Revisions to the Cenozoic Stratigraphy of Harney Basin, Southeastern Oregon

GEOLOGICAL SURVEY BULLETIN 1475

Revisions to the Cenozoic Stratigraphy of Harney Basin, Southeastern Oregon

By GEORGE W. WALKER

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A formal designation and description of three major units of volcanic rocks with extensive regional correlations throughout southeastern Oregon

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REVISIONS TO THE CENOZOIC STRATIGRAPHY OF HARNEY BASIN, SOUTHEASTERN OREGON

By GEORGE W. WALKER

ABSTRACT

Harney Basin in southeastern Oregon has persisted as a site of deposition during essentially all of late Cenozoic time; the basin is filled with a sequence of continental volcanic, volcaniclastic, and tuffaceous sedimentary rocks derived from voluminous and widespread basaltic and rhyolitic volcanism. Many rock units are confined to small areas of Harney Basin, whereas others extend beyond the limits of the basin. Included among the latter are a few thick prisms of basalt and related palagonite tuffs, and several late Miocene ash-flow tuffs that cover tens of thousands of square kilometers in eastern Oregon.

The ash-flow tuffs, which represent unique time-stratigraphic marker horizons, occur in lithologic sequences within a number of neighboring depositional basins, where they have been given various formal and informal formational names. In order to clarify the stratigraphic nomenclature of Harney Basin and adjacent regions, three of the ash-flow tuffs—the Devine Canyon Ash-flow Tuff, the Prater Creek Ash-flow Tuff, and the Rattlesnake Ash-flow Tuff—are redefined as formations. In this report their distribution and relations to other stratigraphic units are described, and the terminology of other formational units of which they formerly were a part is revised.

INTRODUCTION

Geologic mapping, petrographic studies, and potassium-argon dating of the Cenozoic rocks in and adjacent to Harney Basin, southeastern Oregon, in the 1960's and early 1970's, provide a basis for establishing a late Cenozoic stratigraphic sequence of the region (fig. 1) in greater detail and precision than heretofore possible. This work also permits clarification and simplification of the current regional stratigraphic nomenclature, particularly where identical units of east-central Oregon have been given several different formal or informal formational names.

In this report the terminology of silicic volcanic rocks in Harney Basin is updated, and some minor modifications are made in subdivision of the stratigraphic column into formational units. Potassium-argon ages have been obtained on some units, and several new names are applied to regionally extensive and distinctive lithologic units within the stratigraphic section (see comparison of old and new names in fig. 2). However, I do not intend to give a complete and

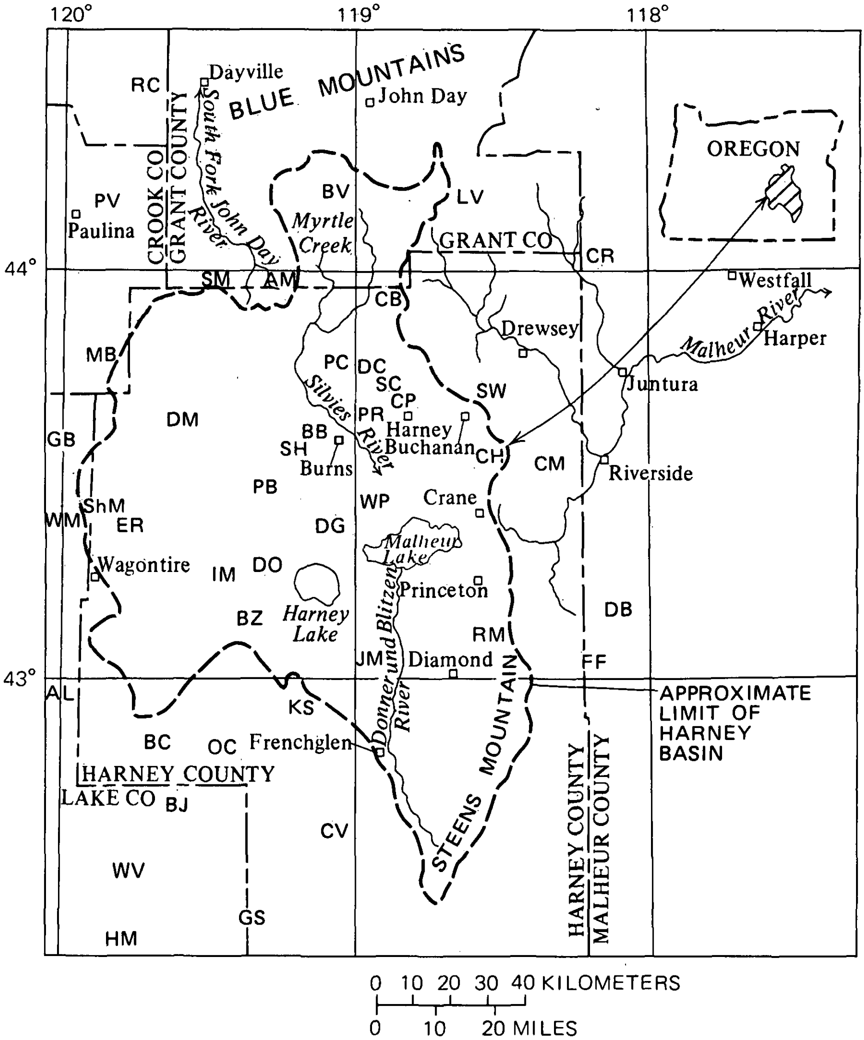

FIGURE 1.—Index map of Harney Basin, Oregon, and adjacent areas. AL, Alkali Lake; AM, Alsup Mountain; BC, Bacon Camp; BV, Bear Valley; BJ, Blue Joint Lake; BB, Burns Butte; BZ, Buzzard Creek; CB, Calamity Butte; CR, Castle Rock; CV, Catlow Valley; CP, Coffee Pot Creek; CM, Coleman Mountain; CH, Crowcamp Hills; DC, Devine Canyon; DG, Dog Mountain; DO, Double O Ranch; DM, Dry Mountain; DB, Duck Butte; ER, Egli Ridge; FF, Follyfarm; GB, Glass Buttes; GS, Guano Slough; HM, Hart Mountain; IM, Iron Mountain; JM, Jackass Mountain; KS, Keg Springs Valley; LV, Logan Valley; MB, Mackey Butte; OC, Orijana Canyon; PB, Palomino Buttes; PV, Paulina Valley; PC, Poison Creek; PR, Prater Creek; RC, Rattlesnake Creek; RM, Riddle Mountain; SH, Sagehen Hills; ShM, Sheep Mountain; SC, Soldier Creek; SM, Snow Mountain; SW, Stinking Water Mountain (Pass); WM, Wagontire Mountain; WV, Warner Valley; WP, Wrights Point.

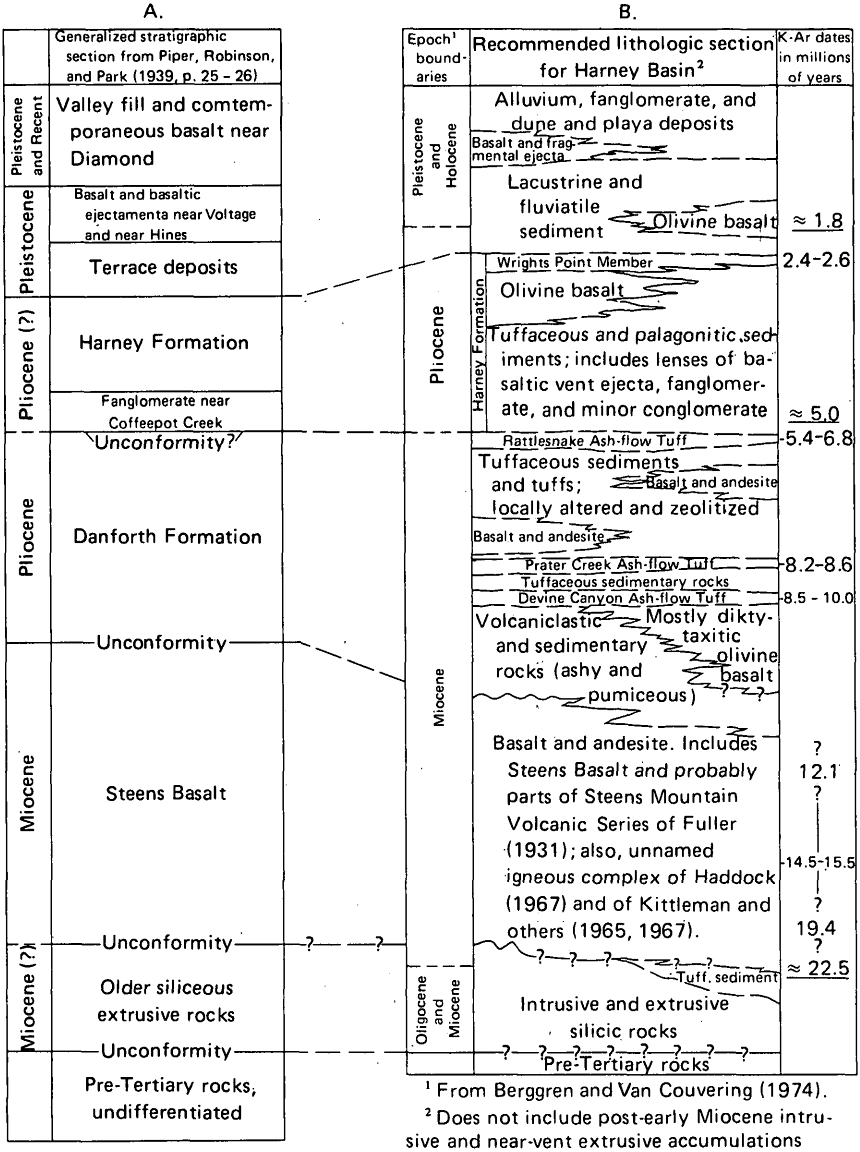

FIGURE 2.—Cenozoic lithologic units of Harney Basin.

comprehensive summary of the lithologic and stratigraphic succession of Cenozoic rocks in Harney Basin, inasmuch as many of the available data are of a reconnaissance nature only.

Cenozoic units exposed in and marginal to Harney Basin consist of continental volcanic, volcaniclastic, and sedimentary rocks of late

Oligocene and younger age,[1] several of which are traceable into adjacent depositional basins where they have been given various formational names. Some units, particularly late Miocene ash-flow tuffs that formed during a brief interval, can be traced over many thousands of square kilometers and are sufficiently distinctive lithologically to be useful as key time-stratigraphic horizons. Other units within Harney Basin are more restricted in areal extent or are found only within the volcanic vent complexes with which they are genetically associated.

Early geologic work in and near Harney Basin by Russell (1884), Waring (1909), Fuller (1931), and Piper, Robinson, and Park (1939) showed that most of the area is underlain by volcanic and volcaniclastic rocks and by moderately to poorly indurated lacustrine and fluviatile deposits, all of Oligocene and younger age. Piper, Robinson, and Park separated the stratigraphic sequence into several units: (1) an unnamed unit of older extrusive silicic rocks; (2) the Steens Basalt, which they considered of Miocene age; (3) the unconformably overlying Danforth Formation, assigned a Pliocene age; (4) the Harney Formation, assigned a Pliocene(?) age; and (5) several unnamed lithologic units, mostly younger than the Harney Formation (fig. 2, col. A). In establishing this basic stratigraphy for Harney Basin, Piper, Robinson, and Park, using the terminology and philosophy then extant, identified several ash-flow tuffs either as rhyolite flows or as tuff-breccia and considered a number of distinct basaltic vent areas as parts of extensive, more or less continuous beds of basaltic tuff.

On the basis of recent mapping of the Burns 2° quadrangle (Greene and others, 1972) that included nearly all of Harney Basin, and mapping of adjacent areas (Shotwell and others, 1963; Walker and Repenning, 1965; Brown and Thayer, 1966; Kittleman and others, 1967; Walker and others, 1967; Swanson, 1969; Parker, 1974), the lithologic character and structural and stratigraphic continuity of many units, some of their facies relations within the basin, aspects of their diagenetic alteration (Walker and Swanson, 1968), and the stratigraphic relations among several individual units are now much better known. Additional information has also been obtained from isotopic potassium-argon ages on several distinct and widespread rock units and on related vent rocks (Parker and Armstrong, 1972; Walker and others, 1974; MacLeod and others, 1976; McKee and others, 1976). Although ash-flow tuffs have been recognized in middle and upper Cenozoic sequences of east-central and southeastern Ore-

[1]Ages of epoch boundaries in this report are from Berggren and Van Couvering (1974) and are younger than those traditionally used in reports on the geology of eastern Oregon. Every attempt has been made in the figures and text to integrate these age differences.

gon for a number of years (Wilkinson, 1950; Thayer, 1956; Wallace and Calkins, 1956; Lund, 1962; Walker, 1970), their use as widespread markers in regional stratigraphic correlations throughout southeastern Oregon is only at an early stage of development and has awaited further identification and mapping of these units over large areas of several thousand square kilometers.

THE DEPOSITIONAL BASIN

As described by Piper, Robinson, and Park (1939, p. 3), Harney Basin " * * * covers about 5,300 square miles in the relatively high and semiarid desert country of southeastern Oregon, in Harney and Grant counties" (fig. 1). The basin comprises most of the east end of the High Lava Plains physiographic province (Dicken, 1950), the lowest part being centered on shallow and ephemeral Harney and Malheur Lakes. The basin is irregularly bounded on the north by parts of the Blue Mountains; on the southeast, by the large and complex tilted fault block that includes Steens Mountain; on the south, by elevated fault blocks separating Harney Basin from the interior basins of Catlow and Warner Valleys; and on the west, by erosional or volcanic constructional high areas, dominated by large Miocene and Pliocene rhyolitic domes that include Wagontire Mountain, Egli Ridge, Sheep Mountain, and Glass Buttes, and by younger basaltic vent complexes and related flows (fig. 1).

The physiographic basin is structurally controlled, with present-day streams generally flowing from marginal areas down dip slopes developed in Miocene and early Pliocene beds into the central part of the basin near Harney and Malheur Lakes. At this time there is no surface outlet to the basin, although in earlier (Pleistocene?), wetter periods, extensive lakes drained eastward through the Malheur River and its tributaries into the Snake River. Even earlier, in middle and late Pliocene time, drainage from the basin may have been southwestward into the Alkali Lake area; but if so, later deformation and volcanism have disrupted this egress.

Regional distribution of middle and upper Miocene basaltic and andesitic rocks (Walker and Repenning, 1965; Brown and Thayer, 1966; Greene and others, 1972), including the Steens Basalt, at least part of the Steens Mountain Volcanic Series (Fuller, 1931; Williams and Compton, 1953), and the unnamed igneous complex of Kittleman and others (1965) and Haddock (1967), as well as overlying volcaniclastic rocks of middle and late Miocene age, indicates that Harney Basin began to evolve as a large structural downwarp and as a site of restricted deposition and sedimentation during middle or late

Miocene time. Perhaps most of the structural collapse associated with formation of the basin was the result of eruption of large volumes of basaltic material and of rhyolitic ash and pumice from large collapse calderas within the basin. The products of this volcanic activity are preserved in basalt flows and palagonite tuffs and in ash-flow tuff sheets and pumiceous sedimentary rocks of late Miocene and early Pliocene(?) age.

STRATIGRAPHY

The upper Cenozoic rocks of Harney Basin form a complexly intertongued and locally faulted assemblage of basalt, andesite, and minor rhyolite domes and flows, together with air-fall and ash-flow tuffs and tuffaceous sedimentary rocks. Most were deposited subaerially, but locally, in the central part of the basin, they formed in a shallow lacustrine environment. The entire sedimentary and volcanic pile appears to represent an essentially continuous depositional sequence marked by many disconformities, several of which occur widely at the bases of extensive ash-flow tuff sheets and basalt flows but apparently represent only brief intervals of time. Some successive stratigraphic units show increased angular discordance; in places, younger units wedge out against elevated and tilted fault blocks, particularly in parts of the basin that have been subjected to more intense faulting partly contemporaneous with volcanism. Abrupt facies changes, appreciable thickening and thinning of individual units across fault scarps, and extensive mantling of older units by younger ones permit the total thickness of the stratigraphic section to be only roughly estimated at between 1,100 and 1,250 m.

In discussing the stratigraphy of Harney Basin, Piper, Robinson, and Park (1939) established formational units (fig. 2, col. A) and designated epochal ages according to the then-current geologic time scale. Although their major lithologic divisions are essentially correct, more recent work has shown that some units contain many more rock types than are present in their type sections, and some of their criteria for distinguishing between units pertain only to local features of no regional significance. On the other hand, some of the most easily recognized and widespread units, such as extensive and distinctive ash-flow tuff sheets, were not used by Piper, Robinson, and Park as stratigraphic markers. It seems desirable, therefore, to describe in greater detail selected rock types in the sequence and to revise the stratigraphic nomenclature, taking into account new data on lithologic variations, areal distribution, and age of the units (fig. 2, col. B) and formally to name key marker horizons useful in regional correlations.

MIOCENE ROCKS

A great variety of rhyolitic and basaltic volcanic and volcaniclastic rocks of Miocene age are exposed in areas marginal to the central lowlands of Harney Basin and undoubtedly occur throughout most and perhaps all of the subsurface beneath younger basin fill. Although their ages are not well established, vertebrate fossils from a few units and limited potassium-argon dating indicate that most are middle and late Miocene, although some may be as old as Oligocene.

INTRUSIVE AND EXTRUSIVE SILICIC ROCKS

Piper, Robinson, and Park (1939, p. 51–52) applied the term "older siliceous extrusive rocks" to rocks that crop out in the northern part of the Crowcamp Hills east of Buchanan, Oreg., on Palomino (Palomina) Buttes west of Burns, Oreg., and in several areas southeast of Malheur Lake. They considered these rocks to be the oldest Cenozoic rocks of Harney Basin, predating the Steens Basalt.

This unit has since been shown to include some intrusive rocks and is accordingly designated "intrusive and extrusive silicic rocks" in this report. Most of these silicic rocks have since been shown (fig. 3) to be middle(?) and late Miocene (MacLeod and others, 1976; McKee and others, 1976) and therefore considerably younger than the Steens Basalt. Some undated silicic rocks southeast of Malheur Lake, however, may be older, although their age cannot be determined by field relations to the much younger surrounding rocks; they may correlate with lithologically similar intrusive and extrusive silicic rocks of the late Oligocene(?) and early(?) Miocene Pike Creek Formation at the east base of Steens Mountain (Fuller, 1931; Walker and Repenning, 1965). Also at the east base of Steens Mountain is the Alvord Creek Formation, composed of bedded silicic tuffaceous sedimentary rocks and tuffs whose stratigraphic relation to the Pike Creek Formation is obscured by poor outcrops and extensive landslide deposits but is considered stratigraphically above it. A flow in or stratigraphically above the Alvord Creek Formation has been isotopically dated at 21.3 m.y. (Evernden and James, 1964), which is early Miocene, and the overlying Steens Basalt (the Steens Mountain Basalt of Fuller, 1931), at about 15 m.y. (Baksi and others, 1967), which is middle Miocene.

Rhyolite from various areas within and near Harney Basin has been studied by potassium-argon dating (fig. 3). Ages of samples from Palomino Buttes range from 6.5 to 5.6 m.y. (Parker, 1974; Walker and others, 1974); one sample from the northern Crowcamp Hills gave 14.7 m.y., and two samples from Duck Butte east of Malheur Lake gave 9.6 and 10.0 m.y. (MacLeod and others, 1976; McKee and others, 1976). Furthermore, isotopic dating on silicic rocks of Burns

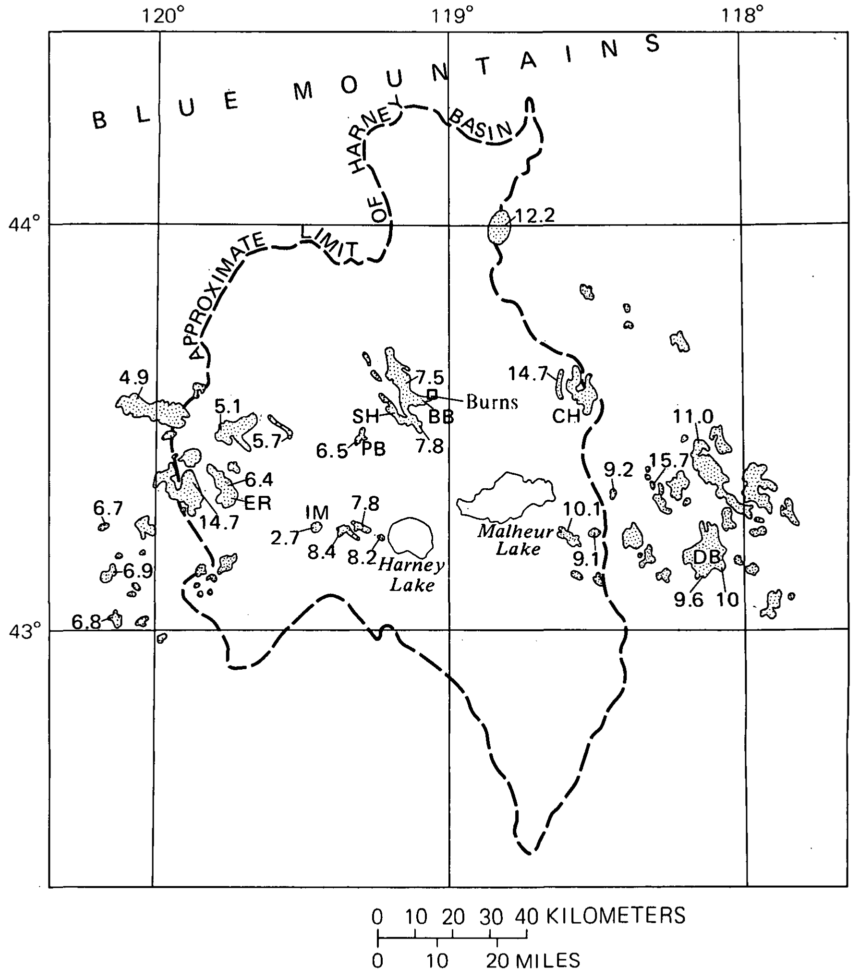

FIGURE 3.—Distribution of and potassium-argon ages on rhyolite domes and related flows (stippled areas) in and adjacent to Harney Basin. CH, Crowcamp Hills; BB, Burns Butte; SH, Sagehen Hills; PB, Palomino Buttes; DB, Duck Butte; ER, Egli Ridge; IM, Iron Mountain.

Butte and Sagehen Hills, which were identified as rhyolite flow units of the Danforth Formation by Piper, Robinson, and Park (1939), which they considered Pliocene, indicated an age of 7.8 to 7.5 m.y.; one age on rhyolite of Iron Mountain, 20 km west of Harney Lake, is 2.7 m.y. (Parker, 1974, p. 43). Another age, on rhyolite of Egli Ridge near the west margin of Harney Basin, is 6.4 m.y. (MacLeod and others, 1976). These and other late Miocene dates are compatible with the known geologic relations in the Harney Basin area and indicate that most masses of intrusive and extrusive silicic rocks in the basin are younger than the Steens Basalt. Omitting possible Pike Creek correlatives, none of these separate units of rhyolitic rocks are shown on the diagram (fig. 2) because of their limited areal extent and uncertain relations to several of the more widely distributed Cenozoic formations.

Intrusive and extrusive silicic rocks of the Harney Basin area range in composition from silicic andesite or mafic dacite through rhyodacite to rhyolite and display a variety of physical and mineralogic characteristics. Outcrops are generally rough and broken in appearance; in places, primary or only slightly modified surfaces of exogenous dome and related flows are manifested by pressure ridges, squeezeups, and coarse, blocky material. The silicic rocks tend to split along flow bands and closely spaced joints, and so most masses are buried under extensive mantles of angular talus.

The rhyolitic rocks are aphyric to porphyritic and have a vitrophyric to aphanitic or microcrystalline groundmass. The rocks contain from trace amounts to as much as about 10 percent of plagioclase (mostly oligoclase) phenocrysts; alkali feldspar and quartz are less common. A few rocks contain trace amounts of mafic phenocrysts, including augite, hypersthene, hornblende, biotite, and magnetite; tridymite commonly lines cavities. The groundmass, which in places was originally partly glassy, consists of a very fine intergrowth of dominantly alkali feldspar, cristobalite, and, in places, oligoclase and quartz or chalcedony. The groundmass texture of the rocks is granular to felty, locally spherulitic, and is largely the result of devitrification of the glass.

Vitrophyre, including obsidian, is common in many of the domal masses, such as Duck Butte just east of Harney Basin, where the rock is slightly inflated, flow banded, and contains a variety of mafic phenocrysts. In other masses the obsidian is hydrated to perlite; generally the older domes (15–14 m.y.) contain little or no obsidian, whereas domes about 10 m.y. old or younger, such as Burns Butte and Egli Ridge, retain parts of their obsidian carapaces.

BASALT AND ANDESITE

Rocks here designated basalt and andesite crop out discontinuously in physiographically and structurally higher parts of Harney Basin, particularly to the northwest, northeast, and southeast. These rocks are probably continuous in the subsurface throughout much of the area, particularly in the eastern part of the basin. In the northwestern part, the unit has been stripped away by erosion in some places and laps out locally against pre-Tertiary rocks: evidence of lapouts becomes more prominent farther to the north. Basalt is probably the dominant rock type, although andesite is locally abundant, for example, at Dog Mountain west of Burns, Oreg. (fig. 1).

Included with the basalt and andesite unit are a variety of rock types, many of which are interlayered or intertongued. Although some types are characteristic of specific areas within Harney Basin, in the absence of detailed geologic mapping the general distribution of the different rocks is poorly known. Most flows are thin (typically <10 m), very widespread, and commonly form thick flow-on-flow sequences; some flows are highly porphyritic and others, nonporphyritic. Plagioclase phenocrysts are most common, forming as much as 50 percent of a few flows; clinopyroxene and olivine phenocrysts occur with the plagioclase phenocrysts, commonly as clots of crystals. The groundmass of some rocks is dense; in others, it consists of a highly porous intergrowth of plagioclase laths with a diktytaxitic texture. Some basalt is of the high-alumina type, characterized by abundant plagioclase and having a mafic mineral content lower than that of tholeiite or alkali basalt; its color index is thus transitional to that of andesite. However, the plagioclase is mostly labradorite, and the silica content is mostly less than 50 percent and typically basaltic.

The basalt commonly forms vertical cliffs composed of a few or many thin (<6 m) flows separated by moderate slopes that are covered with abundant talus and other erosional debris. Some flows display crude columnar jointing, whereas others show no columns and are moderately to strongly flow jointed. Flat to gently sloping uplands are commonly covered with a pavement of angular blocks, with little intervening soil. Stone polygons occur locally on flat surfaces, and stone stripes are almost universal on moderate to steep slopes.

The basalt is texturally and mineralogically diverse, consisting of dense aphanitic and micro- to fine-grained flows, as well as flows that are coarsely and abundantly porphyritic and glomeroporphyritic. The microtexture is commonly intergranular, ophitic or subophitic, and diktytaxitic; rarely is it intersertal. Many flows are olivine bearing, and a few contain hypersthene.

Plagioclase phenocrysts constitute from less than 1 to about 5 percent of many rocks and as much as 50 percent of a few flows on Steens Mountain. Some basalt contains less than 1 percent olivine phenocrysts, and a few flows are characterized by small amounts of augite or hypersthene phenocrysts. Aphyric rocks and the groundmass of porphyritic rocks consist of plagioclase, augite, magnetite, glass, and, in many rocks, olivine; small crystals of hypersthene occur in a few flows. Alteration products are mostly yellowish-brown montmorillonite and unidentified clay minerals.

On Dry Mountain, west of Burns, Oreg., most flows in the basalt and andesite unit are composed of hypersthene andesite that is dark gray, aphyric, and microcrystalline. They consist of plagioclase, hypersthene, minor augite and magnetite, and a large proportion of glass.

In the southeastern part of the area on Steens Mountain, highly porphyritic basalt, interlayered with other andesite and basalt, contains as much as 50 percent plagioclase phenocrysts, commonly as flow-alined elongate tablets as long as several centimeters in maximum dimension. The groundmass is medium light gray, because of abundant plagioclase laths, micrograined to fine grained, and commonly very porous, with a diktytaxitic texture. The overall appearance of the basalt is of a coarse-grained rock, and, like most such rocks, it is relatively nonresistant to erosion and forms rounded slopes covered by fine angular detritus.

In a few places the basalt and andesite unit appears to interfinger with underlying and overlying units but generally is bounded by unconformities with much relief, and so its thickness is extremely variable. The unit is relatively thin in the northwestern part of the area, where its laps pre-Tertiary rocks, but appears to be at least 150 m thick in the Mackey Butte area, about 150 m thick on Snow Mountain, about 200 m thick in the gorge of Myrtle Creek (fig. 1), and perhaps as much as 300 m thick on Alsup Mountain, east of the South Fork John Day River. In the northeastern part of the area, the unit reaches an apparent thickness of about 450 m on Calamity Butte, decreasing to about 60 m on Stinking Water Mountain near Buchanan, Oreg. To the east, the unit thickens again, apparently reaching 300 m or more on Coleman Mountain. The basalt and andesite unit locally thickens southward toward the northern extension of Steens Mountain but possibly thins and even pinches out in places against highs of the older intrusive and extrusive silicic rocks. On Riddle Mountain the thickness of the unit is about 450 m, and on the northern extension of Steens scarp near Follyfarm, Oreg., about 600 m. The sequence thickens still further southward toward the summit of Steens Mountain, where Fuller (1931) reported a thickness of over 900 m, including many flows of highly porphyritic, plagioclase-rich basalt.

An upper limit to the age of the basalt and andesite unit is set by the 9.2- or 9.3-m.y. date on the onlapping Devine Canyon Ash-flow Tuff (named in this report). A sequence of tuffaceous sedimentary rocks between the basalt and andesite unit and the Devine Canyon Ash-flow Tuff suggests that a substantial interval of time separates these units. Vertebrate fossils in the intervening sedimentary rocks include both Barstovian (middle Miocene) and Clarendonian (late Miocene) faunas, the former indicating a minimum age of about 12 m.y. A lower limit to the age of the unit is set by that of the underlying Alvord Creek Formation on the east front of Steens Mountain, an overlying or interbedded flow dated at 21.3 m.y. by Evernden and James (1964). Potassium-argon dates on the basalt and andesite within and marginal to Harney Basin include 19.4 m.y. on porphyritic basalt near Calamity Butte (Greene and others, 1972), 12.1 m.y. (Evernden and James, 1964) for andesite of Stinking Water Pass, and 15.3 m.y. on a porphyritic flow of Riddle Mountain (Greene and others, 1972). A sample of the porphyritic Steens Basalt collected farther south, high on the west slope of Steens Mountain, gave 14.7 m.y. on a plagioclase separate and 14.5 m.y. on the whole rock (Evernden and others, 1964). A number of samples collected just beyond the basin, on the east-facing scarp of Steens Mountain, gave ages ranging from 15.5 to 14.7 m.y. (Baksi and others, 1967). Thus it appears that the basalt and andesite unit ranges widely in age from 19 to about 12 m.y., that is, middle and late Miocene. It is possible, however, that the 12.1 m.y. date on the porphyritic basalt near Calamity Butte is too young, perhaps owing to alteration of the sampled flow; moreover, rocks of several distinct ages and magmatic events may have been grouped together. Radiometric ages indicate that the actual age of the bulk of these rocks is little more than 15.5 to 14.5 m.y., a date according with field observations that suggest a limited age span.

The basalt and andesite unit correlates with several other major basaltic and andesitic units of eastern Oregon. Indeed, part of the unit in northwestern Harney Basin has been mapped as the Columbia River Basalt Group and in the southeast, as the Steens Basalt. Other nearby coeval volcanic sequences include the lower part of the Strawberry Volcanics, the Owyhee Basalt, and the unnamed igneous complex of Haddock (1967) and Kittleman and others (1967). It is possible that with detailed mapping, the basalt and andesite unit may be subdivided, some parts being assigned to the aforementioned units; but such subdivisions and correlations would be unwise until further mapping, potassium-argon dating, and petrochemical-petrographic studies have been made.

VOLCANICLASTIC AND SEDIMENTARY ROCKS

In the southeastern part of Harney Basin adjacent to the Donner und Blitzen River, near Princeton, Oreg., and in the hills between Crane and Riverside, Oreg., a unit of volcaniclastic and sedimentary rocks laps with slight angular discordance onto the basalt and andesite unit and, in areas just south of the basin, appears to interfinger with some of the uppermost flows of the unit. The volcaniclastic and sedimentary rocks range in total thickness from near 0 to about 125 m on scarps near Diamond, Oreg., and east of Jackass Mountain. In thicker sections the unit commonly forms gentle slopes and is poorly exposed beneath a rimrock of the Devine Canyon Ash-flow Tuff. Rocks in this unit are of slightly different ages throughout Harney Basin, as determined from their stratigraphic position with respect to dated underlying basalt flows and overlying ash-flow tuffs. The few diagnostic vertebrate fossils collected from the unit in areas south of Harney Lake, along the north wall of Keg Springs Valley (fig. 4), indicate that both Barstovian and Clarendonian stages are represented in this part of the section.

Most of the volcaniclastic and sedimentary rocks consist of poorly sorted, coarse- to fine-grained rhyolitic and rhyodacitic sedimentary debris mixed with mineral and rock fragments of underlying basalt and andesite. The bulk of these rocks is composed of fine pumice and glass shards and varying amounts of clay, probably largely the alteration product of volcanic ash. Some parts of the sequence are fine grained, thin bedded, and well sorted and suggest a lacustrine deposition. In places, individual beds are only a few centimeters or so thick. Other parts are massive and exhibit little or no bedding; these parts are interpreted as water-laid sediments deposited on gentle flood plains adjacent to a shallow lake. Some discontinuous beds are composed of well-sorted pumice lapilli mostly a centimeter or less in diameter, and still other beds, of air-fall origin, are largely glass shards or alteration products of shards. Individual beds are grayish yellow, yellowish gray, very pale orange, very light gray, or nearly white.

Included within this unit is a pumiceous ash-flow tuff discontinuously exposed in the hills north, east, and southeast of Buchanan, Oreg. (Greene and other, 1972). This unnamed ash-flow tuff, which is medium gray where still glassy and yellowish gray where devitrified, is apparently of limited areal extent; however, on regional stratigraphic grounds, it may be equivalent to the thin vitric tuff in the upper member of the Juntura Formation of Bowen, Gray, and Gregory (1963, fig. 5), although its full geographic distribution remains unknown. Because the original distribution and stratigraphic position of the ash-flow tuff are so poorly known, it is not shown as a separate unit on the diagram (fig. 2). The volcaniclastic and sedimentary rocks are considered to be middle(?) and late Miocene.

ASH-FLOW TUFFS AND RELATED ROCKS

Stratigraphically and apparently conformably above the volcaniclastic and sedimentary rocks is a sequence of tuffs and tuffaceous sedimentary rocks. Several widespread ash-flow tuff sheets dominate

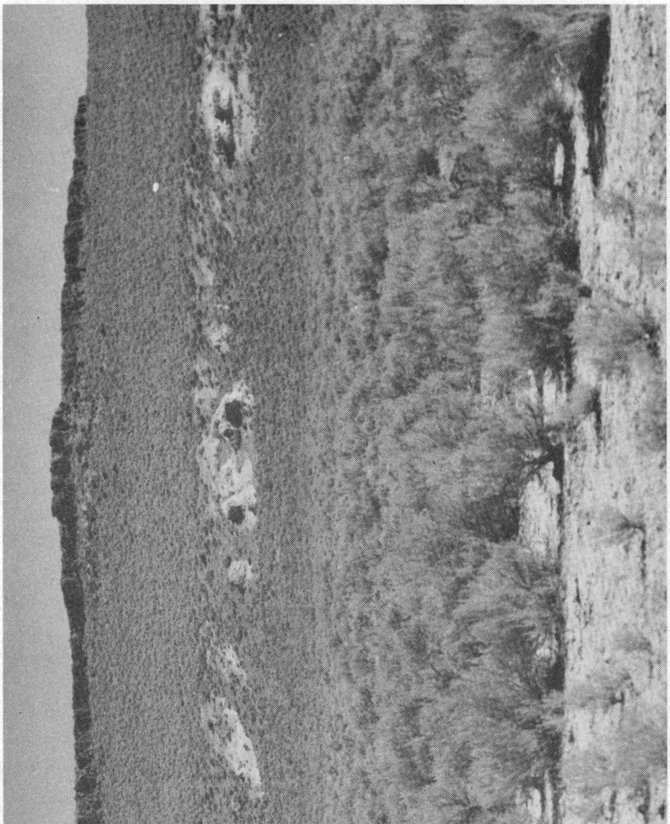

FIGURE 4.—Keg Springs Valley, looking north to light outcrops of vertebrate-bearing (Barstovian) tuffaceous sedimentary rocks at base of slope, overlain by poorly exposed tuffaceous sedimentary rocks containing sparse Clarendonian vertebrate fauna in gentle slopes and capped by the Devine Canyon Ash-flow Tuff, which has been dated at about 9.2 or 9.3 m.y. Outcrops in floor of Keg Springs Valley are part of Miocene basalt and andesite unit.

the sequence, but poorly exposed, intervening bedded tuffaceous sedimentary rocks and some restricted basalt and andesite flows are also included (fig. 2).

Sedimentary interlayers between the ash-flow tuffs thicken toward the central part of Harney Basin and thin progressively toward the margins of the basin. These bedded sedimentary deposits are poorly indurated and form smooth, gentle slopes largely barren of outcrops; hence their lithologic character can be observed only in a few widely distributed natural outcrops and roadcuts. Discontinuous layers of air-fall tuff, commonly less than a few tens of centimeters thick, occur at the base and top of all the ash-flow tuffs described here. These represent a minor but important part of the volcanic and depositional processes involved in the emplacement of the ash-flow tuffs; however, they are so poorly exposed throughout the region that little is known of their geographic distribution, thickness, or lithologic character. In most areas they have been arbitrarily mapped with the tuffaceous sedimentary rocks that separate most of the ash-flow tuffs.

Originally this sequence and the underlying volcaniclastic and sedimentary rocks were included in the Danforth Formation by Piper, Robinson, and Park (1939, p. 43–49), who tentatively assigned the formation to the Pliocene on the basis of its stratigraphic position and freshwater fossil shells. Within the formation they identified several members of tuff-breccia and a basal spherulitic rhyolite, now all recognized as widespread ash-flow tuff sheets.

These ash-flow tuffs are by far the best and most easily recognized marker units throughout vast areas of southeastern Oregon because of their distinctive character and wide distribution, in places many kilometers beyond the limits of Harney Basin. Recent mapping and isotopic dating of these and related units in and adjacent to Harney Basin have demonstrated that considerable confusion exists regarding their full extent and correlation with rocks of adjacent depositional basins, and so single widespread ash-flow tuffs have been given various formational names in different areas. Because some ash-flow tuffs are readily recognized, easily mapped, and regionally extensive, they are here redefined as formations. The preexisting formations to which they were originally assigned either are redefined or, in the case of the Danforth Formation, abandoned.

DEVINE CANYON ASH-FLOW TUFF

The term "welded tuff of Devine Canyon" has been informally used (Greene, 1972, Greene and others, 1972; Greene, 1973) for a thin but distinctive crystal-rich vitric ash-flow tuff that lies stratigraphically above the volcaniclastic and sedimentary rocks. The tuff, which covers more than 18,000 km^2, is centered on the east half of Harney Basin and extends north, south, and east of the basin (fig. 5). This unit is here formally named the Devine Canyon Ash-flow Tuff for exposures in and near Devine Canyon (lat 43°44.5′ N., long 119°00′ W.). The ash-flow tuff is particularly well exposed in Devine Canyon about 1 km north-northeast of its confluence with Poison Creek (fig. 6), designated its type locality, where the unit is over 30 m thick

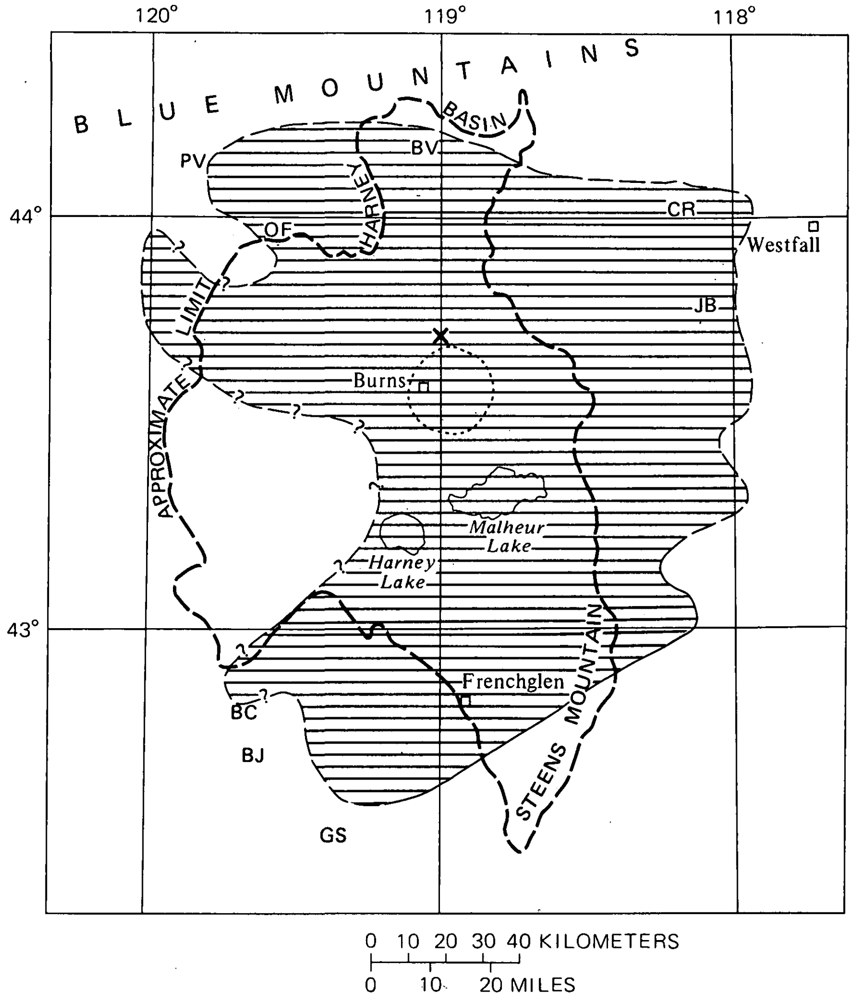

FIGURE 5.—Distribution of the Devine Canyon Ash-flow Tuff (horizontal lines) and its type locality (×). Caldera from which ashflow erupted is not exposed but is apparently within area outlined by dots. PV, Paulina Valley; BV, Bear Valley; CR, Castle Rock; JB, Juntura Basin; BC, Bacon Camp; BJ, Blue Joint Lake; GS, Guano Slough.

(Greene, 1973). The base of the ash-flow tuff is not exposed, but in nearby canyons it rests disconformably on the Miocene volcaniclastic and sedimentary rocks and with angular discordance on Miocene basalt and andesite, as well as on pre-Tertiary rocks. It apparently is conformably overlain by poorly exposed tuffaceous sedimentary rocks of late Miocene age. The unit was originally included by Piper, Robinson, and Park (1939) as the basal spherulitic rhyolite member of the Danforth Formation, a formation name that is here abandoned inasmuch as it was poorly defined originally and is of questionable validity now that the Devine Canyon, Prater Creek, and Rattlesnake Ash-flow Tuffs are separated from it.

The lithologic character, petrography, and petrochemistry of the Devine Canyon Ash-flow Tuff, as well as descriptions of a number of measured sections, were given by Greene (1973). Distribution of the unit has been established largely through regional mapping (Walker and Repenning, 1965; Walker and others, 1967; Davenport, 1971; Greene and others, 1972). Throughout the area of outcrop, the ash-

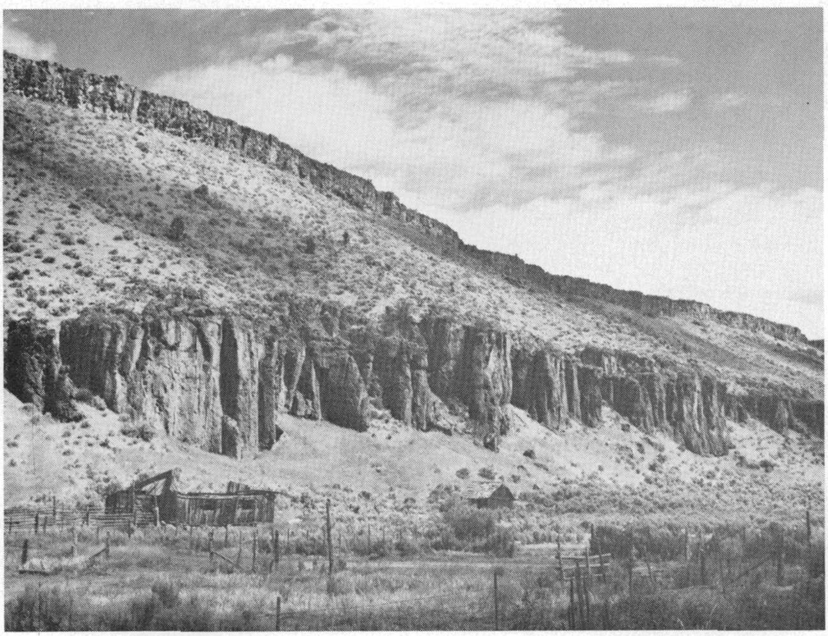

FIGURE 6.—Type locality of Devine Canyon Ash-flow Tuff, Devine Canyon, about 1 km north-northeast of confluence with Poison Creek. Lower ledge constitutes its welded columnar part. Overlying slope is underlain by nonwelded parts of Devine Canyon Ash-flow Tuff and overlying bedded tuffaceous sedimentary rocks. Upper ledge, at skyline, is welded part of Prater Creek Ash-flow Tuff. Photograph taken from U.S. Highway 395, about 15 km north of Burns, Oreg.

flow tuff is generally greenish gray to light gray, densely to moderately welded, is composed of flattened and stretched glass shards and pumice fragments, and has as much as 30 percent crystals and crystal fragments (mostly sodic sanidine, some quartz, and minor but ubiquitous green, iron-rich clinopyroxene). The thinner distal ends of the ash-flow tuff sheet tend to be glassy, whereas thicker sections, exposed closer to the central part of Harney Basin, exhibit more devitrification and locally extensive vapor-phase alteration. Chemically the ash-flow tuff is quite uniform and is composed of fairly normal peraluminous rhyolite (table 1). Potassium-argon dates on the unit (table 2), obtained at different times and from several laboratories, range from 10.0 to 8.5 m.y. (Laursen and Hammond, 1974; Walker and others, 1974), but most are about 9.2 or 9.3 m.y. (fig. 7). The ash-flow tuff is thus late Miocene, in the terminology of Berggren and Van Couvering (1974).

The Devine Canyon Ash-flow Tuff extends widely in all directions from its type locality; its distal ends lie as far south as Guano Slough in the western part of Catlow Valley, and on the west slope of Steens Mountain south of Frenchglen, Oreg. (fig. 5), reaching southwestward from Harney Basin to Bacon Camp at the mouth of Lynch Draw, about 11 km northwest of Blue Joint Lake. The tuff has been recog-

TABLE 1.—*Potassium-argon ages on selected volcanic units of Harney Basin and adjacent areas*

Unit	Age (m.y.)	Location (lat N.,	long W.)	Reference
Wrights Point Member of Harney Formation.	2.4±0.07	43°27.0′	119°00.5′	Greene, Walker, and Corcoran, 1972.
Do	2.6±0.3	43°26.7′	119°00.4	Parker and Armstrong, 1972; Parker, 1974.
Rattlesnake Ash-flow Tuff	6.4±0.2	44°46.9′	119°27.9′	Parker and Armstrong, 1972.
Do	6.4±0.1	44°26.6′	119°38.7′	Do.
Do	6.4	44°26′	119°21′	Evernden, Savage, Curtis, and James, 1964.
Do	6.6±0.2	44°19′	119°30′	Parker and Armstrong, 1972.
Do	6.8±0.33	43°37.7	119°04.2′	Greene, Walker, and Corcoran, 1972.
Do (?)	5.4±0.20	43°47.2′	119°18.9′	Do.
Do	6.6±0.20	43°09.0′	119°22.4′	Parker and Armstrong, 1972.
Do	6.7±0.4	43°09.0′	119°22.4′	Do.
Do	6.7±0.2	44°29.8′	119°42.3′	Dalrymple, Cox, Doell, and Grommé, 1967.
Do	5.95±0.18	--do--	--do--	Do.
Prater Creek Ash-flow Tuff	8.2±0.12	43°14.2′	119°14.3′	Parker, 1974.
Do	8.6±0.2	43°09.9′	119°22.4′	Parker and Armstrong, 1972.
Devine Canyon Ash-flow Tuff	8.5±0.3	43°00.6′	118°38.1′	Greene, 1973.
Do	8.9	43°47.1′	118°16.8′	Evernden, Savage, Curtis, and James, 1964.
Do	8.9	43°47.2′	118°17.6′	Laursen and Hammond, 1974.
Do[1]	9.1±0.3 10.0±0.3	42°35.6′	119°16.5′	Walker, Dalrymple, and Lanphere, 1974.
Do	9.2±0.50	43°45.5′	118°59.9′	Greene, Walker, and Corcoran, 1972.
Do	9.15±0.19	43°47.1′	118°16.8′	Dalrymple, Cox, Doell, and Grommé, 1967.
Do	9.45±0.21	43°41.7′	119°54.1′	Walker, Dalrymple, and Lanphere, 1974.
Do	9.7±0.3	42°35.6′	119°16.5′	Walker and Repenning, 1965; Greene, 1973.

[1]Single sample of vitrophyre. One date (10.0 m.y.) on alkali feldspar and the other (9.1 m.y.) on glass.

TABLE 2.—*Average chemical composition of the Devine Canyon, Prater Creek, and Rattlesnake Ash-flow Tuffs*

[Analyses are on both vitric and devitrified facies and, where appropriate, were recalculated to water-free basis. Analytical data: Greene (1973), Parker (1974), Enlows (1976), and U.S. Geological Survey (unpub. data)]

	Devine Canyon Ash-flow Tuff		Prater Creek Ash-flow Tuff		Rattlesnake Ash-flow Tuff	
	Average (18)[1]	σ	Average (4)	σ	Average (12)	σ
SiO_2	75.8	1.1	74.7	1.2	77.0	1.0
Al_2O_3	11.6	.6	12.3	1.0	12.1	.5
FeO[2]	2.4	.8	2.9	1.5	.9	.4
MgO	.2	.2	.3	.3	.2	.2
CaO	.4	.2	.3	.5	.6	.5
Na_2O	3.8	.5	4.4	.2	3.5	.5
K_2O	4.9	.5	4.4	.1	4.9	.7
TiO_2	.21	.04	.15	.0	.16	.05
P_2O_5	.05	.03	------	------	.05	.15
MnO	[3].04	.2	------	------	[4].17	.31

[1]Number of analyses used in computations.
[2]All Fe reported as FeO.
[3]For P_2O_5 and MnO (15 analyses).
[4]For P_2O_5 and MnO (5 analyses).

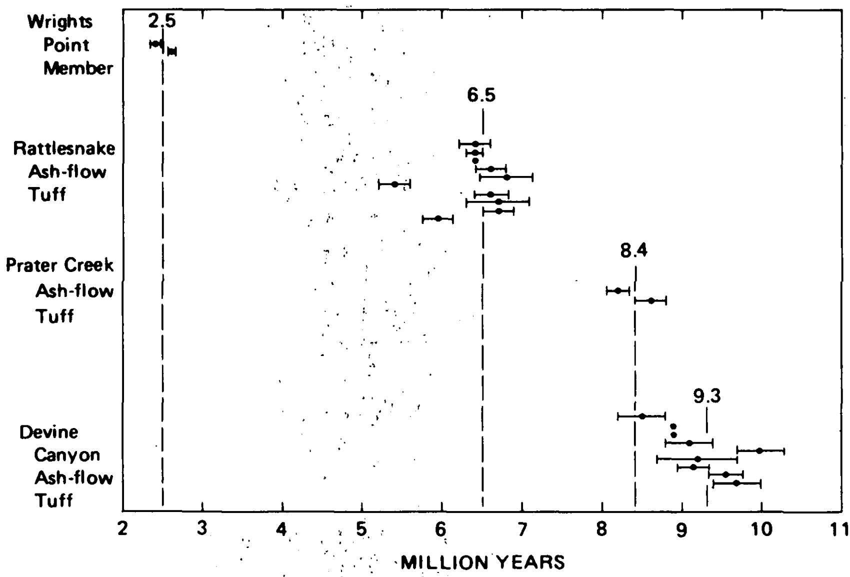

FIGURE 7.—Plot of potassium-argon ages (including analytical errors) for the Wrights Point Member of the Harney Formation and for the Rattlesnake, Prater Creek, and Devine Canyon Ash-flow Tuffs.

nized in Paulina Valley, about 80 km northwest of the Devine-Poison Canyon area, and discontinuously eastward from Paulina, Oreg., to Bear Valley. Within this segment of the Blue Mountains, the unit was previously included in the silicic marginal facies of what was then called the Columbia River Group near Paulina, Oreg.; in the Rattlesnake Formation and Tertiary and Quaternary volcanic and fluviatile deposits, undifferentiated (Brown and Thayer, 1966); and in the Danforth Formation (Davenport, 1971). Northeast of Harney Basin the unit has been traced into Juntura Basin, where it was identified by Bowen, Gray, and Gregory (1936) as the basal welded-tuff member of their newly defined Drewsey Formation. The unit has been traced discontinuously northeast of Juntura Basin to areas east of Castle Rock and into the headwaters of Bully Creek, where it was included in the marginal facies of the Bully Creek Formation of Kittleman and others (1965), a few kilometers west and northwest of Westfall, Oreg. (fig. 5).

It is appropriate to apply to this unit a single name, the Devine Canyon Ash-flow Tuff, throughout its wide lateral extent. Formal naming of this formational unit, however, requires redefinition of several other formations in which it was earlier included. For instance, the Drewsey Formation is here adopted and redefined to exclude its basal welded-tuff member (the Devine Canyon Ash-flow Tuff), and so the (restricted) Drewsey comprises a basal tuff agglomerate and upper tuff and sandstone members (Bowen and others, 1963, fig. 6). Thus redefined, the Drewsey Formation rests conformably on the Devine Canyon Ash-flow Tuff. The Miocene and Pliocene section in Juntura Basin now includes the middle Miocene Juntura Formation of Bowen, Gray, and Gregory (1963), the unconformably overlying Devine Canyon Ash-flow Tuff, the conformably overlying upper(?) Miocene (previously Pliocene) Drewsey Formation, and the upper Miocene or lower Pliocene Drinkwater Basalt of Shotwell and others (1963). Likewise, the Devine Canyon Ash-flow Tuff is separated from the Bully Creek Formation of Kittleman and others (1965), although the distribution of the tuff in rocks previously assigned to the Bully Creek Formation is incompletely known. Redefinition of several units north of Harney Basin to exclude the Devine Canyon Ash-flow Tuff is also necessary, but the only unit of immediate concern here is the Rattlesnake Formation, discussed in succeeding pages.

PRATER CREEK ASH-FLOW TUFF

A devitrified, crystal-poor ash-flow tuff of late Miocene age is exposed in several areas marginal to the central part of Harney Basin (fig. 8). Although the full geographic extent of this tuff and its relation to other units are not well known, it forms a sufficiently distinctive stratigraphic marker in parts of Harney Basin to be mapped as a separate unit (Greene and others, 1972; Parker, 1974). This tuff is separated from the underlying Devine Canyon Ash-Flow Tuff by as much as 50 m of bedded tuff and tuffaceous sedimentary rocks that mostly exhibit textures and structures indicating aqueous transport and deposition. The ash-flow tuff, which Greene, Walker, and Corco-

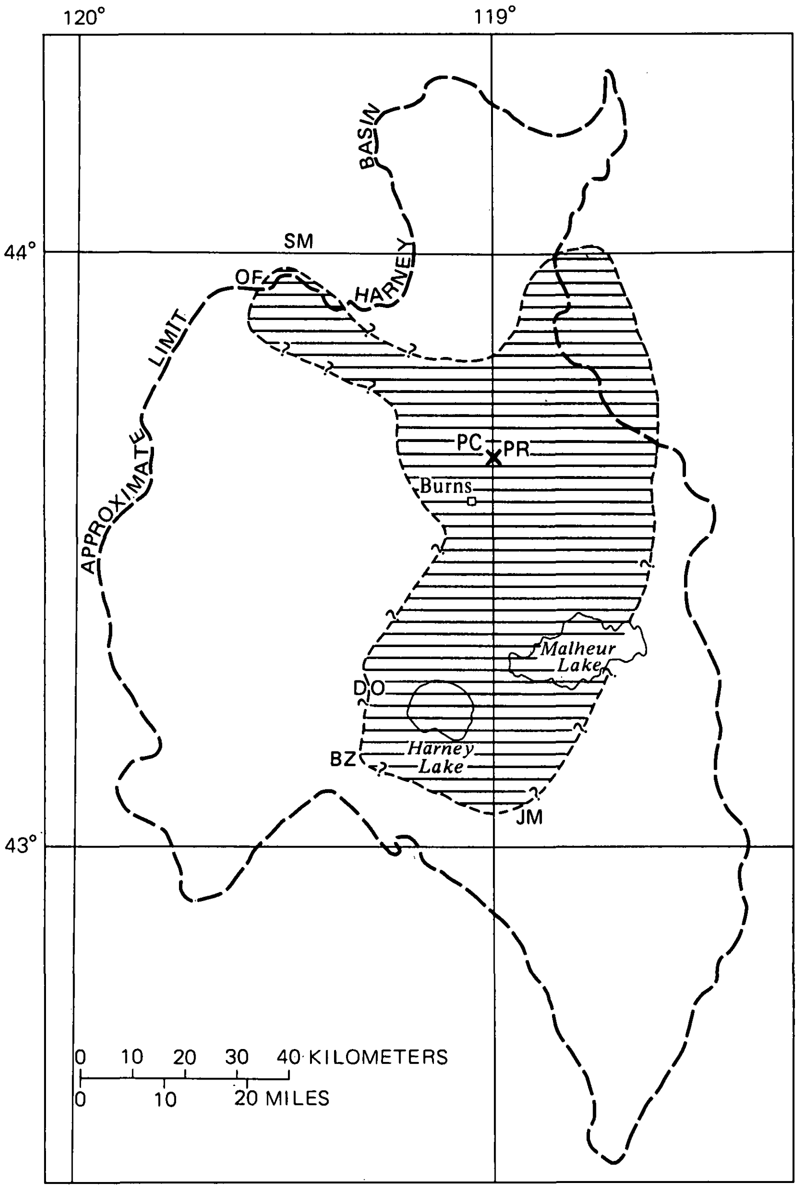

FIGURE 8.—Approximate distribution of the Prater Creek Ash-flow Tuff (horizontal lines). BZ, Buzzard Creek; DO, Double O Ranch; JM, Jackass Mountain; PC, Poison Creek; PR, Prater Creek; SM, Snow Mountain; type section, ×.

ran (1972) informally designated the ash-flow tuff of Prater Creek, is here named the Prater Creek Ash-flow Tuff for its exposures along Prater Creek, about 17 km northeast of Burns, Oreg. The new formation, originally part of the Danforth Formation of Piper, Robinson, and Park (1939), is exposed principally in south-flowing stream drainages north and northeast of Burns but also in a small area near Snow Mountain northwest of Burns (Davenport, 1971); in one locality near Jackass Mountain south of Burns; and, according to Parker (1974, p. 13–14), in areas near Double O Ranch and Buzzard Creek southwest of Burns (fig. 8). Excellent and easily accessible exposures on the walls of Poison Creek, adjacent to U.S. Highway 395 (fig. 9), about 11 to 12 km north of Burns, Oreg. (lat 43°41′N., long 119°00′W.), are here designated the type section; lithologic variations in the unit can be seen in reference sections in Prater Creek, a few kilometers northeast of Poison Creek, and in stream drainages west of Poison Creek.

The type section, which is about 12 m thick, consists dominantly of partly to highly inflated pale-grayish-red, completely devitrified tuff with abundant grayish-pink 2-cm or smaller lithophysae, the larger of which contain lenticular or crescent-shaped vesicles in the plane of foliation. Away from the type section the ash-flow tuff is commonly pinkish gray or pale reddish brown, mostly dense, although a zone of inflated lithophysae is recognizable in many outcrops, generally occurring between dense outer zones. A maximum thickness of about 30

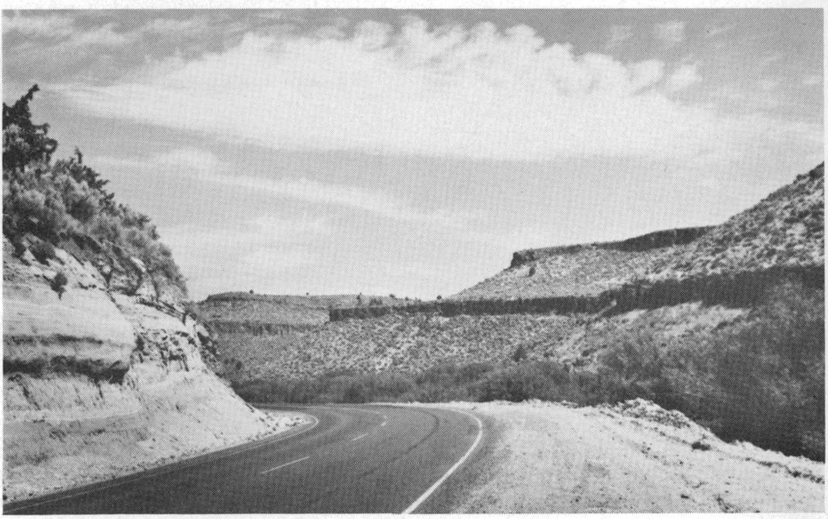

FIGURE 9.—View north along Poison Creek Canyon near its junction with Devine Canyon, about 11 km north of Burns, Oreg., on U.S. Highway 395, showing type section of the Prater Creek Ash-flow Tuff (middle ledge), the Rattlesnake Ash-flow Tuff (upper ledge), and characteristic gentle slopes between ash-flow tuffs that are underlain by bedded tuffs, tuffaceous sedimentary rocks, and minor nonwelded parts of the ash flows. Pumiceous sedimentary rocks in roadcut at left underlie the Prater Creek Ash-flow Tuff.

m has been measured by Parker (1974) on outcrops of the unit near Double O Ranch, although at this locality the base of the unit is not exposed. Flattened and devitrified pumice fragments are present throughout but not abundant in the ash-flow tuff, and only rare lithic fragments have been identified. Crystals and crystal fragments of alkali feldspar and quartz make up only a fraction of a percent of the tuff throughout its entire extent.

The Prater Creek Ash-flow Tuff is directly overlain by as much as 40 m of bedded tuff and tuffaceous sedimentary rocks that, in turn, are overlain by an ash-flow tuff. This latter tuff, which has been given several different names within southeast Oregon, including Rattlesnake Formation and welded tuff of Double O Ranch, is here designated the Rattlesnake Ash-flow Tuff.

Isotopic dates on two whole-rock samples of Prater Creek Ash-flow Tuff indicate an age of about 8.4 m.y. (Parker, 1974, p. 13), that is, late Miocene. Chemically the Prater Creek Ash-flow Tuff is peraluminous rhyolite, slightly more mafic than other ash-flow tuffs in the area (table 2).

RATTLESNAKE ASH-FLOW TUFF

A locally thick and very widespread pumiceous ash-flow tuff has been mapped from areas near John Day, Dayville (Brown and Thayer, 1966; Enlows, 1976), and Paulina, Oreg. (Davenport, 1971), and in Logan Valley south through Harney Basin (Greene and others, 1972) to outcrops marginal to Catlow Valley near Hart Mountain (Walker and Repenning, 1965), and west of Alkali Lake (Walker, 1963)(fig. 10). The ash-flow tuff, which apparently erupted from a caldera now buried beneath younger basin fill in Harney Basin, is thickest (>60m) and most continuously exposed in and adjacent to the west-central part of the basin. The outcrops near John Day, Paulina, Logan Valley, Hart Mountain, and west of Alkali Lake are at or near the distal ends of this vast tuff sheet, where the unit is mostly less than 10 and commonly only 3 or 4 m thick. In distal areas the ash-flow tuff is composed of a single flow unit, but near Harney Basin it is locally composed of several ash flows that apparently cooled as a single unit. The Rattlesnake Ash-flow Tuff represents a remarkably well defined time-stratigraphic marker exposed over a region of 35,000 to 40,000 km^2 and, according to Parker (1974), originally covering nearly 50,000 km^2 of east-central and southeastern Oregon.

Within southeastern Oregon the unit has been variously identified as part of Rattlesnake Formation (Merriam, 1901; Calkins, 1901; Brown and Thayer, 1966), as the Rattlesnake welded tuff or Rattle-

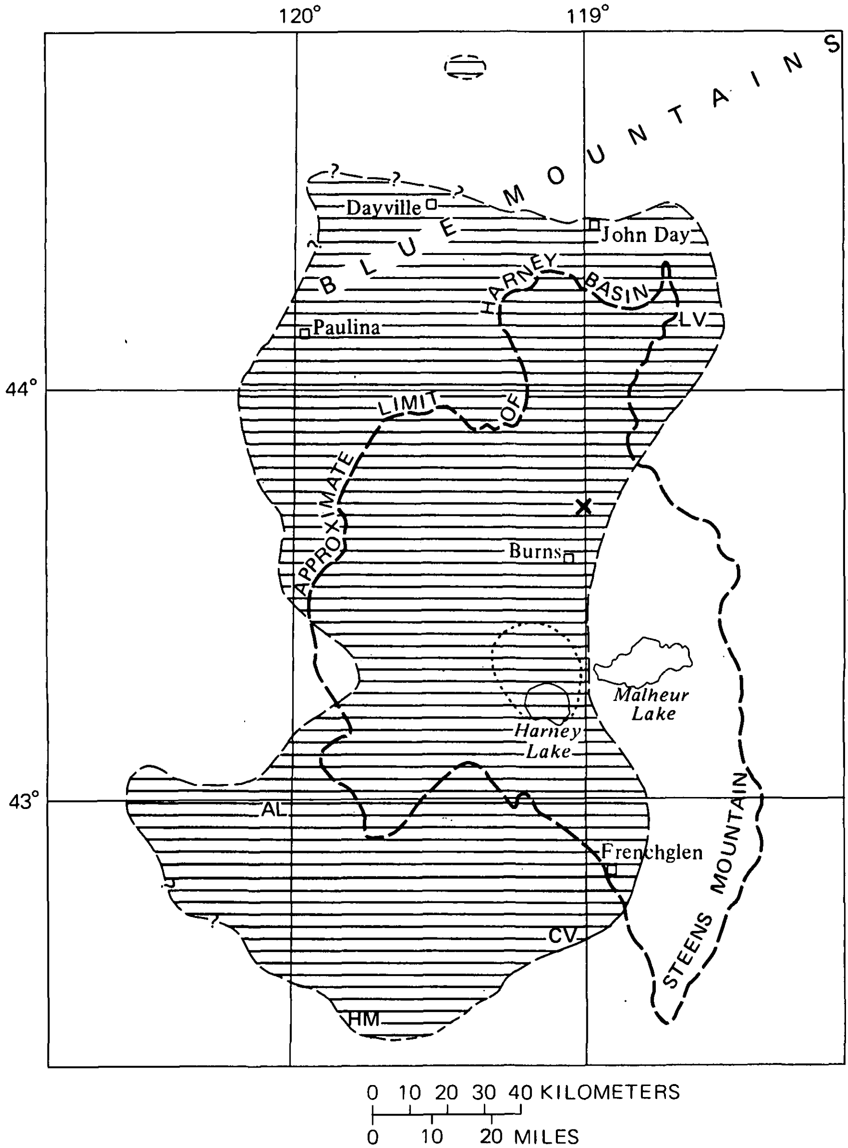

FIGURE 10.—Distribution of the Rattlesnake Ash-flow Tuff (horizontal lines) and its type locality (×). Caldera from which ash flow erupted is not exposed but is apparently within area outlined by dots. AL, Alkali Lake; CV, Catlow Valley; HM, Hart Mountain; LV, Logan Valley.

snake Ignimbrite Tongue of the Rattlesnake Formation (Enlows, 1976), as the Rattlesnake ignimbrite member of the Danforth Formation (Davenport, 1971), as the " * * * [upper] * * * tuff breccia member" of the Danforth Formation (Piper and others, 1939), and as the welded tuff of Double O Ranch (Greene and others, 1972). The stratigraphic value of this widely distributed and easily recognized ash-flow tuff suggests that a single formal name, rather than several local names, be applied to it. Which of the local names, if any, should take precedence and be applied throughout the extent of the tuff is not obvious, and none is wholly satisfactory. On the basis of current knowledge of its distribution and stratigraphic importance, it seems highly inappropriate to restrict the ash-flow tuff to the status of a member or tongue of a geographically more restricted and lithologically diverse formation, as would be the case with the Rattlesnake Formation or the Rattlesnake Ignimbrite Tongue; it likewise seems inappropriate to name the tuff for nontypical exposures near its distal end. Furthermore, to formalize the name "Double O Ranch" (Greene and others, 1972) is hardly justified, inasmuch as the massive rhyolitic outcrops at the Double O Ranch are not derived from this ash-flow tuff; the thickest and perhaps most typical exposures of the tuff in this general area occur about 5 km south of the ranch on a fault scarp forming the northeast wall of an unnamed valley (lat 43°12.5′ N., long 119°19.7′ W.).

Because several names have been applied to this distinctive and important ash-flow tuff and because it has been included as a member of various formations, extensive modification of the stratigraphic nomenclature in the region is required. Inasmuch as most workers in Oregon have referred to the ash-flow tuff in the field as the Rattlesnake tuff or welded tuff, in deference to its occurrence as part of the Rattlesnake Formation alongside Rattlesnake Creek, west of Dayville, Oreg., the tuff is here redefined as a formation and given the name "Rattlesnake Ash-flow Tuff." Its new type locality is on Poison Creek (lat 43°39.5′ N., long 118°59.7′ W.) about 10 km north of Burns, Oreg., along U.S. Highway 395, where easily accessible roadcuts and natural outcrops on the west side of the highway expose a nearly complete and typical section. At this locality the unit is about 20 m thick, consisting of dense gray basal vitrophyre less than 1 m thick; an overlying less densely welded, spherulitic glassy zone 2 m thick; a lithophysal zone 14 to 15 m thick, characterized by massive rounded outcrops (fig. 11); a zone 2 m thick forming gentle slopes and characterized by decreased compaction and vapor-phase alteration; and an upper ledge about 1 m thick, cemented by transported silica and other vapor-phase minerals. Nonwelded and noncemented ash-flow and (or) air-fall material above the upper resistant ledge has been removed by erosion.

The original type locality for the Rattlesnake Formation, on Rattlesnake Creek about 1.6 km west of Cottonwood, Oreg. (approxi-

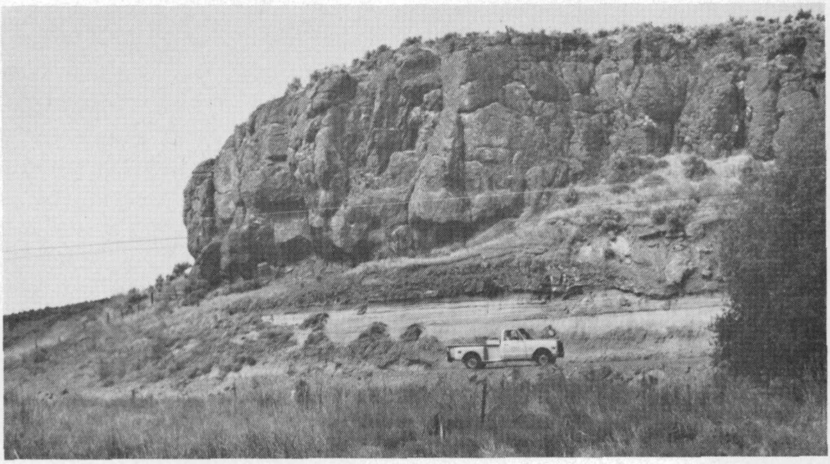

FIGURE 11.—Type locality of the Rattlesnake Ash-flow Tuff about 10 km north of Burns, Oreg., on west side of U.S. Highway 395. The tuff extends from the top of light, bedded deposits, behind pickup truck, to skyline.

mately lat. 44°29′ N., long 119°39′ W.; see also Enlows, 1976, fig. 1 and p. 3), is here considered as a reference locality for the Rattlesnake Ash-flow Tuff. The ash-flow tuff at this locality is about 12 m thick, consisting of a single flow and cooling unit of poorly to moderately welded pumiceous tuff.

Several additional reference localities in and marginal to Harney Basin provide data on lithologic variations in this widespread unit. One reference locality is established in the southwestern part of Harney Basin, within a few kilometers of the source caldera of the ash-flow tuff, south of Double O Ranch at lat 43°12.5′ N., long 119°19.7′ W., where the unit is exposed on the wall of an unnamed canyon. Here the unit is over 60 m thick and is well represented by basal vitrophyre (about 1 m thick), an overlying zone of densely welded material with large flattened pumice fragments and elongate gas pockets (about 2.5 m thick), a zone of vapor-phase-altered and lithophysal material (58 m thick), and a capping cliff-forming zone (about 2 m thick) cemented by minerals that were transported in the vapor phase. Other reference localities are in the southwestern part of the outcrop area on the fault scarp 100 m or more north of the mouth of Orijana Canyon (lat 42°49.3′ N, long 119°29.8′ W.), and on the fault scarp east of U.S. Highway 395 about 16 km northeast of Alkali Lake, where the ash-flow tuff is easily accessible and well exposed, showing some of the secondary laminar flowage features characteristic of some of the thicker parts of the formation.

Lithologically the unit is remarkably consistent throughout, as indicated by modal analyses of samples of the ash-flow tuff from widely separated localities. These analysis show that the unit, where unaffected by vapor-phase recrystallization or devitrification, is composed largely of flattened glass shards and pumice lapilli (about 94–99 percent), lithic fragments (1–5 percent) that are more abundant toward the distal ends, and crystals and crystal fragments (about 1 percent or less). The crystals are mostly alkali feldspar (sanadine and anorthoclase) and contain lesser amounts of quartz, magnetite, a distinctive green, iron-rich augite, and minor zircon. Throughout much of the unit the glass has been converted by vapor-phase alteration and devitrification to alkali feldspar, cristobalite, tridymite, and quartz.

The Rattlesnake Ash-flow Tuff, originally described in most earlier literature as Pliocene in age, is late Miocene, in the terminology of Berggren and Van Couvering (1974). The formation has been isotopically dated at a number of localities (Evernden and others, 1964; Greene and others, 1972; Parker and Armstrong, 1972), the most consistent ages ranging from 6.7 to about 6.4 m.y. (table 1) and averaging about 6.5 m.y. (fig. 7).

Redefinition of the ash-flow tuff as a formation requires additional revisions to the stratigraphic nomenclature of the region (table 3). The name "Rattlesnake Formation," which included in its type section (1) a lower unit of geographically limited fanglomerate, (2) the Rattlesnake welded tuff or ignimbrite tongue, and (3) an overlying geographically restricted fanglomerate, is herewith abandoned. The name "Rattlesnake" is retained only for the widespread ash-flow tuff.

PLIOCENE ROCKS

Marginal to the central part of Harney Basin, a sequence of volcanic flows, breccias, sedimentary rocks (composed exclusively of volcanic debris), and air-fall tuff rests with only slight discordance on the Rattlesnake Ash-flow Tuff. This sequence, which constitutes most of the Harney Formation (Piper and others, 1939), is of much more limited geographic extent than the widespread ash-flow tuff sheets. It is exposed principally in erosional bluffs south of Burns, Oreg., particularly in areas marginal to Harney Lake.

As originally described by Piper, Robinson, and Park (1939, p. 38–41) from outcrops on the east face of Dog Mountain (fig. 1), the Harney Formation consists of massive basaltic tuff and breccia, sandstone and siltstone, and some noncemented gravel, as well as of a few scoriaceous and massive basalt flows. These same authors indicated (p. 39) that members of the formation are " * * * characteristically inconstant in thickness and in physical character and that the

TABLE 3.—*Revisions to stratigraphic nomenclature*

Name of new or former unit	General location	Modifications
Harney Formation	Harney Basin	Redefined. New reference section on Wrights Point, inasmuch as lithologies of type section on east face of Dog Mountain are geographically restricted and not typical. Here includes fanglomerate near Coffeepot Creek of Piper, Robinson, and Park (1939). Base is at top of Rattlesnake Ash-flow Tuff; top is poorly defined but locally is at top of Wrights Point Member.
Danforth Formation	Harney Basin	Abandoned. Originally poorly defined and included lithologies now recognized as very widespread ash-flow tuffs extending many kilometers beyond Harney Basin that have here been redefined as formations. In ascending order they are: Devine Canyon Ash-flow Tuff, Prater Creek Ash-flow Tuff, and Rattlesnake Ash-flow Tuff. Tuffaceous sedimentary rocks between ash-flow tuffs, which are geographically restricted and lithographically diverse, are left unnamed.
Rattlesnake Ash-flow Tuff.	Large area of south-central and southeastern Oregon.	New formation, composed of a single ash-flow tuff cooling unit, previously identified as Rattlesnake welded tuff or Rattlesnake Ignimbrite Tongue of Rattlesnake Formation, the Danforth Formation, welded tuff of Double O Ranch, and locally, as part of silicic marginal facies of the Columbia River Group or as undivided volcanic and fluviatile deposits. Elimination of term "welded tuff" from name permits inclusion of nonwelded parts of ash flow.
Rattlesnake Formation	John Day Basin and adjacent areas.	Abandoned. Middle member of formation is here redefined as a formation and named Rattlesnake Ash-flow Tuff. Geographically limited lower and upper fanglomerate members of Rattlesnake Formation of former usage are left for future workers in region to name.

TABLE 3.—*Revisions to stratigraphic nomenclature*—Continued

Name of new or former unit	General location	Modifications
Prater Creek Ash-flow Tuff.	Harney Basin	New formation, originally an unidentified part of the Danforth Formation of Piper, Robinson, and Park (1939).
Devine Canyon Ash-flow Tuff.	Large area of south-central and southeastern Oregon.	New formation. A very widespread crystal-rich ash-flow tuff, included by previous workers in the Danforth, Rattlesnake, Drewsey, and Bully Creek Formations and in the silicic marginal facies of the Columbia River Group. It was previously designated the ash-flow tuff of Devine Canyon.
Drewsey Formation	Juntura Basin	Redefined to exclude basal crystal-rich ash-flow tuff, which is herein redefined as a formation and named Devine Canyon Ash-flow Tuff.
Bully Creek formation of Kittleman and others (1965).	Harper Basin	No change except to recognize that near the distal ends of this formation, west of Westfall, the Devine Canyon Ash-flow Tuff is interlayered in it. More detailed work required to redefine formation.
Silicic marginal facies of Columbia River Group.	Areas S. of John Day Valley.	Probably should be abandoned, inasmuch as it locally includes distal parts of Devine Canyon Ash-flow Tuff, Prater Creek Ash-flow Tuff, and probably Rattlesnake Ash-flow Tuff. Furthermore, the Columbia River Group has been renamed the Columbia River Basalt Group and is largely restricted to basalt flow sequences.

type section probably does not disclose all facies." Some deviations from the type section, noted by them, include: (1) noncemented and crossbedded gravel exposed on the south face of Wrights Point (fig. 1), (2) fine-grained stratified white volcanic ash(?); and (3) an associated lentil of pumiceous(?) basalt. The top of the formation is marked by the basalt flows capping Wrights Point.

Recent mapping by Greene, Walker, and Corcoran (1972) indicated that the type section of the Harney Formation on Dog Mountain is the eroded wall of a Pliocene basaltic tuff ring (maar). Hence this section, which is dominated by palagonitized basaltic debris, is atypical and of extremely limited geographic extent, like the individual strata that make up the sequence. Such an ill-defined and restricted formation is of questionable usefulness, but I nonetheless recommend the name be retained for the diverse volcanic and sedimentary section, more than 150 m in total thickness, that is exposed in the central part of Harney Basin, directly overlying the Rattlesnake Ash-flow Tuff and including the basalt flows capping Wrights Point. A new reference section is here designated on Wrights Point, where recently excavated roadcuts on State Highway 205 in sec. 33, T. 24 S., R. 31 E. (lat 43°26.5′ N., long 119°00′ W.) expose crossbedded and channeled conglomerate, tuffaceous sandstone and siltstone, several ash beds (Niem, 1974), and the capping basalt flows.

The fluvial deposits in the north-central part of Harney Basin, originally identified as fanglomerate near Coffeepot Creek by Piper, Robinson, and Park (1939, p. 41–42) and considered by them to be of Pliocene(?) age, are here considered a lateral and perhaps early facies of the Harney Formation of Pliocene age. The fanglomerate, composed of gravel, sand, and silt, forms the divide between Coffeepot and Soldier Creeks, about 15 km east-northeast of Burns, Oreg.; it occupies virtually the same stratigraphic position as similar deposits beneath the basalt flows capping Wrights Point.

Niem (1974, p. 37) applied the informal name Wrights Point basalt to two thin (about 3–9 m thick) basalt flows that cap Wrights Point. These flows are here formally named the Wrights Point Member of the Harney Formation, and Wrights Point (lat 43°26.5′ N, long 119°00′ W.) is designated its type locality. The member, which occurs at the top of the formation, consists of several diktytaxitic olivine basalt flows that erupted from vents about 20 km west of Wrights Point in the vicinity of Palomino Buttes. A late Pliocene or early Pleistocene age was assigned by Piper, Robinson, and Park (1939, p. 40–41) to these flows as part of their Harney Formation, and recently determined isotopic (K-Ar) dates (2.6 m.y., Parker, 1974; 2.4 m.y., Walker and others, 1974) indicate a late Pliocene age, in the terminology of Berggren and Van Couvering (1974). Olivine basalt flows of about this same age and stratigraphic position extend west nearly to the west margin of Harney Basin. Many basaltic vents, in the form of eroded cinder cones and palagonitic tuff cones and rings, occur north and northwest of Harney Lake, but individual flows have not been traced into these vents. The basalt and the underlying sedimentary rocks have been displaced by a series of north-trending normal faults that form part of the Brothers fault zone (Walker, 1969a; Lawrence, 1976); maximum displacements are generally less than 6 m.

REGIONAL CORRELATIONS

Attempts at regional correlations among the Cenozoic volcanic and volcaniclastic units of southeastern Oregon and adjacent areas in Idaho are not entirely satisfactory. This is due in large part to the geographically limited and lenticular nature of many units, the lateral facies changes of some units, including transitions from subaerial basalt through altered basalt to subaqueously deposited palagonite tuff and breccia, and the complex intertonguing of diverse units that erupted from numerous and widely distributed vents. Furthermore, correlation of reasonably well dated sections in which epoch boundaries have been revised to current standards (Berggren and Van Couvering, 1974) with sections inadequately or incorrectly dated or for which no isotopic dating is available introduces special problems of establishing even an approximate age equivalence. In some of these inadequately dated sections, the given epochal age is poorly constrained and commonly based on inconclusive fossil control or extrapolation according to apparent stratigraphic position. Refinements of regional correlations by means of magnetostratigraphic methods (Watkins and Baksi,1974) have been made, but much more effort is necessary to extend this technique thoughout the section.

Even with these restrictions it seems appropriate to outline probable or possible correlations of the Cenozoic units in several of the depositional basins of the region (pl. 1). Only the widespread Devine Canyon and Rattlesnake Ash-flow Tuffs, both erupted from vents in Harney Basin, can be traced nearly continuously into sections in adjoining basins. The Devine Canyon Ash-flow Tuff in the Juntura Basin, formerly considered a basal member of the Drewsey Formation by Bowen, Gray, and Gregory (1963), has been traced discontinuously into the Bully Creek Formation of Kittleman and others (1965) in Harper Basin, and north of Harney Basin discontinuously into areas south of John Day, Oreg., particularly those marginal to Bear Valley and in Paulina Valley. In the John Day area, the Devine Canyon Ash-flow Tuff has not been mapped separately and was included within members of the Columbia River Group, in the Rattlesnake Formation, or in volcanic and fluviatile deposits, undivided, as used by Brown and Thayer (1966). In Paulina Valley, Davenport (1971) included rocks herein assigned to the Devine Canyon Ash-flow in his Danforth Formation, which incorporates both the Rattlesnake Formation and upper parts of the volcanic and fluviatile deposits, undivided, of Brown and Thayer. The John Day, Picture Gorge, and Mascall Formations and the Strawberry Volcanics of the John Day area have lithologic and temporal counterparts in and marginal to Harney

Basin, represented by the Oligocene and Miocene sequence of intrusive and extrusive silicic rocks, the overlying basalt and andesite unit that includes the Steens Basalt, and the still younger ashy and pumiceous sedimentary rocks (fig. 2). The ashy and pumiceous sedimentary sequences in both areas are not adequately dated isotopically, but both contain Barstovian fauna; ages on most underlying flows range from 16 to 15 m.y. The basalt sequences show both some petrochemical similarities and differences (Walker, 1969b), and the magnetostratigraphy is different within basalt sections of each area (Watkins and Baksi, 1974).

Correlation among units is tenuous in areas east of Harney Basin except where the Devine Canyon Ash-flow Tuff can be recognized. The Miocene ashy and pumiceous sedimentary rocks underlying the Devine Canyon Ash-flow Tuff are nearly equivalent to the Juntura and Drip Spring Formations of other authors and are probably the temporal equivalents of the Deer Butte Formation of Kittleman and others (1965). The 19.7-m.y. age on the Deer Butte Formation (pl. 1) is considered to be in gross error, inasmuch as the best dates on the underlying Owyhee Basalt range from 15 to 13 m.y. (Laursen and Hammond, 1974) and are most likely between 13.9 and 13.1 m.y. (Watkins and Baksi, 1974, p. 171 and table 10). From currently available geologic data, the Owyhee Basalt seems to occur in a distinct volcanic pile, but all or part of the sequence may be equivalent to upper parts of the basalt and andesite sequence in Harney Basin and to the basement complex of the Juntura Basin. Nonetheless, paleomagnetic data suggest that the Steens Basalt (which represents a significant part of the basalt and andesite sequence) and the Owyhee Basalt are characterized by separate polarity intervals (Watkins and Baksi, 1974). Tuffs and tuffaceous sedimentary rocks situated between the Devine Canyon and Rattlesnake Ash-flow Tuffs, including the Prater Creek Ash-flow Tuff and several unnamed or informally named, areally limited ash-flow tuffs in Harney Basin, correlate in Juntura Basin with the Drewsey Formation; in Harper Basin with the Grassy Mountain Formation of Kittleman and others (1965) and probably with upper parts of the Bully Creek Formation; in the Owyhee Reservoir area, with the Grassy Mountain Formation of Kittleman and others (1965); and with the Idavada Volcanics of the western Snake River plain (pl. 1).

The Harney Formation as redefined in this paper, as well as other volcanic and sedimentary units younger than the Rattlesnake Ash-flow Tuff, appear to be too limited geographically and too diverse lithologically to permit meaningful correlations with sections in adjacent basins.

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