Geologic Reconnaissance of the Antelope-Ashwood Area North-Central Oregon

WITH EMPHASIS ON THE JOHN DAY FORMATION OF LATE OLIGOCENE AND EARLY MIOCENE AGE

GEOLOGICAL SURVEY BULLETIN 1161-D

Prepared in cooperation with the State of Oregon, Department of Geology and Mineral Industries

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By DALLAS L. PECK

CONTRIBUTIONS TO GENERAL GEOLOGY

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By Dallas L. Peck

ABSTRACT

This report briefly describes the geology of an area of about 750 square miles in Jefferson, Wasco, Crook, and Wheeler Counties, Oregon. About 16,000 feet of strata that range in age from pre-Tertiary to Quaternary are exposed. These include the following units: pre-Tertiary slate, graywacke, conglomerate, and meta-andesite; Clarno Formation of Eocene age—lava flows, volcanic breccia, tuff, and tuffaceous mudstone, chiefly of andesitic composition; John Day Formation of late Oligocene and early Miocene age—pyroclastic rocks, flows, and domes, chiefly of rhyolitic composition; Columbia River Basalt of middle Miocene age—thick, columnar jointed flows of very fine grained dense dark-gray basalt; Dalles Formation of Pliocene age—bedded tuffaceous sandstone, siltstone, and conglomerate; basalt of Pliocene or Pleistocene age—lava flows of porous-textured olivine basalt; and Quaternary loess, landslide debris, and alluvium. Unconformities separate pre-Tertiary rocks and Clarno Formation, Clarno and John Day Formations, John Day Formation and Columbia River Basalt, and Columbia River Basalt and Dalles Formation.

The John Day Formation, the only unit studied in detail, consists of about 4,000 feet of tuff, lapilli tuff, strongly to weakly welded rhyolite ash flows, and less abundant trachyandesite flows and rhyolite flows and domes. The formation was divided into nine mappable members in part of the area, primarily on the basis of distinctive ledge-forming welded ash-flow sheets. Most of the sheets are composed of stony rhyolite containing abundant lithophysae and sparse phenocrysts. One sheet contains 10 to 20 percent phenocrysts, mostly cryptoperthitic soda sanidine, but including less abundant quartz, myrmekitic intergrowths of quartz and sanidine, and oligoclase. The rhyolitic ash flows and lava flows were extruded from nearby vents, in contrast to some of the interbedded air-fall tuff and lapilli tuff of dacitic and andesitic composition that may have been derived from vents in an ancestral Cascade Range. The John Day is dated on the basis of a late Oligocene flora near the base of the formation and early Miocene faunas near the top of the formation.

The middle Miocene and older rocks in the Antelope-Ashwood area are broadly folded and broken along northeast-trending faults. Over much of the area the

rocks dip gently eastward from the crest of a major fold and are broken along a series of steeply dipping antithetic strike faults. Pliocene and Quaternary strata appear to be undeformed.

At the Priday agate deposit, chalcedony-filled spherulites (thunder-eggs) occur in the lower part of a weakly welded rhyolitic ash flow. The so-called thunder-eggs are small spheroidal bodies, about 3 inches in average diameter; each consists of a chalcedonic core surrounded by a shell of welded tuff that is altered to radially oriented fibers of cristobalite and alkalic feldspar.

INTRODUCTION

The area of this report covers about 750 square miles of Jefferson, Wasco, Crook, and Wheeler Counties in north-central Oregon (fig. 1). This sparcely populated area contains the small ranch communities of Ashwood and Antelope; the nearest town is Madras, some 20 miles west of Ashwood. A network of gravel and dirt roads covers the area, and U.S. Highway 97 crosses the northwestern part. The area lies at the southern edge of the Columbia Plateau in the foothills of the Ochoco Mountains, at an altitude of 1,600 to 5,500 feet, and forms the drainage divide between the John Day River on the east and the Deschutes and Crooked Rivers on the west and south. The climate is semiarid, and most of the hills are barren except for scattered sagebrush and juniper. Trees and brush line the permanent streams, however, and the higher parts of the country south and east of Ashwood are forested with yellow pine.

A reconnaissance geologic map of the Antelope-Ashwood area was prepared as part of a continuing cooperative program with the Oregon

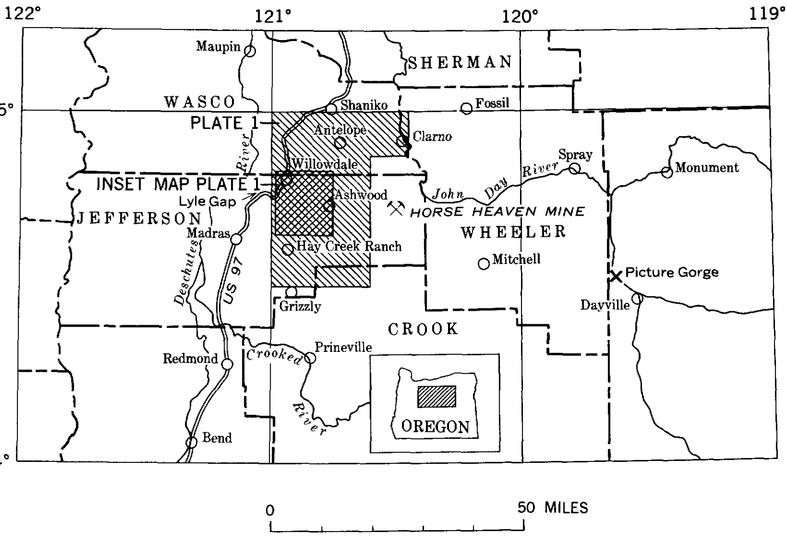

FIGURE 1.—Index map of part of north-central Oregon.

Department of Geology and Mineral Industries to prepare a geologic map of Oregon. Rocks of the John Day Formation, and particularly the welded ash flows, were the only rocks studied in detail. The ash flows are well exposed in the central part of the Antelope-Ashwood area and currently are the subject of widespread interest. The geology was plotted on aerial photographs and on a 1:125,000-scale base map that was enlarged from a part of the Army Map Service Bend Sheet. A total of about 30 days was spent in the field during June, July, and August 1957 and August 1958. Richard Q. Lewis assisted in the mapping in July 1957. Francis G. Wells of the U.S. Geological Survey and Richard L. Hay of the University of California made many helpful suggestions during the course of the investigation. Specimens and information of the Priday agate deposit, supplied by Lynn A. Peck of Seattle Heights, Wash., are gratefully acknowledged. This study greatly depended on the stratigraphic framework provided by Aaron C. Waters, which is based on his years of study of the geology of north-central Oregon.

STRATIGRAPHY

Rocks exposed near Antelope and Ashwood range in age from pre-Tertiary to Quaternary, but most of the area mapped (pl. 1) is underlain by lower and middle Tertiary volcanic rocks of rhyolitic andesitic, and basaltic composition. The stratigraphy of the mapped area is summarized in table 1.

PRE-TERTIARY ROCKS

Slate and less abundant graywacke, chert-granule conglomerate, and meta-andesite underlie the Eocene Clarno Formation southeast of Hay Creek Ranch (pl. 1). The rocks dip mostly 15° to 30° to the southeast and strike N. 30°–60° E. over an outcrop width of 2 miles, suggesting a thickness of more than 5,000 feet. No discordance between cleavage and bedding was observed.

The slate is dark gray, spangled on some cleavage surfaces with fine flakes of mica. Thin interbeds of fine- to medium-grained graywacke, locally cut by thin discontinuous quartz veins, make up less than 10 percent of the unit. Beds of chert-granule conglomerate are rare. An intercalated flow(?) of microporphyritic meta-andesite was noted at the forks of an intermittent stream in sec. 25, T. 11 S., R. 15 E.; the andesite has been altered to an aggregate of oligoclase, a carbonate mineral, clinozoisite, quartz, and sericite.

The age of the pre-Tertiary rocks is unknown. A few small poorly preserved clamlike fossils were collected from thinly interbedded slate and graywacke in sec. 30, T. 11 S., R. 16 E., but are not identifiable (D. L. Jones, oral communication, 1959).

TABLE 1.—*Bedded rocks of the Antelope-Ashwood area, north-central Oregon*

[Thickness: Nd, not determined]

System	Formations and mapped units	Lithology	Thickness (feet)
Pleistocene and Recent	Alluvium	Sand, silt, gravel, and pumice mostly in major stream valleys.	Nd
	Landslide debris	Chiefly blocks of Columbia River Basalt, basalt of Pliocene or Pleistocene age, and tuff of the John Day Formation.	Nd
Pleistocene	Loess	Windblown silt and fine sand capping flat-topped hill north of Trout Creek.	0–50
Pliocene or Pleistocene	Basalt	Flows of diktytaxitic olivine basalt derived from several small shield volcanoes.	0–100
Pliocene	Dalles Formation	Bedded tuffaceous sandstone, siltstone, and conglomerate.	0–800
		Unconformity	
Middle Miocene	Columbia River Basalt	Thick columnar-jointed flows of very fine grained, dense, dark-gray basalt.	0–800+
		Unconformity?	
Late Oligocene and early Miocene	John Day Formation	Tuff, lapilli tuff, strongly to weakly welded rhyolite ash flows, and less abundant lava flows of trachyandesite and rhyolite and domes of rhyolite.	4,000±
		Unconformity	
Eocene	Clarno Formation	Lava flows, volcanic breccia, tuff, and tuffaceous mudstone, mostly of andesitic composition. Thin layers of red saprolite occur within and at top of the formation.	5,800+
		Unconformity	
	Pre-Tertiary rocks	Slate and less abundant graywacke, chert-granule conglomerate, and meta-andesite.	5,000+

CLARNO FORMATION

Volcanic rocks of the Eocene Clarno Formation unconformably overlie the pre-Tertiary rocks southeast of Hay Creek Ranch and crop out over most of the southeastern half of the mapped area. In a well-exposed section south of Ashwood along Trout Creek, the Clarno consists of lava flows and coarse volcanic breccia of porphyritic pyroxene andesite, less abundant tuff and tuffaceous mudstone, and sparse rhyolite. Most of the flows and breccia are altered, displaying a greenish cast on fresh surfaces. There is a thin layer of reddish-brown saprolite at the top of the Clarno, providing a distinctive marker horizon, and layers of saprolite are also locally interbedded in the upper part of the formation. In a few areas, such as sec. 3, T. 12 S., R. 15 E., relatively unaltered columnar-jointed flows of dark-gray porphyritic augite andesite occur at the top of the formation; these were included with the Clarno Formation in the mapping, but further study may show them to be younger. In sec. 21, T. 11 S., R. 16 E., a narrow intracanyon flow of this andesite underlies a welded rhyolite ash flow of the John Day Formation and overlies a lens of cobbly conglomerate; the conglomerate in turn overlies altered andesite of the Clarno Formation.

The Clarno Formation was not studied in any detail during the present investigation but has been described by Waters and others (1951, p. 111–115) from exposures in the nearby Horse Heaven mining district (pl. 1). There the Clarno is more than 5,800 feet thick and is divisible into four mappable units as follows (Waters and others, 1951, p. 112–114):

Unit 1.—A basal unit, 600 feet thick, of platy andesite flows interbedded with layers of varicolored clay.

Unit 2.—An overlying unit, 1,350 feet thick, of tuff, bedded tuffaceous clay, volcanic mudflow deposits, and a few thin lava flows, all of andesitic composition.

Unit 3.—About 1,750 feet of tuffaceous clay containing a few beds of coarse tuff and few andesite flows.

Unit 4.—White tuff, largely rhyolitic in composition, that is at least 2,100 feet thick.

The petrography of the andesite flows and breccia of the Clarno Formation has been described by Calkins (1902, p. 122–141) and by Waters and others (1951, p. 114–115). The flows are chiefly pilotaxitic and hyalopilitic augite andesite containing zoned phenocrysts of plagioclase slightly more sodic than An_{50}. Typically the andesites are altered, with the formation of iddingsite, zeolite, chlorite, carbonate, serpentine, clay minerals, and hematite.

The Clarno Formation has been dated as Eocene on the basis of fossil plants collected east of the Antelope-Ashwood area at localities on Cherry Creek, Current Creek, and near Clarno (Knowlton, 1902, p. 102–103; Arnold, 1952, p. 68–72; Scott, 1954). Vertebrate fossils also have been collected near Clarno in recent years but have not as yet been reported on.

JOHN DAY FORMATION

Unconformably overlying the Clarno Formation is a sequence predominantly of tuff and welded tuff that is assigned to the John Day Formation of late Oligocene and early Miocene age. Exposures of the formation form a band roughly 8 miles wide that extends from Clarno southwestward across the Antelope-Ashwood area (fig. 1 and pl. 1).

The John Day Formation was named and described from exposures along the John Day River between Clarno and Picture Gorge (Marsh, 1875, p. 52; Merriam, 1901a) where it consists of 1,000 to 2,000 feet of richly fossiliferous, varicolored andesitic to rhyolitic tuff and tuffaceous claystone (Merriam, 1901b, p. 291–303; Calkins, 1902, p. 143–

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159). These were mostly deposited as ash falls (Coleman, 1949 [1]; and Hay 1962a; 1963), or as loess derived from a source area of fresh ash falls (Fisher and Wilcox, 1960). West of the John Day River, the formation contains increasingly abundant lapilli tuff, welded tuff, and rhyolitic domes and flows, as noted previously by Waters (1954), and less abundant flows of trachyandesite (Peck, 1961).

In the area between Willowdale and Ashwood (pl. 1), the formation is about 4,000 feet thick. Strongly to weakly welded rhyolitic ash flows make up about one-quarter of the formation and serve as distinctive mapping horizons; they are intercalated with poorly indurated tuff and lapilli tuff—mostly massive ash-fall deposits but including much less abundant bedded water-laid tuff. In the lower part of the formation, local rhyolite flows are derived from a large complex of rhyolite domes. Trachyandesite flows of basaltic appearance occur near the base of the John Day. Although Hodge (1932a) originally assigned the lower and middle parts of these strata to his Clarno Formation, they are assigned to the John Day Formation in this report because they overlie the Clarno unconformably, contain a flora of late Oligocene age at their base (p. 18), and extend eastward into the type John Day Formation.

LITHOLOGY

The John Day Formation has been divided into nine conformable members (columnar section, fig. 2) in the area between Ashwood and Willowdale (pl. 1). As the rocks of these members dip to the west and northwest with few exceptions, progressively younger beds are exposed from east to west. The members are described from oldest to youngest in the following pages.

Member A.—The basal member unconformably overlies the Clarno Formation and consists of a 400-foot sequence of tuff and welded tuff. The sequence is well exposed on the county road 2 miles west of Ashwood. At the base is a strongly welded rhyolite ash-flow sheet, as much as 100 feet thick; it is composed chiefly of light-gray stony rhyolite containing sparse lithophysae but includes a 20-foot-thick vitric layer at the base. The rhyolite contains about 5 percent phenocrysts that average about 1 mm in diameter. Quartz and feldspar are equally abundant; biotite and hornblende are rare. The feldspar is chiefly optically monoclinic soda sanidine ($((-)2V = 42°–48°$; $n_x =$

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[1] Coleman, R. G., 1949, The John Day Formation in the Picture Gorge quadrangle, Oregon: Oregon Coll. Masters thesis.

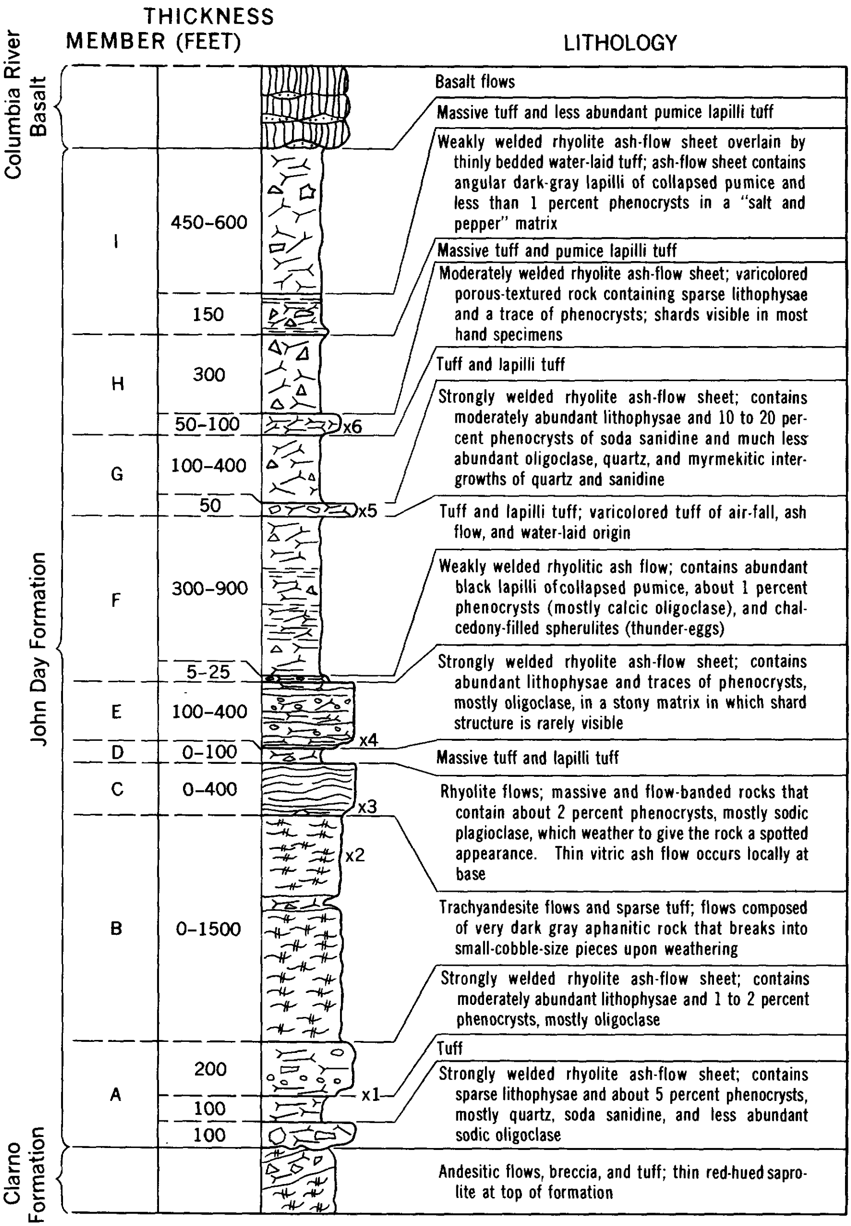

FIGURE 2.—Generalized columnar section of the John Day Formation between Ashwood and Willowdale, north-central Oregon. Crosses indicate stratigraphic position of chemically analyzed samples listed in table 2.

1.524, $n_y=1.528$, $n_z=1.529\pm0.001$[2]) but includes less abundant oligoclase, about An_{15-20} ($n_y=1.542\pm.002$, $(-)2V=65°-70°$). The ash-flow sheet is overlain by about 100 feet of poorly exposed tuff that has yielded fossil leaves of late Oligocene age (p. 18). A strongly welded rhyolite ash-flow sheet, as much as 200 feet thick, overlies the tuff and forms the upper part of member A. It is composed chiefly of light-gray stony rock containing moderately abundant lithophysae and about 2 percent phenocrysts of oligoclase (about An_{20}). A vitric layer as much as 40 feet thick forms the base of the ash-flow sheet. The chemical analysis of a sample (DLP–58–42) of this layer is listed in table 2, column 1.

TABLE 2.—*Chemical analyses and norms of rocks from the John Day Formation near Ashwood, north-central Oregon*

[Analyses and norms (except No. 5) by P. L. D. Elmore, I. H. Barlow, and S. D. Botts, using rapid method. Location shown on pl. 1; stratigraphic position on fig. 2]

Sample	1	2	3	4	5	6
Analyses (weight percent)						
SiO_2	71.8	54.7	71.5	73.8	75.40	72.2
Al_2O_3	13.0	13.2	12.0	11.4	13.56	11.4
Fe_2O_3	1.3	1.7	1.1	1.7	.21	1.4
FeO	.26	11.4	2.3	.85	.61	.66
MgO	.12	1.9	.0	.10	.07	.33
CaO	.87	6.2	1.2	.78	.38	.61
Na_2O	2.3	2.8	3.9	2.2	4.64	2.9
K_2O	5.0	2.0	3.2	4.8	4.40	3.4
H_2O	5.4	2.0	4.1	4.2	1.38	6.0
TiO_2	.16	1.8	.30	.18	.04	.16
P_2O_5	.01	.68	.04	.02	.09	.01
MnO	.03	.28	.16	.05	Trace	.08
CO_2	.05	1.3	.26	.05	(1)	.07
Total	100	100	100	100	100.78	99
Sp gr (powder)	2.26	2.77	2.41	2.34	(1)	2.29
Norms (weight percent) [2]						
Quartz	40	13	35	43	30.69	44
Orthoclase	31	12	20	30	26.30	21
Albite	20	25	35	19	39.57	26
Anorthite	4.4	18	4.4	4.1	1.12	3.3
Corundum	2.3	----------	.6	1.2	.72	2.0
Diopside:						
Wollastonite	----------	.1	----------	----------	----------	----------
Ferrosilite	----------	.1	----------	----------	----------	----------
Hypersthene:						
Enstatite	.3	5.0	----------	.2	.93	.9
Ferrosilite	----------	18	3.2	----------	.10	----------
Magnetite	.5	2.7	1.7	2.2	.23	2.0
Hematite	1.1	----------	----------	.3	----------	.2
Ilmenite	.3	3.7	.6	.5	----------	.3
Apatite	----------	1.8	----------	----------	.34	----------
Normative feldspar (molecular percent)						
Orthoclase	54	22	33	55	38	41
Albite	38	46	60	37	60	53
Anorthite	8	32	7	8	2	6

[1] Not determined.
[2] Calculated to 100 percent on a H_2O-free basis after subtracting normative calcite.

[2] Determined on a spindle stage at known temperature with index oils graduated in 0.002 intervals and checked on a Zeiss refractometer.

DESCRIPTION OF ANALYZED SAMPLES

1. Welded tuff (DLP-58-42; lab. No. 153830); collected from vitric base of ash-flow sheet of member A in sec. 12, T. 10 S., R. 16 E. at 3,350 feet altitude on bank of county road 1.9 miles S. 62° W. of Ashwood. Yellowish gray vitric rock containing 2 percent crystals and crystal fragments (avg. 1 mm in diam) of sodic oligoclase in shards and ash of glass (n=1.50); a small part of the glass is devitrified to cristobalite and feldspar, as shown in the lower X-ray diffraction chart of figure 7.
2. Trachyandesite (DLP-58-41; lab. No. 153829); collected from flow of member B in sec. 10, T. 10 S., R. 16 E. at 3,725 feet altitude on bank of county road 2.6 miles S. 61° W. of Ashwood. Medium-dark-gray aphanitic rock containing laths (avg. 0.05 mm in length) of calcic andesine (An_{40-45}), 36 percent; in pale-brown glass (n=1.51), 37 percent; grains of ferriferous pigeonite ($n_\gamma=1.730\pm0.003$), $2V$ estimated to be 15°-20°), 18 percent; magnetite, 5 percent; and alteration minerals, chiefly a carbonate mineral, 4 percent.
3. Welded tuff (DLP-58-32; lab. No. 153827); collected from vitric ash flow at base of rhyolite flow of member C in sec. 12, T. 10 S., R. 15 E., along north bank of Wilson Creek 200 yards above forks. Grayish-black rock with pitchy luster, contains 2 percent crystals and crystal fragments (avg one-fourth mm in diam) of calcic oligoclase and a trace of clinopyroxene and opaque minerals, in welded shards and ash of glass (n=1.50): the glass is slightly more devitrified to cristobalite and feldspar than sample DLP-58-42, as determined by X-ray diffraction studies.
4. Welded tuff (DLP-58-50; lab. No. 153831); collected from vitric base of ash-flow sheet of member E in sec. 18, T, 8 S., R. 17 E., on bank of county road 2.6 miles S. 25° W. of Antelope. Medium-gray vitric rock containing about one-fourth of 1 percent crystals and crystal fragments of calcic oligoclase and a trace of altered pyroxene and amphibole in welded shards and ash of glass (n=1.50); the glass is partially devitrified to cristobalite and feldspar, as shown in the upper X-ray diffraction chart of figure 7.
5. Rhyolite from near Antelope; collected and analyzed by F. C. Calkins (1902, p. 156). Described as a rhyolite flow rock containing crystals of sanidine, rarely more than 2 mm in diameter, as well as sparce magnetite, zircon, and apatite, in a devitrified groundmass. Judging from Calkins' excellent description, the rock is a welded tuff, very probably from the welded ash-flow sheet of member G.
6. Welded tuff (DLP-58-39A; lab. No. 153828); collected from vitric base of welded ash-flow sheet of member H in sec. 20, T. 9 S., R. 15 E. in roadcut on east side of former U.S. Highway 97, one-half mile south of Pacific States Cut Stone Quarry. Medium-light-gray rock containing a trace of crystals and crystal fragments of sodic plagioclase and quartz in welded shards and ash of pale-brown glass (n=1.50); the glass is slightly less devitrified to cristobalite and feldspar than sample DLP-58-50, as determined by X-ray diffraction studies.

Member B.—A sequence of trachyandesite flows is well exposed on the county road 2½ miles west of Ashwood. The sequence is as much as 1,500 feet thick east of Teller Butte but thins to the north and south and was not recognized in the Antelope Creek drainage in the northern part of the mapped area, nor in the Willow Creek drainage at the southern edge of the area (pl. 1). The flows are composed of very dark gray aphanitic rock containing sparse small vesicles (¼ to 1 inch in diameter) and rare phenocrysts of olivine. The flows break into rounded fist-size pieces upon weathering. Thin lenses of ash-fall tuff locally lie between flows. In the trachyandesite, felted laths of plagioclase that average An_{45} are set in equally abundant pale-brown glass; clinopyroxene (ferriferous pigeonite) and magnetite are less abundant, and olivine is rare. A plug of trachyandesite in sec. 14, T. 11 S., R. 16 E., probably represents the vent from which the flows were extruded. A chemical analysis of the trachyandesite (sample DLP-58-41) is listed in table 2, column 2.

Member C.—Rhyolite flows as much as 400 feet thick and a complex of rhyolite domes are exposed in the basins of Wilson Creek, Pony Creek, and part of Trout Creek. The flows are exposed along Wilson Creek, where they occupy about the same stratigraphic position as the trachyandesite flows of member B that crop out farther east; rhyolite may overlie the latter at a locality along the divide between Wilson and Trout Creeks, but the relationships there are not clear because of poor exposures. Rhyolite in the flows is indistinguishable from that in a large complex of domes that cut the Clarno Formation and the lower part of the John Day, forming a crescentic outcrop 7 to 10 miles in diameter north of Ashwood. Rudely columnar jointed rhyolite of the domes forms cliffs (fig. 3) that rise over 1,000 feet above Trout Creek. Rubbly rhyolite breccia interbedded with tuff at the south margin of the dome complex indicates an exogenous origin, and the lithologic similarity of dome rock and flows suggests that the flows were derived from the domes.

Both domes and flows consist of light-gray to pinkish-gray and red massive rhyolite and flow-banded rhyolite, the latter containing contorted layers of contrasting color ranging from 0.1 to 10 mm in thickness. The rhyolite typically contains about 2 percent phenocrysts as much as 2 mm long. These weather to give the rock a spotted appearance. The phenocrysts consist of sodic plagioclase and traces of altered pyroxene and opaque minerals, and lie in a devitrified groundmass of anhedral quartz and alkalic feldspar. A welded rhyolite ash flow is exposed beneath the rhyolite flow at one locality in Wilson Creek, and the chemical analysis of a sample (DLP–58–32) of this ash flow is listed in table 2, column 3.

Member D.—A layer as much as 100 feet thick of poorly indurated light-gray to yellow tuff and less abundant lapilli tuff overlies both the rhyolite of member C and the trachyandesite flows of member B. In part of the area this layer is mapped separately as member D, but in places it has been grouped with member E.

Member E.—A ledge-forming rhyolite ash-flow sheet, 100 to 400 feet thick, overlies members B, C and D, and is well exposed along the upper course of Pony Creek. The ash-flow sheet is strongly welded and is typically composed of platy layers alternating with thinner massive layers that contain abundant lens-shaped lithophysae. Except for a basal vitric layer, the sheet is composed of light-gray to pale-red stony rock in which shard structure has been largely destroyed by recrystallization and is rarely visible, even with a microscope. Only traces of phenocrysts are present, mostly calcic oligoclase but including less abundant quartz and rare altered pyroxene. The underlying tuff of member D has locally been mapped with member E. The chemical analysis of a sample (DLP–58–50) of the vitric base of the ash flow is listed in table 2, column 4.

Member F.—This member consists of 300 to 900 feet of poorly indurated tuff and lapilli tuff and an underlying weakly welded ash flow that is well exposed at the Priday agate deposit south of Pony Butte, The tuff and lapilli tuff are colored in shades of green, yellow, red,

FIGURE 3.—Rhyolite dome in the lower part of the John Day Formation, exposed along Trout Creek 3 miles north of Ashwood, Oreg.

and gray; they are mostly massive ash-fall deposits, but include some bedded water-laid tuff. The basal ash flow is 5 to 25 feet thick fairly well indurated, and is light gray speckled with abundant chips and blocks of black glass as much as 4 inches in diameter. In the basal 4 to 6 inches of the ash flow, fragments are progressively flattened downward and the rock is moderately to strongly welded. In many localities this basal welded portion is altered to clay and opal, and contains abundant chalcedony-filled spherulites (thunder-eggs) (see

p. 23–25. The angular fragments of glass (n=1.50) in the ash flow are collapsed pumice lapilli in which tubular structures and perlitic cracks are conspicuous. The lapilli lie in a matrix of glass shards and ash that contain a few fragments of hyalopilitic lava and about 1 percent phenocrysts (averaging one-fourth mm in diameter) of calcic oligoclase (An_{25}) and a trace of quartz and altered pyroxene.

Member G.—A basal ledge-forming ash-flow sheet, 50-feet thick, and overlying poorly indurated tuff and lapilli tuff, 100 to 400 feet thick, constitute member G. Good exposures of the basal sheet can be found at the crest of the hogback that extends along the east side of the lower valley of Hay Creek. The sheet is composed of pink to purplish-red and very pale orange stony rock containing moderately abundant lithophysae and 10 to 20 percent phenocrysts. The phenocrysts, which consist of crystals and crystal fragments that average one-half mm in diameter, lie in a finely devitrified matrix derived from glass shards and ash; vitroclastic texture is evident microscopically but not in hand specimens. A chemical analysis of a sample of this ash flow sheet was made by Calkins (1902, p. 156) and is listed in table 2, column 5.

Soda sanidine cryptoperthite forms most of the phenocrysts, but less abundant quartz and rare oligoclase ((–)2V=55° to 60°) are also present. Myrmekitic intergrowths of quartz and sanidine partly rim many sanidine crystals (fig. 4) and occur as separate angular fragments. The sanidine crystals are stubby prisms elongate parallel to the axis. With a very few exceptions the crystals are optically monoclinic, lacking grid twinning and having parallel extinction of the trace of the 010 cleavage on 001 cleavage flakes. Zoning is apparent as a result of variable extinction in crystals cut nearly perpendicular to the acute bisectrix. The optic axial angles of nine sanidine grains, measured conoscopically, range from 39° to 48° and average 43°. n_x=1.524–5, n_y=1.529–30, n_x=1.530–1±0.001 in three grains from one sample.[3] In X-ray diffraction charts that were obtained from sanidine separated from two samples, the $\bar{2}01$ and 111 peaks are compound, indicating a cryptocrystalline nature of the sanidine. Diffraction charts of the same samples after homogenization by heating at 800° C for 6 hours closely resemble Donnay and Donnay's (1952, fig. 3, p. 123) pattern for $Na_{0.61}K_{0.39}AlSi_3O_8$. The position of the $\bar{2}01$ peak (=4.118 and 4.122, measured at one-fourth degree per min), in comparison with Bowen and Tuttle's curve (1950, fig. 2, p. 493), indicates an average composition of $Or_{43}AbAn_{57}$ (molecular percent). The absence of $1\bar{1}1$ and $1\bar{3}0$ peaks strongly suggests monoclinic symmetry.

The ash-flow sheet of member G may be correlative with a thin layer

[3] Determined on a spindle stage of known temperature with index oils graduated in 0.002 intervals and checked on a Zeiss refractometer.

of crystal-rich air-fall tuff in the John Day Formation near Mitchell (east of the map area, see fig. 1), which has been described by Hay (1962b; 1963, p. 205). The air-fall tuff contains abundant crystals of soda sanidine, quartz, and myrmekite. A chemically analyzed sample of the sanidine has the molecular composition $Or_{41}Ab_{56}An_3$, remarkably similar to that of the sanidine of the ash-flow sheet near Willowdale. The sanidine in the air-fall tuff is not cryptoperthitic, in contrast to crystals from the welded ash-flow sheet, but this difference no doubt reflects quicker cooling in the ash fall.

Member H.—A ledge-forming rhyolite ash-flow sheet, 50 to 100 feet thick, and an overlying 300-foot thickness of poorly indurated pumice lapilli tuff and tuff compose member H. The ash-flow sheet is well exposed at the Pacific States Cut Stone Co. quarry, 1½ miles south of Willowdale. This moderately welded sheet is varicolored in shades of red, orange, and gray and contains sparse lithophysae. Shards are visible in most hand specimens. The rocks contain only a trace of phenocrysts of sodic plagioclase and quartz, which lie in a matrix of moderately deformed shards and ash composed of partially devitrified

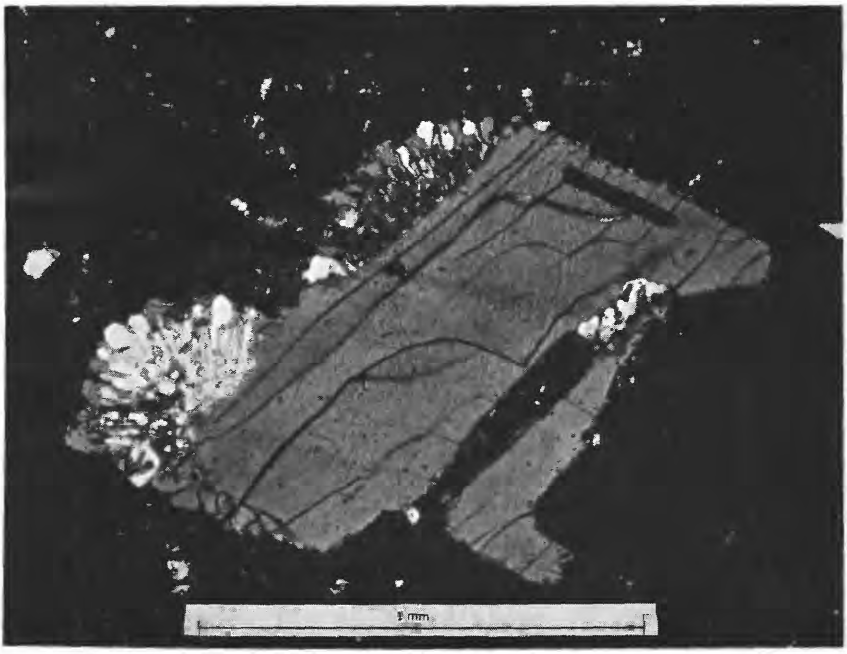

FIGURE 4.—Photomicrograph of a soda sanidine crystal partly rimmed by myrmekitic intergrowths of quartz and sanidine; the crystal is a devitrified rhyolite welded ash-flow sheet of the John Day Formation (member G) near Willowdale, Oreg.

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glass. The chemical analysis of a sample (DLP–58–39A) from the vitric base of the ash-flow sheet is listed in table 2, column 6.

Member I.—The uppermost member of the John Day Formation consists of 600 to 750 feet of tuff, which are well exposed on the west side of the valley south of the confluence of Hay and Trout Creeks. The upper 450 to 600 feet is light-gray and yellowish-gray poorly indurated tuff and lapilli tuff, consisting chiefly of massive air-laid deposits but including less abundant finely bedded and crossbedded water-laid tuff. Vertebrate fossils occur in the tuff at several localities (p. 18). Underlying this is 25 feet of light-gray thinly bedded and cross-bedded water-laid tuff, which in turn overlies a poorly indurated ash-flow sheet, 125 feet thick. The sheet is nonwelded except for a weekly welded 25-foot layer at the base and consists of light-gray lapilli tuff containing abundant dark-gray angular lapilli of collapsed pumice as much as one-half inch in diameter in a "salt and pepper" matrix of glassy shards and ash (glass=1.50). The tuff contains less than 1 percent phenocrysts, mostly oligoclase, and 1 to 2 percent angular fragments of andesite and schist.

WELDED ASH FLOWS

The moderately to strongly welded ash-flow sheets are more resistant to erosion than the poorly indurated tuffs that enclose them; they crop out as ledges or cap hogbacks, and can be easily traced in the sparsely timbered area between Ashwood and Willowdale. Some of the ash-flow sheets may represent only a single ash flow, such as the sheet in the basal part of member F that contains thunder-eggs; others probably contain a number of ash flows and constitute one or more cooling units (as defined by Smith, 1960a, p. 157; 1960b, p. 812).

The welded ash-flow sheets are rudely columnar jointed (fig. 5) and generally are composed of alternating layers containing few and many lithophysae. The lithophysae-rich layers are massive, mostly 1 to 4 feet thick, and contain 10 to 30 percent lens-shaped lithophysae (fig. 6), which generally average 2 to 4 inches in greater diameter. The lithophysae-poor layers average 5 to 10 feet in thickness and are more resistant to erosion; they have a platy structure formed by abundant disc-shaped cavities less than a millimeter in thickness that lie in light-colored discontinuous bands. Both the disc-shaped cavities and lithophysae are lined with euhedral to anhedral crystals of quartz, tridymite, alkalic feldspar, iron-oxide minerals, and, rarely, cristobalite. Probably disc-shaped cavities formed in flattened pumice lapilli by vapor-phase crystallization, as described by Ross and Smith, (1961, p. 27). Possibly each pair of a massive and a platy layer represents a single ash flow. At a locality in the ash-flow sheet of member G (along the Wilson Creek Road in sec. 8, T. 10 S., R. 15 E.), the lithophysal cavities are irregular in shape and size and are concentrated in a pipe, which cuts across the layering of the sheet; the pipe was probably formed by fumerolic action during cooling of the sheet.

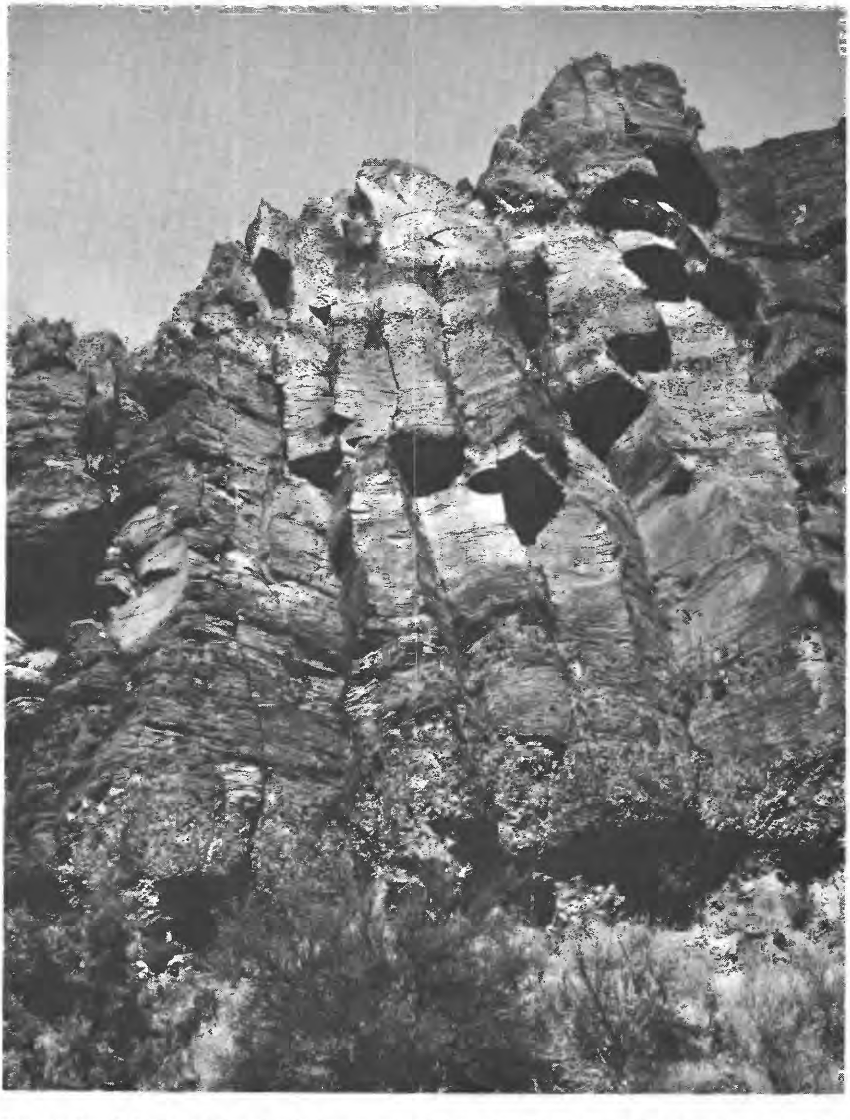

FIGURE 5.—Columnar-jointed ash-flow sheet of the John Day Formation (member E), looking upward at a steep angle. Thin lithophysae-rich layers alternate with thicker platy layers containing few lithophysae. Lowest layer is about 3 feet thick. Photograph taken along Pony Creek, Jefferson County, Oreg.

FIGURE 6.—Lithophysae in a welded ash-flow sheet of the John Day Formation (member E). Near base of photograph is a penny for scale. Photograph taken along Pony Creek, Jefferson County, Oreg.

The middle and upper parts of each sheet consist of stony light-gray to reddish rock that is moderately to strongly welded and is finely devitrified, chiefly to chalcedonic quartz, alkalic feldspar, and tridymite. A marked upward increase in porosity was noted in some sheets, such as the basal one in member A and the ash-flow sheet in member H. In other sheets that may have been emplaced at higher temperatures, notably member E, no such increase was observed, and the top of the sheet is composed of dense stony rock. The vitric-crystal ash-flow sheet of member G, where exposed in sec. 28, T. 9 S., R. 15 E., is composed of two units, each of which becomes more porous upward. Each of these units is layered owing to uneven concentration of lithophysae, and may represent a number of ash flows that cooled as a unit.

At the base of each welded ash-flow sheet is a layer of nonwelded tuff, overlain by gray vitric welded tuff in which deformed shards are discernible with a hand lens. The welded tuff is isotropic and appears little altered in thin section, but X-ray diffractometer studies indicate that it is partially devitrified to cristobalite and alkalic feldspar, as shown in the charts of figure 7. The upper chart was prepared from the most devitrified of the analyzed samples of vitric welded tuff listed in table 2, and the lower chart was prepared from the least devitrified. Chemical analyses (table 2) indicate that the welded tuff is hydrated, containing 4 to 6 percent water.

Phenocrysts constitute from a trace to 20 percent (by volume) of each ash-flow sheet. Soda sanidine, oligoclase, and quartz are most abundant; biotite, hornblende, pyroxene, zircon, and opaque minerals are rare.

Chemical analyses of samples from welded ash-flow sheets (table 2) show that they are rhyolitic in composition and contain an average

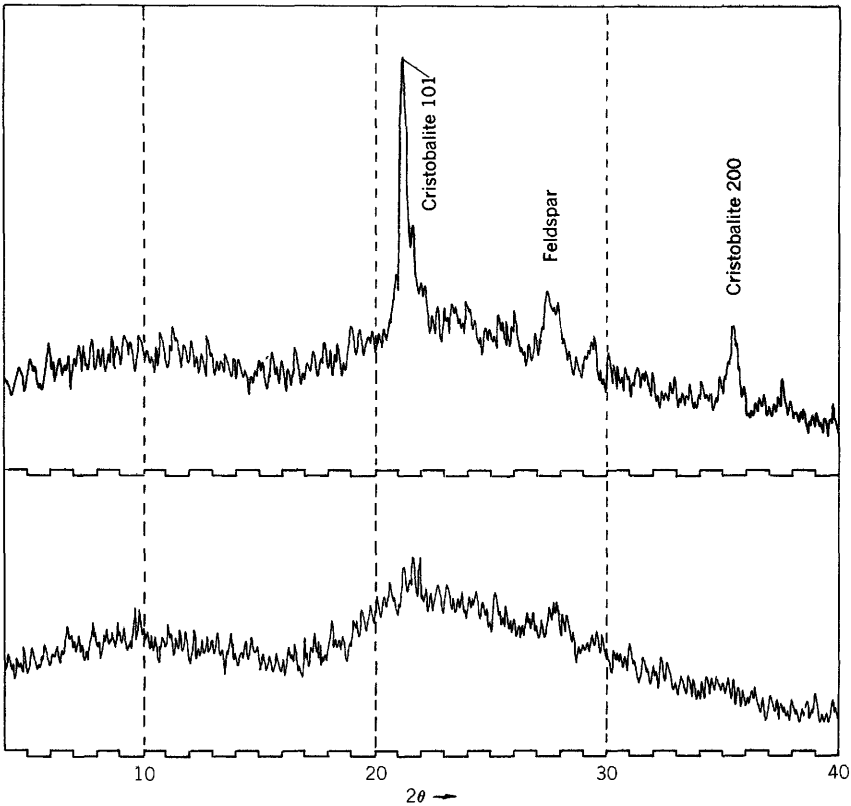

FIGURE 7.—X-ray diffraction charts of hydrated volcanic glass that is partly devitrified to cristobalite and alkalic feldspar. The glass is from the basal parts of two welded ash-flow sheets in the John Day Formation. Upper chart is from sample DLP–58–50, an analysis of which is given in table 2, col. 4; lower chart is from sample DLP–58–42, an analysis of which is given in table 2, col. 1. Charts prepared at 1° per minute and 400 counts per second, using CuKα radiation.

of about 37 percent normative quartz and 57 percent normative feldspar (on a water-free basis) with the average composition $Or_{46}Ab_{50}An_6$.

AGE AND CORRELATION

The John Day Formation in the Antelope-Ashwood area is late Oligocene and early Miocene in age. Fossil plants, collected from member A by Jack A. Wolfe at a locality in sec. 10, T. 10 S., R. 16 E. (pl. 1), are similar to the Bridge Creek and Willamette Junction floras and are of late Oligocene age (J. A. Wolfe, written communication, 1959). They comprise the following species:

Pinus wheeleri Cockerell
Metasequoia occidentalis (Newberry) Chaney
Typha lesquereuxi Cockerell
Alnus "*carpinoides* Lesquereux"
Betula "*heteromorpha* Knowlton"
Carpinus grandis Unger
Ulmus speciosa Newberry
Zelkova oregoniana (Knowlton) Brown
Cercidiphyllum crenatum (Unger) Brown
Platanus aspera Newberry
Crataegus newberryi Cockerell
Acer glabroides Brown
Heterodentaum (Chaney) MacGinitie
Macrophyllum Pursh

Fossil leaves collected from the lower part of the John Day Formation immediately east of the mapped area near Clarno are also assigned to the late Oligocene (J. A. Wolfe, oral communication 1961).

Fossil vertebrates have been collected from the upper member of the John Day Formation in the northern part of the Antelope-Ashwood area and also farther west in the valley of Trout Creek and near the confluence of Trout Creek and the Deschutes River (Hodge, 1932b). The fossils were identified by E. L. Packard, R. A. Stirton, and W. D. Matthew. The approximate position of three localities in the Antelope-Ashwood area (loc. 700, 702, and 709 of Hodge, 1932b, p. 697) are marked on plate 1. As reported by Hodge, the fossils are in part identical to those collected from the John Day at its type locality, fossils that are usually assigned to the early Miocene (Wood and others, 1941); some fossils from west of the map area, however, are of younger early Miocene age.

Volcanic rocks contemporary with those of the John Day Formation are widely exposed on the western slope of the Cascade Range in Oregon (Peck, 1960a, 1960b). They are mostly massive poorly welded ash-flow deposits of dacitic, andesitic, and rhyodacitic pumice lapilli tuff, which were extruded from a belt of vents near the eastern margin of the present Western Cascade Range. The tuffs typically contain about 10 percent phenocrysts of feldspar, chiefly andesine, and less abundant pyroxene and magnetite.

SOURCE OF THE VOLCANIC MATERIAL

Volcanic material in the John Day Formation in the Antelope-Ashwood area includes products of both local and distant volcanism. The rhyolite dome complex and its associated flows were emplaced through vents located a few miles north of Ashwood, and the trachyandesite flows from a vent (pl. 1) 8 miles south of Ashwood. Most of the ash-flow sheets thin northward and northeastward from Ashwood and become less strongly welded, indicating that the ash flows as well as some of the associated tuff and lapilli tuff were derived from vents near Ashwood or to the south or west.

The source of much of the tuff and lapilli tuff in the John Day, however, may well have been some distance from the Antelope-Ashwood area. Calkins (1902), Coleman (1949),[4] Fisher and Wilcox (1960), and Hay (1962a; 1963) have determined that much of the tuff in the John Day Formation in the John Day basin is dacitic or andesitic in composition; phenocrysts are mostly andesine, and quartz is lacking in many tuffs. Sparse data obtained in the present study on ash-fall deposits in the upper part of the formation in the Antelope-Ashwood area agree with the earlier studies. These rocks thus differ in composition from locally derived rhyolitic volcanic rocks but are similar to contemporaneous pyroclastic rocks in the Cascade Range. Furthermore, lapilli tuffs are increasingly abundant from east to west toward the Cascades. A reasonable conclusion is that some of the tuff, lapilli tuff, and tuffaceous claystone in the John Day Formation, both in the Antelope-Ashwood area and along the John Day River, was formed from ash carried eastward in the air from vents in an ancestral Cascade Range, as suggested by Hodge (1932b, p. 701–702), Coleman (op. cit.), and Hay (1962a, 1963).

COLUMBIA RIVER BASALT

Flows of Columbia River Basalt of middle Miocene age, at the southern margin of the Columbia Plateau, cap a prominent south-facing scarp in the northern part of the mapped area (pl. 1), and occur as scattered outliers farther south. The basalt thins southward from a maximum thickness of more than 800 feet as the result of erosion and the lapping out of successively higher flows. The basalt unconformably overlies the John Day Formation in the John Day basin

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[4] Coleman, R. G., 1949, The John Day Formation in the Picture Gorge quadrangle, Oregon: Oregon State Coll. Masters thesis.

(Merriam, 1901b, p. 299). Presumably it is also unconformable in the Antelope-Ashwood area, but widespread landslides at the contact obscure the relations, and the contact was not studied in sufficient detail to confirm an unconformity.

The basalt occurs as thick columnar-jointed flows of dense, fine-grained dark-gray rock. A thin section of a sample from the lower part of the basal flow in Cow Canyon consists of fine-grained hyalo-ophitic basalt containing poorly terminated laths of sodic labradorite (¼ to ½ mm in length), granules and stubby prisms of augite, and scattered granules of magnetite in light-brown glass; the glass is crowded with tiny dendrites of magnetite and crystallites of plagioclase and pyroxene.

The Columbia River Basalt is dated as middle Miocene on the basis of lower Miocene vertebrate fossils from the underlying John Day Formation in the Antelope-Ashwood area and the John Day basin, and middle or upper Miocene vertebrate and plant fossils from the overlying Mascall Formation in the John Day basin (Downs, 1956).

DALLES FORMATION

Bedded tuffaceous strata of the Dalles Formation of Pliocene age unconformably overlie the John Day Formation and Columbia River Basalt west of Hay Creek, at the western edge of the mapped area. There the formation ranges from 0 to about 800 feet in thickness and becomes thicker to the west toward the center of a Pliocene basin near Madras. Equivalent strata near Madras were mapped as the Madras Formation by Hodge (1941).

The Dalles consists chiefly of light-colored, thin- to medium-bedded and crossbedded tuffaceous sandstone and siltstone. Coarse conglomerate containing cobbles and boulders of Columbia River Basalt locally lies near the base of the formation (for example, in the draw north of U.S. Highway 97 and east of Lyle Gap, in sec. 24, T. 14 S., R. 9 E.). Probably most of the formation in the mapped area is fluviatile.

The Dalles Formation is dated as Pliocene on the basis of fossil plants, vertebrates, and diatoms collected near Madras and The Dalles (Chaney, 1944).

BASALT OF PLIOCENE OR PLEISTOCENE AGE

Overlying the Dalles and older formations are flows of olivine basalt of Pliocene or Pleistocene age that were extruded from three small shield volcanoes in the southern part of the Antelope-Ashwood area. The most prominent series of flows forms a sinuous flat-topped ridge 12 miles long that extends northwestward from near Hay Creek

Ranch; the ridge is cut at Lyle Gap by U.S. Highway 97. These flows, which were extruded from a vent 1½ miles south of Teller Butte, first flowed due west 4½ miles, and then turned northward along the former course of Hay Creek. Another series of flows were erupted from a vent in the southwestern corner of the mapped area, 3 miles northwest of Grizzly; they flowed down the broad valley of Willow Creek to the west and northwest, beyond the edge of the map area. The third series of flows cap a small, high plateau 11 miles east of Hay Creek Ranch. Each series of flows is about 100 feet or less in total thickness; the shield volcanoes from which they were extruded are roughly half a mile in diameter and rise 200 feet above the surrounding lava plain. A small cinder core, shown on plate 1, is located in T. 12 S., R. 15 E., 1 mile southeast of a basalt shield volcano.

The flows are mostly 10 to 30 feet thick, rudely columnar jointed, and have little associated breccia or intercalated tuff and ancient soil. The upper part of the flows are highly vesicular and have a ropy filamented surface coated with iron oxides. The vesicles are small (about one-half inch in diameter), round to elliptical, and have smooth surfaces that are free from coatings for the most part, although some are coated with clay, calcite, and cristobalite. Some of the lava flowed through tubes below the chilled surface of the lava; a filled tube about 5 feet in diameter is marked by a circular vesicular zone near the base of a 20-foot flow at Lyle Gap. The characteristics of the flows compare closely with those of highly fluid pahoehoe described by Wentworth and Macdonald (1953, p. 33–57).

The basalt is medium dark gray, fine grained, and has a porous appearance due to the abundance of minute voids. A network of laths of sodic labradorite about one-half mm long forms about 50 percent of the rock; prisms and granules of augite lie between and partly enclose the laths, making up another 30 percent; brown glass with crystallites totals 10 percent; blades of ilmenite and less abundant grains of magnetite total 5 percent, and subhedral grains of olivine make up the remaining 5 percent. An additional 10 to 20 percent of the rock consists of angular diktytaxitic voids that average three-fourths mm in diameter.

The precise age of the flows is not known. As they overlie the Pliocene Dalles Formation, they must be Pliocene or Quaternary in age. The preservation of the small shield volcanoes suggests a youthful age; since their formation, however, Hay Creek has cut a valley 800 feet deep and has severed the connection between the Hay Creek flows and their vent. On this basis the flows appear to be late Pliocene or early Pleistocene in age.

QUATERNARY LOESS, LANDSLIDE DEBRIS, AND ALLUVIUM

Massive deposits of pale-brown silt and fine sand, as much as 50 feet thick, cap a flat-topped ridge 7 miles north of Ashwood, and thinner unmapped deposits locally overlie Columbia River Basalt near the north edge of the Antelope-Ashwood area. The deposits resemble loess of the Pleistocene Palouse Formation, which is widely distributed in the Columbia Basin to the north, and they are presumed to be of the same age and origin.

Landslides are widespread in the Antelope-Ashwood area, but only a few of them are shown on the reconnaissance geologic map (pl. 1). Many slides have taken place where poorly indurated tuff or sedimentary rocks of the John Day and Dalles formations are capped by resistant layers of dense, competent rock, such as Columbia River Basalt, basalt of Pliocene or Pleistocene age, or welded ash-flow sheets of the John Day. Small slides have occurred also on the clayey saprolite at the base of the John Day. Slides are particularly widespread where the strata dip approximately parallel to the ground surface, as on the hillside west of Clarno.

Alluvial deposits of sand, silt, gravel, and pumice form the floors of some of the stream valleys; alluvium was mapped along the John Day River, Hay Creek, and Trout Creek, but smaller unmapped areas are present along other streams. Stream valleys are wide and alluvial deposits widespread where the streams are eroded in poorly indurated tuff and sedimentary rocks of the John Day and Dalles Formations; the streams have steep-walled canyons with narrow bottoms in more resistant rocks, such as the rhyolite dome complex and welded ash-flow sheets of the John Day.

INTRUSIVE ROCKS

Small plugs and dikes of biotite rhyolite intrude rocks of the Clarno Formation near Ashwood and southeast of Hay Creek Ranch (pl. 1). In the Horse Heaven mining district, Waters and others (1951) have mapped other rhyolite plugs and dikes, as well as plugs of hornblende andesite, augite andesite, and augite-hypersthene andesite. The rhyolite plugs probably are of late Oligocene or early Miocene age and may represent feeders of some of the ash flows in the John Day Formation.

A small elongate plug of trachyandesite intrudes tuff of member A of the John Day Formation 7 miles east of Hay Creek Ranch. Undoubtedly this plug fills the vent that fed at least some of the lithologically similar flows in the lower part of the John Day Formation; hence, the plug is of late Oligocene or early Miocene age.

STRUCTURE

The lower and middle Tertiary rocks of the Antelope-Ashwood area are gently folded and broken along faults that in general trend northeastward.

Two broad poorly defined major anticlines cross the area; one extends diagonally northeastward from the exposed pre-Tertiary rocks near Hay Creek Ranch to the ridge crest west of Clarno, and the other, which is not shown on the geologic map, trends almost due east across the north edge of the area. In general the beds dip 10° or less on the flanks of these major folds, but they dip more steeply, averaging 15° to 25°, in a belt extending north-northeastward along the east side of lower Hay and Trout Creeks. The beds dip as steeply as 75° on the west side of the area of exposed pre-Tertiary rocks near Hay Creek Ranch. Dips are reversed across several minor folds, most of which also trend northeastward.

The rocks on the western limb of the major northeastward-trending anticline are broken along a series of faults, most of which trend northeastward. The faults dip steeply westward, and the west side of most faults has been displaced upward relative to the east side—antithetic to the displacement by folding. A particularly well marked line of faults lies about 1 mile west of the Priday agate deposit (pl. 1). Near the deposit, beds of the John Day Formation west of the fault are displaced upward relative to those to the east (section A–A, pl. 1), with a maximum throw of about 1,000 feet. Farther north, Columbia River Basalt and beds of the John Day Formation that lie west of the fault are displaced downward relative to those to the east; on the canyon wall north of Trout Creek, most of member F and all of members G, H, and I are cut out along the fault, indicating a stratigraphic throw of about 1,500 feet.

Beds of the Dalles Formation and younger rocks do not appear to be folded or faulted in the mapped area. The latest recorded deformation in the Antelope-Ashwood area thus took place during the late Miocene.

PRIDAY AGATE DEPOSIT

The Priday agate deposit, located south of Pony Butte in sec. 35, T. 9 S., R. 15 E. (inset map, pl. 1), has yielded thousands of chalcedony-filled spherulites (thunder-eggs). The deposit is about 10 miles from Ashwood and 6 miles from U.S. Highway 97 on a county road that is only partly graveled. Most of the spherulites are taken from a layer that is 10 to 20 feet below the ground surface; the layer is exposed in an open pit by bulldozing and blasting, and the spherulites dug by hand.

The spherulites are chiefly in the lower few feet of a weekly welded rhyolitic ash flow (fig. 8) at the base of member F of the John Day Formation, but some are in pumice lapilli higher in the ash flow and in the upper few inches of the underlying stony ash-flow sheet (number E). The weakly welded ash flow (described on p. 10), which is 10 to 20 feet thick at the deposit, is composed of black perlitic angular lapilli of collapsed pumice in a matrix of shards and ash. Locally the basal part of the ash flow is altered to clay and to less abundant opal. Chalcedony-filled spherulites are widely distributed at this horizon; formerly they were recovered in large numbers from a locality about 1 mile northeast of the present Priday deposit.

The Priday deposit is on a low mesa supported by the resistant ash-flow sheet of member E and is surrounded by the underlying tuffs of member D (inset map, pl. 1). The spherulite horizon is preserved in a northward trending graben in which the Priday ash flow has been downdropped about 100 feet. The fault bounding the west side of the graben is exposed about 100 feet (in 1958) west of the pit, where it trends N. 10° E. and dips 80° E. West of this fault the Priday ash flow with its enclosed spherulites has been uplifted and eroded.

FIGURE 8.—Spherulite-bearing ash flow at the base of member F of the John Day Formation, exposed in the open pit of the Priday agate deposit. Chalcedony-filled spherulites (thunder-eggs) occur near the base of the ash flow. The excavation in shadow near the bottom of the photograph was dug in recovering the spherulites.

The thunder-eggs from the Priday deposit and other localities in Oregon and Idaho have been described in detail and illustrated by Dake (1938), Ross (1941), Renton (1951) and Brown (1957), so that a brief description will suffice here. They are small spheroidal bodies, about 3 inches in average diameter, and have a cauliflowerlike surface crossed by low ridges. Most consist of an outer shell of pale-brown aphanitic rock and a core of white to bluish-gray chalcedony. The outer shell of each thunder-egg is composed chiefly of shards, fine ash, and collapsed pumice lapilli, all of which are altered to radially oriented sheaves of fibrous cristobalite and alkalic feldspar. The chalcedonic cores commonly contain concentric and planar bands and dendritic mineral growths and range in shape from round and highly irregular forms to geometrically regular pyritohedrons and cubes, each face of which is an inward-pointing pyramid (Ross, 1941, pl. 2, fig. d; Brown, 1957, pl. 3, fig. 3). These appear as squares and stars in section.

A reasonable explanation of the origin of the thunder-eggs has been advanced by Ross (1941, p. 732). He concluded that spherulites formed during cooling of the ash flow and were disrupted by the pressure of volatiles exsolved from the ash; the resultant cavities were later filled by chalcedony during alteration of the enclosing ash flow.

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