CENOZOIC STRATIGRAPHY OF THE OWYHEE REGION, SOUTHEASTERN OREGON

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MUSEUM OF NATURAL HISTORY
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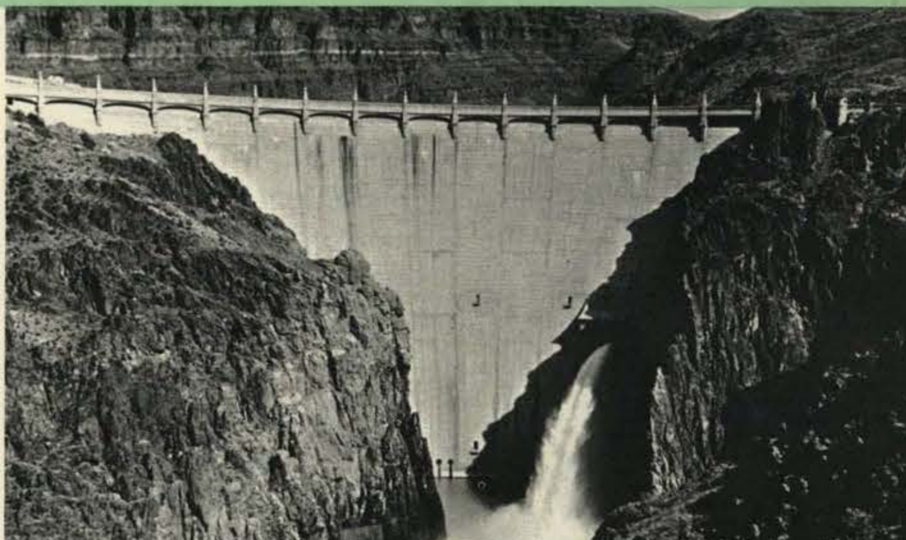

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ABSTRACT

Late Cenozoic terrestrial sedimentation and volcanism produced more than 6000 ft of complexly interstratified rocks in the Owyhee region, southeastern Oregon. Deposition upon a basement of peripherally exposed Paleozoic and Mesozoic rocks began in Miocene time and continued intermittently through the Pleistocene. High-angle block faulting related to the adjacent Basin and Range Province created hundreds to thousands of feet of structural relief. Faulting and concomitant erosion formed north-trending basins that received Miocene, Pliocene, and Pleistocene deposits.

The rocks described range from late Miocene to sub-historic. They are dated through mammalian chronology, stratigraphic relations, and potassium-argon chronology. About 30 stratigraphic units are discussed, of which 12 are named and defined. Extrusive rocks are olivine-poor clinopyroxene basalts, porphyritic andesine rhyolites, and rhyolitic welded ash-flow tuffs. Clastic rocks are arkoses, granite-cobble conglomerates, air-fall tuffs, and fluviatile and lacustrine bentonitic volcaniclastic rocks variously adulterated with plutonic detritus.

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Cenozoic Stratigraphy of the Owyhee Region, Southeastern Oregon

by

LAURENCE R. KITTLEMAN, ARTHUR R. GREEN, ALLEN R. HAGOOD, ARVID M. JOHNSON, JAY M. MCMURRAY, ROBERT G. RUSSELL, AND DENNIS A. WEEDEN

INTRODUCTION

This paper is a compilation of portions of the senior author's thesis (L. R. Kittleman, 1962, Ph. D. thesis Univ. of Oreg.) and six theses written by the co-authors in collaboration with the senior author (A. R. Green, 1962; A. R. Hagood, 1963; A. M. Johnson, 1961; J. M. McMurray, 1962; R. G. Russell, 1961; D. A. Weeden, 1962; *all* M.S. theses, Univ. of Oreg.). Field work began in the summer of 1958 and continued intermittently through the summer of 1964. Any errors in compilation or interpretation are the responsibility of the senior author.

The territory considered here as the Owyhee region is primarily in Malheur County, southeastern Oregon (Fig. 1). The region is a rugged upland with an elevation of about 4500 feet that is drained principally by the Malheur and Owyhee rivers, which are tributaries of the Snake River. Annual precipitation of about 10 inches and temperature that ranges from about −30 to +110°F. foster a habitat dominated by sagebrush, grass, and juniper. Elevations range approximately from 2400 to 6500 feet. The region is desolate, and hard-surfaced roads merely traverse the periphery (Fig. 1). Many of the unpaved roads in the interior (Fig. 2) are seasonally impassable, and access at all seasons is best by four-wheel-drive vehicle.

The Owyhee region is bounded on the north by the Blue Mountains, on the east by the western Snake River Plain (Malde, 1959), and on the southwest by Steens Mountain and

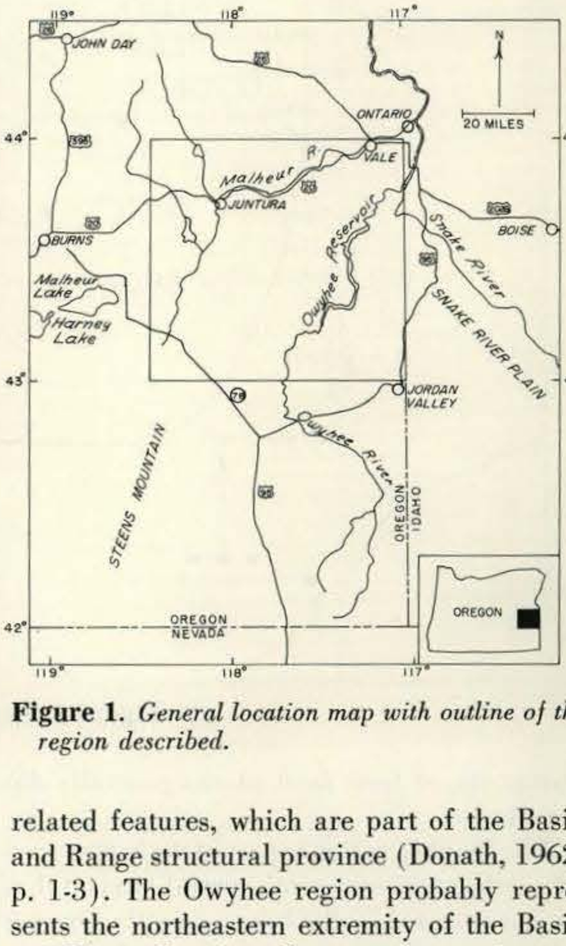

Figure 1. *General location map with outline of the region described.*

related features, which are part of the Basin and Range structural province (Donath, 1962, p. 1-3). The Owyhee region probably represents the northeastern extremity of the Basin and Range Province, but its structure is complicated by interaction with structures of adjoining provinces. The region is dominated structurally by block faulting of northerly, northeasterly, and northwesterly trends. Dips greater than 30° are rare, and dip is produced mainly by tilting of fault blocks and by drag along faults. Vertical displacement of individual faults is measured in hundreds, rarely

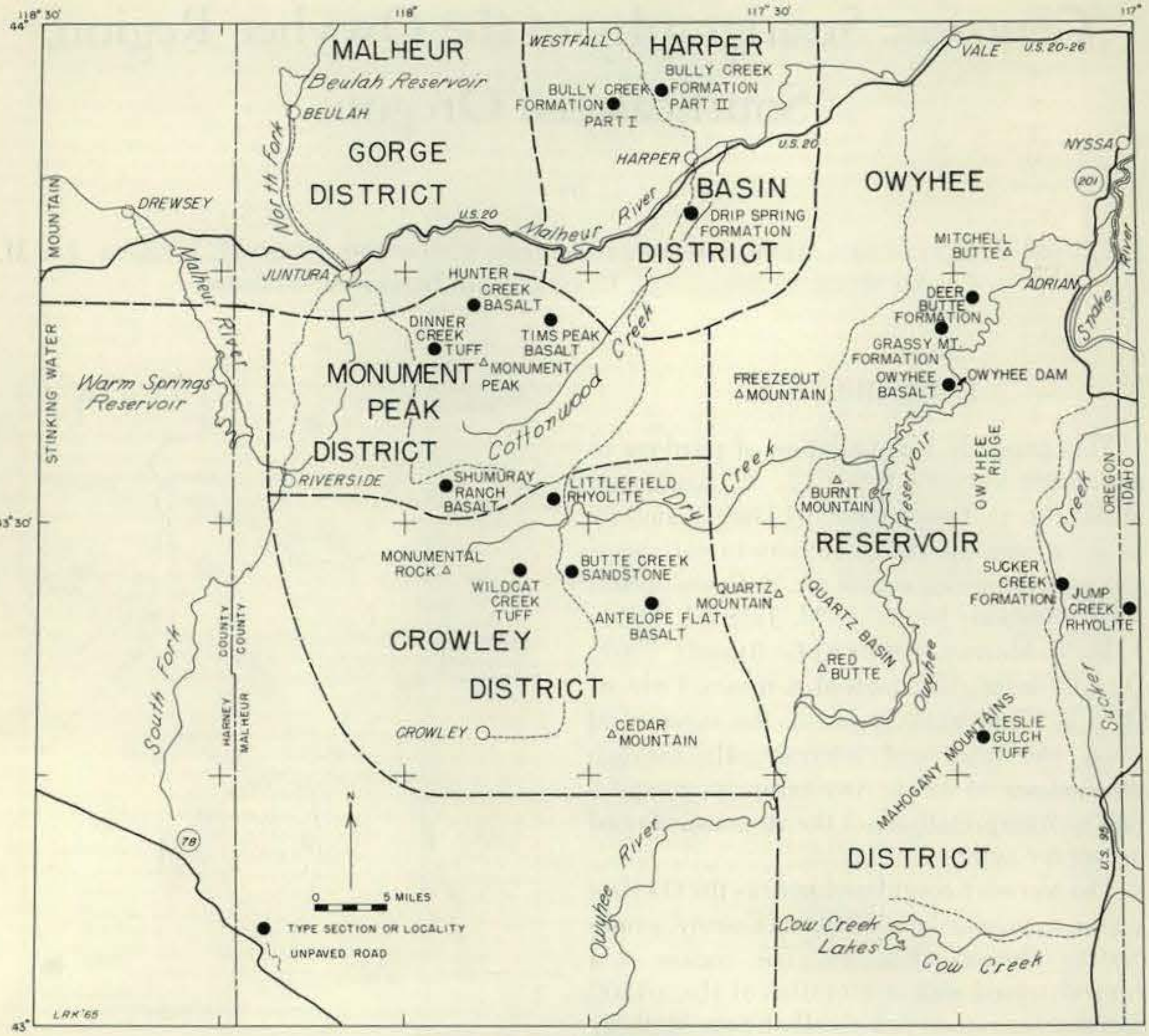

Figure 2. *Regional index map.*

thousands, of feet; fault planes generally dip steeply.

The Owyhee region is part of the larger area of southeastern and south-central Oregon that is characterized by flat-lying or gently dipping continental extrusive and fragmental volcanic rocks of Miocene, Pliocene and Pleistocene age. Exposures of Mesozoic and Paleozoic rocks occur marginally in the Pueblo Mountains, south of Steens Mountain; in the Blue Mountains; and in adjacent parts of western Idaho.

The rocks considered in this paper range in age from late (possibly middle) Miocene through Pleistocene, and are dated through mammalian fossils, stratigraphic relations, and potassium-argon chronology. They are a complex sequence of lenticular intercalated basalt; rhyolite; rhyolitic ash-flow tuff; autoclastic, fluviatile, lacustrine, and air-fall volcaniclastic deposits; and diatomite. The thickness exposed in a single section is not more than about 2000 feet.

In general the stratigraphic sequence described here is believed to have been formed as follows: Thick (many hundreds or thousands of feet), extensive, multiple-flow basaltic and rhyolitic bodies were extruded in Miocene time, and formed the structural foundation for further accumulation. In later Miocene time, these basal volcanic platforms were deformed into elongate basins and ridges by north-trending step faults, and dissected by erosion. Sedimentary deposition in the basins began in late Miocene time and continued, with local interruptions, into the Pliocene. Accumulation was accompanied by frequent, but sporadic, extrusions of thin (tens of feet) flows of basalt and ash-flow tuff, and by intrusions of basalt and peperite (*peperite: See* Carozzi, 1960, p. 86-91). Filling of some of the basins was complete by middle Pliocene time, and thin, plateau-forming basalts covered former ridges in later Pliocene and Pleistocene time.

Geologic studies within the Owyhee region prior to this investigation are few. Bryan (1929) considered the geology in the vicinity of the present site of Owyhee Dam (Fig. 2), and Renick (1930) discussed some aspects of the geology of the eastern part of the region. Work by Kirkham (1931a, 1931b) was restricted mainly to the western Snake River Plain. R. E. Corcoran, R. A. Doak, P. W. Porter, F. I. Pritchett, and N. C. Privrasky mapped the geology of parts of the Mitchell Butte quadrangle (Fig. 3) (*all* 1953, M.S. theses, Univ. of Oreg.). The geology of the Beulah area was mapped by R. G. Bowen (1956, M.S. thesis, Univ. of Oreg.); the Drinkwater Pass area by W. L. Gray (1956, M.S. thesis, Univ. of Oreg.); and the Stinking Water Creek area by C. D. Gregory (1962, M.S. thesis, Univ. of Oreg.) (Fig. 3). Shotwell (1963) studied the paleontology of the Juntura area (Fig. 2) and included a summary of the work of Bowen, Gray, and Gregory. The stratigraphy of the western Snake River Plain was described by Malde and Powers (1962). A geologic map of the Mitchell Butte quadrangle was presented by Corcoran and others (1962). The Owyhee upland area is described by Baldwin (1964, p. 125). For a more complete discussion of previous work, see Kirkham (1931a) and L. R. Kittleman (1962, Ph. D. thesis, Univ. of Oreg.).

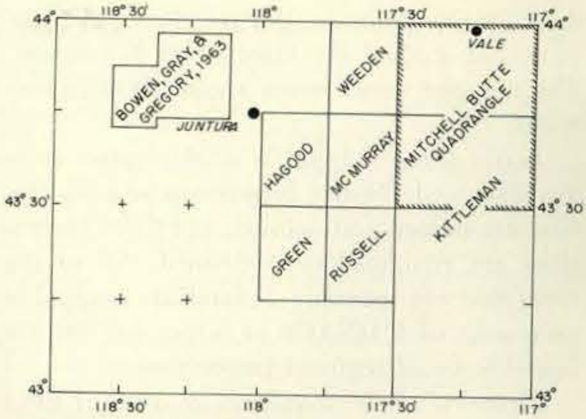

Figure 3. *Responsibility map.*

ACKNOWLEDGEMENTS

This study was sponsored by the Museum of Natural History, University of Oregon, principally through grants and programs of the National Science Foundation. The authors are indebted to the Department of Geology, University of Oregon, for the use of equipment and facilities.

Appreciation is expressed to J. A. Shotwell, Museum of Natural History, University of Oregon, for identification and interpretation of mammalian fossils and for much other assistance during all phases of this study. The authors are grateful for information and discussion contributed by G. H. Haddock, Department of Geology, University of Oregon; H. E. Malde, U. S. Geological Survey, Denver, Colorado; D. H. McIntyre, Department of Geology; Washington State University; and G. W. Walker, U. S. Geological Survey, Menlo Park, California. Field and laboratory assistants were G. H. Haddock, D. L. Hicks, H. C. Hixson, and G. L. Millhollen.

STRATIGRAPHY

General Statement

The stratigraphy discussed here was developed during areal geologic mapping by the authors. The area for which each is responsible is shown in Figure 3, along with areas mapped previously by others. One of the authors, A. M. Johnson, did not do areal mapping, but studied the Deer Butte Formation. The mapped area covers about 3000 square miles.

Thirty three mappable stratigraphic units are discussed. Twelve formations and 8 members are named and defined, and three formations are re-named or re-defined. All of the units that are formally defined are mappable on a scale of 1:125,000 or larger and are believed to be of regional importance.

Elements of the sequence, because of their continental volcanic origin, are inherently lenticular, discontinuous, complexly related, and independently distributed. The authors believe that the best approach in such a stratigraphic province is to apply separate formal or informal names to igneous units that are petrogenically distinct and to sedimentary units that are deposited in separate basins. Even lithologically similar bodies of sedimentary rock in adjacent basins may have different chronologic boundaries and stratigraphic sequences. It has been our practice to apply separate names to bodies of rock that have not been shown to be consanguinous or laterally contiguous between basins. In at least one case, that of the distinction between the Grassy Mountain Formation and the Antelope Flat Basalt, later work has demonstrated the validity of this approach.

Petrographic terms used in this paper conform to general usage, except those for volcaniclastic rocks, which are according to the system proposed by Fisher (1961), but with modifications from Hay (1952). In the present article use is frequently made of Fisher's terms, "volcanic sandstone" and "volcanic conglomerate," which indicate textural attributes and the presence of volcanic particles but do not connote the mode of genesis of the rock. The term, "epiclastic volcanic sandstone," however, describes a rock that consists primarily of sand-size particles of previously-existing volcanic rock; and the term "tuff," connotes an indurated rock composed of sand-size particles produced by volcanic explosion and deposited as an ash-fall (*See* Fisher, *op. cit.* for details of the classification). Hay (1952) has suggested that rocks which are mixtures of volcanic and non-volcanic particles be described by the adjectives, "rich," "medium," or "lean," according as they contain more than 80, 20 to 80, or less than 20 percent volcanic material, respectively. Thus lean volcanic sandstone is a sandstone that contains less than 20% volcanic particles.

Ash-flow tuffs are described by the terminology of Smith (1960) and Ross and Smith (1961). Names of colors are from the Rock Color Chart (Goddard and others, 1951).

The composition of some rocks in the Owyhee region is between that of typical basalt and that of typical andesite. Color index is not a suitable criterion because many of the rocks contain glass, which may have occult mafic constituents; and chemical analyses are not numerous enough to be used as a basis of classification. In this paper, a rock will be called basalt if the plagioclase of the groundmass is more calcic than An_{49}, as determined by measurement of maximum extinction angles in albite twins.

The mineralogic compositions that are given for igneous rocks are averages of modal analyses based upon at least 500 points per thin section. Silica content is estimated by the glass-bead method (Kittleman, 1963).

The Owyhee region consists of sub-areas that have distinct stratigraphic columns, so it is not possible to present a single stratigraphic section that meaningfully represents the whole region. For this discussion, the region is subdivided into districts based upon lateral discontinuity of stratigraphy (Fig. 2). The exact boundaries are arbitrary, and the districts have no significance other than convenience for discussion. The generalized stratigraphic column that represents each district is given in Figure 4.

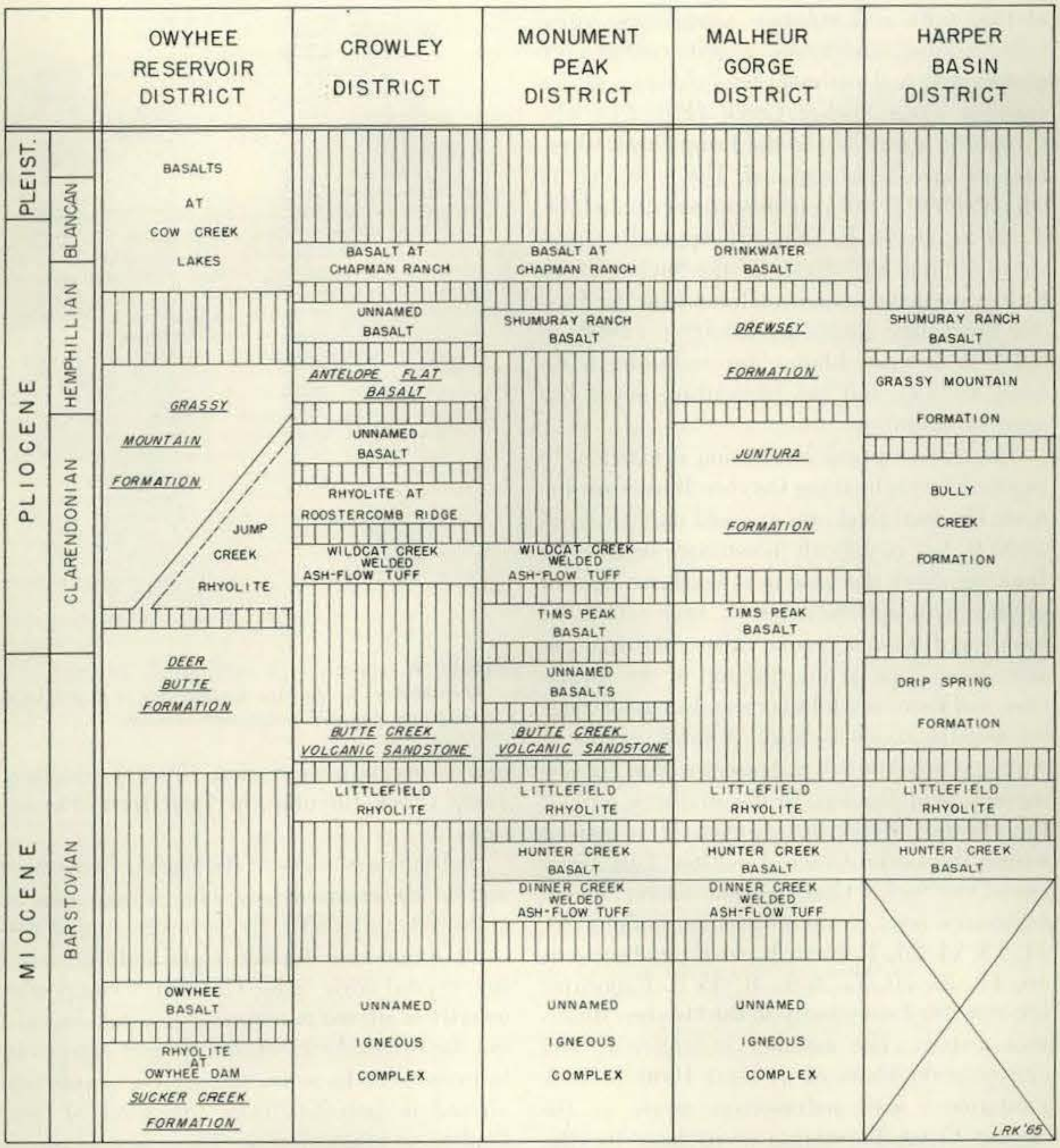

Figure 4. *Regional correlation chart of principal stratigraphic units discussed in this paper. Stratigraphic units that are paleontologically controlled are underscored. Not to scale.*

Owyhee Reservoir District

SUCKER CREEK FORMATION: The name Sucker Creek[1] Formation is given here to the altered tuffs and volcanic sandstones, vitric tuffs, arkose sandstones, granite-cobble conglomerates, and carbonaceous volcanic shales exposed along Sucker Creek (Fig. 2).[2] The formation is overlain by the Jump Creek Rhyolite; its base is not exposed. The type section, which is 590 ft thick, is in sections 28 and 33, T. 24 S., R. 46 E. (Fig. 5; Appendix, measured section A).[3] Strata of the Sucker Creek Formation have been correlated with the Payette Formation named by Lindgren (1898, p. 632) in western Idaho (for example, Kirkham, 1931a), but the correlation never has been substantiated.

The Sucker Creek Formation is extensively exposed throughout the Owyhee Reservoir district. The total thickness exposed may be about 1600 ft, but is difficult to estimate because of faulting. Near the base is at least one flow of olivine-poor, aphanitic basalt, here called the basalt at Bishop's ranch. Other extrusive basalts occur locally near the top of the formation, and there is a tabular rhyolitic body near the middle at one locality. A thick, extensive rhyolitic ash-flow tuff is present within the formation, near the top, in the southern part of the Owyhee Reservoir district. It is named herein the Leslie Gulch Ash-Flow Tuff Member of the Sucker Creek Formation for typical exposures near Leslie Gulch in sections 10, 11, 13, 14, 24, T. 26 S., R. 44 E., and sections 16, 17, 19, 20, T. 26 S., R. 45 E. Exposures are restricted essentially to the Owyhee Reservoir district. The member is lenticular and attains a thickness of at least 1000 ft. It is gradational with sedimentary strata of the Sucker Creek Formation at its base locally,

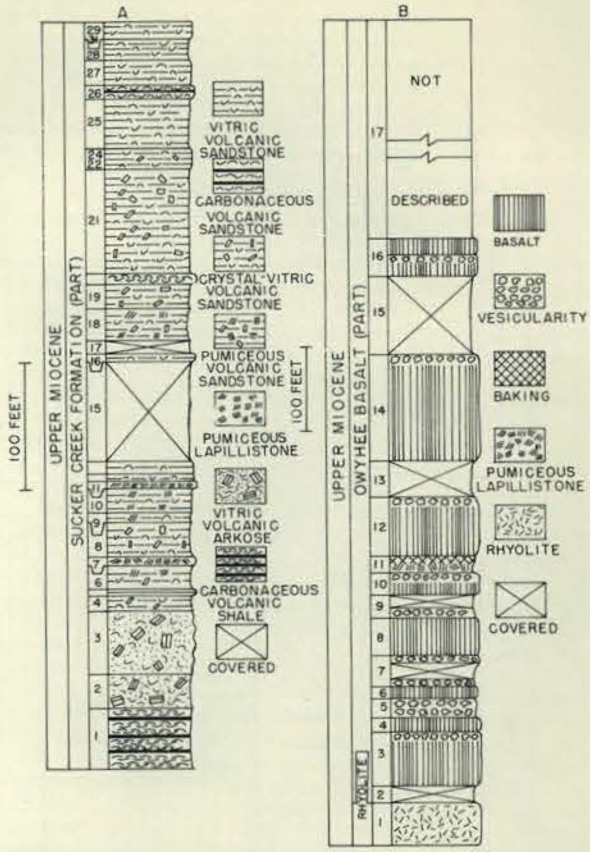

Figure 5. *Graphic type sections. A. Sucker Creek Formation; B. Owyhee Basalt. See text for locations and detailed measured sections.*

and is overlain by Sucker Creek Formation, Jump Creek Rhyolite, or Deer Butte Formation.

Sedimentary rocks of the Sucker Creek Formation are a varied assemblage dominated by yellowish-gray (5Y7/2), severely altered volcanic sandstones derived from andesine-bearing crystal-vitric ash. The vitric component usually is altered to montmorillonite minerals, but the original vitroclastic texture commonly is preserved. In some beds, glass shards are altered to pseudomorphs composed of heulandite or clinoptilolite. There are strata of slightly altered, crystal-poor vitric ash in which the shards are transparent and have an index of refraction of about 1.50. The arkosic rocks, which have a sparse volcanic component of montmorillonite, (authigenically derived from volcanic glass) glass shards, sanidine, and

[1] The original spelling, "Succor," occasionally is used locally; however, the spelling, "Sucker," is used on the Mitchell Butte quadrangle of the U. S. Geological Survey.

[2] The definition given in this article is identical to that in the senior author's thesis (L. R. Kittleman, 1962, Ph.D. thesis, Univ. of Oreg.; Dissertation Abstracts, XXII, 12, 1962).

[3] Civil-grid designations refer to the Willamette Meridian, Malheur County, Oregon, *unless otherwise indicated.*

andesine, mainly contain quartz, plagioclase (probably oligoclase), biotite, and muscovite. These are believed to be derived from granitic batholithic rocks to the east. The sedimentary rocks of the Sucker Creek Formation probably are mainly fluviatile, but subordinate thinly laminated and carbonaceous strata suggest lacustrine deposition.

The Leslie Gulch Ash-Flow Tuff Member is composed of sparse phenoclasts of quartz and sanidine in an altered vitroclastic matrix, and it has the characteristics of ash-flow tuff described by Ross and Smith (1961). The rock is always at least moderately indurated, but it seldom shows characteristics of welding or compression (Ross and Smith, 1961, p. 8), and it may be a *sillar*, as described by Ross and Smith (1961, p. 5, 14). Locally it is severely silicified and the vitroclastic texture is obliterated, perhaps secondarily or deuterically in the zone of vapor-phase crystallization (Smith, 1960, p. 152).

Assignment of the Sucker Creek Formation to the late Miocene is based upon Barstovian mammalian fossils of the Sucker Creek fauna collected near the type locality by Scharf (1935) and by J. A. Shotwell (UO 2409)[4] (written communication, April 1961). The formation also contains the Succor (*sic, See* footnote 1) Creek flora, of Mascall age (middle-late Miocene) (Chaney, 1959, p. 113). A basalt in the Sucker Creek Formation, possibly equivalent to that at Bishop's ranch, has provided a potassium-argon age of 16.7 m.y. (Evernden and James, 1964, p. 971, sample KA 1285).

JUMP CREEK RHYOLITE: The name Jump Creek Rhyolite is given in this paper to the grayish-red to gray porphyritic rhyolite exposed in the type area, near the origins of Jump Creek, in sections 4, 5, 8, 9, T. 1 N., R. 5 W., and sections 27, 28, 33, 34 T,. 2 N., R. 5 W., Boise Meridian, Owyhee County, Idaho. The unit ranges from about 100 to perhaps as much as 800 ft in thickness. It is underlain by the Sucker Creek Formation and forms surficial exposures throughout most of its extent, except near Cow Creek Lakes, where it is overlain by thin extrusive basalts of late Pliocene and Pleistocene age. The rhyolite is widely exposed within the Owyhee Reservoir district. Rocks of the Jump Creek Rhyolite were named Owyhee Rhyolite by Kirkham (1931b, p. 579); however, the term "Owyhee" is preoccupied by the name "Owyhee Basalt" (Bryan, 1929, p. 52).

The Jump Creek Rhyolite is a grayish-red (5R4/2), pale-red (5R6/2), medium dark-gray (N4), pale purplish-gray (5P7/1), or brownish-gray (5YR4/1) porphyritic andesine rhyolite. Its lithology is heterogeneous but broadly consistent. The groundmass is partially or completely devitrified glass, commonly with eutaxitic crystallites, pigmented with unaltered or hematitized magnetite grains that range in size from dust to 2 mm. Phenocrysts, which form about 10% of the rock, are predominately subhedral andesine laths as much as 5 mm long. Microphenocrysts of hypersthene, apatite, zircon, sanidine, and quartz are present sporadically. The rock usually has pronounced flow foliation expressed as planes of parting and as banding of iron-oxide pigments. The unit is a prominent mesa former.

Chronologic relations of the Jump Creek Rhyolite are ambiguous. In the type area it overlies the late Miocene Sucker Creek Formation, but its relation to the late Miocene Owyhee Basalt, which also directly overlies the Sucker Creek Formation, is unknown. The rhyolitic body at Owyhee Dam is superficially similar to the Jump Creek, but is not certainly related to it. At a locality on the western margin of the Snake River Plain, the Jump Creek Rhyolite appears to underlie the early Pliocene Poison Creek Formation, but, at nearby localities, the rhyolite overlies strata also assigned to the Poison Creek Formation. At present, it can be concluded only that the Jump Creek Rhyolite is younger than the Sucker

[4] Fossil-locality number, Museum of Natural History, University of Oregon.

Creek Formation (late Miocene) and older than the basalts at Cow Creek Lakes (late Pliocene through Pleistocene). The Jump Creek Rhyolite may be laterally equivalent to part of the Idavada Volcanics defined by Malde and Powers (1962, p. 1200), of the western Snake River Plain. The Idavada Volcanics are believed to be of early Pliocene age (Malde and Powers, 1962, p. 1201).

OWYHEE BASALT: The Owyhee Basalt was named by Bryan (1929, p. 52) for the thick, multiple-flow basalt exposed in the Owyhee River gorge near Owyhee Dam, but a type section was not selected. The section near the west abutment of Owyhee Dam is designated here as the type section (Fig. 5; Appendix; measured section B). It is in the SE 1/4 sec. 20, T. 22 S., R. 45 E. The Owyhee Basalt, as considered here, includes the Blackjack Basalt of Bryan (1929, p. 55). The two units are petrographically gradational, and they are not differentiable for mapping.

The unit is exposed continuously in the central part of the Owyhee Reservoir district (Fig. 2), where it attains a thickness of about 1300 ft and contains as many as 12 flow units. It is overlain by strata of the Deer Butte and Grassy Mountain formations on the west and north and is truncated by erosion on the south.

The basalt is composed of multiple flow units of pilotaxitic, intersertal and intergranular, microporphyritic, olivine-poor basalt. Flows characteristically have scoriaceous tops, and there are interbeds of altered vitric tuff and pumiceous lapillistone. The lower flow units are ophitic and contain more olivine. Upper units are trachytic and foliated and are pyroxene and olivine poor. The silica content of the Owyhee Basalt ranges from about 50% in the lower flow units to 60% in the upper, even though the smallest determinable plagioclase laths in the upper units are labradorite.

The Owyhee Basalt is underlain by the Sucker Creek Formation and overlain by the Deer Butte Formation, both of which contain mammalian faunas of Barstovian (late Miocene) age. Although the unit has been correlated variously with the basaltic sequence in the vicinity of Steens Mountain (Fig. 1) and with basalts exposed in Malheur Gorge, here called the unnamed igneous complex, neither correlation has been demonstrated.

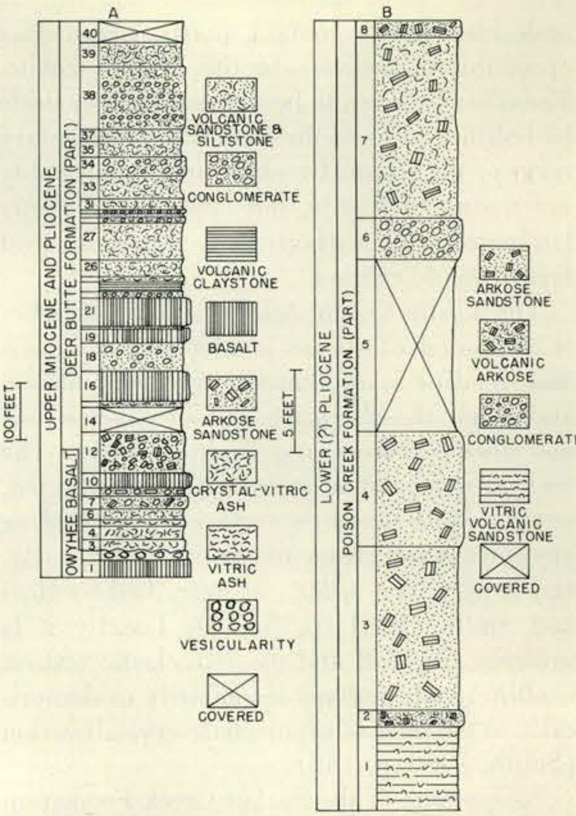

Figure 6. *Graphic type sections. A. Deer Butte Formation; B. Poison Creek Formation. See text for locations and detailed measured sections.*

DEER BUTTE FORMATION: The name Deer Butte Formation is given here to the assemblage of altered volcaniclastic rocks, extrusive basalts, arkose sandstones, and granite-cobble conglomerates exposed at Deer Butte (Fig. 2), the type locality, in E 1/2 sec. 21, T. 21 S., R. 45 E. (Fig. 6; Appendix, measured section E).[5] The unit is underlain unconformably by the Owyhee Basalt and is overlain unconformably by the Grassy Mountain Formation, the base of which is marked by white pumiceous lapil-

[5] The definition given in this article is identical to that in the senior author's thesis (L. R. Kittleman, 1962, Ph.D. thesis, Univ. of Oreg.; Dissertation Abstracts, XXII, 12, 1962).

listone or by friable arkose sandstone. The Deer Butte Formation is part of the Idaho Group defined by Malde and Powers (1962, p. 1202).

The Deer Butte Formation is exposed extensively in the western part of the Owyhee Reservoir district. It is 950 ft thick at the type locality, but at least 2000 ft is exposed locally, and the aggregate thickness may be 3000 ft.

The formation is subdivided here into seven named members (ascending order): (1) The Red Butte Member is named for exposures on the northwestern side of Red Butte, the type section (SE 1/4 sec. 22, T. 25 S., R. 43 E.). (2) The Orlano Spring Member is named for exposures at the type section, near Orlano Spring (E 1/2 sec. 15, T. 25 S., R. 43 E.). (3) The name Holdout Member is given to strata exposed at the type section (SW 1/4 SE 1/4 sec. 28, T. 24 S., R. 43 E.). (4) The name Quartz Mountain Basalt Member is given to the extrusive basalt at the type locality, on the slope of Quartz Mountain (SW 1/4 sec. 32, T. 24 S., R. 43 E.). (5) The Burnt Mountain Member is named for Burnt Mountain, two miles southeast of the type locality (N 1/2 sec. 23, T. 22 S., R. 43 E.). (6) The name Sourdough Basin Basalt Member is given to the basalt exposed on the southwestern side of Sourdough Basin and at the type locality, on the northern side of Dry Creek inlet (N 1/2 sec. 24, T. 23 S., R. 43 E.). (7) The Mitchell Butte Member is named for exposures on Mitchell Butte (sec. 1, 2 and 12, T. 21 S., R. 45 E.). Descriptions of these members and detailed type sections are given by A. M. Johnson (1961, M.S. thesis, Univ. of Oreg.) and by L. R. Kittleman (1962, Ph.D. thesis, Univ. of Oreg.).

Part of the Deer Butte Formation may be laterally contiguous with strata of the Poison Creek Formation of Buwalda (1923, p. 5) along the western margin of the Snake River Plain. The definition of the Poison Creek Formation (*loc. cit.*) did not include a type section, and exposures near Poison Creek grade (SW 1/4 sec. 16, T. 2 N., R. 5 W., Boise Meridian, Owyhee County, Idaho), beyond the limits of Figure 2, are designated here as the type section (Figure 6; Appendix, measured section F).

The Deer Butte Formation consists of yellowish-brown (10YR5/2) to yellowish-gray (5Y8/1) altered vitric volcanic sandstones, volcanic carbonaceous shales, very pale-orange (10YR8/2) to reddish-brown (10R4/4) arkose sandstones, arkose granite- and chert-cobble conglomerates, laharic breccias, and extrusive basalts (and related shallow basaltic intrusions). The altered volcanic sandstones contain variable proportions of crystal fragments, unaltered silicic and mafic volcanic glass shards, and pumice, in a matrix of montmorillonitic and halloysitic clay minerals. The arkose sandstones have a sparse volcanic component of clay, shards, and crystal fragments. Feldspathic and granitic constituents are believed to be derived from plutonic sources in adjacent parts of Idaho. Vectors from cross stratification are dispersed, but suggest a generally northward direction of transport. Fluviatile and subordinate lacustrine deposition are indicated.

There are two major (Quartz Mountain and Sourdough Basin members) and several minor sheets of extrusive basalt, usually as single flow units 20 to 50 feet thick. These basalts are coarse grained, ophitic, and hypocrystalline. They contain roughly 40% labradorite, 20% clinopyroxene, 5% olivine, 10% opaque minerals, 10% glass, and 10% alteration products.

The basaltic members are near the middle of the formation, and the lower members tend to be fine grained and the upper members more conglomeratic; although each principal lithologic type occurs to some extent in all parts of the formation. Relationships suggest early accumulation of fine-grained material in the deeper parts of the depositional basin and later accumulation of conglomeratic material and encroachment on the margins of the basin.

The major part of the Deer Butte Formation is assigned an age of late Miocene on the basis of mammalian faunas (UO 2465; UO 2430) of Barstovian age; however, the upper part of the unit apparently is Pliocene (probably early Pliocene), since mammalian fossils collected at the type locality of the Poison Creek Formation (UO 2472), believed to be laterally contiguous with the upper part of the Deer Butte Formation, are of Pliocene, probably Clarendonian, age (J. A. Shotwell, written communication, April 1961). The Deer Butte Formation may be at least partly equivalent to the Drip Spring Formation of the Harper Basin district.

GRASSY MOUNTAIN FORMATION: The Grassy Mountain Basalt was named by Bryan (1929, p. 55) for volcaniclastic rocks and intercalated basalts on Grassy Mountain. It is proposed that the name be changed to Grassy Mountain Formation, because the unit is not entirely basalt. The lower boundary of the unit here is extended to include strata of characteristic lithology (and age) that unconformably overlie the Deer Butte Formation. The section designated here as the type is in two parts: (I) The Kern Basin section in SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 36, T. 21 S., R. 44 E., and (II) the Lone Willow Spring section in E $\frac{1}{2}$ sec. 24, T. 21 S., R. 44 E., (Fig. 7; Appendix, measured section I). The formation is part of the Idaho Group defined by Malde and Powers (1962, p. 1202).

The Grassy Mountain Formation is exposed as a prominent mesa former in parts of the Owyhee Reservoir and Harper Basin districts, where it overlies various units of late Miocene or Pliocene age. It is about 1100 ft thick in the composite type section, which may be near the axis of the depositional basin, but it is generally much thinner.

The Grassy Mountain Formation contains very light-gray (N8) pumiceous lapillistone, which characteristically marks the base; yel-

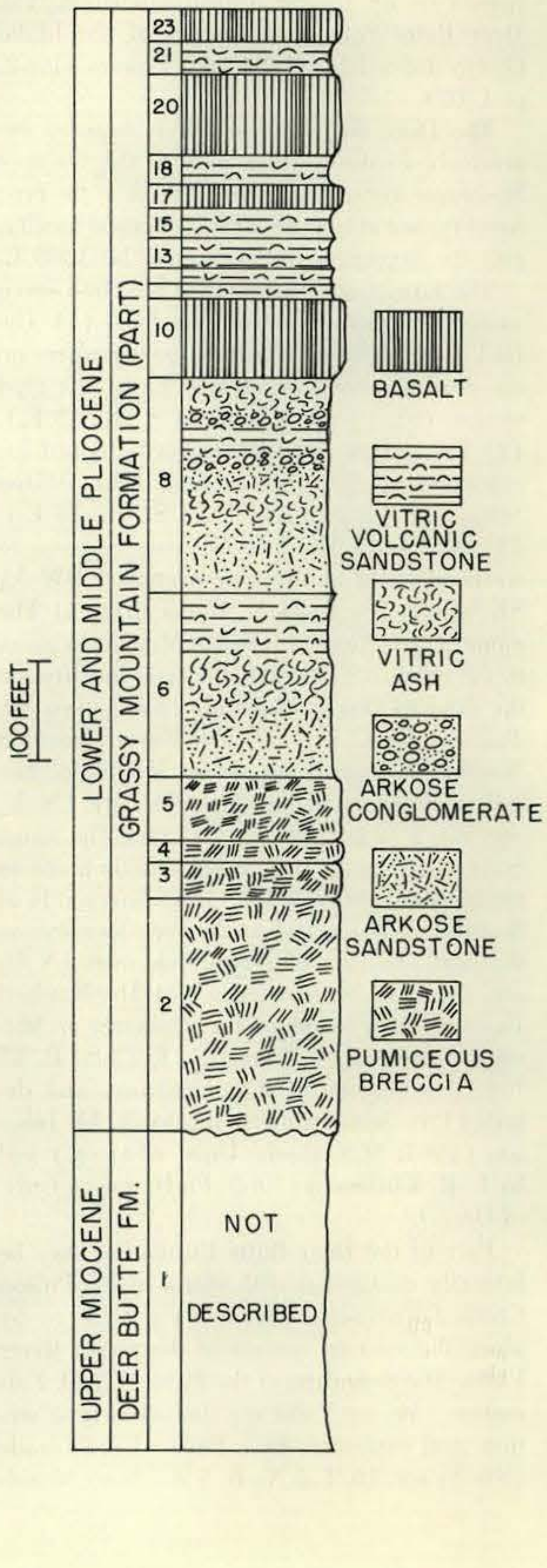

Figure 7. *Graphic type section; Grassy Mountain Formation. See text for location and detailed measured section.*

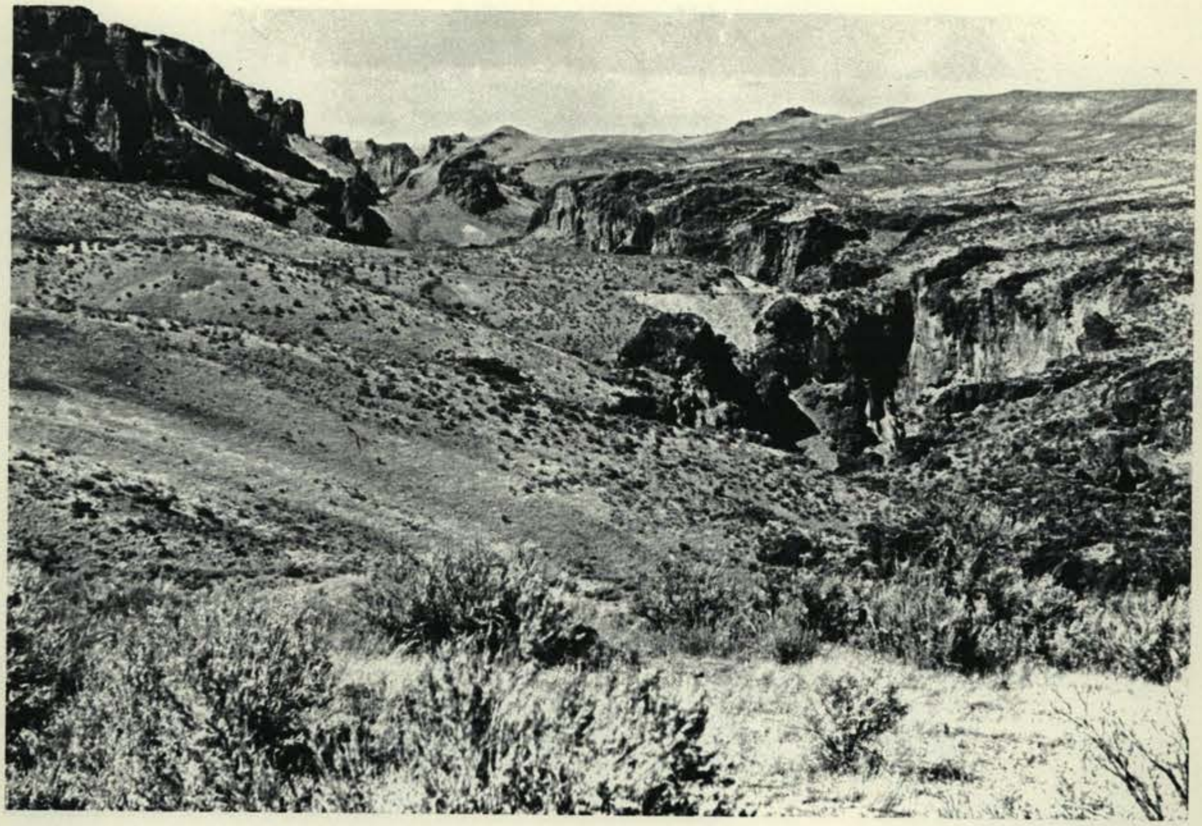

Plate 1. *Sucker Creek Gorge viewed from the south—Sucker Creek flows in a cleft in the Leslie Gulch Member, the top of which can be seen in the right middleground of the photograph. Cliffs of the Jump Creek Rhyolite are visible at the upper left.*

lowish-gray (5Y8/1) friable arkose sandstones with a variable volcanic component; arkose granite-cobble conglomerates; rich volcanic conglomerates; pale yellowish-gray (5Y8/2) vitric volcanic standstones severely altered to montmorillonite minerals; and olivine basalts. The basalts are coarse grained, ophitic, and holocrystalline. They contain about 40% labradorite, 20% clinopyroxene, 15% olivine, 10% opaque minerals, and 15% alteration products. The silica content is about 45%. There are four flow units in the type area.

The Grassy Mountain Formation is assigned to the early and middle Pliocene on the basis of Clarendonian and Hemphillian mammalian faunas (UO 2359; J. A. Shotwell, written communication, April 1961). It is, in part, chronologically correlative with the Antelope Flat Basalt, of the Crowley district, and with the Thousand Creek Formation of Merriam (1910, p. 43) in southern Oregon and northern Nevada.

BASALTS AT COW CREEK LAKES: In the southwestern part of the Owyhee Reservoir district is a sequence of six or eight extrusive olivine basalts here informally called the basalts at Cow Creek Lakes. They generally overlie an eroded surface of Sucker Creek Formation or of Jump Creek Rhyolite. Individual flows are 20 to 50 ft thick and are in contact or separated by thin interbeds of altered tuff. Some flows were eroded and channeled before extrusion of the succeeding flow. The basalts are microdiktytaxitic and intergranular to ophitic. They contain about 40% labradorite, 30% clinopyroxene, 15% olivine, 10% opaque minerals,

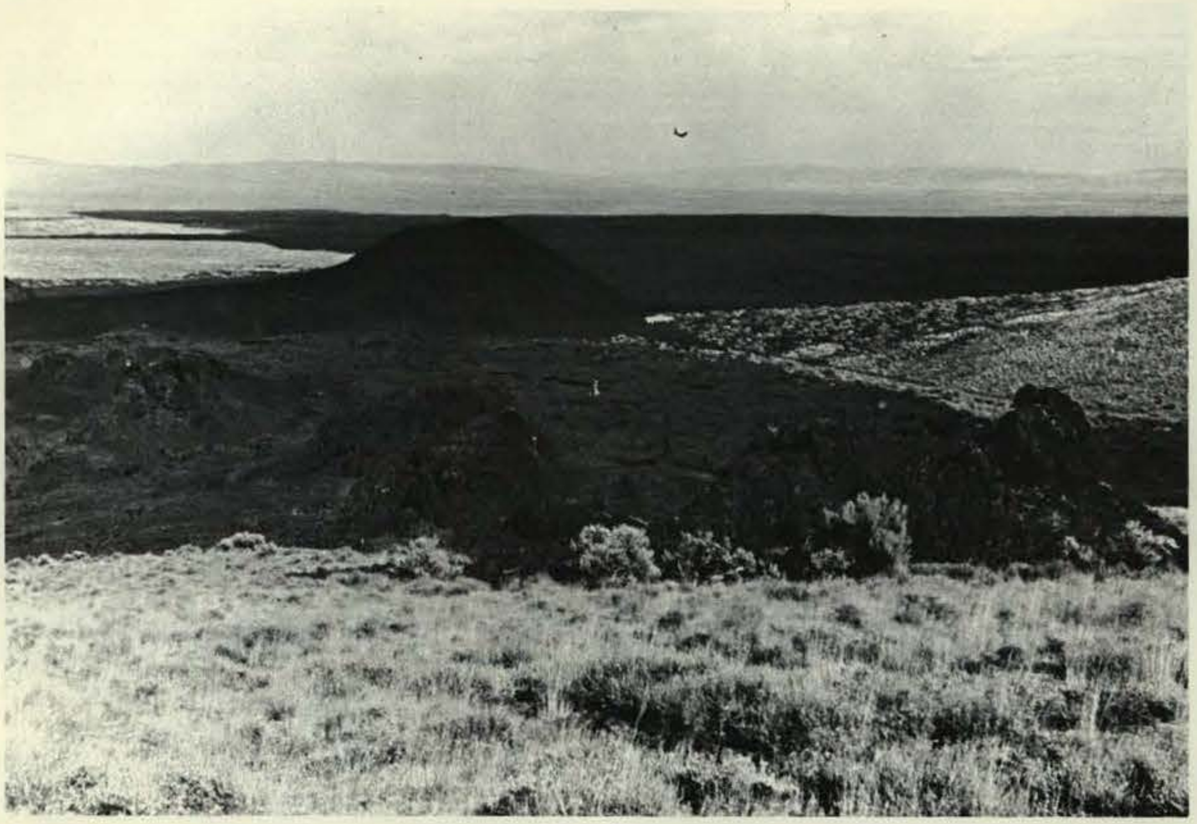

Plate 2. *Morcom Crater and associated lava flows viewed from the west—The basaltic lava that erupted from the vent flowed mainly eastward. A row of spatter cones is visible in the foreground.*

and 10% glass. The silica content is about 45%.

The flows locally overlie the Antelope Flat Basalt, of middle Pliocene age. Surfaces of the older units in the sequence have soils on them equal in development to those on nearby early and middle Pliocene basalts; but the younger units display original surface features in great detail and are nearly free of vegetation. The sequence thus may extend from middle or late Pliocene to sub-historic time.

TOPOGRAPHIC RELATIONS: The rocks of the Owyhee Reservoir district accumulated in a north-trending basin of deposition that persisted at least from late Miocene to middle Pliocene time, though with change in the position of the axis. Rocks older than the basin can be seen only on the eastern extremity in Idaho, where volcanic rocks believed to be of Miocene age overlie Cretaceous granitic rocks.

The present areal distribution of stratigraphic units in the Owyhee Reservoir district is determined by the basinal configuration that is partly depositional and partly structural. Topography is influenced by north-trending normal faults. The oldest Cenozoic rocks exposed, those of the Sucker Creek Formation, are overlain in the north by generally west-dipping Owyhee Basalt, which forms Owyhee Ridge, 5000 ft in elevation, between the Owyhee Reservoir and Sucker Creek (Fig. 2). The lower reach of Sucker Creek occupies a strike valley in the Sucker Creek Formation, but the middle reach is incised in the resistant Leslie Gulch Member (Pl. 1) and, in the south, flows on irregularly dipping and flat-lying Sucker Creek Formation. The Owyhee Basalt becomes

Plate 3. *Pahoehoe lava near the rim of Morcom Crater—The billowy, ropy crust of the lava extends to the eastern rim of the crater in the middle distance. This flow unit is one of the most recent of several that spilled eastward over the rim.*

thinner southward, apparently by progressive deletion of basal units, until the thin edge is truncated by erosion. South of Owyhee Ridge the drainage divide between the Owyhee River and Sucker Creek is composed largely of the Leslie Gulch Member and of Jump Creek Rhyolite, and the ridge merges with the Mahogany Mountains, which attain an elevation of 6500 ft. These are capped by the Jump Creek Rhyolite, which defines a crude, southeast-plunging anticline and is overlapped, at the base of the mountains, by plateau-forming basalts of the Cow Creek Lakes area (Pl. 2, 3).

The lower reach of the Owyhee River flows on the Deer Butte Formation, which overlaps the topographic prominence of the Owyhee Basalt on the west and north and encroaches into the valley of Sucker Creek on the northeast. South of Mitchell Butte, the Owyhee River is incised 1000 ft in Owyhee Basalt and follows a sinuous course for 20 mi through the basaltic highland. The basalt is breached in the vicinity of Owyhee Reservoir (Pl. 4) and underlying rocks are exposed. Near the mouth of Dry Creek, the Owyhee Basalt dips beneath the Deer Butte Formation on the west side of the Reservoir and is truncated on the east side. The valley follows a course determined by fault lineaments as well as by the unconformity between the Deer Butte and Sucker Creek formations that was once the eastern margin of a basin in which the Deer Butte Formation accumulated. West of Owyhee Dam, the Owyhee Basalt is overlain with angular unconformity by the Deer Butte Formation and the Grassy Mountain Formation. The latter forms the faulted, basalt-capped plateaus of Sourdough Mountain, Freezeout Mountain, and Grassy

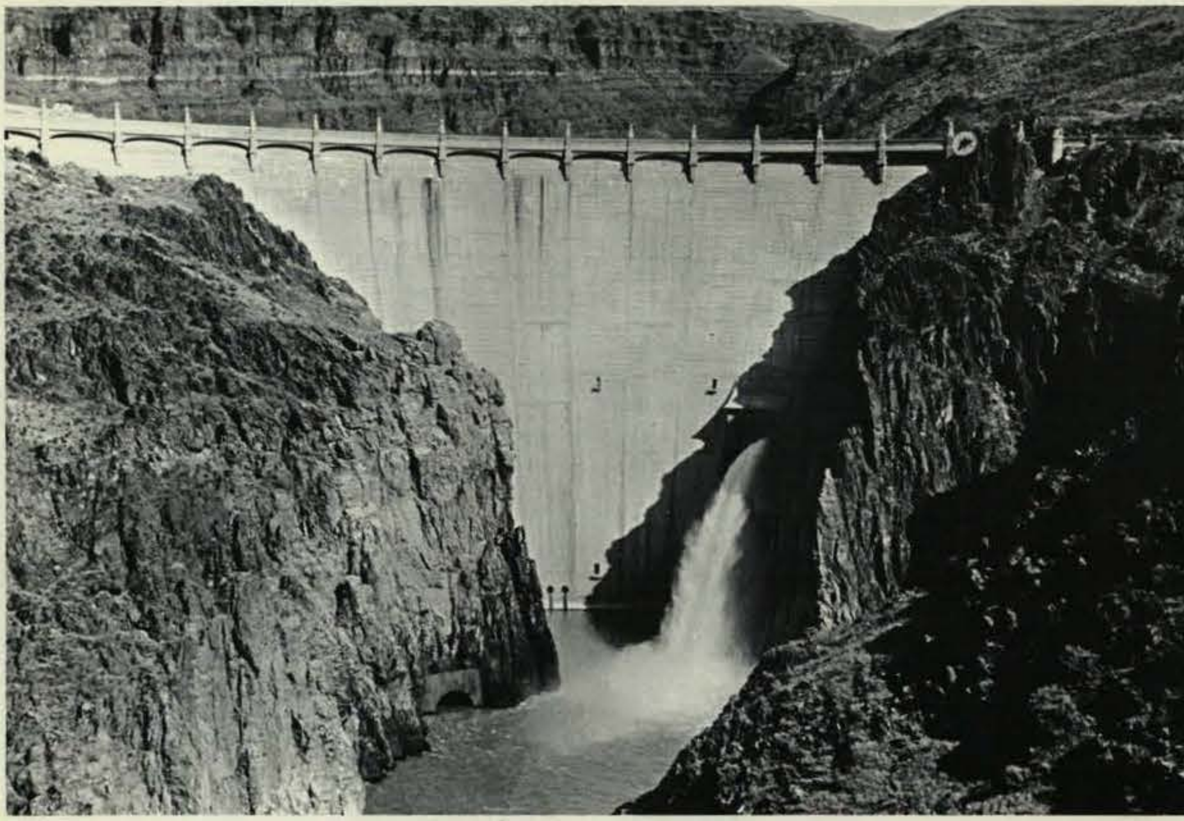

Plate 4. *Owyhee Dam—The abutments of the dam are in flow-foliated rhyolite. Nearly vertical foliation is visible at the abutment on the right. The cliffs above the parapet of the dam are Owyhee Basalt. The thin, white band is a stratum of pumiceous lapillistone.*

Mountain. South of Dry Creek the Grassy Mountain Formation is absent, and heterogeneous, flat-lying strata of the Deer Butte formation, locally disarranged by north-trending faulting, extend to the southern end of Owyhee Reservoir.

Crowley District

UNNAMED IGNEOUS COMPLEX: The oldest exposed stratigraphic unit in the Crowley district is a thick (thousands of feet), multiple-flow basaltic and andesitic assemblage here informally called the unnamed igneous complex. The complex is exposed throughout the Crowley, Monument Peak, and Malheur Gorge district, where it is at least 2000 ft. thick. The unit was deeply dissected to form a surface that must have had, and still has, hundreds of feet of relief. As the name suggests, the unnamed igneous complex is heterogeneous; however, several consistent aspects may be distinguished within it. These are named informally the *autoclastic breccia phase*, the *basaltic breccia phase*, and the *Monumental Rock sequence*. Other parts of the complex are not distinguished by name, and relationships between the various aspects are poorly known.

The *autoclastic breccia phase* is exposed in the central part of the Crowley district, where it is about 600 ft thick. It contains intercalated autoclastic basaltic breccia and dense aphanitic basalt. The rock is intersertal to intergranular, microcrystalline, clinopyroxene basalt with a silica content near 50%.

The *Monumental Rock sequence* is exposed in the central part of the Crowley district and in the southwestern part of the Monument Peak district, and it is believed to overlie the *auto-*

clastic breccia phase. It contains about 600 ft of multiple-flow, porphyritic, intergranular, olivine-clinopyroxene basalt with about 30% phenocrysts of sodic bytownite as much as 15 mm long. The whole-rock silica content is about 50%. This porphyritic unit is gradational upward into foliated, aphanitic, trachytic andesite or andesitic basalt, about 700 ft thick, whose silica content is near 62%.

The *basaltic breccia phase* is exposed in the central part of the Monument Peak district, where it is at least 2000 ft thick. It consists of alternating aphantic and porphyritic basalts and basaltic autobreccias. The rock generally is ophitic to intergranular, hypocrystalline, clinopyroxene basalt, commonly with phenocrysts of labradorite as much as 4 cm long. The silica content is about 50%

In general, the coarsely crystalline aspects of the unnamed igneous complex contain about 40% labradorite, 25% clinopyroxene, 5% olivine, 10% opaque minerals, 10% glass, and 5% alteration products.

The unnamed igneous complex is overlain, indirectly, by rocks which contain mammalian fossils of Barstovian (late Miocene) age.

LITTLEFIELD RHYOLITE: The unnamed igneous complex is overlain, in the Crowley district, by the Littlefield Rhyolite, which is named here for exposures at Littlefield ranch, in sec. 35, T. 23 S., R. 40 E. (Photo Reference: BBC 17N-108, 6.6 N, 3.7 E).[6] The rhyolite is widely distributed in parts of the Crowley, Monument Peak, Harper Basin, and Malheur Gorge districts, where it is prominently exposed in ridges and in canyon walls. Its thickness ranges to nearly 500 ft. It was dissected and block faulted, probably in late Miocene time, and forms basins of deposition for later rocks.

The rock is flaggy, grayish-red (10R4/2) or dark-gray (N3), multiple-flow, porphyritic rhyolite with a silica content of about 70%. It is conspicuously flow foliated, with compositional banding and partings at intervals of a few millimeters to a few centimeters. Foliation locally is slightly folded, chaotically contorted, or auto-brecciated by deformation during emplacement. The matrix is glassy, microlitic, pilotaxitic, and locally spherulitic; and it commonly is completely or irregularly devitrified. There are sparse phenocrysts a few millimeters long of sanidine, intermediate plagioclase, orthoclase, clinopyroxene, hypersthene, and magnetite. The groundmass is pigmented by finely disseminated magnetite, hematite-rimmed magnetite, and hematite. The rock contains layers and auto-intrusions of black, perlitic vitrophyre. Although the unit is exceptionally wide spread, no petrographic evidence that it is an ash-flow tuff is apparent.

The Littlefield Rhyolite is overlain, probably unconformably, by rocks of the Butte Creek Volcanic Sandstone, which contain Barstovian (late Miocene) mammalian fossils; no fossils have been found in underlying rocks. Although the Littlefield Rhyolite resembles the Jump Creek Rhyolite lithologically and may occupy a similar stratigraphic position, study of heavy-mineral suites suggests that the two rhyolitic units are not related.

BUTTE CREEK VOLCANIC SANDSTONE: The name Butte Creek Volcanic Sandstone is given here to volcanic sandstones and volcanic-pebble conglomerates exposed along Butte Creek and at the type locality, in the SW$\frac{1}{4}$ sec. 23, T. 24 S., R. 40 E. (Fig. 8; Appendix, measured section D). The Butte Creek overlies the Littlefield Rhyolite and is overlain by the Wildcat Creek Ash-Flow Tuff. The unit is flat lying or gently dipping and thinly mantles the Littlefield Rhyolite in the eastern part of the Crowley district. It usually is concealed by soil and is exposed sporadically in shallow gullies. No complete exposed section is known. The type section is about 50 ft thick, and the total thick-

[6] The Photo Reference permits location on aerial photographs. BBC indicates Soil Conservation Service 1:20,000 photography and AMS indicates Army Map Service 1:54,000 photography; both are followed by the photograph number. Decimal numbers and directions indicate coordinate distance in inches respectively north (N) and east (E) from the southwestern (lower-left) corner of the contact print.

ness of the unit probably is not more than 100 ft.

The Butte Creek Volcanic Sandstone is composed of thinly to thickly bedded, pale yellowish-gray (5Y8/2), altered vitric volcanic sandstones, volcanic-pebble conglomerates, and laharic breccias. The dominant component is transparent, colorless, silicic glass shards, which are enclosed in a matrix of halloysite-like clay mineral that probably is an alteration product of the glass. There is a subordinate crystal component of sanidine and intermediate plagioclase. The conglomerates contain pebbles of pumice, perlite, and massive glass.

The Butte Creek Volcanic Sandstone contains Barstovian (late Miocene) mammalian fossils of the Skull Springs fauna (Gazin, 1932) and of the Red Ridge Basin fauna (UO 2495; J. A. Shotwell, oral communication, 1961). A potassium-argon determination of sanidine from the rock in the Red Ridge Basin fossil quarry gave an age of 15.1 m.y. (Evernden and others, 1964, p. 190, sample KA 1029).

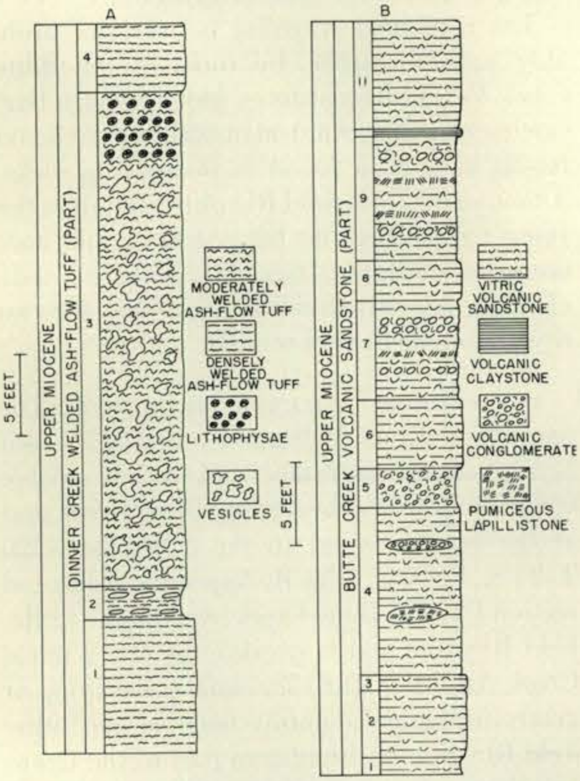

Figure 8. *Graphic type sections. A. Dinner Creek Welded Ash-Flow Tuff; B. Butte Creek Volcanic Sandstone. See text for locations and detailed measured sections.*

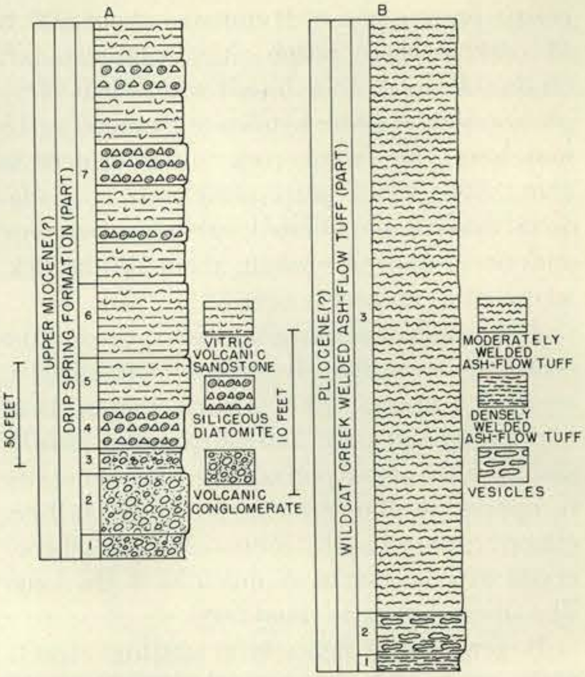

Figure 9. *Graphic type sections. A. Drip Spring Formation; B. Wildcat Creek Welded Ash-Flow Tuff. See text for locations and detailed measured sections.*

WILDCAT CREEK WELDED ASH-FLOW TUFF: The unit that usually overlies the Butte Creek Volcanic Sandstone is the Wildcat Creek Welded Ash-Flow Tuff, which is named here for exposures at the type locality, near the head of Wildcat Creek, in the SW 1/4 NW 1/4 sec. 29, T. 24 S., R. 40 E. (Fig. 9; Appendix, measured section H). The Wildcat Creek occurs as discontinuous ledge- and mesa-forming exposures in the Crowley and Monument Peak districts. Its thickness, including upper and lower zones of no welding (Smith, 1960, p. 154), reaches 200 ft, although only the zones of partial and dense welding are usually exposed.

The unit displays the textures and zonation characteristics of welded ash-flow tuff (Ross and Smith, 1961). The zones of no welding are poorly indurated vitric tuffs. The zones of partial and dense welding are prominent cliff formers. The zone of partial welding has a matrix of grayish-red (5R4/2) and pale reddish-brown (10R5/4), microvesicular rhyolitic ash-flow tuff with compressed, welded, flow-oriented, devitrified shards pigmented with hematite dust. There are abundant black, pumiceous phenoclasts and sparse 1-mm phenoclasts of potassium feldspar and clinopyroxene. This zone locally has chaotic foliation and columnar jointing. The zone of dense welding is medium light-gray (N6) to black perlitic glass with welded vitroclastic texture.

The Wildcat Creek locally overlies two other cooling units (Smith, 1960, p. 157) of welded ash-flow tuff that have limited distribution and that occupy depressions in the dissected surface of the unnamed igneous complex. These units, which are described by A. R. Green (1962, M.S. thesis, Univ. of Oreg., p. 77-82), are crystal-poor, pumiceous, welded ash-flow tuffs that have the characteristic zones of welding and crystallization. Their age is unknown.

The Wildcat Creek Welded Ash-Flow Tuff is underlain by the Butte Creek Volcanic Sandstone, which contains Barstovian fossils, but no fossil-bearing rocks are known to overlie it. Its age may be late Miocene or Pliocene.

RHYOLITE OF ROOSTERCOMB RIDGE: In the north-central part of the Crowley district is a rhyolitic dike and associated flows that form the feature known as The Roostercomb. The body is a dike 100 to 1000 ft wide in its northern part and passes southward into at least two flow units about 150 ft thick. The rock is very dusky-red (10R2/2) to dusky-blue (5PB4/2) porphyritic rhyolite. It has about 5% rounded phenocrysts of quartz in a partly devitrified glassy, microlitic groundmass. There is about 10% basaltic inclusions about 1 cm in diameter that contain labradorite, iddingsitized olivine, hypersthene, clinopyroxene, and opaque minerals. No large- or small-scale flowage structures are apparent. The whole-rock silica content is about 65%.

The rhyolite flow lies on a surface of Wildcat Creek Welded Ash-Flow Tuff and unnamed igneous complex, and the dike intrudes the Wildcat Creek Ash-Flow Tuff, of late Miocene or younger age.

ANTELOPE FLAT BASALT: The Antelope Flat Basalt is named here for exposures near Antelope Flat in the SE¼SW¼ sec. 12, T. 25 S., R. 41 E. Photo Reference: BBC 22N-149, 4.4 N, 5.7 E). The unit is proxene basalt with interbeds of altered volcanic sandstones; there are volcanic standstones and conglomerates at the base locally. It is widely exposed in the western part of the Owyhee Reservoir district and the eastern part of the Crowley district, where it unconformably overlies various units of late Miocene age. Probably there are not more than four flows less than 300 ft in total thickness, but the apparent stratigraphic complexity and thickness are exaggerated by faulting.

The rock is microcrystalline, microporphyritic, intergranular, olivine-poor basalt of laterally and stratigraphically uniform lithology. It contains about 50% labradorite, 15% clinopyroxene, 5% olivine, 5% opaque minerals, and 15% glass. The silica content is about 60%.

Volcaniclastic rocks at the base of the Antelope Flat Basalt contain a Hemphillian (middle Pliocene) mammalian fauna (UO 2451; J. A. Shotwell, oral communication, 1960). The Antelope Flat Basalt is a chronologic equivalent of the Grassy Mountain Formation, and both units apparently lie on the same erosion surface on upper Miocene rocks; however, they are not known to the contiguous and are chemically and petrographically different.

UNASSIGNED BASALTS: Three basaltic units that occur within and adjacent to the Crowley district are of limited areal extent and are given informal names. These are the unnamed basalt southwest of Crowley, the basalt at Seaburn reservoir, and the basalt at Chapman ranch.

The first, apparently the oldest, is limited to a small area southwest of Crowley, where it unconformably overlies the Littlefield Rhyolite, and it is composed of several flow units. The rock is porphyritic, ophitic olivine basalt which contains about 45% labradorite, 20% clinopyroxene, 20% olivine, and 10% opaque minerals. There are phenocrysts of labradorite as much as 2 cm long. The silica content is about 50%. This basalt apparently is older than the Antelope Flat Basalt, since it is cut by faults that do not cut the Antelope Flat.

The basalt at Seaburn reservoir is in the southeastern part of the Crowley district. It appears to have erupted from a small vent about one mile in diameter, and there are several flow units. The rock is glomeroporphyritic, intergranular, olivine basalt, in which labradorite phenocrysts are as long as 8 mm. There is about 40% labradorite, 25% clinopyroxene, 25% olivine, and 5% opaque minerals; and the silica content is roughly 50%. The flows overlie the Antelope Flat Basalt.

The basalt at Chapman ranch is in the western parts of the Crowley and Monument Peak districts and forms the upper rim-rock of the canyon of the South Fork of the Malheur River. It is about 50 ft thick, usually as a single flow unit. It is ophitic, microdiktytaxitic olivine basalt, noticeably unweathered, that contains about 50% labradorite, 25% clinopryoxene, 15% olivine, and 5% opaque minerals. The silica content is near 50%. The unit overlies the welded ash-flow tuff member of the Drewsey Formation, which is of middle Pliocene age.

TOPOGRAPHIC RELATIONS: Andesitic and basaltic rocks of the unnamed igneous complex, the oldest exposed in the district, now compose the divide between the Owyhee and Malheur rivers, and they once formed the western margin of the basin in which Miocene and Pliocene rocks accumulated. They must have been exposed to erosion during part of late Miocene time, for, in the Crowley district, the Dinner Creek Welded Ash-Flow Tuff and Hunter Creek Basalt are absent and the Littlefield Rhyolite laps against the northern and eastern sides of the long-lived ridge of unnamed igneous complex. To the east, the rhyolite, cut by north-trending normal faults, is overlain by dissected younger rocks and, near the eastern border of the district, disappears beneath a cover of Antelope Flat Basalt, which extends as far eastward as Quartz Mountain, where it overlies the Deer Butte Formation. In a few places, as in the canyon of Dry Creek, the basalt is incised, and the Deer Butte Formation can be seen to overlie the Littlefield Rhyolite.

Exposures of the Wildcat Creek Welded Ash-Flow Tuff form a rim-rock along the eastern escarpment of unnamed igneous complex. The tuff is cut by a rhyolitic dike that produces a prominence known as The Roostercomb (Pl. 5). The upland of unnamed igneous complex is penetrated by canyons that contain intracanyon flows of welded tuff, and the surface of the upland is capped by the Shumuray Ranch Basalt. To the west the young, plateau-forming basalt of the Chapman ranch area laps onto, or is faulted against, the central ridge of unnamed igneous complex.

MONUMENT PEAK DISTRICT

DINNER CREEK WELDED ASH-FLOW TUFF: In the Monument Peak district, the eroded surface of the unnamed igneous complex is overlain by the Dinner Creek Welded Ash-Flow Tuff, named here for exposures on Dinner Creek and at the type locality, on Conroy Creek, in the NW¼SE¼ sec. 30, T. 21 S., R. 39 E. (Fig. 8; Appendix, measured section C). The unit crops out as a prominent ledge former in the Monument Peak and Malheur Gorge districts and is present an undetermined distance northward beyond the boundary of the present study. Its thickness ranges from 20 to 200 ft.

The Dinner Creek is a pale-brown (5YR5/2) to grayish-red (10R4/2) rhyolitic welded ash-flow tuff. Where is is completely displayed, it has a lower zone of no welding; a zone of dense welding; an upper zone of partial weld-

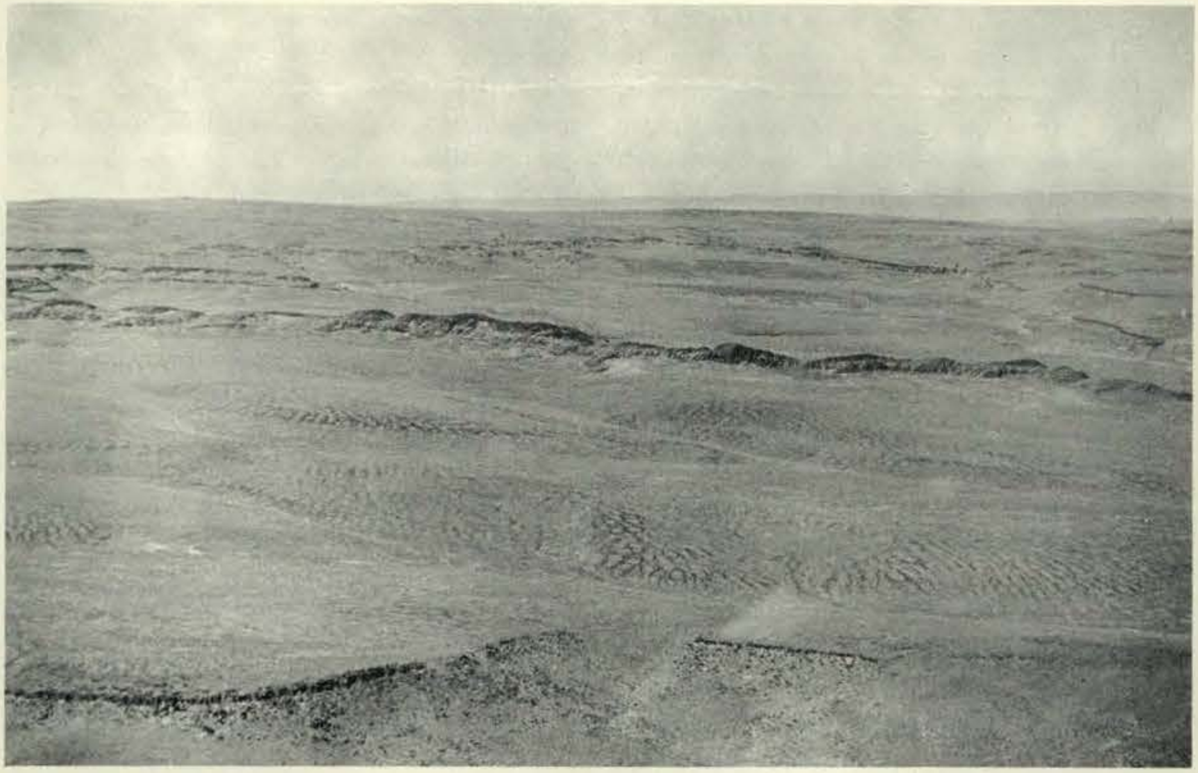

Plate 5. *Oblique aerial photograph of The Roostercomb ridge; looking west—The Roostercomb (middle distance) is a silicic dike. Rocks of the unnamed igneous complex capped by Shumuray Ranch Basalt are in the distance. The rim-rock in the foreground is Wildcat Creek Welded Ash-flow Tuff. Patterned ground formed by stone polygons is visible in the middle distance. Field of view is about 3 miles wide near the middle of the photograph.*

ing, which includes a lithophysal zone; and perhaps an upper zone of no welding. Locally there is an upper zone of dense welding at the at the top of the zone of partial welding, the origin of which is not understood. The lower zone of no welding and most of the zone of dense welding usually are obscured by talus.

The zone of dense welding is pale-brown (5YR5/2) to light-gray (N7) devitrified, perlitic glass with pronounced compressed vitroclastic texture and sparse phenoclasts of intermediate plagioclase and anorthoclase. The partially welded zone is grayish-red (10R4/2), devitrified, lithoidal ash-flow tuff which contains phenoclasts of plagioclase and anorthoclase. The partially welded zone is grayish-red (10R4/2), devitrified, lithoidal ash-flow tuff which contains phenoclasts of plagioclase, anorthoclase, hypersthene, pumice, and basalt. Lithophysae, as much as 30 cm in diameter, contain coatings of tridymite overgrown by opal. The silica content of the groundmass is about 72%.

The Dinner Creek Ash-Flow Tuff is overlain, indirectly, by the Butte Creek Volcanic Sandstone, which is late Miocene age. No underlying unit has been dated.

HUNTER CREEK BASALT: The Hunter Creek Basalt is named here for exposures on Hunter Creek, the type locality, in the SW¼SW¼-NW¼ sec. 26, T. 21 S., R. 39 E. (Photo Reference: BBC 15N-54, 6.2 N, 2.0 E). It is underlain by the Dinner Creek Welded Ash-Flow Tuff and overlain by the Littlefield Rhyolite. The basalt is exposed extensively in the Monument Peak, Malheur Gorge, and Harper Basin districts, usually as stone-striped slopes and domical hills. Its thickness is 150 feet at the type locality and ranges from 3 to 400 ft. The Hunter Creek contains one to several flow units, and is petrologically uniform over a large area. Usually it rests upon the partially welded zone of the Dinner Creek Welded Ash-Flow Tuff, but locally overlies friable tuff. It is overlain by the Littlefield Rhyolite.

The rock is felty, microcrystalline, intergranular, intersertal basalt with 35% labradorite, 30% clinopyroxene, 15% opaque minerals, and 20% glass. The silica content is about 53%.

No fossil-bearing rocks below the Hunter Creek Basalt are known. It is overlain, indirectly, by the Butte Creek Volcanic Sandstone, which contains Barstovian fossils.

UNASSIGNED BASALTS: Two areally limited basaltic units crop out in the northern part of the Monument Peak district. One, called the unnamed multiple-flow basalt, is 15 to 100 ft thick, and consists of pilotaxitic, intersertal, clinopyroxene basalt or andesitic basalt with a silica content of about 60%. It overlies the Butte Creek Volcanic Sandstone, of late Miocene age, and underlies the Tims Peak Basalt. The other unit, called the unnamed basalt and volcanic breccia, ranges to 350 feet in thickness. It includes basaltic pyroclastic material composed of bombs, blocks, and agglomerate, and flow units of ophitic and intersertal basalt whose silica content is about 50%. The unit overlies the unnamed multiple-flow basalt and underlies the Tims Peak Basalt.

TIMS PEAK BASALT: The Tims Peak Basalt is named here for the ophitic clinopyroxene basalt exposed at the type locality, near Tims Peak in the SE$\frac{1}{4}$ sec.34 , T. 21 S., R. 40 E. (Photo Reference: BBC 24N-80, 6.6 N, 3.7 E). The basalt occurs in the northern part of the Monument Peak district, where it forms a prominent plateau, and in the Malheur Gorge district. It is 10 to 250 ft thick as one or several flow units. The rock is microdiktytaxitic clinopyroxene basalt with distinctive ophitic patches a few millimeters in diameter that have unit extinction. It is about 40% labradorite, 20% clinopyroxene, 15% olivine, 4% opaque minerals, 10% glass, and 10% diktytaxitic void spaces; and has a silica content of about 50%.

The Tims Peak Basalt overlies the Butte Creek Volcanic Sandstone of late Miocene age, and underlies the Wildcat Creek Welded Ash-Flow Tuff or the Juntura Formation (G. H. Haddock, oral communication, January 1965).

SHUMURAY RANCH BASALT: The name Shumuray Ranch Basalt is given here to the basalt exposed at the type locality in the S$\frac{1}{2}$ sec. 30, T. 23 S., R. 39 E. (Photo Reference: BBC 25N-47, 4.2 N, 4.2 E), near Shumuray Ranch (NW$\frac{1}{4}$ sec. 29, T. 23 S. R. 39 E.).

The basalt occurs in the northwestern part of the Crowley district, and in the southern part of the Monument Peak district, where it is a mesa former about 50 ft thick, but ranges to 150 ft and contains several flow units. The surface on which the basalt rests slopes northward, and some outcrops show evidence of being exhumed intracanyon flows. The unit is underlain by thin unnamed volcaniclastic strata that are underlain by Wildcat Creek Welded Ash-Flow Tuff, and by basalts of the Grassy Mountain Formation. No overlying rocks are known.

The Shumuray Ranch Basalt is microporphyritic, trachytic to pilotaxitic, intersertal, and intergranular to ophitic. It is about 50% silica and contains about 50% labradorite, 10% clinopyroxene, 10% partially iddingsitized olivine, 10% opaque minerals, and 15% glass.

The basalt overlies the Grassy Mountain Formation in the eastern part of the Monument Peak district, and so is of early Pliocene age or younger.

RHYOLITIC INTRUSION: In the north-central part of the Monument Peak district is a domical rhyolitic intrusion about one mile in diameter that arches rocks of the unnamed igneous complex Dinner Creek Welded Ash-Flow Tuff, Hunter Creek Basalt, and Littlefield Rhyolite;

Plate 6. *View southeastward from Monument Peak—The rim-rock of the plateau is Tims Peak Basalt underlain in the canyons to the south (right) by Littlefield Rhyolite and Hunter Creek Basalt.*

the Tims Peak Basalt apparently is not affected. Strata on the northeast flank of the structure are overturned. The rhyolite is dense, light gray (N7), microcryptocrystalline, lithoidal rhyolite, whose silica content is about 73%.

TOPOGRAPHIC RELATIONS: The Monument Peak district (Fig. 2) is a dissected plateau that rises above the South Fork of the Malheur River and Cottonwood Creek, a tributary of the Malheur. The surface of the plateau, cut by north-trending faults, is at an elevation of about 5000 ft, 1000 to 2000 ft above drainage ways, and promontories rise to nearly 6000 ft. Heights along the western border of the district are at the northern extremity of the ridge of the unnamed igneous complex that dominates the Crowley district to the south. In the Monument Peak district this ridge is largely buried by younger rocks, which overlap it on the east and north; the Dinner Creek Tuff and Hunter Creek Basalt are exposed in canyon walls and are overlain by the Littlefield Rhyolite and Tims Peak Basalt, (Pl. 6) which form the surfaces of the plateau.

Near the center of the district, a rhyolitic magma intruded into or below rocks of the unnamed igneous complex and created a domical structure in which the rocks dip away from the intrusion on all sides and are even overturned locally (Pl. 7). The crest of the dome has been breached by erosion, and the intrusive rhyolite in the interior exposed. South of the core tilted platy rock of the Littlefield Rhyolite form the landmark, Monument Peak. Evidently the intrusion and doming occurred between the times of formation of the Littlefield Rhyolite and Tims Peak Basalt, for the latter seems not to be tilted and apparently was limited in its extent by the presence of the dome.

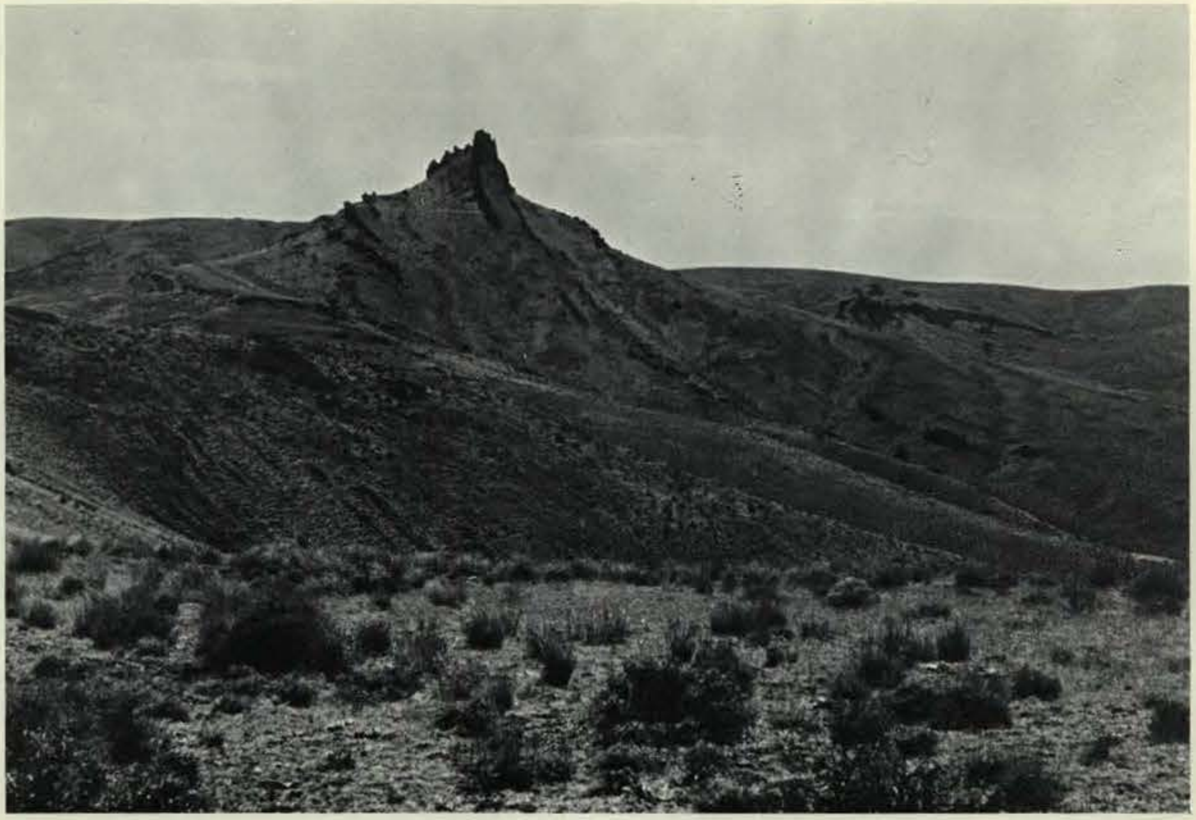

Plate 7. *Tims Peak viewed from the northwest—The peak is composed of ledgy basalts of the unnamed igneous complex. The rocks are overturned toward the north (left) by an intrusive rhyolitic body beyond the right-hand margin of the photograph. Stratigraphic top is toward the left.*

In the eastern part of the district, the rimrock of Tims Peak Basalt is dissected by headwater tributaries of Cottonwood Creek and the underlying Littlefield Rhyolite exposed. The rhyolite is cut by north-trending normal faults, downthrown on the east. The structural depression created by the cumulative displacement along these faults is responsible, at least in part, for the trough in which sedimentary rocks of the Drip Spring Formation accumulated and which today is also a topographic depression occupied by the lower reach of Cottonwood Creek. The trough in contiguous both topographically and structurally with Harper Basin to the north. East of Cottonwood Creek, rocks of the Drip Spring formation are overlain by plateau-forming basalts of the Grassy Mountain Formation, but the latter probably conceal a ridge of Littlefield Rhyolite that is the counterpart of the Littlefield Rhyolite in the plateaus to the west.

Malheur Gorge District

JUNTURA FORMATION: The Juntura Formation was named and described by Bowen, Gray, and Gregory (1963, p. 25-28), whose description is summarized here: The Juntura Formation is exposed in the western part of the Malheur Gorge district, where it has a composite thickness of about 1200 ft and unconformably overlies the unnamed igneous complex or various younger units. Lower, middle, and upper members are recognized. The lower member, which is about 400 ft thick, contains light-colored altered volcanic sandstones, a welded ash-flow tuff about 30 ft thick, and, at the top, a flow unit of palagonite basalt about 25 ft thick. The middle member is about 500 ft thick. It consists of thin-bedded to massive diatomite with subordinate thin-bedded, friable reworked vitric tuff; and has a basal zone of porcelanite. The upper member, about 400 ft thick, contains light-colored altered volcanic sandstone, reworked vitric tuff and lapillistone, and cross-stratified conglomerates and conglomeratic sandstone.

The upper member of the Juntura Formation contains mammalian fossils of the Black Butte fauna (principally UO 2337) described by Shotwell and Russell (1963, p. 42-69), who consider the fauna to be of Clarendonian (early Pliocene) age.

DREWSEY FORMATION: The Drewsey Formation was named and described by Bowen, Gray, and Gregory (1963, p. 28-31). Their report is summarized as follows: The Drewsey Formation is about 1000 ft thick and overlies the Juntura Formation with slight angular unconformity. It is exposed in the western part of the Malheur Gorge district. The formation is divided into three members (ascending order) the rhyolitic welded tuff member, the tuff agglomerate member, and the tuff and sandstone member.

The welded tuff member is 15 to 35 ft thick and has upper and lower zones of no welding, which are absent locally, and is moderate gray (N5) and glassy. Phenoclasts are euhedra of sanidine and grains of quartz and aegirite-augite 1 to 4 mm in diameter. The tuff agglomerate member is generally 75 to 100 ft thick, and contains basaltic agglomerate, tuff, and diatomite. The tuff and sandstone member is about 700 ft thick. It contains well indurated, stratified, altered volcanic sandstones.

The tuff and sandstone member of the Drewsey Formation contains mammalian fossils of the Drinkwater (UO 2361, 2362, 2366), Otis Basin (UO 2346, 2347), and Bartlett Mountain (UO 2339, 2357) faunas. These are described by Shotwell (1963, p. 70-77), who assigns them to the Hemphillian (middle Pliocene). A potassium-argon analysis of sanidine from the welded tuff member of the Drewsey Formation has provided an age of 8.9 m.y. for that member (Evernden and others, 1964, p. 192, sample KA 1225).

DRINKWATER BASALT: The Drinkwater Basalt is named and described by Bowen, Gray, and Gregory (1963, p. 31): It occurs in the western part of the Malheur Gorge district, where it unconformably overlies the Drewsey Formation and is a prominent mesa former. The basalt is about 15 to 60 ft thick. It contains about 50% labradorite, 20% intergranular clinopyroxene, 10% opaque minerals, 5% olivine, and 15% glass. Usually only one flow unit is present.

The Drinkwater Basalt overlies the Drewsey Formation, which is of middle Pliocene age; no stratigraphic unit is known to overlie it.

TOPOGRAPHIC RELATIONS: The Malheur Gorge district (Fig. 2) like those south of it, is a dissected upland of Littlefield Rhyolite and older rocks that generally dip gently eastward and are repetitiously exposed by north-trending faults. The upland surface stands at an elevation of about 5000 ft, and promontories reach 6000 ft. The Malheur River follows a sinuous course that transects the structural fabric and incises resistant volcanic rocks to a depth of 2000 ft below the upland, so that basalts of the unnamed igneous complex are exposed in Malheur Gorge. The topographic basin in the vicinity of Juntura apparently also existed in early Pliocene time, for thick, lacustrine and fluviatile rocks of the Juntura and Drewsey formations rest on a surface that truncates various Miocene strata. The Pliocene basin-filling sedimentary rocks are extensive north and west of Juntura, and are in contact with the unnamed igneous complex, Dinner Creek Tuff, Hunter Creek Basalt, and Tims Peak Basalt. East of Juntura, the higher upland surfaces generally are composed of Hunter

Plate 8. *Northward view in the Malheur Gorge district—Ledge-forming Dinner Creek Welded Ash-Flow Tuff and overlying Hunter Creek Basalt are cut by minor faults. One set trends northward away from the observer, the other east-west across the photograph.*

Creek Basalt, and the Dinner Creek Tuff forms prominent ledges on the walls of canyons (Pl. 8). On the eastern margin of the district, the older rocks of the section are overlain by Littlefield Rhyolite, which is overlapped by sedimentary rocks of the Harper Basin.

Harper Basin District

DRIP SPRING FORMATION: The sedimentary deposits of the Harper Basin district occupy a structural and topographic basin formed mainly by faulted and dissected rocks of the Littlefield Rhyolite. The strata that directly overlie the Littlefield Rhyolite are here named the Drip Spring Formation for Drip Spring (SW 1/4 NE 1/4 sec. 3, T. 22 S., R. 41 E.). The type locality of the formation is in the SE 1/4 sec. 20 T. 20 S., R. 42 E. (Fig. 9; Appendix, measured section G). The Drip Spring Formation is exposed extensively in the southern part of the Harper Basin district and intermittently in the northern part. At the type section 260 ft is exposed, but 700 ft is present along the middle reach of Cottonwood Creek, and the aggregate thickness may be 1500 ft.

The formation contains dominantly dark yellowish-brown (10YR4/2), yellowish-gray (5Y8/1), and pale yellowish-brown (10YR6/2) altered volcanic sandstones, peperites, feldspathic and arkose sandstones, diatomites, siliceous diatomites, and carbonaceous volcanic shales that include both slope- and cliff-forming strata.

No diagnostic fossils have been found in the Drip Spring Formation. It overlies the Littlefield Rhyolite, which is late Miocene or older, and underlies the Grassy Mountain Formation, which is early and middle Pliocene. The lithology of the Drip Spring Formation resembles that of the Deer Butte Formation, which occupies a similar stratigraphic position (Fig. 4).

BULLY CREEK FORMATION: The Bully Creek Formation is named here for volcanic sandstones and diatomites exposed in the Harper Basin district. The type section is in two parts: (I) SW 1/4 sec. 7 T. 19 S., R. 41 E., and (II) NW 1/4 sec. 11, T. 19 S., R. 41 E. (Fig. 10; Appendix, measured section J). The unit is widely exposed in the northern part of the Harper Basin district, where it unconformably overlies rocks of the Littlefield Rhyolite and of the Drip Spring Formation and underlies rocks of the Grassy Mountain Formation. The thickness of the formation in the center of the basin is unknown. If it is assumed that stratum 14 and strata 10-14 of parts I and II, respectively, of the type section correspond (Fig. 10), the formation is at least 440 ft thick.

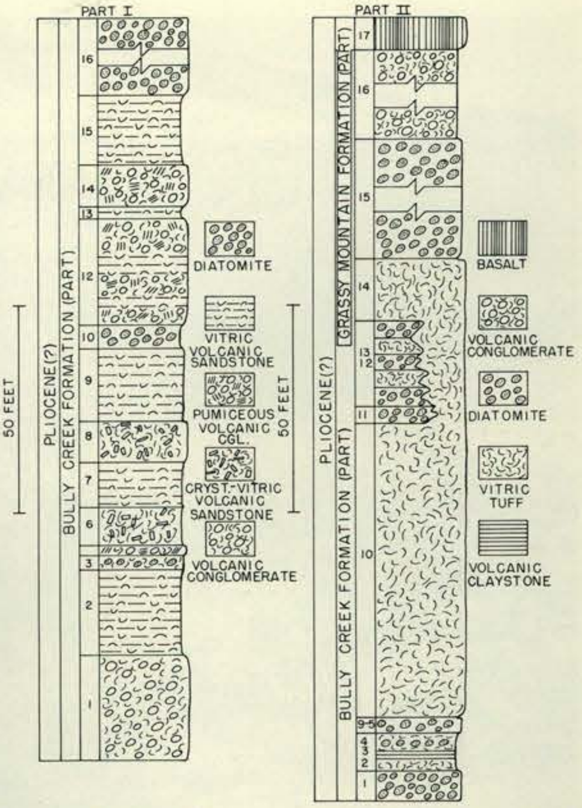

Figure 10. *Graphic type sections; Bully Creek Formation. See text for locations and detailed measured sections.*

The Bully Creek Formation is composed of epiclastic volcanic conglomerates, altered volcanic sandstones, and indurated vitric tuffs near the base; diatomite in the middle; and volcanic conglomerate near the top. The diatomite is white (N9), friable, thin bedded to massive, and nearly pure.

The Bully Creek Formation overlies the Littlefield Rhyolite, which is late Miocene or older and underlies the Grassy Mountain Formation, which is early and middle Pliocene. No diagnostic fossils have been found. Its stratigraphic position is similar to that of the Juntura Formation, which also contains prominent diatomites and which has an early Pliocene mammalian fauna.

TOPOGRAPHIC RELATIONS: The topographic depression here called Harper Basin (Fig. 2) is eroded in sedimentary rocks formed in a depositional basin that existed near the end of Miocene time. The elongate basin was formed by cumulative subsidence along north-trending faults that cut the Littlefield Rhyolite. The rocks first deposited in this trough are those of the Drip Spring Formation, exposed mainly in the south end of the basin, in the Monument Peak district. Later, perhaps in the Pliocene, sediments of the Bully Creek Formation accumulated in a lake, the presence of which is indicated by diatomite hundreds of feet thick, with which the tuffs of the formation are interbedded. The diatomite forms the brilliant-white cliffs and ledges that are characteristic of the Harper Basin district (Pl. 9).

The Bully Creek Formation rests upon faulted Littlefield Rhyolite and Hunter Creek Basalt on the western and northern margins of the basin, but at the eastern side, the Bully Creek is overlain by a rim-rock of Grassy Mountain Formation, here mainly basalt, that dips gently eastward into the Owyhee Reservoir district.

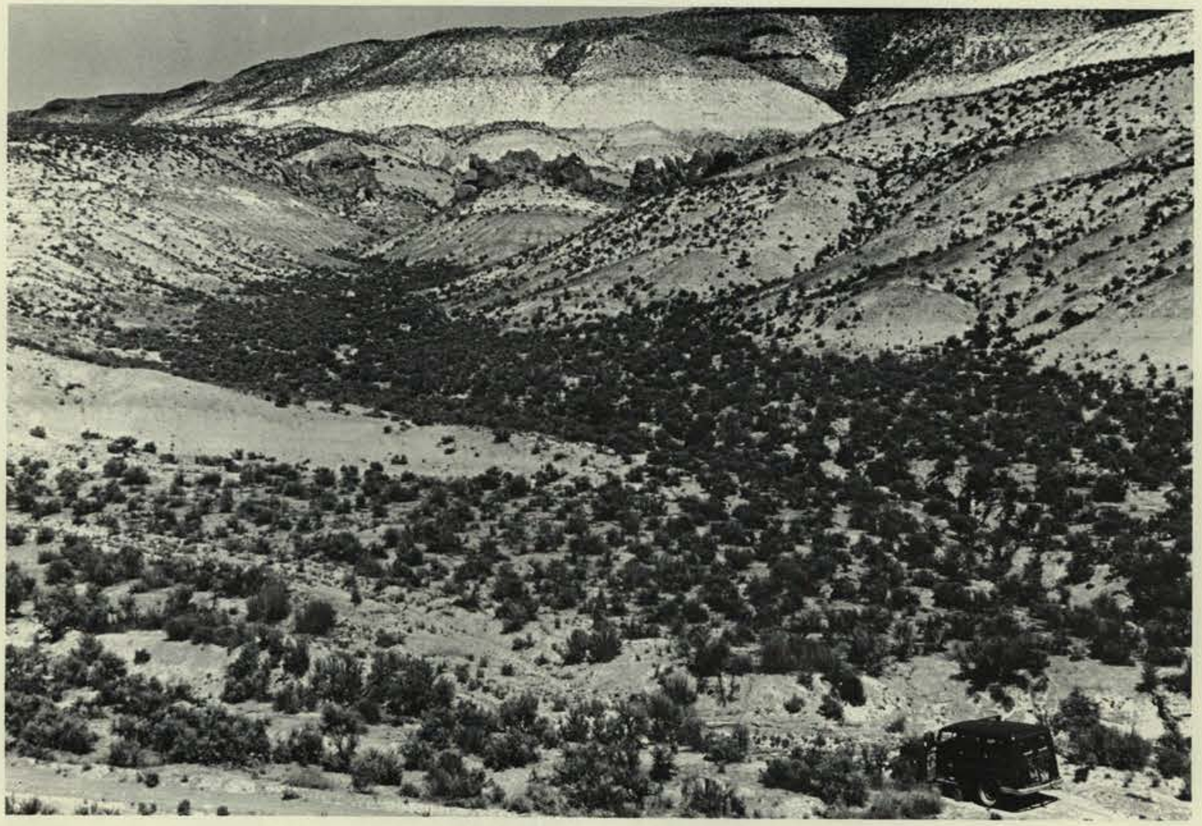

Plate 9. *Type locality of the Bully Creek Formation—The jagged ledge in the middle distance is the vitric tuff of unit 10 of the type section (part II). It is overlain by white diatomite and darker-colored volcanic conglomerate. The rim-rock on the skyline is Grassy Mountain basalt.*

DISCUSSION AND SUMMARY

This article reports on an assemblage of extrusive, pryoclastic, and volcaniclastic rocks that contain varied floras and faunas and that were affected by successive stages of faulting, erosion, and basin filling. Many details of petrology, eruptive sequence, and tectonic history remain to be established; and various complex or unusual lithologic types, such as ash-flow tuff, laharic breccia, and adulterated volcaniclastic rocks warrant continuing study. Major features, however, have been clarified:

The important stratigraphic elements of the Owyhee region are shown schematically in Figure 11. Perhaps the oldest rocks exposed are those of the Sucker Creek Formation, Owyhee Basalt, and unnamed igneous complex. In the western part of the region, the unnamed igneous complex was succeeded, after erosion and perhaps faulting, by the Dinner Creek Welded Ash-Flow Tuff, Hunter Creek Basalt, and Littlefield Rhyolite. The rocks of this basal sequence then were deformed and eroded, probably in late Miocene time. Filling of the north-trending basins in this surface began in late Miocene time, and continued, with minor shifting of basinal axes and local interruptions, through middle Pliocene time. During accumulation, explosive volcanism occurred with sufficient frequency that clastic deposits are dominated mainly by volcanic fragments; however, it is believed that most pyroclastic material was deposited ultimately as fluviatile detritus, because adulteration by extra-basinal plutonic detritus is widely evi-

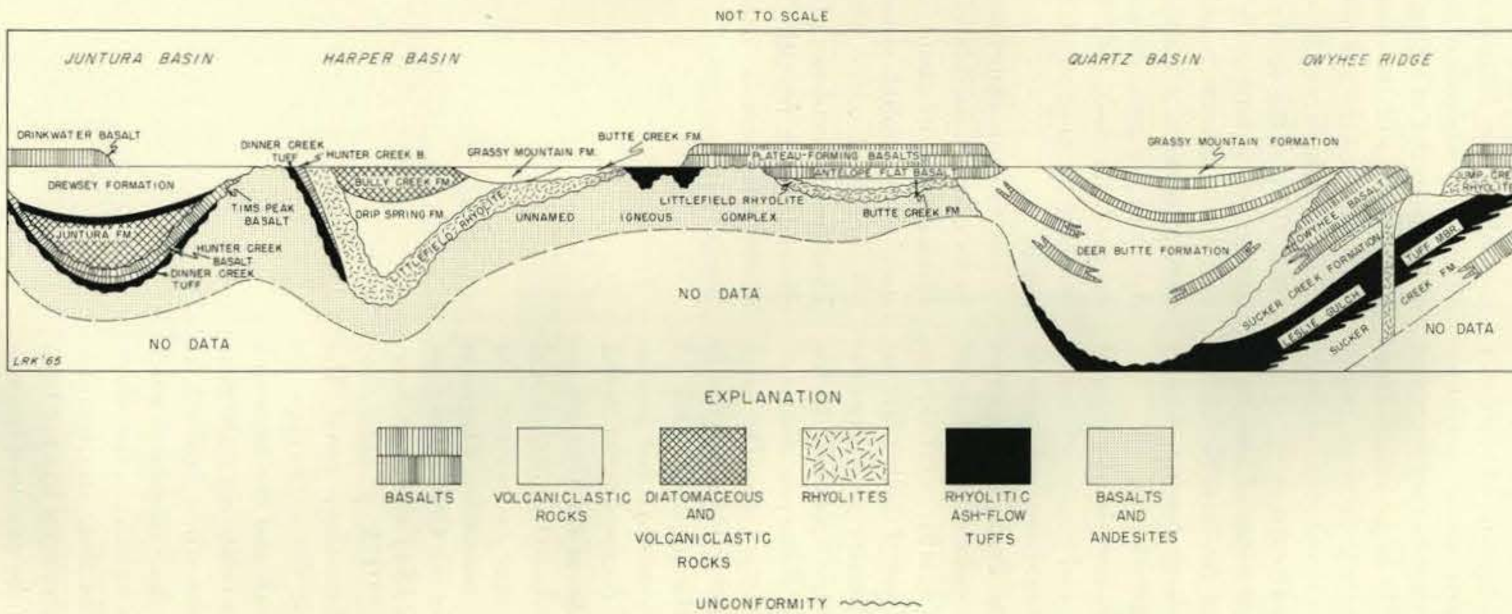

Figure 11. *Greatly generalized stratigraphic diagram for the Owyhee region.*

dent. There were, nevertheless, volcanically quiescent periods long enough for accumulation locally of important deposits of relatively pure diatomite. Prominent arkose sandstone and granite-cobble conglomerate may represent brief periods of unusually large runoff from peripheral sources of plutonic detritus, rather than significant lapses in volcanic activity. There were sporadic local extrusions of basaltic lava and shallow intrusions of basalt and peperite, which produced the basaltic bodies within the Deer Butte, Drip Spring, Grassy Mountain, and Juntura formations.

Basin filling was nearly complete by the end of middle Pliocene time, and younger flows of the Grassy Mountain Formation, and flows of the Antelope Flat, Tims Peak, Shumuray Ranch, and Drinkwater basalts covered former interfluves. Intermittent basaltic extrusions continued locally and formed both plateaus and intracanyon flows. Activity probably continued through late Pliocene time, and, in the Cow Lakes area (Owyhee Reservoir district), continued nearly into historic time. The later events, however, are not paleontologically documented, owing to the apparent lack of late Pliocene sedimentary deposits and fossils.

There is no regular compositional trend among the extrusive rocks of the Owyhee region. A variation diagram based upon chemical analyses of a suite of nine rocks from the Owyhee region closely resembles diagrams that represent suites from the Crater Lake region (Williams, 1942, p. 154) and from Newberry Crater (Williams, 1935, p. 302), but there is no large-scale chronologic trend. The oldest major elements of the extrusive sequence, the Owyhee Basalt and the unnamed igneous complex, both are relatively mafic near the base and become more silicic upward, so that rocks of the younger flows contain as much as 60% silica. These two units may, therefore, be genetically related, but their stratigraphic or exact chronologic equivalence has not been established. Extrusion of the unnamed igneous complex was followed, after a haitus, by eruption of the rhyolitic Dinner Creek Welded Ash-Flow Tuff, and that, relatively quickly, by the Hunter Creek Basalt. The Hunter Creek is succeeded by the Littlefield Rhyolite, a major silicic unit hundreds of feet thick and hundreds of square miles in extent. Later extrusive rocks are basaltic, with the exception of several rhyolitic ash-flow tuffs and perhaps the Jump Creek Rhyolite, which may be as young as early Pliocene. The basaltic units generally are mutually similar petrographically and show only minor variations in texture and in degree of secondary alteration. Although most contain labradorite in the groundmass, their silica content ranges from about 45% to 60%. The youngest flows are the most mafic, but there is no regular trend.

The volcanic component of the sedimentary rocks consists mainly of glass shards with a silica content of about 70%, potassium feldspar, dipyramidal quartz, and intermediate plagioclase; basaltic glass generally is rare. Thus there is evidence of silicic volcanism synchronous with basaltic lavas, although some of the volcaniclastic material may have come from distant sources.

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APPENDIX

Measured Section A

Type Section, Sucker Creek Formation

Sucker Creek, Malheur County, Oregon

Part I: S½SW¼ sec. 28, T. 24 S., R. 46 E., Willamette Meridian

Part II: NE¼NW¼ sec. 33, T. 24 S., R. 46 E., Willamette Meridian

Photo Reference: AMS 1620, 6.5 N, 3.7 E[7] Part I measured by L. R. Kittleman, September 1960; part II measured by L. R. Kittleman and G. L. Millhollen, August 1963; hand level, tape and Brunton.

Unit	*Description*	*Thickness in feet*
	Top of measured section; top of part II	
	Sucker Creek Formation (part):	
31	VITRIC VOLCANIC SANDSTONE, slightly altered, very light (N8) silvery-gray, very fine-grained, extremely friable, thinly laminated; about 80% clear, colorless glass shards (n=1.503); about 17% clay; slope former	3
30	VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1), very fine-grained, thinly bedded to laminated, well indurated (conchoidal fracture); well preserved relict vitroclastic texture; glass completely altered; blocky weathering; slope former	3.5
29	VITRIC VOLCANIC SANDSTONE, slightly altered, very light (N8) silvery-gray, very friable; fresh glass shards with subordinate clay; slope former	1
28	VITRIC VOLCANIC SANDSTONE, same as unit 30	15.8
27	VITRIC VOLCANIC SANDSTONE, severely altered, pale yellowish-gray (5Y9/1), thinly bedded, moderately indurated; very minor fraction of fine-silt-size crystal fragments in clay matrix; cliff former	20
26	CARBONACEOUS CRYSTAL-VITRIC VOLCANIC SHALE, moderately altered, brownish-gray (5YR5/1), very fine relict vitroclastic texture; 86% clay with residue of abundant, fine- to medium-grained clear, colorless glass shards; common wood-carbon fragments; common angular, subhedral plagioclase (andesine) (some turbid); some angular quartz; cliff former	10
25	VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y7/2), massive, moderately indurated; lacks relict texture; 94% clay; contains platy clay aggregates, perhaps shard pseudomorphs, and subordinate very fine-grained angular quartz and feldspar; slope former	38.6
24	CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y7/2), massive, moderately indurated; lacks relict texture; non-clay fraction contains rare fine-grained clear, colorless glass shards; rare massive sideromelane fragments (about 0.3 mm); common subhedral feldspar and angular quartz; slope former	1.5
23	CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y7/1), fine- to medium-grained, excellent relict vitroclastic, texture, massive, moderately indurated; 92% clay; residue contains dominant platy clay aggregates, perhaps shard pseudomorphs; common plagioclase (andesine; 0.06-1.2 mm); weathers to slopes mantled by swelling clay	10.5
22	CRYSTAL-VITRIC VOLCANIC SANDSTONE, moderately altered, yellowish-gray (5Y8/1), thinly laminated and cross-laminated, grossly massive, fine-grained; 68% clay; non-clay fraction (32%); dominant clear, colorless glass shards, abundant biotite and muscovite; common subhedral plagioclase (andesine); ledge former	3.5
21	CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1), moderatly indurated, massive; more than 90% clay; non-clay fraction (about 10%) contains dominant plagioclase, probably andesine (to 0.7 mm); common subhedral beta-quartz pseudomorphs; rare, coarse-grained colorless and grown glass shards; common coarse-grained, round, pumiceous lithic clasts; rare biotite; slope former	82
	Base of part II	

[7] The Photo Reference permits location on aerial photographs. BBC indicates Soil Conservation Service 1:20,000 photography and AMS indicates Army Map Service 1:54,000 photography; both are followed by the photograph number. Decimal numbers and directions indicate coordinate distance in inches respectively north (N) and east (E) from the southwestern (lower-left) corner of the contact print.

Top of part I

20 VITRIC VOLCANIC SANDSTONE, slightly altered, very light (N8) silvery-gray, very friable, dominantly fine-grained; clear, colorless glass shards; (n=1.498); weathered to sculptured forms 5

19 CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1), massive, moderately friable; contains 75% clay with non-clay fraction of dominant coarse-grained clear, colorless glass shards (n=1.503); subordinate angular, fine-grained quartz and plagioclase (calcic andesine); slope former 20

18 PUMICEOUS CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered yellowish-gray (5Y7/2), well indurated, good relict vitroclastic texture; contains more than 80% clay with abundant very fine- to medium-grained corroded or skeletal,, clear, colorless glass shards; abundant fine-grained, anhedral feldspar, probably andesine; common medium-grained, clear, angular quartz, common siliceous, in part pumiceous, lithic clasts (to 2 mm); rare altered sideromelane; slope former 23

17 COVERED by mantle of swelling clay 10

16 LITHIC-VITRIC VOLCANIC SANDSTONE, severely altered, olive-green (10Y6/2); ledge former 2

15 COVERED by mantle of swelling clay 82

14 ZEOLITIC CRYSTAL-LITHIC-VITRIC VOLCANIC SANDSTONE, severely altered, grayish yellow-green (5GY7/2), moderately indurated, massive; more than 80% clay; abundant coarse-grained subhedral plagioclase; common coarse-grained angular quartz; abundant authigenic zeolite, possibly clinoptilolite; rare hornblende; abundant coarse-grained lithic clasts of mafic and silicic scoria and rhyolite; slope former 5

13 ZEOLITIC VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y7/2); massive, moderately indurated; 86% clay with dominant medium-grained zeolitic shard pseudomorphs; common medium-grained clear, angular quartz; rare subhedral beta-quartz pseudomorphs (0.15 mm); plagioclase, probably andesine, rare; slope former 2.5

12 ZEOLITIC LITHIC-CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, dusky yellow-green (5GY5/2), massive, moderately indurated; more than 70% clay with abundant zeolite (not pseudomorphic); rare clear, angular quartz (0.6 mm); rare subangular frosted, turbid quartz (1 mm); rare vitroclastic epiclastic fragments (1.5); slope former 5

11 ALTERED PUMICEOUS LAPILLISTONE, pale yellowish-gray (5Y8/1); ledge former 2.5

10 PUMICEOUS ZEOLITIC VITRIC VOLCANIC SANDSTONE, severely altered, grayish yellow-green (5GY7/2, vitroclastic texture, moderately indurated, thinly bedded; more than 70% clay with medium-grained non-clay residue: common pumice fragments and basaltic scoria (1 mm); abundant cavity-filling and pseudomorphic (after shards) zeolite; abundant montmorillonitized scoria fragments (1.5 mm); common angular clear quartz, (0.6 mm); rare zoned feldspar; ladge former 21

9 ZEOLITIC PUMICEOUS CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1), relict vitroclastic texture, massive, moderately indurated; more than 70% clay; remainder with abundant very fine-grained zeolitized shards; abundant feldspar, probably andesine; slope former, with mantle of swelling clay 4.7

8 CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y7/2), massive, well indurated; about 80% clay; remainder; dominant medium-grained angular and subhedral plagioclase (andesine); common medium-grained clear and altered glass shards; common fine-grained magnetite; slope former; mantled by swelling clay 28

7 CALCAREOUS PUMICEOUS LAPILLISTONE, severely altered, dusky yellow-green (5GY6/2) moderately indurated; frothy clay pellets with interstitial calcite; some pellets may represent filling of glass bubbles; forms ledge weathering to hoodoo forms. 7

6 PUMICEOUS CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y7/2), well indurated, massive, texture destroyed; about 60% clay; remainder very fine-grained; dominant subhedral plagioclase, probably andesine; common clear and zeolitized shards; common montmorillonitized pumice frag-

ments (to 4 mm); trace angular quartz and hornblende; slope former 16

5 CLAYSTONE, very light gray (N8), well indurated; probably volcanic; ledge former 4.7

4 ZEOLITIC CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, grayish-yellow (5Y8/4), moderately indurated, pronounced relict vitroclastic texture, massive; 96% clay; remainder contains dominant fine-grained zeolitized shard pseudomorphs; common clear, colorless glass shards; abundant plagioclase; slope former 9.4

3 ALTERED LEAN CRYSTAL-VITRIC VOLCANIC ARKOSE, yellowish-gray (5Y7/2) to very light-gray (N8), coarse-grained, moderately friable, cross-bedded; about 10% clay matrix, probably volcanic, with subangular quartz and turbid plagioclase (near calcic oligoclase); common biotite and muscovite (about equal proportions); rare sanidine; rare subhedral beta-quartz pseudomorphs; slope and ledge former 50

2 MEDIUM VOLCANIC ARKOSE, severely altered, yellowish-gray (5Y7/2), medium-grained, moderately friable, thinly laminated; arkose sand in matrix of bentonitic clay (56%); detrital fraction dominantly turbid, subanguar feldspar probably plagioclase); abundant subangular quartz; rare clear, angular feldspar, (probably volcanic); slope former 25

1 *INTERBEDDED*: CARBONACEOUS VOLCANIC ARENACEOUS SHALE, severely altered, light brownish-gray (5YR6/) *and* CARBONACEOUS SANDSTONE; shales 95% clay; detrital grains fine- to medium-grained; abundant biotite and muscovite; abundant, slightly turbid angular plagioclase, probably andesine; rare subhedral beta-quartz pseudomorphs; contains characteristic Mascall-type pollen flora; weathers to moderate redish-brown slopes mantled by swelling clay 73

Total measured thickness of Sucker Creek Formation 585

Base of measured Sucker Creek Formation (part)
Base of measured section

Measured Section B

Type Section, Owyhee Basalt

Owyhee Dam, Malheur Country, Oregon

SE¼ sec. 20, T. 22 S., R. 45 E., Willamette Meridian; Photo Reference: BBC 21N-33, 4.0 N, 5.0 E.; measured by L. R. Kittleman and G. L. Millhollen, August 1963; alidade

Unit	*Description*	*Thickness in feet*

Top of measured section

Owyhee Basalt:

17 Not measured in detail: FOUR BASALTIC FLOW UNITS *and INTERBEDDED* VOLCANICLASTIC ROCKS 480

Top of detailed measured section

16 BASALT, medium dark-gray (N4), massive, microporphyritic, pilotaxitic, holocrystalline, intergranular; SiO_2 about 54%; plagioclase phenocrysts (1 mm), An_{68}, show several different twinning laws; groundmass: fine-grained plagioclase (undeterminable) and intergranular clinopyroxene; abundant finely disseminated opaque grains; scoriaceous at top; overlain by 15 feet of basalt (inaccessible) 43

15 COVERED, probably sedimentary 91

14 BASALT, brownish-black (5YR2/1), dense, diabasic; crudely flow-foliated to massive; microporphyritic (plagioclase); severely altered; olivine common 125

13 COVERED, probably sedimentary 42

12 BASALT, medium dark-gray (N4), crudely flow-foliated (2-5 mm), microporphyritic, piltaxitic, intergranular, holocrystalline; plagioclase phenocrysts (1.5 mm), about An_{60}, zoned, with Carlsbad and albite twinning; groundmass plagioclase, about An_{67}, very fine-grained; rare phenocrystic clinopyroxene with reaction rims; rare iddingsite pseudomorphic after olivine; abundant finely intergranular opaque grains; scoriaceous at top 70

11 PUMICE-LAPILLI VOLCANIC-GRANULE CONGLOMERATE, light-gray (N7), thin- to thick-bedded, planar cross stratification; coarse sand- and granule-size silicic pumice (severely altered), tachylite, (subangular), and microvesicular sideromelane; fragments to 5 mm in diameter; rare, rounded quartz grains; upper 16 feet baked by overlying flow (moderate red, 5R5/4) 20

10 BASALT, brownish-gray (5YR4/1) with light bluish-gray (5B7/1) alteration films, flow-foliated (5 mm), with elongated vesicles; microporphyritic, holocrystalline, pilotaxitic, intergranular; plagioclase phenocrysts (1 mm), zoned, embayed, with sieve texture; Carlsbad twinning, albite twin lamellae lacking; laths with attached olivine and pigeonitic grains; groundmass plagioclase not determinable; abundant, intergranular magnetite and chlorophaeite; SiO_2 about 54%; scoria (5 ft) at top 28

9 MOSTLY COVERED, includes scoria at top of unit 8 27

8 BASALT, aphanitic, medium-gray (N6), prominently flow-foliated (0.5-1 cm); elongated vesicles; graditional into scoria at top of unit 7 46

7 MOSTLY COVERED, includes scoria of unit 6 and a covered flow with scoriaceous top exposed, reddish purple (5RP6/4) (8 feet) 29

6 BASALT, brownish-black (5YR2/1), pilotaxitic, intergranular, with elongate ophitic patches, holocrystalline, flow-foliated (5-10 cm); plagioclase (about 0.2 mm) poorly determinable (about An_{47}); very fine-grained, intergranular and ophitic pigeonite; abundant finely disseminated opaque grains; abundant intergranular chlorophaeite, probably after pigeonite; amygdular saponite surrounded by diverging pilotaxitic texture; SiO_2 about 50%; scoracious at top 13

5 BASALTIC SCORIA, at top of unit 4, moderate-red (5R5/4) 28

4 BASALT, dense, olive-black (5Y2/1), microporphyritic, pilitic, intergranular, holocrystalline; plagioclase phenocrysts, 0.06 mm (An_{70}), 0.2 mm (An_{60}); large plagioclase phenocrysts zoned and embayed; abundant saponite, pseudomorphic after olivine and as amygdules; rare unaltered olivine; abundant fine-grained opaque grains; SiO_2 about 52% 11

3 BASALT, very pale-brown (5YR6/2) mottled with gray (N7); crudely flow-foliated; locally contorted; moderately vesicular and amygdaloidal; amygdules lined with saponite or chlorophaeite; microcrystalline, intergranular; SiO_2 about 52%; top locally scoriaceous, red 64

2 COVERED 20

Total measured thickness of Owyhee Basalt 1137

Base of Owyhee Basalt

Unconformity

1 Unnamed RHYOLITE not measured

Base of measured section

Measured Section C

Type Section, Dinner Creek Welded Ash-Flow Tuff

Conroy Creek, ½ mile north of Lower Deacon Flat Reservoir, Malheur County, Oregon

NW¼SE¼ sec. 30, T. 21 S., R. 39 E., Willamette Meridian; Photo Reference: BBC 25N-59, 4.3 N, 5.0 E.; measured by L. R. Kittleman and G. L. Millhollen, August 1963; tape and hand level

Unit *Description* *Thickness in feet*

Top of measured section

Dinner Creek Welded Ash-Flow Tuff (part):

4 UPPER ZONE OF DENSE WELDING: WELDED ASH-FLOW TUFF, moderate reddish-brown (10R4/4), dense, conchoidal fracture, vague foliation, slightly porphyritic, pronounced welded vitroclastic texture; shard pseudomorphs clearly outlined by hematite dust; devitrification complete; shard pseudomorphs composed of weakly polarizing needles oriented normal to shard boundaries; feldspar (about 1 mm) euhedral to anhedral, corroded; plagioclase (not determinable), sanidine, orthoclase; rare autoclasts and basaltic (?) xenoclasts (about 1 mm) 4

3 ZONE OF PARTIAL WELDING: WELDED ASH-FLOW TUFF, pale-brown (5YR5/2), weathering moderate-brown; abundant, irregular vesicles (to 30 cm), compact, vaguely hyaline, lithophysal in upper five feet, pronounced welded vitroclastic texture; devitrification complete; shard outlines well preserved; some shards axiolitic; appressed vesicles (about 0.5 mm) filled with tridymite; some autobrecciation-like sheared textures; feldspar subhedral to corroded and skeletal, aligned (to 3 mm); plagioclase; rare opaque grains; cavities, when occupied, filled in the order tridymite-opal-chalcedony 30

2 ZONE OF DENSE WELDING (part): WELDED ASH-FLOW TUFF, mottled grayish-red (10R4/2) and pale yellowish-brown (10R6/2); numerous horizontally aligned vesicles causing re-entrant in cliff; compact but with granular weathered surfaces; welded vitroclastic texture not apparent; microtexture autobrecciate; both clasts and matrix with welded vitroclastic texture, but fabric of clasts rotated; some tridymite (pre-becciation); devitrification complete, cf. unit 1; sparse feldspar: sanidine or anorthoclase, orthoclase, plagioclase; tridymite (pre-opalization) as cavity filling; rare euhedral, hematite-rimmed opaque grains and zircon — 2

1 ZONE OF DENSE WELDING (part): WELDED ASH-FLOW TUFF, pale-brown (5YR5/2), dense, homogeneous, with subconchoidal fracture, irregular, randomly oriented vesicles to 10 cm common, with partial to complete silica fillings, but not lithophysal; welded-vitroclastic texture not apparent without magnification; pronounced welded vitroclastic microtexture, with envelopment and compression adjacent to phenoclasts; devitrification complete; secondary crystallites oriented normal to shard boundaries, but seldom axiolitic; brown pigment in groundmass not resolvable; large more nearly perfect shard ghosts not pigmented; sparse feldspar phenoclasts: subhedral, anhedral, and rounded (0.5-1 mm); orthoclase (?), sanidine, and subordinate plagioclase (near oligoclase); cavity fillings, when complete, have paragenesis: tridymite-opal-spherulitic chalcedony; base not exposed — 8

Total measured thickness of Dinner Creek Welded Ash-Flow Tuff (part) — 44

Base of measured Dinner Creek Welded Ash-Flow Tuff (part)

Base of measured section

Measured Section D

Type Section, Butte Creek Volcanic Sandstone
Wildcat Creek, Malheur County, Oregon

SW¼SW¼ sec. 23, T. 24 S., R. 40 E., Willamette Meridian; Photo Reference: BBC 17N-105, 3.2 N, 3.0 E.; measured by L. R. Kittleman and G. L. Millhollen, July 1963; tape

Unit — *Description* — *Thickness in feet*

Top of measured section

Butte Creek Volcanic Sandstone (part):

11 VITRIC VOLCANIC SANDSTONE, severely altered, fine-grained, silty, very pale yellowish-gray (5Y9/1), massive, thinly cross-laminated; slightly pebbly (igneous rock fragments to 1 cm); authigenic clay (45%); glass shards (54%): clear glass plates and ribbed plates; trace very fine-grained sanidine and possibly quartz — 6.5

10 VOLCANIC CLAYSTONE, white (N9) — 0.25

9 *INTERBEDDED:* VOLCANIC-GRANULE CONGLOMERATE, (80%) slightly altered, coarse-sandy, medium gray (N6), thin-bedded, cross-stratified; authigenic clay (8%); equant tubular pumice (1.5 mm) (50%); glass shards and microvesicular etched shards (n=1.510); sanidine (8%); *and* VOLCANIC SANDSTONE, coarse-grained, pale yellowish-gray (5Y9/1), slightly altered, thin-bedded — 7.5

8 VITRIC VOLCANIC SANDSTONE, severely altered, fine-grained, silty, yellowish-gray (5Y8/1), massive; authigenic clay (85%); glass shards (14%): thin, clear plates and ribbed plates (n=1.515); common sanidine; rare plagioclase (calcic oligioclase) — 2.5

7 *INTERBEDDED:* VOLCANIC-PEBBLE CONGLOMERATE, (50%) slightly altered, sandy, silty, yellowish-gray (5Y8/1) and medium-gray (N6); thick-bedded, cross-laminated; perlite granules (1-2 mm) (80%); tubular pumice pebbles (to 20 mm) (10%); massive, ribbed, etched clear glass (2 mm) (2%); sanidine and ribbed, clear glass plates in sand fraction; *and* VOLCANIC SANDSTONE, moderately altered, fine-grained, silty, pale yellowish-gray (5Y9/1), thick-bedded; authigenic clay (15%); glass shards (80%): thin, clear plates, massive ribbed plates, tubular pumice (n=1.515) — 6

6 VOLCANIC SANDSTONE, severely altered, fine-silty, pale yellowish-gray (5Y9/1), massive; authigenic clay (45%); glass shards (54%): thin, clear plates and ribbed plates; trace very fine-grained sanidine 4.5

5 VOLCANIC-PEBBLE CONGLOMERATE, slightly altered fine-sandy, yellowish-gray (5Y8/1) and medium-gray (N6), thin-bedded, very friable, thinly cross-bedded, (planar); lenticular; proportion of pebbles decreasing laterally; authigenic clay (10%); pebbles and coarse sand of perlite vitrophyre (70%), rounded to subrounded; glass shards: microvesicular plates and ribbed plates; small amounts of sanidine 2.3

4 VITRIC VOLCANIC SANDSTONE, moderately altered, fine-grained, silty, yellowish-gray (5Y8/1), thin-bedded, friable; authigenic clay (25%); glass shards (70%): clear, thin plates; clear, tubular, equant, microvesicular shards; trace dark-colored shards; with lenticular laminae and thin beds of pumice and perlite pebbles; rare sanidine and plagioclase (0.3-1.0 mm) 10

3 VITRIC VOLCANIC SANDSTONE, moderately altered, fine-grained, pale yellowish-gray (5Y8/2), thin-bedded; cf. unit 2 0.8

2 VITRIC VOLCANIC SANDSTONE, severely altered, silty, fine-grained, pale yellowish-gray (5Y9/1), crudely thick-bedded, moderately indurated; authigenic clay (45%); glass shards (n=1.515) (40%): clear, thin plates; small amounts of sanidine, clear quartz, euhedral oligoclase (to 3 mm) (An_{25}) 4

1 VITRIC VOLCANIC SANDSTONE, moderately altered, silty, medium-grained, pale yellowish-gray (5Y8/2) thin-bedded, friable; authigenic clay (20%); glass shards (75%): clear, thin plates, ribbed plates, and entire bubbles; small amounts of very fine-grained sanidine Not measured (less than 2 feet)

Total measured thickness of Butte Creek Volcanic Sandstone (part) 44.4

Base of measured Butte Creek Volcanic Sandstone (part)

Base of measured section

Measured Section E

Type Section, Deer Butte Formation

Deer Butte, Malheur County, Oregon

E½ sec. 21, T. 21 S., R. 45 E., Willamette Meridian; Photo Reference: AMS 1803, 5.0 N, 2.5 E.; measured by A. M. Johnson, August 1960; hand level

Unit	*Description*	*Thickness in feet*

Top of measured section

Deer Butte Formation (part):

Mitchell Butte Member (part):

40 COVERED, not top of butte, remainder of section covered 48

39 MEDIUM VOLCANIC SANDSTONE, grayish-orange (10YR6/4); globular glass shards, feldspar, quartz; interbedded pebble conglomerate lenses; pebbles include granite, rhyolite, quartzite, and chert; granules include quartz and chert 46

38 LEAN VOLCANIC SANDY SILTSTONE and interbedded small-pebble conglomerate, pale grayish-orange (10YR8/4) and grayish-orange (10YR7/4); massive siltstone near center of unit; a few arkose lenses; some of lenses contain gastropods; quartz, feldspar, chert 114

37 MEDIUM VOLCANIC SANDSTONE, feldspathic, very thin-bedded 20

36 PEBBLE CONGLOMERATE, lenticular; cross-stratified, medium-scale, low-angle, simple; thin interbed of siltstone 4

35 RICH VOLCANIC SILTSTONE, pale grayish-orange (10YR8/4); very thin-bedded; slope former 22

34 PEBBLE CONGLOMERATE, grayish-orange (10YR6/4); small pebble size; few clay galls; few pelecypods; cross-stratified, medium-scale, low-angle, planar; lean volcanic sandstone matrix; rhyolite, chert pebbles; gypsum and calcite cement in part 33

33 RICH VOLCANIC SILTSTONE, pale yellowish-brown (10YR6/2); popcorn weathering surface; slope-former 40

32 PEBBLE CONGLOMERATE, grayish-orange (10YR6/4); cross-stratified, medium-scale, low-angle, planar; chert, granite porphyry, granite, rhyolite pebbles; lean volcanic, feldspathic matrix; ledge former 6

31 MEDIUM VOLCANIC SANDSTONE, yellowish-gray (5Y7.5/2); glass shards partly altered; quartz, subrounded; lenticular body 15

30 PEBBLE CONGLOMERATE, grayish-orange (10YR6/4) 7

29 MEDIUM VOLCANIC SANDSTONE, yellowish-gray (5Y7/2); similar to unit 31, however, tabular body 4

28 SMALL-PEBBLE AND GRANULE CONGLOMERATE, grayish-orange (10YR-6.5/4); ledge-former 10

27 MEDIUM VOLCANIC SANDSTONE, yellowish-gray (5Y7.5/2), very fine-grained, massive in part, thin-bedded in part; few plant remains; slope former 66

26 MEDIUM VOLCANIC SILTSTONE, yellowish-gray (5Y7/2), thin-bedded, cross-stratified, small-scale, low-angle, simple; slope former 36

25 LEAN VOLCANIC SANDSTONE, pale yellowish-brown (10YR7/2), very fine-grained; interbedded with siltstone, cross-stratified, small-scale, high-angle, simple; quartz, feldspar, glass devitrified; flow-rolls 5

24 MEDIUM VOLCANIC SILTY CLAYSTONE, light brownish-gray (5YR7/1), thin-bedded; popcorn weathering surface; pinnacle former 16

23 SMALL-PEBBLE CONGLOMERATE, gray-orange (10YR6/4), cross-stratified, medium-scale ,low-angle, simple; irregular surface at base; tabular body; ledge former 7

22 RICH VOLCANIC SANDSTONE; grades westward into volcanic breccia; thickness varies 4

Total exposed thickness of Mitchell Butte Member 503

Sourdough Basin Basalt Member (?):

21 OLIVINE BASALT, dusky-brown (5YR-2/2); vesiculated in upper part, columnar jointing well developed; ledge former 60

20 RICH VOLCANIC SANDSTONE, interbed between basalts 5

19 OLIVINE BASALT, olive-black (5Y2/1); vesiculated; thoroughly altered; slope-former 24

Total thickness of Sourdough Basin Basalt Member (?) 89

Burnt Mountain Member (?):

18 Largely COVERED. In part MEDIUM VOLCANIC-GRANULE CONGLOMERATE, pale yellowish-brown (10YR6/2) 52

17 VOLCANIC BRECCIA, matrix dark yellowish-brown (10YR5.5/2); angular fragments of vesiculated basalt from 4 cm to 60 cm in diameter; includes rounded pebbles of chert and rhyolite; calcareous cement; volcanic sandstone matrix 4

Total thickness of Burnt Mountain member 56

Quartz Mountain Basalt Member(?):

16 OLIVINE BASALT, brownish-black (5YR2/1); baked zone at base, ranges from 1 to 2 feet thick; highly vesiculated at base; calcite amygdules; ledge former 54

Total thickness of Quartz Mountain Basalt Member 54

Orlano Spring Member(?):

15 RICH VOLCANIC SANDSTONE, pale yellowish-brown (10YR6/2); quartz, feldspar, mostly glass shards 4

14 COVERED, may be largely the same as unit 15 50

13 ARKOSIC SANDSTONE, grayish-orange (10YR7/4); tabular body; cross-stratified, medium-scale, low-angle, simple 6

12 LARGE-PEBBLE AND COBBLE CONGLOMERATE, massive; lenticular body; base irregular; contains small lenses of arkose; calcareous and siliceous cement; granite, rhyolite, chert, quartzite, and quartz pebbles and cobbles 64

11 ARKOSIC SANDSTONE, grayish-orange (10YR7/4); lenticular body; laps on units 9 and 10 4

10 OLIVINE BASALT, brownish-gray (5YR-3.5/1), porphyritic; very fresh; calcite and zeolite-filled amygdules; relationships to sedimentary rocks not clear; appears to be stratigraphic equivalent of unit 9; base not exposed 25

9	SMALL-COBBLE AND LARGE-PEBBLE CONGLOMERATE, very irregular base; lenticular; small lenses of arkose included; cobbles and pebbles largely granite and rhyolite, some chert, quartz, quartzite	12
8	ARKOSIC SANDSTONE, pale yellowish-brown (10YR6/3), medium-grained; lenticular; a few scattered pebbles; cross-stratified, medium-scale, low-angle, simple; quartz, feldspar, mica; angular to rounded	6
7	SMALL-PEBBLE CONGLOMERATE, moderate yellowish-brown (10YR5/4); lenticular in form; a few cobbles included; granite, rhyolite, chert, and quartz pebbles	10
6	RICH VOLCANIC SILTSTONE, grayish-red (10R4/2); small lenses of feldspathic sandstone included; pinnacle-weathering	10
5	VITRIC-CRYSTAL TUFF(?), light olive-gray (5Y5/2); may be a rich volcanic sandstone	12
4	VITRIC-CRYSTAL TUFF(?), very pale-orange (10YR8/2); glass in part devitrified	24
3	VITRIC-CRYSTAL TUFF(?), light olive-gray (5Y5/2); same as unit 5	20
	Total thickness of Orlano Spring Member(?)	247
	Total measured thickness of Deer Butte Formation (part)	949
	Owyhee Basalt (part):	
2	SCORIA, dusky-red (5R3/4); vesicles contain secondary minerals, probably zeolites	18
1	BASALT, olivine-free	25
	Total measured thickness of Owyhee Basalt (part)	43
	Total measured thickness of section	992
	Base of measured section	

Measured Section F

Type Section, Poison Creek Formation

Poison Creek Grade, Owyhee County, Idaho

SW¼ sec. 16, T. 2 N., R. 5 W., Boise Meridian; Photo Reference: AMS 3274, 5.2 N, 4.0 E.; measured by L. R. Kittleman and G. L. Millhollen, July 1963; tape and hand level

Unit	*Description*	*Thickness in feet*
	Top of measured section	
	Poison Creek Formation (part):	
8	FINE MICACEOUS ARKOSE, yellowish-gray (5Y8/1), weathering dark reddish-brown, slightly clayey, moderately sorted, well indurated, thin-bedded, angular to subangular; size 0.5 to 0.33 mm; plagioclase, probably sodic (about 90%); quartz (less than 10%), fine-grained; vague planar cross lamination (units of a few cm); ledge former	1
7	FINE LEAN VOLCANIC ARKOSE, pale greenish-yellow (10Y8/2), weathering dark yellowish orange, moderately indurated, crudely laminated; moderately sorted; clay cemented (20%); quartz (less than 10%) and plagioclase, both angular; less than 5% biotite and muscovite; becoming coarse-grained upward; poor ledge former	11
6	RHYOLITE-PEBBLE CONGLOMERATE, very pale-orange (10YR8/2), well indurated, thick-bedded; clasts of altered rhyolite, angular to sub-rounded, 1-10 mm; clay cement; ledge former	2.5
5	COVERED: probably montmorillonitic claystone; slope former	10.5
4	COARSE MICACEOUS ARKOSE, yellowish-gray (5Y8/1); moderately friable, massive, vague planar cross stratification; mineralogy like that of unit 3; ledge former	7
3	COARSE MICACEOUS ARKOSE, pale grayish-orange (10YR8/4), weathering light-brown (5YR6/4), moderately indurated, massive; clay-cemented, well sorted, loosely packed; subangular frosted quartz (about 50%) and plagioclase (about 50%), probably oligoclase; less than 5% biotite and muscovite; planar cross lamination (2 to 5 cm); ledge former	10

2 COARSE LEAN VOLCANIC ARKOSE, yellowish-gray (5Y7/2), micaceous, clay cemented (about 15%), friable, well sorted, thin-bedded; low packing density, but grains in mutual contact; angular quartz (about 50%) and sodic plagioclase, with less than 5% muscovite; ledge former 1

1 ALTERED VITRIC VOLCANIC SANDSTONE, severely altered very pale yellowish-gray (5Y8/.5), moderately friable, thick-bedded, relict vitroclastic texture; sparse silt-size crystal fraction of angular quartz; slope former Not measured

Total measured thickness of Poison Creek Formation 43

Base of measured Poison Creek Formation (part)

Base of measured section

Measured Section G

Type Section, Drip Spring Formation

Cottonwood Creek, Malheur County, Oregon

SE¼ sec. 20, T. 20 S., R. 42 E., Willamette Meridian; Photo Reference: BBC 9N-189, 5.0 N, 3.5 E.; measured by L. R. Kittleman and G. L. Millhollen, August 1963; hand level and tape

Unit	*Description*	*Thickness in feet*

Top of measured section

Drip Spring Formation (part):

7 *INTERBEDDED:* SILICEOUS DIATOMITE, yellowish-gray (5Y8/1), thin-bedded; diatom tests in opaline matrix; opalization partial to complete; severely fractured; *and* ZEOLITIZED VITRIC VOLCANIC SANDSTONE, white (N9), moderately friable, thinly laminated to thin-bedded, good relict vitroclastic texture; zeolite (probably heulandite) pseudomorphic after glass shards; sparse plagioclase clasts 126.8

6 VITRIC VOLCANIC SANDSTONE, severely altered, moderate dusky-yellow (5Y7/4), moderately indurated, thinly laminated to massive; chaotic structure with load casts; concretionary (calcite); partially zeolitized glass shards including sideromelane (n=1.580); sparse plagioclase clasts; good relict vitroclastic texture; slope former 35.3

5 ZEOLITIZED VITRIC VOLCANIC SANDSTONE, yellowish-white (5Y8/2); friable, thin-bedded; zeolite (probably heulandite) pseudomorphic after glass shards in clay matrix (45%); pronounced relict vitroclastic texture; ledge former 24.1

4 SILICEOUS DIATOMITE, very light gray (N8), extremely indurated, severely fractured, thin-bedded; diatom tests in dense matrix of opal; few chalcedony veinlets; forms slopes; lenticular 20.7

3 *INTERBEDDED:* ZEOLITIZED VOLCANIC SANDSTONE, severely altered, yellowish-orange (10YR6/4), fine-grained, thinly laminated to thin bedded; sparse clastic crystalline grains; sanidine; heulandite(?) pseudomorphic after glass shards; *and* VOLCANIC-CLAYSTONE PEBBLE CONGLOMERATE, severely altered, yellowish-orange (10YR6/4), calcareous, zeolitized, medium-grained matrix, moderately indurated; heulandite(?)

pseudomorphic after glass shards; *and* EPICLASTIC VOLCANIC ORTHOCONGLOMERATE, severely altered, yellowish-orange (10YR6/4), zeolitized, thick bedded to massive; pebbles of volcanic clay-stone, rhyolite, and altered basalt; clasts to 2 cm in diameter; in matrix of volcanic claystone; moderately indurated 11.9

2 PALAGONITIC EPICLASTIC VOLCANIC-BOULDER PARACONGLOMERATE, yellowish-gray (5Y7/2), mottled grayish-brown (5YR3/2), gypsiferous; boulders of palagonitized basalt to 60 cm in diameter; friable; massive; matrix of authigenic clay and palagonite shards to 2 mm diameter with abundant heulandite(?) and sparse quartz and plagioclase; lenticular; absent within 200 feet laterally; cliff former 30

1 *INTERBEDDED:* EPICLASTIC VOLCANIC-PEBBLE VOLCANIC ORTHOCONGLOMERATE, calcareous, yellowish-gray (5Y7/4), moderately indurated; phenoclasts (1-5 mm) of volcanic claystone, rhyolite, and chert; matrix, authigenic clay, authigenic heulandite(?); sparse quartz grains; thin bedded with thin festoon cross bedding; cliff former; *and* VOLCANIC SANDSTONE, severely altered, moderate yellowish-gray (5Y7/4), moderately indurated; sparse clastic quartz 11.5

Total measured thickness of Drip Spring Formation 260.3

Base of measured Drip Spring Formation (part)

Base of measured section

MEASURED SECTION H

TYPE SECTION, WILDCAT CREEK WELDED ASH-FLOW TUFF

Upper Wildcat Creek, Malheur County, Oregon

SW¼NW¼ sec. 29, T. 24 S., R. 40 E., Willamette Meridian; Photo Reference: BBC 25N-158, 5.4 N, 5.8 E.; measured by L. R. Kittleman and G. L. Millhollen, July 1963; hand level and tape

Unit *Description* *Thickness in feet*

Top of measured section

Wildcat Creek Welded Ash-Flow Tuff (part):

3 ZONE OF PARTIAL WELDING: WELDED ASH-FLOW TUFF, pale-red (5R6/2), grayish-red (5R4/2), with dark-gray (N3) elongated lenticles and laminae; foliated; microvesicular; chaotic dark laminae and lenticles on scale of mm to cm; lithic clasts and autoclasts to 8 mm; laminae sporadically hyaline; chaotic assemblage of black, nearly opaque glass in contorted laminae alternating with devitrified, hematite-pigmented groundmass; welded vitroclastic texture obscure; black glass contains green patches with hematite aureoles; sparse feldspar (to 1 mm), euhedral, sharply defined outer zone; mostly sanidine, trace plagioclase (near andesine), complex twinning; rare, altered clinopyroxene; cavities empty or filled with chalcedony and possibly tridymite; unit crudely columnar; columns extend height of cliff; column sides to 2.5 m; contorted foliation visible on weathered surface 35

2 ZONE OF MODERATELY DENSE WELDING: WELDED ASH-FLOW TUFF, pale reddish-brown (10R5/4), dense, not hyaline; with horizontally flattened vesicles and irregular cavities (5 to 10 cm); crudely platy (5 cm); columnarity of unit 3 continues imperfectly downward into unit 2; definite foliation visible without hand lens; welded vitroclastic texture clear, but shards not sharply outlined; shards defined by hematite dust; strongly appressed, not chaotic or recurved; devitrification complete; secondary crystallites oriented normal to shard boundaries, truncated by boundaries; rare feldspar (1 mm), subhedral, sub-parallel to foliation: sanidine or orthoclase; trace clinopyroxene, pleochroic in greens; trace altered

mafic xenoclasts; rare, hematite-rimmed magnetite (about 0.2 mm); vesicles, when lined, contain lath-shaped, low-birefringence crystallites or opal 2.5

1 ZONE OF DENSE WELDING (base not exposed): WELDED ASH-FLOW TUFF, medium light-gray (N6), weathering dark yellowish-brown (10YR4/2), slightly perlitic, compact, hackly fracture, brittle; welded vitroclastic texture visible with hand lens 1

Total measured thickness of Wildcat Creek Welded Ash-Flow Tuff 38.5

Base of exposed Wildcat Creek Welded Ash-Flow Tuff

Base of measured section

Measured Section I

Type Section, Grassy Mountain Formation

Part I, Kern Basin, Malheur County, Oregon
Part II, Lone Willow Spring, Malheur County, Oregon

Part I: SW¼SW¼sec. 36, T. 21 S., R. 44 E., Willamette Meridian; Photo Reference: AMS 1802, 2.5 N, 3.0 E. Part II: E½ sec. 24, T. 21 S., R. 44 E., Willamette Meridian; Photo Reference: AMS 1802, 5.0 N, 3.7 E. Measured by L. R. Kittleman and A. M. Johnson, September 1960; alidade

Unit	*Description*	*Thickness in feet*
	Top of measured section	
	Grassy Mountain Formation (part):	
	Top of part II	
23	OLIVINE-CLINOPYROXENE BASALT	Not measured
22	Baked zone: VITRIC VOLCANIC SANDSTONE, reddish-brown (10R4/7), with sideromelane shards	3
21	VITRIC VOLCANIC SANDSTONE, severely altered, pale yellowish-gray (5Y8/2), massive; with sideromelane shards; grades upward into unit 22	28
20	OLIVINE-CLINOPYROXENE BASALT	98
19	Baked zone: VITRIC VOLCANIC SANDSTONE, severely altered, reddish-brown (10R4/7); with sideromelane shards	3
18	VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1), massive; grades laterally into LEAN VOLCANIC ARKOSE, pale-brown (5YR6/2), medium-grained, poorly sorted; subangular to rounded; friable; with ostracode fragments; grades upward into unit 19	23
17	OLIVINE-CLINOPYROXENE BASALT	25
16	Baked zone: VITRIC VOLCANIC SANDSTONE, severely altered, reddish-brown (10R4/4); with sideromelane shards	2
15	VITRIC VOLCANIC SANDSTONE, severely altered, pale olive-gray (5Y7/1), massive; with partly palagonitized sideromelane shards	23
14	VITRIC VOLCANIC SANDSTONE, severely altered, pale yellowish-gray (5Y8/2); pumiceous	10
13	CONGLOMERATIC VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/2); with sparse granules of detrital quartz	21

12 CRYSTAL-VITRIC VOLCANIC SANDSTONE, severely altered, pale yellowish-gray (5Y8/2), massive; proportion of crystal fragments increasing upward 15

11 COVERED 15

Total measured thickness of part II 266

Base of part II

Top of part I

10 OLIVINE-CLINOPYROXENE BASALT 81

9 Baked zone: VITRIC VOLCANIC SANDSTONE, severely altered, (10R7/4) 2

8 *INTERBEDDED:* ARKOSE SANDSTONE, yellowish-gray (5Y8/1), fine-grained, friable; GRANITE-COBBLE CONGLOMERATE; VITRIC TUFF, light-gray (N7); *and* VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1) 212

7 FELDSPATHIC SANDSTONE, yellowish-gray (5Y8/1), medium-grained, moderately indurated 3

6 *INTERBEDDED:* ARKOSE SANDSTONE, yellowish-gray (5Y8/1), fine-grained, friable; GRANITE-COBBLE CONGLOMERATE; VITRIC TUFF, light-gray (N7); *and* VITRIC TUFF-CLAYSTONE, yellowish-gray (5Y8/1) 180

5 PUMICEOUS-BOULDER TUFF-BRECCIA, light-brown (5YR6/6), massive; with basalt and rhyolite boulders to 30 cm in diameter 67

4 PUMICEOUS TUFF-BRECCIA, very light-gray (N8), massive to thick-bedded; with fragments of quartz, sanidine, biotite and beta-quartz pseudomorphs; altered to white, non-swelling, montmorillonite-bearing clay 22

3 PUMICEOUS BASALT-COBBLE TUFF-BRECCIA, very light-gray (N8), massive; with fragments of quartz, sanidine, biotite, and beta-quartz pseudomorphs; altered to white, non-swelling, montmorillonite-bearing clay 39

2 PUMICEOUS TUFF-BRECCIA, very light-gray (N8); with fragments of quartz, sanidine, biotite, and beta-quartz pseudomorphs; altered to white, non-swelling, montmorillonite-bearing clay 240

Total measured thickness of Grassy Mountain formation 1112

Base of Grassy Mountain Formation

Unconformity

Deer Butte Formation (part):

1 ARKOSE SANDSTONE, yellowish-gray (5Y8/1), fine-grained, friable, thick-bedded; upright fossil stumps at upper contact. Deer Butte Formation, including unit 1, not described in detail 660

Total measured thickness of Deer Butte Formation 660

Total measured thickness of part I 1506

Total thickness of measured section 1772

Base of measured section

Measured Section J

Type Section, Bully Creek Formation

Harper Basin, Malheur County, Oregon

Part I: SW¼ sec. 7, T. 19 S., R. 41 E., Willamette Meridian; Photo Reference: BBC 18N-12, 7.9 N, 4.8 E. Part II: NW¼ sec. 11, T. 19 S., R. 41 E., Willamette Meridian; Photo Reference: BBC 19N-87, 6.0 N, 5.5 E; measured by L. R. Kittleman and G. L. Millhollen, August 1963; hand level and tape

PART I

Unit	*Description*	*Thickness in feet*
	Top of measured section	
	Bully Creek Formation (part):	
16	DIATOMITE, white (N9), massive, fractured	50.5
15	VITRIC VOLCANIC SANDSTONE, severely altered, yellowish-gray (5Y8/1), fine-grained, moderately indurated, massive; intricately fractured; plagioclase abundant; glass shards (n=1.508); grades upward into unit 16	17.7
14	PUMICEOUS VOLCANIC-PEBBLE VOLCANIC PARACONGLOMERATE, light-gray (N7), friable, moderately altered, massive, chaotic; pebbles of perlite and sideromelane (15%) (n=1.580); vitric matrix; contains tabular inclusions of underlying unit; becoming finer grained upward; forms hoodoos	10.1
13	*INTERBEDDED:* CRYSTAL-VITRIC VOLCANIC SANDSTONE *and* VITRIC VOLCANIC SANDSTONE, thin bedded; as unit 6	3
12	PUMICE-GRANULE VOLCANIC CONGLOMERATE, moderately altered, greenish-yellow (10Y7/2), moderately indurated; phenoclasts of plagioclase and sanidine; glass shards (n=1.515); grading upward into *INTERBEDDED:* PUMICE-GRANULE VOLCANIC CONGLOMERATE *and* VITRIC VOLCANIC SANDSTONE, severely altered, light-gray (N8), fine-grained	25.3
11	*INTERBEDDED:* DIATOMITE, white (N9); *and* VITRIC SIDEROMELANE VOLCANIC SANDSTONE, slightly altered medium light-gray (N6), medium-grained, moderately indurated, thin bedded; sideromelane (60%) (n=1.582)	1.5
10	DIATOMITE, white (N9), massive; intricately fractured	5.1
9	VITRIC VOLCANIC SANDSTONE, moderately altered, yellowish-gray (5Y8/1), fine-grained, massive, moderately indurated; nearly 100% glass shards (n=1.520); rare anisotropic grains	17.7
8	*INTERBEDDED:* CRYSTAL-VITRIC VOLCANIC SANDSTONE *and* VITRIC VOLCANIC SANDSTONE, thin bedded; as unit 6	10.1
7	VITRIC VOLCANIC SANDSTONE, moderately altered, very light-gray (N8), fine-grained, moderately indurated; nearly 100% clear glass shards (n=1.52); sparse diatom tests; plumose columnar structures to 2 cm diameter	10.1
6	*INTERBEDDED:* CRYSTAL-VITRIC VOLCANIC SANDSTONE (40%), moderately altered very light-gray (N8), moderately friable, blocky; glass shards (n=1.508); sparse sanidine and rare biotite; VITRIC VOLCANIC SANDSTONE (40%), light-gray (N7), slightly altered, moderately friable; glass shards (n=1.510) have coating of white, waxy clay; rare sanidine; VITRIC VOLCANIC SANDSTONE (10%), moderately altered, light-gray (N6), well indurated; clear glass shards with sideromelane (20%) (n=1.595) and sparse andesine; *and* CRYSTAL-VITRIC VOLCANIC SANDSTONE (10%), moderately altered, moderate yellowish-gray (5Y7/4), medium-grained, moderately indurated; glass shards (n=1.527) coated with white waxy clay; common sanidine and plagioclase; sparse biotite	8.8
5	PUMICE-GRANULE VOLCANIC CONGLOMERATE, pale yellowish-gray (5Y9/1), moderately indurated; sparse sanidine and plagioclase	1
4	PENECONTEMPORANEOUSLY DEFORMED STRATUM; consists of two units: (upper) PUMICE-GRANULE-VOLCANIC CONGLOMERATE, light-gray (N7), moderately indurated, thin bedded; granules in matrix of authigenic clay; (lower) VITRIC VOLCANIC SANDSTONE, moderately altered; very light-gray (N8), very fine-grained, moderately indurated; glass shards (n=1.515); with sparse plagioclase	1

3 *INTERBEDDED:* DIATOMITE (60%), yellowish-white (5Y9/1), blocky; VITRIC VOLCANIC SANDSTONE (30%), slightly altered, medium light-gray (N6), very fine-grained, moderately friable, thin bedded; nearly 100% clear glass shards (n=1.520); *and* VITRIC VOLCANIC SANDSTONE (10%), severely altered, light-gray (N7), moderately indurated, thin bedded, sideromelane shards common; contains plant fossils; unit is slope former 3.3

2 VITRIC VOLCANIC SANDSTONE, severely altered, pale yellowish-gray (5Y8/2), well indurated, massive; determinable clastic grains negligible; slope former 20.2

1 Base not exposed: EPICLASTIC VOLCANIC PARACONGLOMERATE, dusky yellowish-gray (5Y6/2), crudely thin- to thick-bedded, with festoon cross bedding, moderately indurated; angular to subangular clasts of basalt, rhyolite, and welded ash-flow tuff to 1 m diameter; large-scale load casts; matrix composed of pumiceous lithic volcanic-pebble conglomerate with basalt, perlite, and rhyolite pebbles and granules, cemented by authigenic clay; abundant sideromelane (n=1.582); rare subhedral beta-quartz pseudomorphs; rare plagioclase; ledge former 25.3

Total measured thickness of Bully Creek Formation (part) 210.7

Base of part I

Base of measured section

PART II

Top part II

Grassy Mountain Formation (part):

17 BASALT Not measured

Unconformity

Bully Creek Formation (part):

16 GLASS-GRANULE VOLCANIC CONGLOMERATE, severely altered, light olive-gray (5Y7/1), mostly covered, thin-bedded to massive, friable; glass shards (n=1.505); sparse plagioclase 65.6

15 DIATOMITE, yellowish-gray (5Y8/2), thinly laminated to massive 84

14 VITRIC VOLCANIC SANDSTONE, slightly altered, yellowish-gray (5Y8/1), fine-grained, very friable, massive; abundant diatom tests; sparse crystalline grains; glass shards (n=1.510); locally contiguous with unit 10 15

13 *INTERBEDDED:* DIATOMITE (30%), grayish-yellow (5Y8/4), thin-bedded; VITRIC VOLCANIC SANDSTONE, moderately altered, yellowish-gray (5Y8/1), fine-grained, moderately friable; glass shards (n=1.540); sparse feldspar(?); *and* PUMICEOUS LAPILLISTONE, slightly altered, light-gray (N7), coarse-grained, friable; equant microvesicular and tubular pumice clasts (n=1.510) 21

12 VITRIC VOLCANIC SANDSTONE, slightly altered, very light silvery-gray (N8), very fine-grained, thin bedded, friable; nearly 100% glass shards (n=1.510); rare undetermined opaque grains 0.6

11 DIATOMITE, white (N9), thinly laminated to thin-bedded 3.7

10 VITRIC TUFF, light silvery-gray (N7), weathers dark yellowish-orange (10YR6/6), medium-grained, very slightly altered, friable, massive, chaotic; nearly 100% glass shards (n=1.515); contains equant and tabular inclusions from unit 9 to 2 m in largest dimension; weathers to hoodoo forms; top and base variable over tens of feet. 70.9

9 *INTERBEDDED:* DIATOMITE (80%), white (N9), *and* VITRIC VOLCANIC SANDSTONE (20%), moderately altered, medium light-gray (N6), very fine-grained, moderately indurated, thin-bedded; clear glass shards, abundant; tachylite (n=1.545) (20%); common labradorite 1.6

8 VITRIC VOLCANIC SANDSTONE, slightly altered, light-gray (N7), fine-grained, moderately indurated; nearly 100% glass shards (n=1.523); rare crystalline grains 0.4

7 VITRIC VOLCANIC SILTSTONE, very light-gray (N8), as unit 6; 0.1 ft slightly altered vitric volcanic sandstone at base; with graded bedding 0.5

6 VITRIC VOLCANIC SILTSTONE, very light-gray (N8), moderately altered, thinly laminated to thin-bedded; regular stratification; nearly 100% glass shards; rare sanidine and diatom tests 0.6

5	VITRIC VOLCANIC SANDSTONE, very slightly altered, light silver-gray (N7), friable, thin-bedded; slump structures and load casts; nearly 100% glass shards (n=1.505); very sparse crystalline material	1
4	*INTERBEDDED:* DIATOMITE, (95%) white (N9), thin-bedded to massive; *and* CRYSTAL-VITRIC VOLCANIC SANDSTONE, slightly altered, very pale yellowish-gray (5Y8/0.5), fine-grained, moderately indurated; abundant; glass shards (n=1.510), abundant plagioclase near labradorite, rare sanidine; rare quartz	8
3	VOLCANIC CLAYSTONE, light-gray (N7), well indurated	0.7
2	LITHIC-VITRIC VOLCANIC SANDSTONE, slightly altered light-gray (N7), very fine-grained, thin-bedded; with silicic glass shards; sanidine; plagioclase, near andesine; undetermined rock fragments	0.2
1	Base not exposed; DIATOMITE, white (N9), slight argillaceous impurity, thick-bedded to massive	7
	Total measured thickness of Bully Creek Formation (part)	280.8

Base of measured Bully Creek Formation (part)

Base of part II

Base of measured section