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CENOZOIC ASH-FLOW TUFFS OF OREGON*

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ABSTRACT

Periodic violent eruptions from many different centers during Cenozoic time deposited vast quantities of pyroclastic material as ash-flow tuffs over most of Oregon, although the Coast Ranges and isolated patches elsewhere in the state appear to have been spared these recurring inundations. Eruptions occurred at different times throughout the Cenozoic, and for purposes of description, they can be separated into three age groups: an older one of Eocene, Oligocene, and Miocene age, an intermediate one of early and middle Pliocene age, and a young group of late Pliocene, Pleistocene, and Holocene age.

Some of these ash-flow tuffs are of small volume, less than a cubic mile, and are related to fissure vents, small domal complexes, or calderas from which several kinds of volcanic products were erupted. A few cover thousands of square miles, have volumes of tens of cubic miles, and apparently are related to a large-scale basinal collapse structure and associated calderas.

Most ash-flow tuffs are rhyolite or dacite; a few are peralkaline soda rhyolite. Older ash-flow tuffs are commonly diagenetically altered to a variety of secondary minerals; of the younger tuffs, only those that erupted into shallow lakes exhibit comparable alteration.

Introduction

Periodic violent eruptions during nearly all of Cenozoic time deposited vast quantities of silicic pyroclastic material over nearly all of Oregon, although the Coast Ranges and some small, isolated patches in other parts of the State do not appear to have been inundated. Much of this pyroclastic material was erupted high into the air, where it cooled, fell, and was incorporated as volcanic ash or pumice and crystal fragments in tuffs and tuffaceous sediments. A large part of this material, however, was erupted as hot, high-density suspensions of pyroclastic material in volcanic gas. These suspensions retained much of their inherent volcanic heat as they flowed as turbulent mixtures down broad slopes of volcanic cones, and laterally from large craters

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or calderas over vast, nearly flat areas. At times they devastated thousands of square miles in a matter of a few hours or a few days. Some of these flow mixtures filled valleys locally to considerable depth, whereas others spread out as very thin (less than 10 feet thick) sheets over peneplained surfaces. The turbulent, hot mixture of gas and pyroclastic material has been variously labelled nuée ardente, tuff flow, incandescent tuff flow, glowing avalanche, and ash flow, to mention a few names, and the material deposited from the mixture labelled as ignimbrite, eutaxite, or ash-flow tuff. Following the usage of Ross and Smith (1961), most geologists in the United States now refer to these incandescent mixtures of gas and pyroclastic material as ash flows and the deposits as ash-flow tuffs, and they will be so termed here.

After emplacement, the ash-flow tuffs were modified by several processes, including compaction and welding of the still hot and plastic pyroclastic material to form welded or sintered tuffs, by secondary flowage to form laminated rock similar in some ways to flow-banded rhyolite, by crystallization of the glassy constituents, and by several kinds of alteration.

Manifestations of this type of volcanic activity are well preserved in the Cenozoic stratigraphic record of Oregon and, although structural complications, erosion, and deep burial of the older ash-flow tuffs hinder comprehensive studies of some of them, several of the younger ash-flow tuffs are well exposed over very large areas, and they afford an excellent opportunity for investigation.

Some of the data obtained over the past few decades on distribution, age, and character of Oregon ash-flow tuffs are summarized in this paper. For those interested in more detailed information on the development of ash-flow tuff terminology, postulated mechanisms of flowage and emplacement, and detailed characteristics of these volcanic products as they occur in Oregon and in other parts of the world, reference should be made to the excellent and comprehensive summaries by Smith (1960a, 1960b) and Ross and Smith (1961).

Historically, these extensive ash-flow tuff sheets in Oregon, as well as elsewhere, were interpreted as rhyolite or dacite with unusual textures that originated from fissures now concealed, inasmuch as centers of eruption seemed to be lacking and the individual flow units covered areas of such immense size. The presence of these extensive sheets of rhyolitic rock in different parts of Oregon was recognized for many years, but the fact that most, though by no means all, of these sheets are deposits from Tertiary and early Quaternary ash flows has been established only within the past few decades, and the origin of a few small rhyolitic sheets is still in doubt.

As early as 1882, Russell (1884, p. 437) recognized the volcanic character and rhyolitic composition of some of these layered rocks. Diller (in Diller and Patton, 1902) identified a distinctive ash-flow deposit (the Quaternary Wineglass Welded Tuff of Williams, 1942) on the northeast wall of Crater Lake caldera as a tuffaceous dacite that appeared to him to be transitional between a flow and a tuff. An early description of the Pliocene Rattlesnake Formation of central Oregon by Merriam, Stock, and Moody (1925, p. 54) indicates that the formation contains a widespread, massive rhyolite flow with tuffaceous phases. Fuller (1931), in discussing the geology of the Steens Mountain area, describes rocks occurring stratigraphically above the Steens Basalt as "acidic lavas" and as well-indurated stratified tuffs, some of which are "... remarkably high in lithophysae and in irregular gas cavities." He (Fuller, 1935) recognized flow features in some tuffs in southeast Oregon and also that parts of these rocks were compacted and vitreous through collapse of pumice fragments. Wells and Waters (1934) identified a glassy dacite tuff south of Cottage Grove that appeared to them to be about the same stratigraphic horizon as

"... a single flow of glassy dacite (vitrophyre)...." a few miles away. Moore (1937, p. 3) indicates that the Pliocene Rattlesnake Formation contains a "pumiceous rhyolite flow," now recognized as a welded tuff.

The foregoing brief descriptions of rhyolitic volcanic rocks exposed in different parts of Oregon include data on texture, structure, and induration indicating close resemblance to both flows and pyroclastic materials. These features were first attributed to the eruption and welding of pyroclastic materials in Oregon ash-flow tuffs by Ross (1941), who considered that a tuff in the John Day Formation, of middle Oligocene to early Miocene age, resulted from complete welding of a glassy, hot, and plastic air-fall ash. Shortly thereafter, Williams (1942) described in considerable detail the development of Crater Lake caldera and the ash-flow tuffs related to this spectacular volcanic center. Allen and Nichols (1945) recognized welded tuff south of Cottage Grove in the Calapooya Formation of Eocene age, during a study of high-alumina clays near Hobart Butte. Several years later, the "rhyolite" of the Rattlesnake Formation was identified as an ignimbrite or welded tuff by Wilkinson (1950), and welded tuffs in eastern Jefferson County, near the Horse Heaven mercury mine, were attributed by Waters and others (1951) to nuées ardentes or glowing avalanches. Since then, welded tuffs or ash-flow tuffs have been reported from many different localities in Oregon (Hausen, 1954; Dole and Corcoran, 1954; Williams, 1957; Lund, 1962, 1966; Hay, 1963; Bowen, Gray, and Gregory, 1963; Dickinson and Vigrass, 1965; Peck, 1964; Peck and others, 1964; Prostka, 1962, 1967; Haddock, 1965; Hampton, 1964; Fisher, 1966; Walker and Repenning, 1965, 1966; Walker, Peterson, and Greene, 1967; Swanson, 1969), although locations of the eruptive centers for many of these sheets are still in considerable doubt.

Age and Distribution

Within the vast region of Cenozoic volcanic rocks that extends essentially from the Willamette Valley to the eastern border of Oregon, ash-flow tuffs have been identified in nearly all parts of the stratigraphic column, the oldest of Eocene or early Oligocene age and the youngest of Holocene age. For purposes of this report these tuffs have been separated arbitrarily into three age groups: an older one that includes Eocene, Oligocene, and Miocene ash-flow tuffs, an intermediate group of early and middle Pliocene age, and a younger group of late Pliocene, Pleistocene, and Holocene age. Outlines of the areas underlain by ash-flow tuffs of these different age groups are shown in figures 1, 2, and 3; the boundaries of these areas are only approximate because of inadequate data on the extent of some ash-flow tuffs beneath younger volcanic and sedimentary cover and because the continuity of some units has been destroyed by structural deformation and erosion. Lack of continuity is particularly evident in the older group of ash-flow tuffs shown on figure 1.

Eocene-Oligocene-Miocene ash-flow tuffs

Some of the older stratigraphic units that contain ash-flow tuffs are the Clarno Formation (Swanson, 1969) of Eocene and early Oligocene age, the middle Oligocene to early Miocene John Day Formation of central and eastern Oregon (Coleman, 1949; Waters, 1954, 1966; Hay, 1963; Peck, 1964; Fisher, 1966; Brown and Thayer, 1966; Walker, Peterson, and Greene, 1967; Swanson, 1969; Swanson and Robinson, 1969), and the Oligocene and early Miocene Little Butte Volcanic Series (Peck and others, 1964; Hausen, 1954) of the western Cascade Range. The Dooley
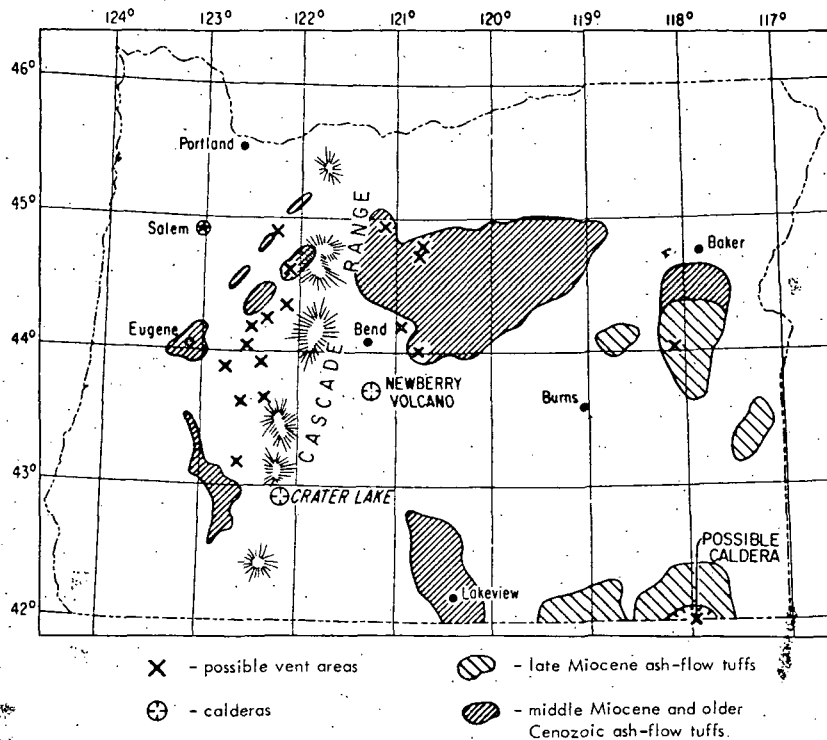
Figure 1. Approximate outcrop areas of Miocene and older Cenozoic
ash-flow tuffs in Oregon.

Figure 2. Approximate outcrop area of early and middle Pliocene
ash-flow tuffs in Oregon. X's denote possible vent areas.
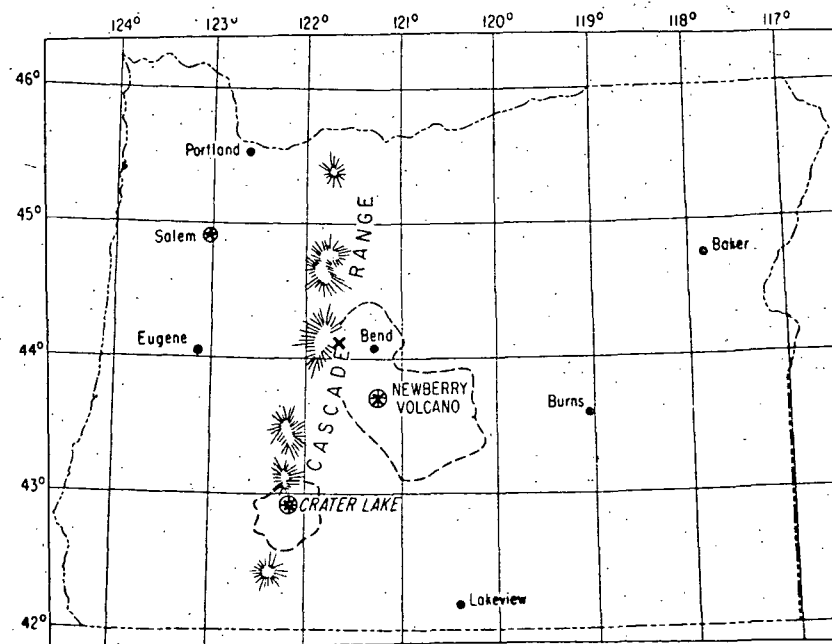
Figure 3. Approximate outcrop areas of late Pliocene, Pleistocene,
and Holocene ash-flow tuffs in Oregon. X's denote vent
areas.

Rhyolite Breccia of Miocene(?) age (Gilluly, 1937), in the area south of Baker,
contains ash-flow tuffs as do units of about the same age near Ironside Mountain in
east-central Oregon and in several areas near Lakeview. Somewhat younger Miocene
ash-flow tuffs are present in several parts of east-central and southeast Oregon: in-
cluded are the Dinner Creek Welded Ash-flow Tuff (Haddock, 1965; Kittleman and
others, 1965); Leslie Gulch Ash-flow Tuff Member of the Sucker Creek Formation
(Kittleman and others, 1965); ash-flow tuffs in the Strawberry Volcanics (Thayer,
1957); and several unnamed units in the Trout Creek Mountains (southern Harney
and Malheur Counties) and in areas westward to Guano Valley along the southeast
border of the State (fig. 1).

Early to middle Pliocene ash-flow tuffs

        Early and middle Pliocene ash-flow tuffs (fig. 2) are almost continuously ex-
posed in the area of Harney Basin and are represented by very extensive but scattered
outcrops in areas to the north in Paulina Basin, in John Day, Bear, and Burnt River
Valleys, and in parts of the Powder River drainage basin east of Baker. Scattered
outcrops of Pliocene ash-flow tuffs also are present near Durkee (Prostka, 1967), in
areas northwest of Westfall (northern Malheur County), Juntura Basin (Bowen, Gray,
and Gregory, 1963), near Crowley (west-central Malheur County), south of Frenchglen,
on the back (west) slope of Steens Mountain, and in areas southwest of Harney Basin
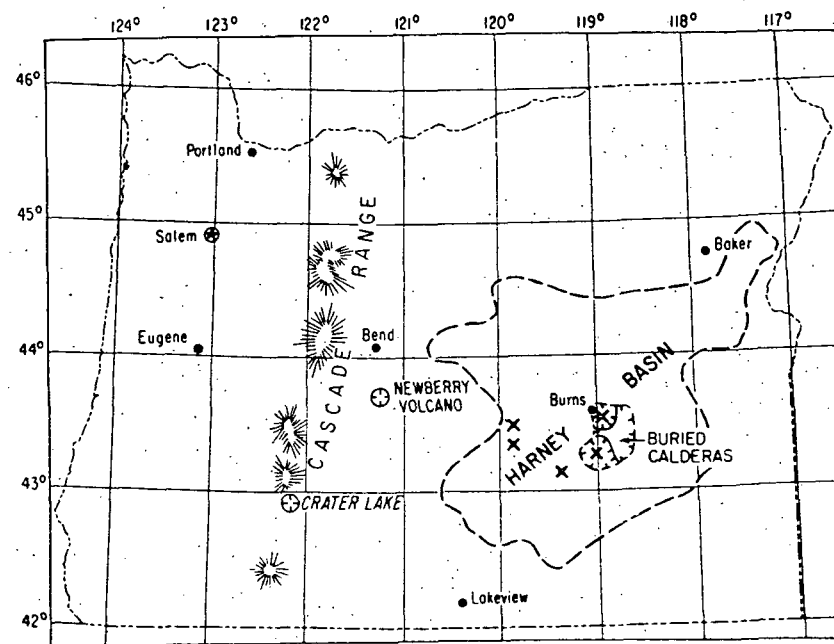
near Poker Jim Ridge, Abert Rim, and Summer Lake Valley.

Several of the ash-flow tuffs are thickest and most continuous in the Harney Basin, particularly the three units beautifully exposed in stream and road cuts along U.S. Highway 395 from about 3 miles to 20 miles north of Burns. They represent parts of what was originally mapped as Danforth Formation by Piper, Robinson, and Park (1939), who regarded the upper part of the pumiceous ash-flow tuff highest in this section and exposed closest to Burns as a tuff breccia member. This highest unit has been briefly described by Lund (1962; 1966) and its possible correlation with other ash-flow tuffs to the north by Campbell and others (1958). The thin distal ends of some of these units that are more extensively exposed in Harney Basin are recognizable many tens of miles to the northwest, north, and northeast of Burns where they can be traced into units of ash-flow tuff originally included in the Rattlesnake Formation, the marginal facies of the Columbia River Group, and the Strawberry Volcanics of Brown and Thayer (1966), the Drewsey Formation of Bowen, Gray, and Gregory (1963), and possibly the Wildcat Creek Welded Ash-flow Tuff of Kittleman and others (1965).

Late Pliocene-Pleistocene-Holocene ash-flow tuffs

A comparatively small volume of ash-flow tuffs of either late Pliocene or Quaternary age is present in two separate areas in and just east of the Cascade Range (figure 3). A widespread, thin ash-flow tuff of late Pliocene or Pleistocene age was erupted "... from a parasitic vent high on the northeast flank of the Broken Top volcano" (Williams, 1957); it is exposed in several parts of the Deschutes River drainage north of Bend. Pumiceous ash-flow tuffs, considered by Williams (1957) to be of Holocene age, also are exposed in canyon walls of the Deschutes River and Tumalo Creek a few miles north of Bend. Many small-volume ash flows of late Pleistocene or Holocene age were erupted from the caldera now occupied by Crater Lake. Some of the more extensive ones are found in the canyons of Rogue River, Annie, Sand, and Sun Creeks, on the margins of Klamath Marsh, and in Pumice Desert. Except for the Wineglass Welded Tuff on the northeast wall of the caldera, most of the ash-flow deposits are either unwelded or show evidence of only slight compaction and welding. Young ash-flow tuffs also have been recognized in the east wall of Newberry Caldera (Higgins and Waters, 1967) and in several areas on the eastern margins of Newberry Volcano; presumably all of these are Pleistocene or Holocene in age. A thin, pumiceous ash-flow tuff that crops out extensively west of Hampton Butte (Walker, Peterson, and Greene, 1967), along the Crook-Deschutes County line has been dated at 3.6 million years (late Pliocene)* (R. F. Marvin, written communication, 1965).

Volume

Although the aggregate volume of ash-flow tuffs in Oregon is prodigious, the volume of most individual tuffs appears to be small to moderate, commonly on the order of a few cubic miles or less, although a few contain about 10 cubic miles; at least two that cover several thousand square miles in southeast Oregon are of considerably larger magnitude. Insofar as volumes of ash-flow units have been studied, those of Eocene-Oligocene-Miocene age appear to be small to moderate;

* Analysts: R. F. Marvin, H. H. Mehnert, J. Obradovich, W. M. Mountjoy, U.S. Geological Survey, Denver, Colorado.

several of those of Pliocene age are large; and those of Pleistocene-Holocene age are very small.

From distribution and thickness data presented by Fisher (1966) and Swanson and Robinson (1968), several of the largest individual ash-flow tuffs of the middle Oligocene to early Miocene John Day Formation total perhaps slightly more than 10 cubic miles (≈ 40 km^3) in volume. The volume of Miocene ash-flow tuffs on the Oregon-Nevada border, in the Trout Creek and Pueblo Mountains area, is unknown but it probably is greater than 10 cubic miles. Most of this pyroclastic material occurs south of the state line in Humboldt County; the volume in Oregon probably totals less than 4 cubic miles. Haddock (1965; 1967) describes a late Miocene ash-flow tuff having a volume of more than 10 cubic miles in the northwestern part of Malheur County. Most of the Miocene and older ash-flow tuffs in the Lakeview area (Lake County) and in the Sucker Creek area (Malheur County) appear to be of small volume, and several near Lakeview appear to be small, linear bodies that filled valleys to a depth of about 50 feet.

Ash-flow tuffs of very large volume -- on the order of 40 to 50 cubic miles (≈ 150 to 200 km^3) or more -- are known to occur in Oregon only in and adjacent to Harney Basin. A pumiceous ash-flow tuff of middle Pliocene age -- that includes the tuff-breccia member of the Danforth Formation of Piper, Robinson, and Park (1939) -- covers more than 4000 square miles mostly northwest, west, and southwest of central Harney Basin and has an average thickness estimated at about 60 feet, giving a total volume in excess of 45 cubic miles. An older, early Pliocene, crystal-rich ash-flow tuff covers more than 7000 square miles to an average depth of about 35 feet, mostly south, north, and east of the central part of Harney Basin; the total volume is probably in excess of 45 cubic miles. A Pliocene ash-flow tuff of soda rhyolitic composition that covers about 20 square miles on the south slope of Wagontire Mountain contains only a fraction of a cubic mile (less than 1 km^3) and appears to be related to local vents (Walker and Swanson, 1968).

The total volume of young ash-flow -- or glowing avalanche -- deposits that emerged from the caldera now occupied by Crater Lake is in the range of 6 to 8 cubic miles (Williams and Goles, 1968, p. 40), although individual flows represent only a small fraction of this figure. Likewise, individual ash flows associated with Newberry caldera appear to be of comparable small volume.

Data on distribution, continuity, and thickness of most other ash-flow tuffs in Oregon are far too sketchy for volume estimates.

General Features of Ash-flow Tuffs of Oregon

The emplacement of hot particulate mixtures composed of different amounts of frothed and fragmented volcanic glass, crystals and crystal fragments, rock particles, and gas on either flat or irregular eroded surfaces has produced ash-flow tuffs of extremely diverse character. Some of the resultant ash-flow tuffs show evidence of having formed from a single outburst of pyroclastic material and are composed of a single more-or-less uniform tapering sheet, generally referred to as a single flow unit. In contrast, others are characterized by horizontal partings, thin interbeds of airfall tuff, or other evidence of having formed from successive outbursts that, in places, built up sequences several hundred feet thick; these are commonly referred to as compound or composite ash-flow tuff sheets. Both single and composite units have been recognized in Oregon, although single units seem to be more abundant.

A few of the ash flows seem to have been little modified after their

Figure 4. Typical outcrops of Pliocene ash-flow tuff that overlie light-colored, vertebrate-bearing late Miocene (Barstovian) tuffaceous sedimentary beds on south margin of Harney Basin, Harney County. The ash-flow tuff is part of a large-volume, crystal-rich, single cooling unit that forms many upland surfaces in the Harney Basin.
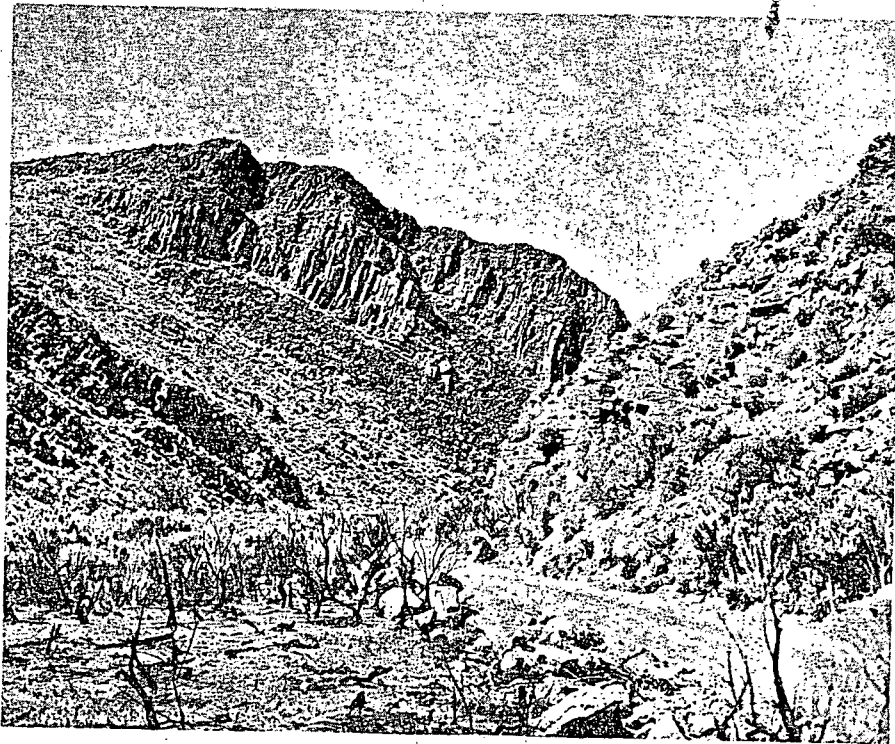

Figure 5. Well-columned late Miocene ash-flow tuff on lower Trout Creek, north base of Trout Creek Mountains, Harney County. In this area, ash-flow tuff occurs in tilted fault blocks.

emplacement. They are thick (commonly tens of feet), nonbedded, poorly indurated units, most of which are poorly sorted and consist of small to moderate amounts of pumice fragments, up to 15 or 20 cm. in size, in a matrix of vitric dust and glass shards. Rock fragments and crystals rarely total more than a few percent. Because these poorly indurated ash-flow tuffs are subject to erosion, they are characterized by gentle slopes and are commonly recognizable only where stream banks or road cuts expose them. Hence their distribution, thickness, and lithologic features are not well known in Oregon or elsewhere.

Because of the inherent heat and gas, most ash flows have been slightly to greatly modified during and shortly after emplacement. Most changes resulted from compaction and partial or complete welding of the plastic glassy fragments and crystallization of the glass to form less porous and more coherent rock. The more resistant parts of ash-flow tuffs commonly form prominent ledges (figures 4 and 5) and, in eastern Oregon, some rim rocks; it is mainly these resistant zones that have been recognized and mapped.

Typically, welded ash-flow tuffs are characterized by lithologically distinct zones that result partly from different degrees of welding during cooling and partly from crystallization of the glassy constituents. Essentially all of the varied characteristics of individual zones described by Smith (1960b) have been recognized in ash-flow tuffs of Oregon; only a very brief summary of these features is presented here, primarily in diagramatic form (figure 6). Individual zones (figures 7 and 8) are nearly always gradational into adjoining zones, although the gradation commonly occurs over a short distance, in places through a few centimeters. The zones vary considerably in thickness within individual flows and from one flow to another. In some ash flows, particularly ones less than 20 feet thick, the zone of dense welding is only a foot or two thick, generally occurring at or near the base of the unit. A few thin ash-flow tuffs are mostly densely welded and probably represent flows with either higher than normal initial heat or very rapid emplacement resulting in high heat retention. In some large-volume ash-flow tuffs that are more than 200 feet thick, the zone of dense welding is 10 to 20 feet thick, in places with dense glass low in the zone and rare to abundant spherulites suspended in glass high in the zone. Above the densely welded zone in thick welded tuffs is a zone of vapor-phase crystallization, commonly 100 to 180 feet thick and characterized by abundant lithophysae (figure 9) or spherulites which in places reach a foot or more in diameter but are mostly less than an inch in size. In many ash-flow tuffs these spherulitic masses are completely or partly filled with chalcedony or quartz; they commonly are referred to as thunder eggs, the official state rock of Oregon. The original vitroclastic texture normally evident in the zone of dense welding is partly or completely destroyed in the vapor-phase zone characterized by abundant lithophysae. Several of the thick ash-flow tuffs also have a zone as much as 15 feet thick of vapor-phase crystallization, above the thick lithophysal zone, that is dense, stony, and highly resistant to erosion (zone 2, fig. 6); characteristically, the groundmass glass has been thoroughly crystallized, and large lumps of pumice, although partly compressed, show no or only slight evidence of crystallization. Material above this zone is mostly not welded or only very slightly welded and, in many places, it has been stripped by erosion down to the resistant stony zone; many ledges and upland surfaces in southeast Oregon are composed of this resistant zone. In the nonwelded zone, fumarolic activity has locally crystallized the glass or introduced cementing mineral substances along pipelike passageways in parts of some ash flows. Differential erosion of the less resistant ash-flow tuff and the cemented material on the pipelike conduits has resulted

A. Zones of welding

ASH-FLOW TUFF

NO WELDING

PARTIAL WELDING

DENSE WELDING

B. Superimposed zones of crystalization

Distribution and relative abundance of lithophysae and spherulites indicated by stars.
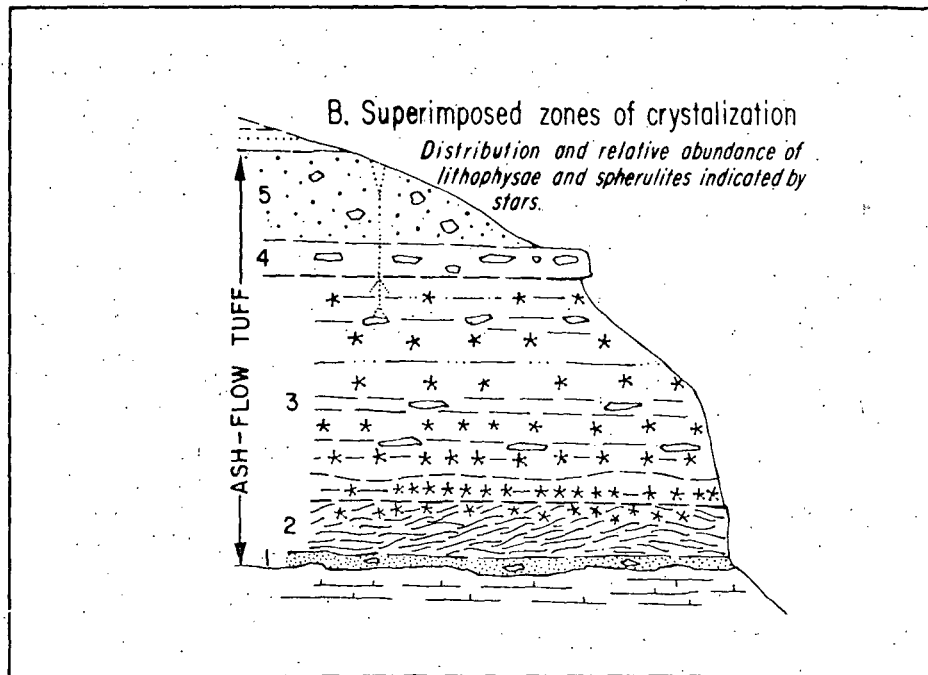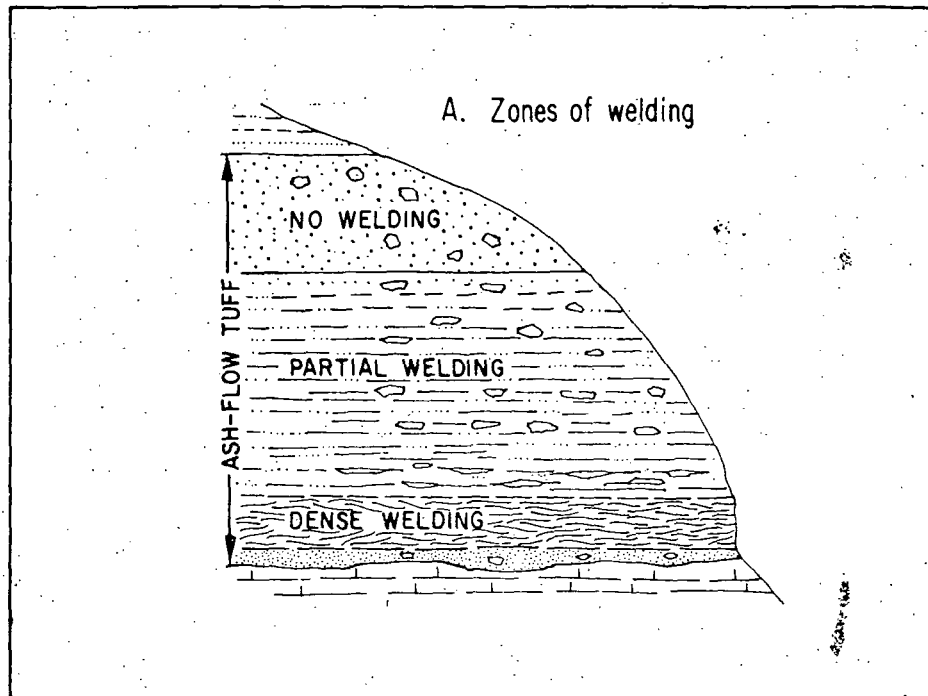
ASH-FLOW TUFF

5
4
3
2

Figure 6. See explanation on page 107.

Figure 6. Sketch sections, showing typical zonal patterns of ash-flow tuffs. The individual zones vary in thickness, in position within flows, and in degree of compaction of plastic glassy fragments and crystallization.

A

Sketch A shows typical zones resulting from compaction and welding. Densely welded zone commonly mostly glass but in a few flows that erupted with an initial high content of crystals the crystals are concentrated in this zone and, locally, constitute up to about 35 percent of zone.

B

Sketch B shows general position and character of zones resulting from crystallization of vitroclastic material.

Zone 1, commonly a thin zone of nonwelded or poorly welded tuff; little or no compaction or crystallization of glass fragments.

Zone 2, normally a comparatively thin zone of moderately to densely welded gray to black glass that commonly shows evidence of crystallization by rare to abundant spherulites, particularly near top of zone. In older ash-flow tuffs glass partly or completely devitrified and hydrated.

Zone 3, zone of vapor-phase crystallization, where present, generally manifest by partial to complete crystallization of glass and by common to abundant lithophysae that give rocks a porous, sponge-like character. Evidence of dense to moderate welding where original texture not destroyed by crystallization. In some flows zone 3 shows strong foliation and local lineation denoting laminar flowage (see Walker and Swanson, 1968); in some flows zone 3 shows prominent columnar jointing.

Zone 4, some ash-flow tuffs exhibit moderately to poorly welded nonporous zone at top of vapor-phase zone that is highly resistant to erosion as a result of crystallization of glass.

Zone 5, top zone of nonwelded material is poorly indurated and commonly has been stripped from ash-flow tuffs. In places, fumarolic activity has crystallized and cemented tuff along nearly vertical channelways.

Figure 7. Well-developed columnar jointing with strong foliation and sheet jointing at 90° to columns in vapor-phase zone of Pliocene ash-flow tuff. Outcrops on south flank of Wagontire Mountain near line between Lake and Harney Counties.

Figure 8. Single cooling unit of Pliocene ash-flow tuff exposed on Buzzard Creek, southwest of Harney Lake. Unit extends from light-colored airfall tuff at base through vertical wall composed of zone of vitrophyre (lower dark band) and upper zone of vapor-phase crystallization; slopes above vertical wall underlain by zone of crystallized tuff containing very abundant lithophysae.
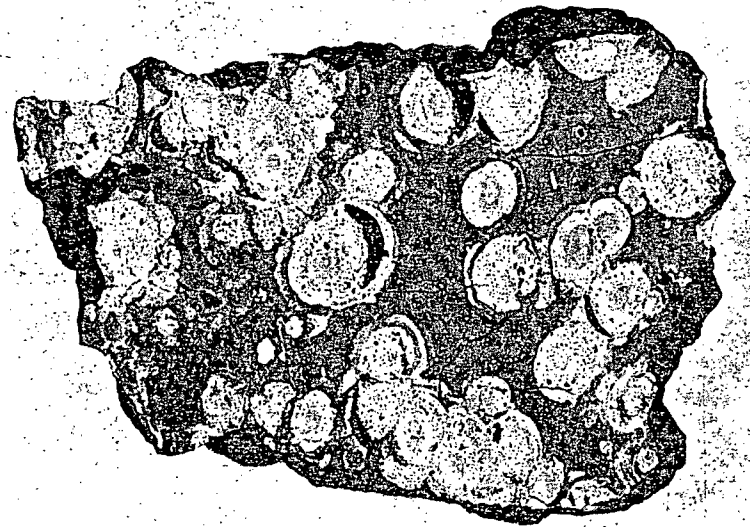
Figure 9. Concentrically banded lithophysae in crystallized ash-flow tuff of Pliocene age. Largest lithophysa about 1.5 inches in diameter.

in some unusual erosion features, such as the Pinnacles on Sand Creek at Crater Lake National Park (see Williams, 1942, Plate 16, or McBirney, 1968, fig. 1).

Composition

Comparisons of some chemical aspects of ash-flow tuffs of Oregon show that all are of rhyolitic to dacitic composition, except the welded basaltic tuff described by Taylor (1969) that presumably has an origin quite different from those described here; some of the rhyolitic to dacitic tuffs are silicic alkalic types. Chemical variations are related partly to geographic distribution of the tuffs and generally not to their age, although there are some distinct petrochemical types within the different age groups.

Most of the ash-flow tuffs contain more than 70 percent SiO_2, commonly about 73 to 74 percent, although the range is from about 67 to nearly 77 percent. Differences in total alkalies, alkali ratios (figure 10), and silica content are related in

Figure 10. Diagram showing relation of alkalies in Oregon ash-flow tuffs. Averages for rhyolite, alkali rhyolite, and rhyodacite are from Nockolds, 1954.

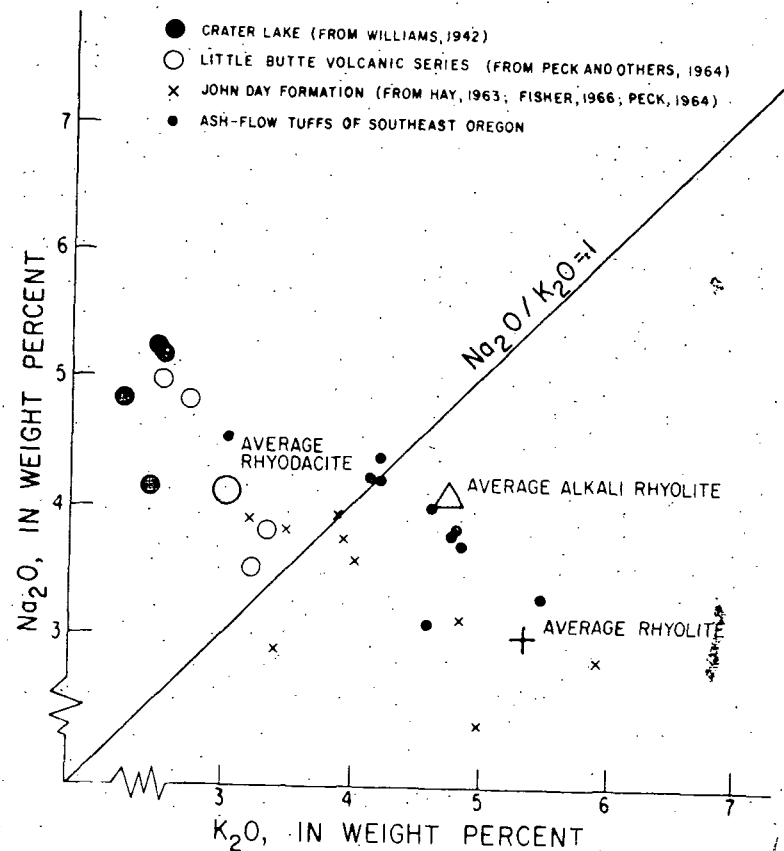part to geographic distribution. Less silicic and more sodic types are present in the Cascade Range and westward to the Willamette Valley. Included are the ash-flow tuffs at Crater Lake (Williams, 1942) that belong to the youngest age group, and those in the Little Butte Volcanic Series (Peck and others, 1964) of the oldest age group. More silicic and more potassic types are present in central and eastern Oregon, although even there some alkalic silicic ash-flow tuffs are abnormally high in soda, low in alumina, and are of soda rhyolite (comenditic) composition (Dickinson and Vigrass, 1965; Walker and Swanson, 1968; Noble, McKee, and Creasy, 1969). Included in the more silicic and more potassic tuffs are some from the John Day Formation of middle Oligocene to early Miocene age (Hay, 1963; Fisher, 1966; Peck, 1964), and a few are from unnamed Pliocene units in southeast Oregon. Rather sparse analytical data indicate that most of the soda rhyolite ash-flow tuffs of eastern Oregon are either of late Miocene or early Pliocene age.

Furthermore, as found elsewhere, some of these ash-flow tuffs show distinct differences in alkali ratios between the glassy vitrophyric parts and the devitrified parts, apparently indicating alkali transfer during hydration and crystallization of the metastable glass.

Some of the soda rhyolitic tuffs contain acmite both in the norm and in the mode; the mode also is characterized by blue sodic amphibole, sodic sanidine or anorthoclase, quartz, basaltic hornblende, magnetite, iron-rich clinopyroxene, and minor accessory minerals. Less sodic, rhyolitic and rhyodacitic ash-flow tuffs generally appear to contain more glass and fewer crystals than the soda rhyolite ash-flow tuffs although there are exceptions, particularly in several tuffs showing evidence of laminar flowage (Walker and Swanson, 1968); the crystals, where present, include sanidine containing small to moderate amounts of soda, sodic plagioclase, quartz, and rarely hornblende, biotite, iron-rich clinopyroxene, magnetite, and minor accessories, including apatite and zircon.

Diagenesis of the vitric material in Miocene and older ash-flow tuffs has resulted in the formation of zeolites, principally clinoptilolite, clay minerals, secondary silica minerals, potassium feldspar, and celadonite. Small to moderate amounts of mordenite and phillipsite also have been recognized in some of these tuffs. Younger, Pliocene ash-flow tuffs have undergone similar types of alteration but apparently only where they erupted into shallow, probably slightly alkaline lakes. In some basins of southeast Oregon, subaerial parts of ash-flow tuffs can be traced laterally into lacustrine sequences; distinct differences are evident in degree of compaction and welding, and in these waterlogged ash-flow tuffs the vitric constituents are converted to erionite, heulandite, clinoptilolite, opal, clay minerals, and other alteration products.

Source Areas

Although a variety of ash-flow tuffs have been identified in many parts of the Cenozoic section of Oregon, only in a few places have individual flows been traced to the vents from which they erupted. Some source or vent areas have been clearly identified, a few other source areas are suspected but need further substantiation by detailed mapping or geophysical surveys, and still others are much in the realm of speculation.

Data on a number of potential local sources for Oligocene and early Miocene ash-flow tuffs of unknown, but apparently rather small, volume in the Little Butte Volcanic Series of the Western Cascades have been compiled by Peck and others (1964, fig. 15), although the relation of individual ash flows to vents has not been established Potential vents for small- to moderate-volume ash-flow tuffs in the middle Oligocene to early Miocene John Day Formation of central Oregon were identified in the Burnt Ranch, Eagle Rock, and Miller Creek areas by Waters (1954, 1966) and in the Ashwood area by Peck (1964). Other possible vents for small volume ash-flow tuffs of the John Day Formation may be obscured by silicic volcanic piles such as those at Powell Buttes, Bear Creek Buttes, and Mutton Mountains. Sources for Miocene and older ash-flow tuffs in the Goose Lake area near Lakeview are not specifically known, although a number of silicic domes and volcanic necks, such as those at Slide, Round, and Dead Indian Mountains and at Fitzwater Point, may bury and obscure the original vents. A late Miocene ash-flow tuff having a volume of more than 10 cubic miles apparently vented from fissure zones now occupied by rhyolite dikes in the Castle Rock area of northern Malheur and southeastern Grant Counties (Haddock, 1965). The late Miocene ash-flow tuffs that straddle the Oregon-Nevada border in the Trout

Creek Mountains area are related to an arcuate structure, possibly a caldera (Walker and Repenning, 1965).

In the Harney Basin area, distribution of the several Pliocene ash-flow tuffs of very large volume -- totaling more than 100 cubic miles of pyroclastic material -- indicates they are related to the structural collapse centered in the area between Burns, Harney Lake, and Malheur Lake. Presumably beneath the Quaternary cover of sediments and basalt flows in this central area are several closely grouped calderas whose precise positions and character can be determined only by investigations of the subsurface, probably by geophysical means. The Pliocene ash-flow tuffs far to the north and east of Harney Basin near John Day and Baker are, in part, related to the calderas in the Harney Basin, although it is likely that some erupted from fissure vents nearer at hand. Several fissure vents have been postulated for Pliocene ash-flow tuffs in the western part of Harney Basin at Wagontire Mountain (Walker and Swanson, 1968) and near Buzzard Creek (Walker, 1969).

Spectacular, little-modified calderas at Crater Lake (Williams, 1942) and at Newberry Volcano (Higgins and Waters, 1967, 1968) mark the most obvious vents for comparatively small ash-flow tuffs there. Ash flows from these calderas are of late Quaternary age -- some less than 10 or 15 thousand years old -- and are associated with large volumes of other volcanic materials, including lava flows and pyroclastic debris not of ash-flow origin.

References

Allen, V. T., and Nichols, R. L., 1945, Clay-pellet conglomerates at Hobart Butte, Lane County, Oregon: Jour. Sed. Petrol., v. 15, no. 1, p. 25-33.

Bowen, R. G., Gray, W. L., and Gregory, D. C., 1963, General geology of the northern Juntura Basin, in Shotwell, J. A., the Juntura Basin: studies in earth history and paleoecology: Am. Philos. Soc. Trans., new series, v. 53, pt. 1, p. 22-34.

Brown, C. E., and Thayer, T. P., 1966, Geologic map of the Canyon City (AMS) quadrangle, Morrow, Umatilla, Union, Baker, Malheur, Grant, Harney, Crook, and Wheeler Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-447, scale 1:250,000.

Campbell, Ian, Conel, J. E., Rogers, J. J. W., and Whitfield, J. M., 1958, Possible correlation of Rattlesnake and Danforth Formations of eastern Oregon [abst.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1678.

Coleman, R. G., 1950, John Day Formation in the Picture Gorge quadrangle, Oregon: Oregon State Univ. master's thesis, unpub.

Dickinson, W. R., and Vigrass, L. W., 1965, Geology of the Suplee-Izee area, Crook, Grant, and Harney Counties, Oregon: Oregon Dept. Geology and Mineral Industries Bull. 58, 109 p.

Diller, J. S., and Patton, H. B., 1902, The geology and petrography of Crater Lake National Park: U.S. Geol. Survey Prof. Paper 3, 167 p.

Dole, H. M., and Corcoran, R. E., 1954, Reconnaissance geology along U.S. Highway 20 between Vale and Buchanan, Malheur and Harney Counties, Oregon: The Ore Bin, v. 16, no. 6, p. 37-39 + 4 p. cross sections.

Fisher, R. V., 1966, Geology of a Miocene ignimbrite layer, John Day Formation, eastern Oregon: California Univ. Pubs. Geol. Sci., v. 67, 73 p.

Fuller, R. E., 1931, The geomorphology and volcanic sequence of Steens Mountain in southeastern Oregon: Washington Univ. Geology Pub., v. 3, no. 1, p. 1-130.

_____, 1935, Collapsed pumice [abst.]: Geol. Soc. America Proc. for 1934, p. 329.

Gilluly, James, 1937, Geology and mineral resources of the Baker quadrangle, Oregon: U.S. Geol. Survey Bull. 879, 119 p.

Haddock, G. H., 1965, Vent location by investigation of lateral and vertical characteristics of a welded ash-flow tuff: Geol. Soc. America Spec. Paper 87, p. 206-207.

_____, 1967, The Dinner Creek Welded Ash-flow Tuff of the Malheur Gorge area, Malheur County, Oregon: Oregon Univ. doctoral diss., 111 p.

Hampton, E. R., 1964, Geologic factors that control the occurrence and availability of ground water in the Fort Rock Basin, Lake County, Oregon: U.S. Geol. Survey Prof. Paper 383-B, p. B1-B29.

Hausen, D. M., 1954, Welded tuffs of Oregon and Idaho: Mississippi Acad. Sci. Jour. 1951-1953, v. 5, p. 209-220.

Hay, R. L., 1963, Stratigraphy and zeolitic diagenesis of the John Day Formation of Oregon: California Univ. Pubs. Geol. Sci., v. 42, no. 5, p. 199-262.

Higgins, M. W., and Waters, A. C., 1967, Newberry caldera, Oregon; a preliminary report: The Ore Bin, v. 29, no. 3, p. 37-60.

_____, Newberry Caldera field trip, in Andesite Conference Guidebook: Oregon Dept. Geology and Mineral Industries Bull. 62, p. 59-77.

Kittleman, L. R., and others, 1965, Cenozoic stratigraphy of the Owyhee Region, southeastern Oregon: Oregon Univ. Mus. Nat. History Bull. 1, 45 p.

Lund, E. H., 1962, Welded tuff in the Danforth Formation [abst.]: The Ore Bin, v. 24, p. 24.

_____, 1966, Zoning in an ash flow of the Danforth Formation, Harney County, Oregon: The Ore Bin. v. 28, no. 9, p. 161-170.

McBirney, A. R., 1968, Compositional variations of the climactic eruption of Mount Mazama, in Andesite Conference Guidebook: Oregon Dept. Geology and Mineral Industries Bull. 62, p. 53-56.

Merriam, J. C., Stock, Chester, and Moody, C. L., 1925, The Pliocene Rattlesnake Formation and fauna of eastern Oregon, with notes on the geology of the Rattlesnake and Mascall deposits: Carnegie Inst. Washington Pub. 347, p. 43-92.

Moore, B. N., 1937, Nonmetallic mineral resources of eastern Oregon: U.S. Geol. Survey Bull. 875, 180 p.

Noble, D. C., McKee, E. H., and Creasy, J. W., 1969, Late Tertiary peralkaline volcanism in north-central Humboldt County, Nevada [abst.]: Geol. Soc. America Program, Cordilleran Sec. Meeting, Eugene, p. 48-49.

Nockolds, S. R., 1954, Average chemical composition of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007-1032.

Piper, A. M., Robinson, T. W., Jr., and Park, C. F., Jr., 1939, Geology and ground-water resources of the Harney Basin, Oregon: U.S. Geol. Survey Water-supply Paper 841, 189 p.

Peck, D. L., 1964, Geologic reconnaissance of the Antelope-Ashwood area, north-central Oregon with emphasis on the John Day Formation of late Oligocene and early Miocene age: U.S. Geol. Survey Bull. 1161-D, p. D1-D26.

Peck, D. L., Griggs, A. B., Schlicker, H. G., Wells, F. G., and Dole, H. M., 1964, Geology of the central and northern parts of the Eastern Cascade Range in Oregon: U.S. Geol. Survey Prof. Paper 449, 56 p.

Prostka, H. J., 1962, Geology of the Sparta quadrangle, Oregon: Oregon Dept. Geology and Mineral Industries Geol. Map Series GMS-1, scale 1:62,500.

_____, 1967, Preliminary geologic map of the Durkee quadrangle, Oregon: Oregon Dept. Geology and Mineral Industries Geol. Map Series GMS-3, scale 1:62,500.

Ross, C. S., 1941, Origin and geometric form of chalcedony-filled spherulites from Oregon: Am. Mineralogist, v. 26, p. 727-732.

Ross, C. S., and Smith, R. L., 1961, Ash-flow tuffs -- their origin, geologic relations, and identification: U.S. Geol. Survey Prof. Paper 366, 81 p.

Russell, I. C., 1884, A geological reconnaissance in southern Oregon: U.S. Geol. Survey Annual Rept. 4, p. 431-464.

Smith, R. L., 1960a, Ash flows: Geol. Soc. America Bull., v. 71, p. 795-842.

_____, 1960b, Zones and zonal variations in welded ash flows: U.S. Geol. Survey Prof. Paper 354-F, p. 149-159.

Swanson, D. A., 1969, Reconnaissance geologic map of the east half of the Bend (AMS) quadrangle, Crook, Wheeler, Jefferson, Wasco, and Deschutes Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-568, scale 1:250,000.

Swanson, D. A., and Robinson, P. T., 1968, Base of the John Day Formation in and near the Horse Heaven mining district, north-central Oregon: U. S. Geol. Survey Prof. Paper 600-D, p. D154-D161.

Taylor, E. M., 1969, A basalt welded tuff in the Cascade Range of Oregon [abst.]: Geol. Soc. America Program, Cordilleran Sec. meeting, Eugene, p. 68-69.

Thayer, T. P., 1957, Some relations of later Tertiary volcanology and structure in eastern Oregon, in v. 1 of Volcanologia del Cenozoico: Internat. Geol. Cong., 20th, Mexico, D. F., 1956 [Trabajos], sec. 1, p. 231-245.

Walker, G. W., 1969, Possible fissure vent for a Pliocene ash-flow tuff, Buzzard Creek area, Harney County, Oregon: U.S. Geol. Survey Prof. Paper 650-C, p. C8-C17.

Walker, G. W., Peterson, N. V., and Greene, R. C., 1967, Reconnaissance geologic map of the east half of the Crescent quadrangle, Lake, Deschutes, and Crook Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-493, scale 1:250,000.

Walker, G. W., and Repenning, C. A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake, Harney, and Malheur Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-446, scale 1:250,000.

_____, 1966, Reconnaissance geologic map of the west half of the Jordan Valley quadrangle, Malheur County, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-457, scale 1:250,000.

Walker, G. W., and Swanson, D. A., 1968, Laminar flowage in a Pliocene soda rhyolite ash-flow tuff, Lake and Harney Counties, Oregon, in Geological Survey Research, 1968: U.S. Geol. Survey Prof. Paper 600-B, p. B37-B47.

Waters, A. C., 1954, John Day Formation west of its type locality [abst.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1320.

_____, 1966, Stein's Pillar area, central Oregon: The Ore Bin, v. 28, no. 8, p. 137-144.

Waters, A. C., and others, 1951, Quicksilver deposits of the Horse Heaven mining district, Oregon: U.S. Geol. Survey Bull. 969-E, p. 105-149.

Wells, F. G., and Waters, A. C., 1934, Quicksilver deposits of southwestern Oregon: U.S. Geol. Survey Bull. 850, 58 p.

Wilkinson, W. D., 1950, Welded tuff member of the Rattlesnake formation [abst.]: Geol. Soc. America Bull., v. 61, p. 1534.

Williams, Howel, 1942, The geology of Crater Lake National Park, Oregon, with a reconnaissance of the Cascade Range southward to Mount Shasta: Carnegie Inst. Washington Pub. 540, 162 p.

_____, 1957, A geologic map of the Bend quadrangle, Oregon, and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Dept. Geology and Mineral Industries, in cooperation with U. S. Geol. Survey, scales 1:125,000 and 1:250,000.

Williams, Howel, and Goles, Gordon, 1968, Volume of the Mazama ash-fall and the origin of Crater Lake Caldera, in Andesite Conference Guidebook: Oregon Dept. Geology and Mineral Industries Bull. 62, p. 37-41.

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GOLD FOUND IN WATER, PLANTS, AND ANIMALS

A recent circular issued by the U.S. Geological Survey summarizes the amounts of gold in ocean water, streams, ground water, plants, and animals. Sea water contains from 0.001 to 44 parts per billion (ppb) gold, and the total amount of gold in sea water, world wide, is estimated to be nearly 27.5 million tons. Ground waters and river waters contain gold in amounts similar to sea water. A few analyses of water from hot springs show gold ranging from 0.01 to 2.2 ppb, averaging about 0.5 ppb.

Varying amounts of gold are contained in the ash of algae, fungi, lichens, mosses, herbs, shrubs, and trees, according to the report. The maximum amount of gold detected in plant ash is 36 ppm (parts per million) and the average is about 7 ppm.

Gold has been looked for in only a few animals. Values range from as little as 0.0012 ppb gold in the dry matter of fish muscle to as much as 430 ppb in human hair. Human teeth show 10 to 30 ppb gold. Marine animals contain the least amount of gold, and terrestrial animals the most.

The report, "Gold Content of Water, Plants, and Animals," by Robert S. Jones, is published as U.S. Geological Survey Circular 625; it may be obtained free upon request from the U.S. Geological Survey, Washington, D.C. 20242.

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GEOCHEMICAL ANALYSES AVAILABLE

The results of all analyses of stream sediments on more than 3000 streams in southwestern Oregon are available for public inspection at the State of Oregon Department of Geology and Mineral Industries offices in Portland, Baker, and Grants Pass. The information consists of semiquantitative chemical analyses for copper, zinc, molybdenum, and mercury, all made in the Department's laboratory in Portland. In addition, semiquantitative spectrographic analyses for 30 elements were made on these samples by the U.S. Geological Survey at its Denver laboratory.

In addition to being available for inspection at the Department's offices, these data, tabulated on approximately 400 pages, will be duplicated upon request for $25. A set of 36 quadrangle maps showing the location of the sample sites and some of the chemical data is available for an additional $25.

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