompass parts of both Albian and Cenomanian Epochs.

The multiple members of two formations, juxtaposing the marine with fluvial and deltaic domains, pose questions regarding those conditions which produced such intertonguing of very different lithic types. The Hudspeth mudstones and siltstones were deposited in quiet marine waters, below wave base. The Gable Creek tongues, prograding into the subsiding marine basin, are largely continental fluvial and deltaic deposits; they probably were deposited by swinging distributaries at deltas of one or more great rivers. Such distributaries must have been sufficiently strong to have carried heavy loads of coarse detritus into the marine basin as prong-shaped protrusions; some may have been fans. Each Gable Creek tongue is transitionally succeeded above by a marine tongue of the Hudspeth Formation, representative of a renewed transgression by the sea.

This intertonguing spells out a story of cyclic changes between marine sedimentation and continental deposition. The sequence could have been the result of episodic subsidence of the basin, a subsidence which is noteworthy in that it had to be of such magnitude in totality as to accommodate over 9,000 feet of mixed marine and continental sediment. On the other hand, with a subsiding marine basin, the huge volumes of coarse clastic debris of the Gable Creek Formation required strongly rising source areas--conjectured to have been on the north and east--which were being actively weathered and eroded by one or more major river systems. Thus, the Gable Creek tongues might represent periodic uplifts of the source areas. A third possibility exists. Given a strongly rising source area being eroded actively by fluvial processes, each conglomerate and sandstone tongue might represent a standstill in basin subsidence. During each standstill, under conditions of stable sealevel, a regression of the sea caused by progradation of the delta front would be recorded by a more coarsely clastic tongue. There really is no basis for selection of one of these mechanisms as being the sole valid cause of the intertonguing. Consequently, there is the fourth possibility that episodic subsidence of the basin and periodic uplift of the source areas, coupled with swinging distributaries at the mouths of major rivers, combined to produce this complex intertonguing of fluvial/deltaic with quiet water marine sediments.

The marine basin was a strange one in that the terminations of the conglomerate and sandstone tongues show a notable absence of winnowing by wave action, of wave-cut features, and of longitudinal sand bodies oriented perpendicular to the regional slope which are indicative of active longshore currents. The absence of these, coupled with the prevalent lamination of the Hudspeth mudstones and siltstones and a very limited fauna, suggests that this basin was isolated and restricted in wave and current action and benthonic activity and was protected from the normal marine and life processes so common to open coastal areas. Thus the picture is formed of a large, sheltered, shallow marine embayment into which major rivers poured huge volumes of clastic debris.

LOWER CLARNO EVENTS

Following the deposition of the last Hudspeth and Gable Creek tongues, the region was subjected to epeirogenic uplift and on the sedimentary rocks there developed a thick regolith, the result of deep weathering. During this uplift broad, low-angle tilting must have occurred, and on the deeply weathered Cretaceous landscape the rocks of the Lower Clarno were deposited with a slight angular discordance.

From fissures or from central vents andesite lava flows poured forth. These very thick, laterally extensive flows form the bulk of the Lower Clarno Formation. The sources of the flows are not known. Large dikes, with Clarno affinities, do exist, but nowhere in the quadrangle have the flows been directly allied to these dikes; and nowhere can central vents be demonstrated as sources for rocks of the Lower Clarno. However, as flow succeeded flow, with intervening intervals during which deep weathering produced regoliths, a thick and areally extensive pile of andesite flows was produced. Each regolith developed on a flow was subsequently overrun by another flow, and was baked to the characteristic brick red color so common to flows in many volcanic areas. During one interval a thick sequence of Lower Clarno tuffaceous sediments was deposited. These sediments, ranging from clays to pebble conglomerates, were dominantly water-laid, and were probably the result of sheet wash transporting to streams the products of pyroclastic ejectamenta from volcanic eruptions. The streams then transported the pyroclastic debris to localized basins and floodplains.

White Butte Intrusion

At about this time White Butte, a piston intrusion of andesite, was emplaced forcibly. Over a mile in greatest diameter, this roughly cylindrical mass rose through the Cretaceous rocks, pushing them back and aside, causing the flanking rocks to be peeled back. As a consequence, the butte is flanked by Cretaceous rocks which dip away steeply from the mountain core in all directions. On the north flank a Gable Creek unit has been faulted, lifted about 500 feet, and its dip reversed.

The dating of this intrusion is speculative; however, a well-defined volcanic breccia (Tcvb) lying on the south side of White Butte, which dips steeply away from the mountain and is more or less concordant with the underlying Cretaceous rocks, apparently participated in the shouldering aside that accompanied the intrusion. This older volcanic breccia, which well might be a lateral facies of the Lower Clarno tuffaceous sediments found farther north, is lapped with profound angular unconformity by nearly flat-lying Upper Clarno mudflows. Therefore, though the dating is indeterminate for the intrusion, it can be established that White Butte is a Lower Clarno event which predates Upper Clarno mudflows derived from Keyes Mountain or some similar central vent.

Perhaps contemporaneously, irregular intrusions and sills with Clarno andesite characteristics were emplaced in a variety of areas. In particular, such intrusions are prevalent along the axial regions of the Mitchell anticline. Some of these intrusions have been dislocated and separated by right-lateral movement along the Mitchell fault--a displacement which apparently occurred during Upper Clarno time. Because these axial intrusions generally are seen only in contact with Cretaceous rocks, a more precise dating of their emplacement is not possible.

Succeeding the episodes during which tuffaceous sediments were deposited, additional Lower Clarno flows were extruded. The latest event ascribed to the Lower Clarno is the uppermost andesite flow preserved in the sequence.

LARAMIDE OROGENY

Following the emplacement of the Lower Clarno rocks there ensued a pronounced orogeny. Most probably of Eocene age, the orogeny produced major folds, the results of horizontal compression. This orogeny, heretofore unnamed in central Oregon, is probably an episode of the Laramide Orogeny, so well-defined farther east in Idaho and Wyoming. During this mountain-making episode the Cretaceous and Lower Clarno rocks were folded into the major Mitchell anticline. These units have the steepest dips in the Mitchell quadrangle aside from the tight folding produced by an earlier orogeny in the Permian metasediments.

Because of the horizontal compressive forces and because of the early Tertiary time this orogeny will be referred to here and subsequently as part of the Laramide Orogeny.

KEYES MOUNTAIN VOLCANIC EPISODE

Following the orogeny and the concomitant uplift and mountain-making, deep weathering and dissection occurred, forming a mature topography with a demonstrable relief of many hundreds of feet. This interval was of unknown duration. In the northwest part of the quadrangle, where the Lower Clarno rocks are directly succeeded by John Day sediments, the interval of weathering and erosion persisted without recognizable rock record until John Day time. This suggests that this part of the quadrangle was a topographically high area of Lower Clarno and Cretaceous rocks, and was the site of active erosion rather than deposition.

But in the southern and eastern parts of the quadrangle the next event was the extrusion and deposition of andesite flows and volcaniclastic sediments belonging to the Upper Clarno Formation. These, in the main, had their origin in Keyes Mountain, an Upper Clarno volcano. From the Keyes Mountain center, episodically as the result of many eruptive events, there was emplaced a complex of lava flows and mudflows dipping away in all directions from the mountain. It is possible that some of the mudflows actually represent eruptive activities of the mountain during which pyroclastic ejecta, showered down on the dissected landscape, were moved down channels as water slurries, the water being derived from the torrential rainstorms resulting from the vast quantities of water vapor vented during explosive phases. Such lahar deposits are difficult to verify; many of the mudflows well might represent fluvial fan and piedmont deposits, the results of more normal running water erosion.

Mitchell Fault--Inception

It is during this Upper Clarno interval of eruptions from Keyes Mountain that the first valid evidence of the Mitchell fault is recorded. At this time the fault had movement of an essentially vertical type, the south side moving down relatively. As a consequence the mudflows developing on the south and southwest flanks of Keyes Mountain are relatively thin north of the fault--probably no more than 400 feet thick at any one locality--whereas south of the fault the mudflow units aggregate over 1,000 feet in uninterrupted thickness. This conjures up a picture of an impressive east-west-trending fault or fault-line scarp facing south; and emanating from Keyes Mountain and crossing the escarpment a series of mudflows debouched into a basin, forming thick fan and piedmont deposits.

During this sequence of volcanic events on Keyes Mountain the fans, represented by the mudflows and finer grained sedimentary units, progressed farther from the mountain than the concomitant lava flows. In isolated basins, some occupied by freshwater lakes, fluvial-deltaic and lacustrine volcaniclastic sediments were deposited.

Lateral Movement Along the Mitchell Fault

Subsequent to the construction of Keyes Mountain, movement once again occurred along the Mitchell fault. This episode resulted in right-lateral strike-slip movement. This new sense of displacement is mainly attested to by the marked offset of the Keyes Creek and Nelson Creek dikes as well as the axis of the Mitchell anticline. Both dikes, probably emplaced along gash fractures which approached the main fault at acute angles, and the fold axis were widely separated by recurrent strike-slip movement along the fault. The dating of these major movements is obscure; however, the Keyes Creek dike does cut through Upper Clarno mudflows derived from Keyes Mountain. Rhyolite intrusions most probably of John Day age have also been cut by the fault.

Following eruption of Keyes Mountain volcano there ensued a time of weathering and erosion, possibly accompanied by differential uplift. This uplift is suggested because Keyes Mountain, as a volcano with quaquaversal dips, has much lower dips on the north flank than on the other flanks as if it had been tilted to the south. Such a tilting to the south well may have uplifted the northern parts of the quadrangle and permitted erosion to strip off any Upper Clarno rocks that may have been present, rocks that are notably absent there today.

A landscape of ridges and valleys was produced; more or less circular knobs, as of ancient hill or mountain tops, can be seen in the old topography. These prominences, showing the effects of deep and protracted weathering and accompanying deep dissection, were then covered progressively by the volcaniclastic sediments of the John Day Formation. Huge thicknesses of tuffaceous sediments, mainly clays, muds and silts, were deposited within internal basins. The resultant varicolored beds have been described by many workers and form the spectacular beds of the John Day Formation. Where topographic highs existed, as beneath "The Prow" of Sutton Mountain, the John Day beds are extremely thin, a hundred feet or less. Where the basinal deeps existed some thousands of feet of sediments were emplaced. High in the sequence there are cross-bedded and -laminated, scour-and-fill, fluvially emplaced siltstones, sandstones, and conglomerates. A picture arises of a mature topography of large basins and an infilling with tuffaceous materials--the products of recurrent volcanic eruptions.

Some workers have looked far afield, as far as the Cascade Range to the west, for sources of these extensive ash-falls. Granting that western sources may have contributed to this thick sedimentary pile, one should look within the Mitchell quadrangle and see that, at that time, there were numerous intrusions of leucorhyolite--e.g., Sargent Butte, Sand Mountain, and the later generation of intrusions in the axial region of the Mitchell anticline, and also intrusions of dacite, such as Tony Butte in the northeastern part of the quadrangle. Any of these intrusions, with conduits to a surface which could not have lain far above, could have been surmounted by central vents. These vents, long since removed by erosion, could have produced locally the explosive eruptive debris that, carried into local basins by normal agencies of erosion, produced the pile of tuffaceous sediments of the John Day Formation.

RENEWED OROGENY

The John Day sedimentation was followed by a renewal of folding in the quadrangle, a folding which mimicked the prior axes. In the lower Bridge Creek valley John Day beds have dips as high as 45°, although 20° maxima are more common. West of the quadrangle in the Painted Hills State Park some faulted open folds are records of this orogenic episode. Although John Day sediments, if ever present on the Mitchell anticline, have long since been stripped away by erosion, the sediments are preserved in the broad, open, plunging synclines of Sutton Mountain to the northwest and Thorn Hollow to the southeast.

COLUMBIA RIVER GROUP

Following this deformational event the John Day and older rocks were weathered and eroded extensively, resulting in a plain of low relief. During this interval of time the broadly folded John Day beds were widely truncated by the erosional processes.

The next rock record of an event is the middle Miocene outpouring of that giant sequence of lava flows, the Columbia River Group, which are so notable in the Pacific Northwest. From dikes and dike swarms--the dikes in secs. 2 and 11, T. 11 S., R. 21 E., as well as the excellent examples farther east on the John Day River in the Monument area--there were extruded by fissure or plateau eruptions a sequence of flows. Some flows are several hundred feet thick; others are much thinner. These bold cliff-formers of the modern-day topography are well-preserved in both the Sutton Mountain and Thorn Hollow synclines, as well as in the north-facing escarpments of the Ochoco Mountains and Mt. Pisgah immediately south of the quadrangle.

RENEWED FOLDING

Following the emplacement of the Columbia River flows, a renewal of deformation caused refolding along the pre-existing axes, and the broad Sutton Mountain and Thorn Hollow synclines achieved their present day structural conformation. Although the Columbia River basalts may once have been continuous over the quadrangle, this deformation led to a significant erosional stripping of much of the basalt. Where the intervening Mitchell anticline was refolded and presumably uplifted, breaching occurred, and the Columbia River basalts through Lower Clarno rocks were stripped away, exposing the Cretaceous rocks.

RECENT EVENTS

Following this episode of folding and the resultant subaerial weathering and erosion there has been recently, most probably during the Pliocene Epoch, considerable faulting. One result has been the production of east-west-trending step faults along the north front of the Ochoco Mountains. As a result of marked uplift Columbia River basalt is found at elevations as high as 7,000 feet on Mt. Pisgah on the summit of the mountains south of the quadrangle. Additionally, in front or north of Mt. Pisgah there is a sequence of down-faulted blocks, each containing Columbia River flows and each bounded by antithetic step faults. In the Mitchell quadrangle there was a similar faulting response, and the last evidence of movement along the Mitchell fault shows a total reversal from its prior history; the drag of adjacent beds indicates some small-scale down north apparent motion.

A mature topography, probably strikingly similar to that of today, developed in the Mitchell quadrangle, and it was on this dissected terrain, in topographically low areas confined to the southeasternmost part of the quadrangle, that the last major event is recorded in the rocks. The cataclysmic eruptions that farther east and south produced thick ignimbrite units permitted a single, thin, wedge-edge of one ignimbrite to "wash" into the area. As evidence of one such Pelean cloud there are preserved in topographically low areas a few feet, 25 as a maximum, of the Rattlesnake ignimbrite.

Following this event and presumably continuing to modern times, there has been some minor vertical faulting in which Rattlesnake and older rocks have participated.

In most recent times, probably those ascribed to the pluvial cycle, the valleys were extensively alluviated--valleys which earlier had been deeply dissected during the formation of a mature topography. Within the valleys a sequence of fluvial and colluvial deposits, in many places more than 100 feet thick, was emplaced. Near the top of this unconsolidated sequence there is at many places the well-defined ash layer which is ascribed to the eruption of Mt. Mazama 6,600 years B.P. This interval of alluviation followed a time of deep dissection. Now the alluviated valleys are once again being deeply dissected under conditions of a semiarid regime. Throughout the Mitchell quadrangle and continuing beyond it there is rapid downcutting, forming deep box canyons and gullies which are exposing the older alluvium. Three pediment levels have been developed on the John Day beds above Bridge Creek and beneath Sutton Mountain, and in this semiarid cycle these are being dissected. This then is the scene of today. Erosion continues, the mature topography is once again being deeply dissected, and as a result of erosion sediment is being transported out of the quadrangle. Destructional forces are at work; the constructional works of sedimentation are purely transitory stream deposits that, geologically, are being moved rapidly out of the quadrangle.

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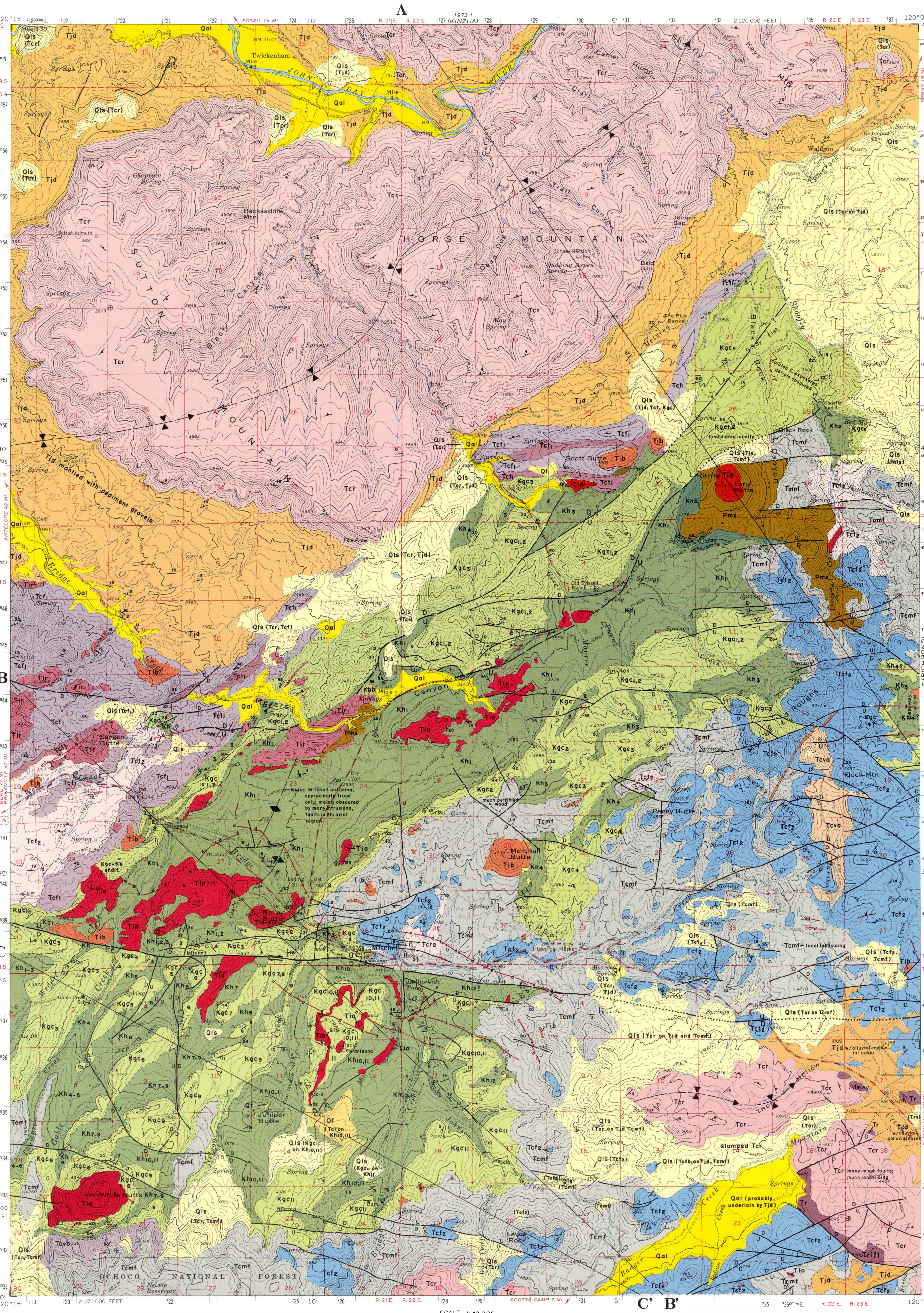
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

GEOLOGIC MAP *of the* MITCHELL QUADRANGLE OREGON

Geology
by
Keith F. Oles, W. D. Wilkinson, and Harold E. Enlows



Base Map, by the U.S. Geological Survey (1966)
Control by USGS, USC&GS, and State of Oregon
Topography by photogrammetric methods from aerial photographs taken 1963. Field checked 1966
Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

UTM GRID AND 1966 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:48 000

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
Medium-duty — Light-duty
Unimproved dirt
U.S. Route — State Route

QUADRANGLE LOCATION

EXPLANATION

STRATIGRAPHIC UNITS

QUATERNARY — PLEISTOCENE

Qal — Alluvial and Colluvial Deposits
(only extensive areas mapped)

Qf — Fan Deposits

Qls — Landslide Deposits
Rock Unit(s) mainly involved indicated in parentheses.

UNCONFORMITY

TERTIARY — PLIOCENE

Tr — Rattlesnake Formation
Thin ignimbrite – westernmost extension of unit.

UNCONFORMITY

MIOCENE

Tcr — Columbia River Group
Basalt flows – probably correlate with Picture Gorge Basalt.

UNCONFORMITY

OLIGOCENE - MIOCENE

Tjd — John Day Formation
Varicolored lacustrine and fluvial tuffs.
Ignimbrite within middle member.

UNCONFORMITY

EOCENE - OLIGOCENE

Upper Clarno

Tcf_2 — *Basalt flows, mainly derived from Keyes Mtn.; generally intracanyon to Tcmf.*

Tcmf — *Mudflows and fanglomerates derived from Keyes Mtn.; intracanyon to Tcf_2*

Tct_2 — *Light-colored fluvial and lacustrine tuffs; finer grained correlatives of Tcmf.*

Tcva — *Vent agglomerate, Keyes Mtn. only.*

UNCONFORMITY

Lower Clarno

Tcf_1 — *Basalt and andesite flows.*

Tct_1 — *Varicolored lacustrine and fluvial tuffs.*

Tcvb — *Volcanic breccias, White Butte area only.*

UNCONFORMITY

CRETACEOUS — ALBIAN - CENOMANIAN

Kgc / Kh — Gable Creek Formation
Twelve numbered fluvial-deltaic and estuarine conglomerate and sandstone units intertonguing with Hudspeth Formation.

Hudspeth Formation
Basal sandstone member (Khb) plus thirteen numbered marine mudstone and siltstone units which intertongue with Gable Creek Formation.

UNCONFORMITY

PERMIAN

Pms — Permian Metasediments
Phyllites, cherts, and crystalline limestones.

INTRUSIONS

Tid — Primarily the dacite plug of Tony Butte

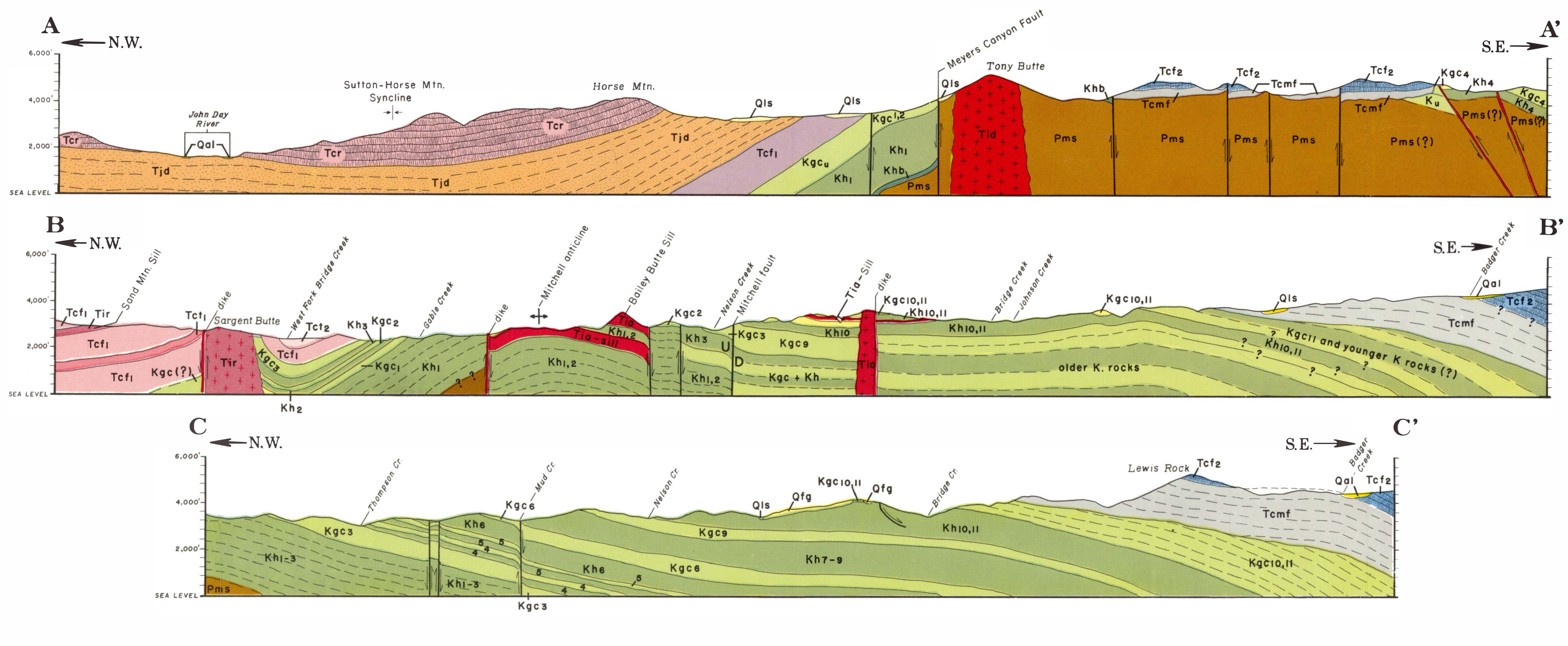
Tib — *Basalt dikes, sills, piston, and irregular intrusions; some with Columbia River basalt lithology, many with Clarno characteristics.*

Tir — *Rhyolite sills, dikes (rare), and irregular intrusions; probably of John Day age.*

Tia — *Andesite and basaltic andesite sills, dikes, piston, and irregular intrusions, probably of Clarno age.*

s — s — s
d — d — d
Tabular intrusions, sills and dikes, of limited outcrop; dikes generally occupy preexisting faults.

Geologic Cross Sections



STRUCTURAL SYMBOLS

Attitudes

Strike and dip of beds

Apparent strike and dip

Folds

Major anticline

Major syncline
(arrows indicate plunge of axis)

Faults

Fault of major displacement

Fault of minor displacement; exposed, inferred, presumably concealed by Quaternary deposits.
(arrows indicate strike-slip movement; U, indicates upthrown block, and D, downthrown block)
(question mark ?, indicates suggested fault by photo-interpretation, but not field verified)

Contacts

Quaternary deposits, concealed

Rock units, exposed and inferred

Cartography by S.R. Renoud
1971