GEOLOGIC MAP OF THE LITTLE BLACK CANYON QUADRANGLE, MALHEUR COUNTY, OREGON

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INTRODUCTION

The Little Black Canyon 7.5' quadrangle is located in Malheur County, Oregon, about 50 km west of the town of Vale. Principal access is by U.S. Highway 20, north 1.6 km from Highway 20 to the town of Harper, and west and northwest from Harper following dirt roads that lead to the eastern part of the quadrangle (fig. 1).

Some formations in the quadrangle were first named and described by Bowen and others (1963) and Kittleman and others (1965). A reconnaissance geologic map (scale 1:63,360) that includes the quadrangle was made by Haddock (1967) as part of a study of the Dinner Creek Welded Tuff of the Malheur Gorge area. Haddock's mapping was incorporated into a geologic map of the Owyhee region at the scale of 1:125,000 (Kittleman and others, 1967), a geologic map of eastern Oregon at the scale of 1:500,000 (Walker, 1977), and a geologic map of the State of Oregon at the scale of 1:500,000 (Walker and MacLeod, 1991). The quadrangle is included in the west half of the Boise 1° x 2° Sheet which was mapped at the scale of 1:24,000 during a cooperative program (COGEOMAP) between the U.S. Geological Survey and the Oregon Department of Geology and Mineral Industries. Geologic mapping of the Little Black Canyon quadrangle at the scale of 1:24,000 was incorporated into the geologic map of the Vale 30 x 60 minute quadrangle (Ferns and others, 1993) at the scale of 1:100,000.

The volcanic rock classification used in this report is by Le Bas and others (1986). The correlations between radiometric ages and geologic ages is by Palmer (1983).

STRATIGRAPHY

The rocks in the quadrangle comprise a flat-lying to gently dipping section of volcanic, pyroclastic, and sedimentary rocks of late Tertiary age. The oldest unit is the basalt of Malheur Gorge (map unit Tm), named for a 600-m-thick section of tholeiitic basalt and basaltic andesite exposed 10 km to the south in Malheur Gorge (Evans, 1990a,b). Only the upper hundred meters are exposed in the Little Black Canyon quadrangle. Stratigraphically, chronologically, petrographically, and geochemically, these rocks are similar to the Imnaha and Grande Ronde Basalts of the Columbia River Basalt Group (G.B. Binger, 1997). The basalt of Malheur Gorge is exposed sporadically for 75 km to the south of the

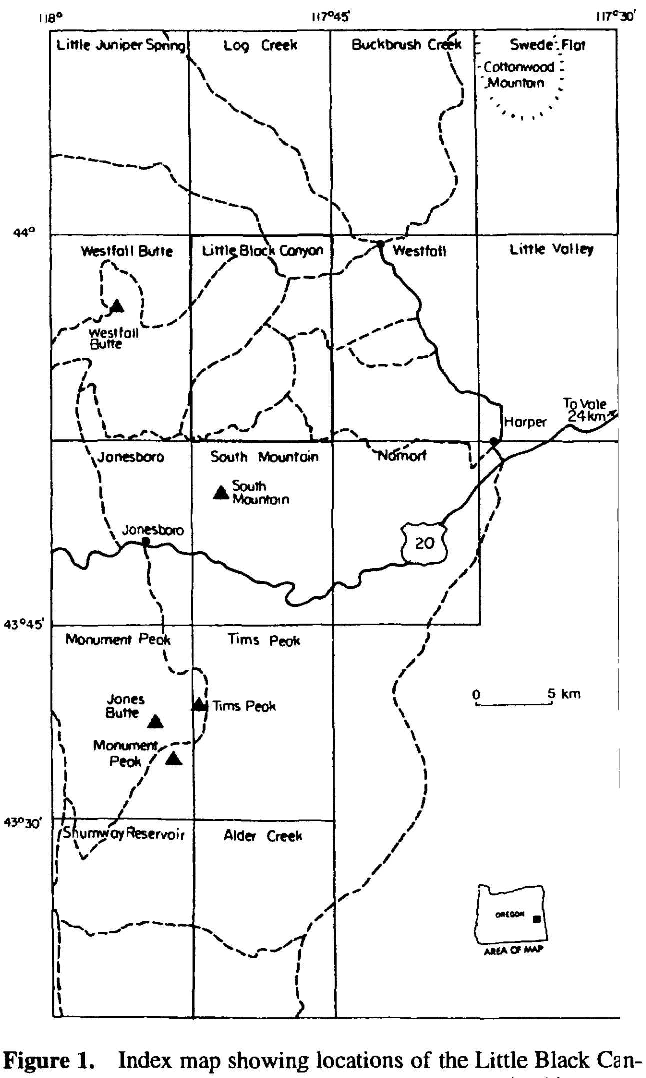

Figure 1. Index map showing locations of the Little Black Canyon quadrangles and other quadrangles mentioned in this report. The broader uninterrupted lines are paved roads. The broader dashed lines are dirt roads. Triangles are peaks and buttes.

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quadrangle; to the north of the quadrangle it is presumably buried beneath younger rocks. A major source vent is located in the Jones Butte area, 20 km to the southwest (Evans, 1996). Samples of the basalt were dated at 16.8±1.2, 16.9±0.67, 17.9±1.76, and 18.5±1.37 Ma ($^{40}Ar/^{39}Ar$ method; Lees, 1994; Lees' samples KL-91-49, KL-91-80, KL-91-164, and KL-92-231). These dates are generally consistent with the 15 Ma age of the overlying Dinner Creek Welded Tuff (see below) and with ages for the stratigraphically equivalent Imnaha and Grande Ronde Basalts of the Columbia River Basalt Group (Baksi, 1989).

The rhyolite of Cottonwood Mountain (map unit Trcm) is an informal name used here for rhyolite correlative with rhyolite extensively exposed on Cottonwood Mountain, 23 km northeast of the Little Black Canyon quadrangle (Evans, unpub. mapping, 1995, Swede Flat 7.5' quadrangle). Brooks and O'Brien (1992b) earlier named a correlative formation 14 km to the west in the Little Valley quadrangle "rhyolite of Bully Creek canyon" (their Trbc). However, to avoid confusion with the name "Bully Creek Formation" (Brooks and O'Brien, 1992a; map unit Tbc of the Little Black Canyon quadrangle as discussed below), a new name is considered preferable. On Cottonwood Mountain, the rhyolite overlies a thick mafic volcanic rock sequence that appears to be stratigraphically equivalent to the basalt of Malheur Gorge and (or) the Columbia River Basalt Group. The rhyolite is exposed near the southeast corner of the quadrangle, where it is overlain by the Hunter Creek Basalt (see below), Littlefield Rhyolite (see below) and a pale brown partly welded tuff tentatively interpreted to be a distal facies of the Dinner Creek Welded Tuff (NE1/4 sec. 18, T. 19 S., R. 41 E.). Lees dated the rhyolite of Cottonwood Mountain in the Swede Flat 7.5' quadrangle, about 10 km to the northeast, at 14.7±0.96 Ma (Lees, 1994; samples KL-92-230). A date close to the older end of the error range (15.66 Ma, middle Miocene) may be close to the actual age of the rhyolite.

The Dinner Creek Welded Tuff (map unit Tdc; Greene and others, 1972) is characterized in the field by cliffs 6 to 30 m high formed by the central strongly welded part of the formation. Less strongly welded parts of the formation above and below the cliffs are commonly concealed by debris from the overlying Hunter Creek Basalt (map unit Th, see below). The average composition of the Dinner Creek is that of an alkali rhyolite (Haddock, 1967; Evans, 1990a, table 1; Evans and Binger, 1997, table 2). In the adjacent Westfall Butte quadrangle (fig. 1; Evans and Binger, 1997), the Dinner Creek increases in thickness from 20 m to at least 120 m and lithic fragments in the welded tuff increase from 2 to 50 percent to the north); a vent source is tentatively inferred to be located north of Westfall Butte. Haddock (1967) and Rytuba and others (1990) had earlier suggested that the Dinner Creek erupted from a vent at Castle Rock, about 30 km west-northwest of the Little Black Canyon quadrangle. However, recent mapping indicates that Castle Rock is not a vent (M.L. Cummings, Portland State University, personal commun., 1996). Two radiometric dates of the Dinner Creek in the Malheur Gorge area are 15.3±0.4 and 14.7±0.4 Ma (K-Ar method; Fiebelkorn and others, 1983). Based on these ages, we estimate the age of the Dinner Creek to be about 15 Ma, or middle Miocene.

The Hunter Creek Basalt (map unit Th; Kittleman and others, 1965) overlies the Dinner Creek Welded Tuff and the rhyolite of Cottonwood Mountain. The Hunter Creek resembles the uppermost part of the basalt of Malheur Gorge in being black, generally aphyric, and containing rare sedimentary interbeds. Chemically the Hunter Creek Basalt is an icelandite (Carmichael, 1974) or a basaltic andesite (Le Bas and others, 1986; table 2, samples 723, 724, 10, 54, 63, and 82). The Hunter Creek pinches out to the west and north in the Westfall Butte quadrangle (Evans and Binger, 1997), but extends as far as 20 km to the east of the Little Black Canyon quadrangle into the Little Valley 7.5' quadrangle (Brooks and O'Brien, 1992b, their map unit Thb) where it overlies rhyolite of Cottonwood Mountain (their map unit Trbc), and some 40 km to the south in the Alder Creek 7.5' quadrangle (Evans and Binger, 1998). Possible vents for the Hunter Creek flows were mapped by Brooks and O'Brien (1992a) to the east in the adjacent Westfall quadrangle. Two lines of evidence strongly suggest that, although Hunter Creek Basalt is younger than Dinner Creek based on its stratigraphic position above the Dinner Creek, the flows erupted relatively soon after the Dinner Creek Welded Tuff was emplaced: (1) a lens of black vitrophyre in the Dinner Creek in the Jonesboro quadrangle (Evans, 1990a, table 1) has a basaltic andesite composition like that of Hunter Creek Basalt, suggesting mingling of rhyolite and andesite magmas prior to eruption of the Dinner Creek, and (2) in sec. 34 and 35, T. 12 S., R. 39 E., Westfall Butte quadrangle (Evans and Binger, 1997), the upper contact of the Dinner Creek appears to be gradational with the Hunter Creek; the dominantly rhyolitic tuff of the upper Dinner Creek grades in a few meters to andesitic tuff at the base of the Hunter Creek. Although the two volcanic units may not have shared the same vents, it is possible that the earlier Dinner Creek eruption helped set the stage for later eruption of the Hunter Creek flows by removal of the upper blocking rhyolite magma. Alternatively, intrusion of the Hunter Creek magma into the Dinner Creek magma chamber may have triggered eruption of the Dinner Creek as a result of rapid increase of pressure in the upper part of the chamber. For these reasons the Hunter Creek is assigned a middle Miocene age, probably very close in age to the Dinner Creek. $^{40}Ar/^{39}Ar$ dates for Hunter Creek are 15.0±0.73, 15.8±0.6, 15.89±0.26, 15.9±0.26, and 18.6±0.63 Ma (Lees, 1994, samples KL-92-269, HOR-9, KL-92-278, KL-91-102, and KL-91-100). The youngest date accords with the hypothesis that the Hunter Creek erupted shortly after the eruption of the Dinner Creek Welded Tuff. The other dates are probably too old.

The Littlefield Rhyolite, in the extreme southeast corner of the quadrangle (map unit Tl, named by Kittleman and others, 1965), is lithologically identical to the rhyolite of

Cottonwood Mountain (map unit Trcm). Littlefield Rhyolite overlies Hunter Creek Basalt and is distinguished from the older rhyolite in the field only by the presence of intervening basalt, or, in one locality, tuffaceous sandstone. Littlefield Rhyolite of the Little Black Canyon quadrangle represents the northwesternmost occurrence of this formation. A few thin remnants are found to the northeast in the Swede Flat 7.5' quadrangle (Evans, unpub. mapping, 1995). A sample of the rhyolite was analyzed for major oxides (table 2, sample 725). Lees (1994, $^{40}Ar/^{39}Ar$ method) dated three samples of the Littlefield Rhyolite at 15.2±0.31, 16.3±0.87, and 16.8±0.4 Ma. The youngest date is tentatively accepted as closest to the true age of the unit.

The pyroclastic and sedimentary rocks unit (map unit Tps) consists largely of tuff, welded tuff, lapilli tuff, and tuff breccia interlayered with subordinate siltstone, sandstone, and conglomerate. It is partly correlative with the sedimentary and pyroclastic rocks unit, Tst, in the Westfall Butte quadrangle to the west (Evans and Binger, 1997). Breccia blocks as much as 2 m across of Dinner Creek Welded Tuff and fine-grained basalt that closely resembles Hunter Creek Basalt suggest that pyroclastic parts of the unit were erupted from a nearby vent, possibly from the volcanic center at Westfall Butte (Evans and Binger, 1997). The lower part of the unit interfingers with flows in the upper part of Hunter Creek Basalt exposed in the overflow channel of Allotment 3 Reservoir, NE1/4 sec. 12, T. 19 S., R. 40 E., and constrains the lower part of the unit to be penecontemporaneous with upper Hunter Creek, that is, to be middle Miocene in age. A 3-m-thick, very vesicular basaltic andesite intrudes the sedimentary and pyroclastic rocks in SE1/4 sec. 19, T. 18 S., R. 40 E., but is not related to Hunter Creek Basalt because it is lithologically different, and has a composition different from Hunter Creek (see table 2, sample 47). If the pyroclastic parts of unit Tps are from the Westfall Butte volcanic center, then these rocks must be older than the middle Miocene Tims Peak Basalt which overlies the Westfall Butte Volcanics (Evans and Binger, 1997). Unit Tps is stratigraphically equivalent to unit Tvt of Brooks and O'Brien (1992a) in the adjacent Westfall quadrangle to the east.

White tuffaceous siltstone and tuff of the Bully Creek Formation (map unit Tbc) overlie the pyroclastic and sedimentary rocks unit. These rocks resemble and are physically continuous with rocks of the type locality of late Miocene Bully Creek Formation of Kittleman and others (1965), widespread to the east in the adjacent Westfall 7.5' quadrangle (Brooks and O'Brien, 1992a). However, "Bully Creek" in the Little Black Canyon quadrangle is overlain by welded tuff (map unit Twt, see below) and lapilli tuff (map unit Tlt, see below), both of which could have come from the Westfall Butte volcanic center, which is of probable middle Miocene age (Evans and Binger, 1997). Also, lacustrine sediments and tuffs identical to those of the Bully Creek Formation underlie the middle Miocene rhyolite of Cottonwood Mountain in the Swede Flat 7.5' quadrangle (Evans, unpub. mapping, 1995). Similarly, a middle Miocene age was noted for the Bully Creek Formation in the eastern part of the Tims Peak quadrangle, two quadrangles to the south (Evans and Keith, 1996). In addition, as described below, emplacement into the Bully Creek of a basaltic sill (map unit Tbp) compositionally like Tims Peak Basalt, inferred by Evans and Keith to be middle Miocene, suggests a middle Miocene age for the Bully Creek. This contradicts the late Miocene age for the formation suggested by Ferns and other (1993), based on identification of the ash-flow tuff stratigraphically above the Bully Creek as the late Miocene Devine Canyon Ash-Flow Tuff of Greene and others (1972). It is also possible that the Bully Creek is diachronous and that the Bully Creek in the Little Black Canyon quadrangle is from the middle Miocene part of the formation.

A basalt porphyry sill (map unit Tbp) appears to intrude the Bully Creek Formation and the pyroclastic and sedimentary rocks unit. A small dike from the upper part of the sill intrudes Bully Creek in SW1/4 sec. 3, T. 19 S., R. 40 E., and this dike or a similar one may have erupted at the paleosurface to produce an hyaloclastite deposit (map unit Thy) nearby in N1/2 sec. 10, same township. Although the basalt porphyry has a sill-like geometry, it could be an invasive flow that began as a basalt flow and burrowed down through less dense sediment to assume a sill-like form. Compositionally, the sill is a high-alumina basalt (table 2, samples 722, 21, 53, and 55) similar to the Tims Peak Basalt. It may have been emplaced in the middle Miocene when the Tims Peak Basalt erupted from a dike swarm farther to the west (Evans and Binger, 1997).

A 100 m-thick lapilli tuff (map unit Tlt) overlies unit Twt, the Bully Creek Formation, and Hunter Creek Basalt in the northern half of the quadrangle. The tuff could also be a product of the middle Miocene Westfall Butte eruptive center and might be correlative with one of the ignimbrites mapped near Westfall Butte (Evans and Binger, 1997).

Alluvial fan deposits (unit QTf) of estimated late Miocene and (or) Pliocene and (or) Quaternary age locally retain their alluvial fan morphology and appear to postdate most of the faulting.

A small landslide deposit (unit Qls) is found in the northwestern part of the quadrangle in NW1/4 sec. 31, T. 18 S., R. 40 E.

Alluvium (unit Qal) is assumed to be Quaternary, possibly largely Holocene. It is most extensive along the Cottonwood Creek drainage in the central part of the quadrangle and farther north along Swamp Creek.

STRUCTURE

The quadrangle is located near the northern end of a 75-km-long horst that forms the west wall of the 50-km-wide Oregon-Idaho graben (OIG; Ferns and others, 1993). Lateral stratigraphic changes across the horst-graben margin along the eastern part of the quadrangle include the apparent disappearance of the Dinner Creek Welded Tuff to the east, the addition of the rhyolite of Cottonwood Mountain to the stratigraphic section to the east, and the pinching out of the Littlefield Rhyolite to the west. As shown in cross-section A-A', the quadrangle contains flat to gently dipping volcanic and sedimentary rocks in broad open folds that are broken in places by mostly steeply dipping north-striking normal faults. The section may have been folded into very broad, open folds. Changes in stratigraphic thicknesses of the map units and unconformities between formations may be a result of emplacement or deposition of the units in an east-west extensional tectonic regime.

An isostatic gravity map of southeastern Oregon (Griscom and Halvorson, 1994) shows relatively elevated gravity anomalies over much of the quadrangle (fig. 2) and even higher gravity anomalies to the northeast and southeast in the adjacent OIG. A shallow rather conspicuous east-south-east-trending anomaly trough in the central part of the quadrangle may reflect an extension of the Adrian fault zone (Ferns and others, 1993), which is well developed at the surface in the adjacent Westfall Butte quadrangle (Evans and Finger, 1997), but has no surface expression in the Little Black Canyon quadrangle. Aeromagnetic features of the quadrangle (Griscom and Halvorson, 1994; fig. 3) also seem to reflect the presence of the Adrian fault zone extension, separating highly magnetic rocks, mainly basalt, to the southwest and less magnetic rocks, possibly sediments or tuff, to the northeast. The highly magnetic rocks would probably include a thick section of basalt of Malheur Gorge. The less magnetic rock could be a small sedimentary basin or caldera concealed beneath Hunter Creek Basalt. The cross-section skirts the

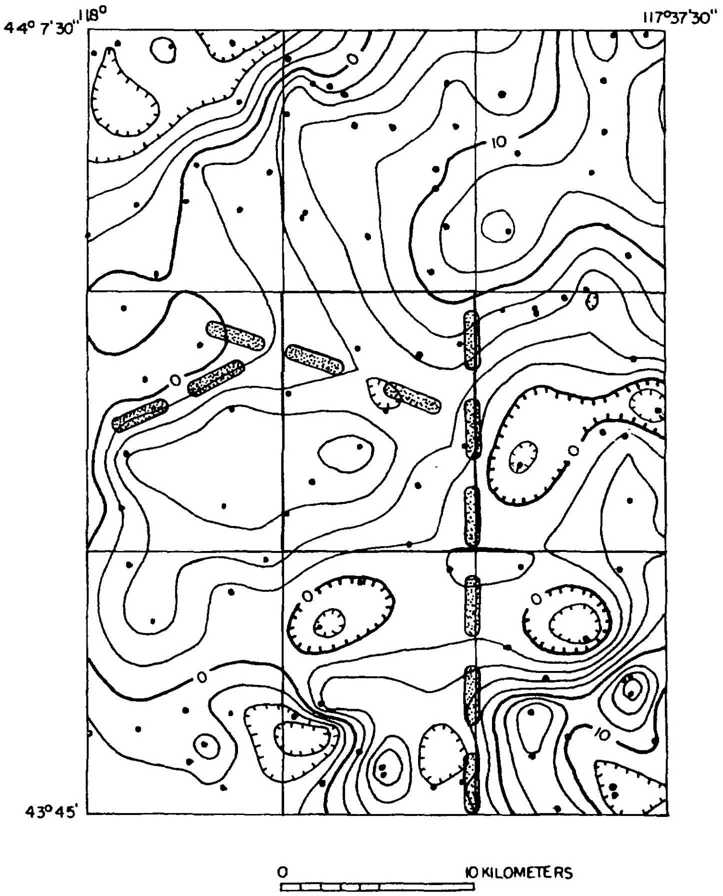

Figure 2. Isostatic residual gravity anomaly map of the Little Black Canyon and adjacent quadrangles. Modified from Griscom and Halvorson (1994). Contour interval 2 milligals. Hachures indicate closed lows. Dots are gravity stations. Stippled hotdogs mark the west-northwest-trending Adrian fault zone of Ferns and others (1993), the northeast-trending fault that passes through Westfall Butte, and the western margin of the Oregon-Idaho graben. See figure 1 for names of quadrangles adjacent to the Little Black Canyon quadrangle.

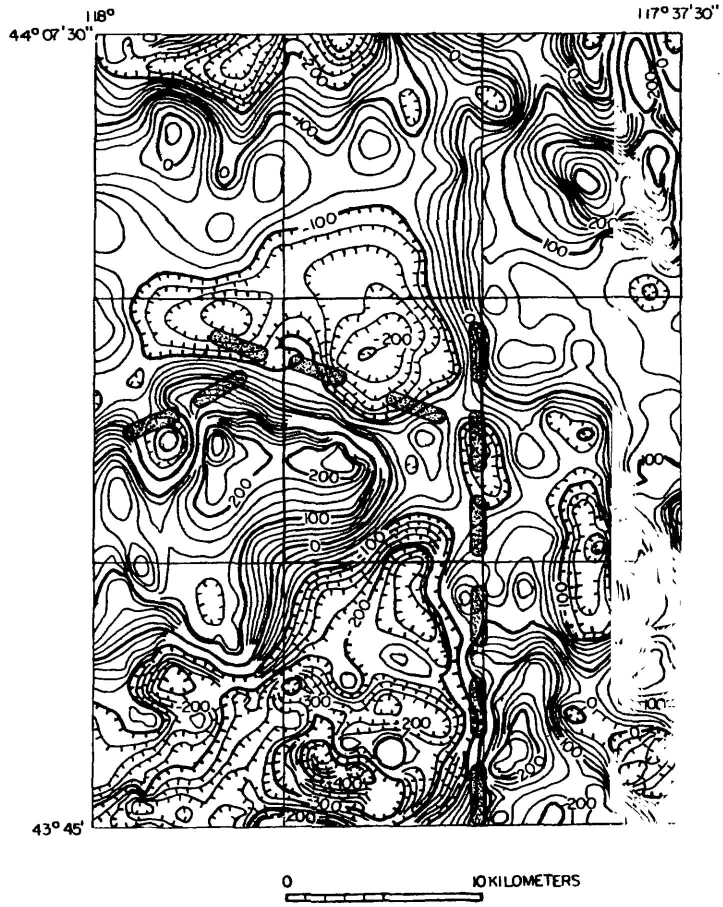

Figure 3. Aeromagnetic map of the Little Black Canyon and adjacent quadrangles. Modified from Griscom and Halvorson (1994). Contour interval 20 nanoteslas. Hachures indicate closed lows. East-west flight lines 1.6 km apart and 610 m above ground. Stippled hot dogs explained in figure 2. See figure 1 for names of quadrangles adjacent to the Little Black Canyon quadrangle.

area underlain by the less magnetic rock. Steep magnetic gradients along the eastern margin of the quadrangle parallel the location of the western margin of the OIG as inferred from stratigraphic relations.

GEOCHEMISTRY

Thirteen samples of unaltered volcanic rocks (table 1) and 19 samples of altered rock (table 4) collected by J.G. Evans during field mapping were submitted for chemical analysis. Five of the unaltered samples, nos. 721 to 725, were analyzed by J.S. Mee and D.F. Siems of the USGS Branch of Geochemistry for major elements using X-ray spectroscopy (Taggert and others, 1990). Total iron is expressed as Fe_2O_3. These samples were also analyzed for major and trace elements (tables 2 and 3; ICP; Briggs, 1990) by P.H. Briggs, J.S. Mee, and D.F. Siems of the USGS using inductively coupled plasma atomic emission spectrometry. Lower limits of detection are implied in the ICP analyses of samples 721-725 in table 3 by numbers preceded by the symbol "<" (element detected but in lower concentrations than the minimum confidence level indicated). Some elements listed in the ICP suite are not included because they occur in uniformly "lower-than-detectable" concentrations and no significant information can be presented by including these elements in table 3. These elements are: silver (Ag), <2 parts per million (ppm); arsenic (As), <10 ppm; gold (Au), <8 ppm; bismuth (Bi), <10 ppm; cadmium (Cd), <2 ppm); tin (Sn), < 5 ppm; tantalum (Ta), < 40 ppm; and uranium (U), < 100 ppm.

The remaining eight unaltered rock samples, nos. 10 to 82, were analyzed for major elements by G.B. Binger at the GeoAnalytical Laboratory of Washington State University, Pullman (Hooper and others, 1993) using X-ray fluorescence. Results of these analyses are presented in table 2 normalized on a volatile-free basis. Total iron is expressed as FeO. These samples were analyzed for 17 trace elements by X-ray fluorescence (table 3).

The altered rocks, described in table 4, were analyzed for major and trace elements by inductively coupled plasma atomic emission spectrophotometry (ICP; Briggs, 1990) by D.L. Fey and Z.A. Brown, of the USGS Branch of Geochemistry. The altered rocks were also analyzed for gold (Au) by flame and graphite furnace atomic absorption spectrophotometry (AA; O'Leary, 1990), and for mercury (Hg) by cold vapor atomic absorption spectrophotometry (O'Leary and others, 1990) by B.H. Roushey and R.M. O'Leary of the USGS Branch of Geochemistry. The results of these analyses are shown in table 5. Lower limits of detection are implied in table 5 by numbers preceded by the symbol "N" (element not detected at the lower confidence limit indicated) or "<" (element detected but in lower concentrations than the minimum confidence limit indicated). Some elements are not included in table 5 because they occur in uniformly lower than detectable concentrations in all the samples. These elements are: Ag, Au (lower limit of detection 0.05 ppm), Bi, Cd, Ho, Sn, and U.

In the field, the indicators that led to selection of the altered rock samples were (1) conspicuously large concentrations of iron oxide and (or) (2) high concentrations of silica, as in veins, nodules, replacement zones, or breccia zones. Silicified Dinner Creek Welded Tuff (sample 266) and chalcedony in the rhyolite of Cottonwood Mountain (sample 662) contained no significant concentrations of elements. Hematite and chalcedony veins in Hunter Creek Basalt (samples 654, 664, and 665) contain elevated concentrations of iron (2.6 to 30 percent), arsenic (20 to 110 ppm), mercury (0.02 ppm, sample 665), copper (24 ppm, sample 664), molybdenum (3 to 9 ppm, samples 664 and 665), manganese (1,700, sample 665), tantalum (50 ppm, sample 665), and zinc (130 ppm, sample 664). The quartz vein in Hunter Creek Basalt (sample 661) contained no significant concentrations of elements. Silicified sediments stratigraphically between rhyolite of Cottonwood Mountain and Hunter Creek Basalt (sample 666) contained 4.8 percent iron and 0.02 ppm mercury. Samples 656 and 658 are from hot-spring deposits found in the sedimentary and pyroclastic rock unit (Tps). Sample 656, a silicified algal mat in a paleo-hot-spring that vented along a north-striking fault at Black Canyon Reservoir. This sample contained 26 ppm arsenic and 0.02 ppm mercury. Sample 658 is from a siliceous paleo-hot-spring vent in the sedimentary and pyroclastic rocks unit (Tps) and appears to be unrelated to any fault. This sample contained 49 ppm arsenic. Samples 655, 657, 658, 660, 669, and 671 are silicified or hematite-enriched sedimentary rock and welded tuff from the sedimentary and pyroclastic rocks unit. These samples contained elevated concentrations of certain elements: iron (5.1, 7.3, and 8.7 percent, samples 660, 655, and 657), arsenic (110 and 120, samples 655 and 669), mercury (0.02 to 0.04, samples 655, 657, 660, 663, and 669), copper (34 and 24, samples 655 and 657), manganese (1,200 and 1,300, samples 657 and 671), molybdenum (8 ppm, sample 655), and zinc (120 and 110, samples 655 and 657). Hematite-cemented sandstone in the Bully Creek Formation (sample 668) contained 16 percent iron, 780 ppm arsenic, 0.03 ppm mercury, 120 ppm copper, 27 ppm molybdenum, and 180 ppm zinc. Samples 659 and 670, silicified breccia, are from sedimentary strata associated with faults and contained elevated concentrations of iron (6.0 and 6.5 percent), arsenic (160 and 49 ppm), mercury (0.02 ppm), copper (52 ppm), and molybdenum (2 ppm). Sample 667, also chalcedony from a fault zone, contained no significant concentrations of elements.

Conspicuously mineralized rocks are not common in the quadrangle. Most are hematite-cemented and (or) silicified sedimentary or pyroclastic rocks, in some places associated with faults and chalcedony veins in Hunter Creek Basalt. The paleo-hot-spring deposits are elevated in arsenic and, locally, mercury and iron, and do not have the variety of other anomalous elements noted above. The Tertiary section from Hunter Creek Basalt on down through the oldest unit exposed, basalt of Malheur Gorge, contains few permeable horizons, so that no significant hot-springs deposits are expected to lie close to the present surface. Relatively thick, well-exposed sections of sedimentary and pyroclastic rocks show few signs of rock alteration. These relations suggest that significant hot-spring deposits at present can only be found by drilling, perhaps in or near the identified paleo-hot-spring deposits at sample sites 656 and 658, and perhaps at depths exceeding 600 m (maximum exposed thickness of basalt of Malheur Gorge on the north side of Malheur Gorge, Jonesboro 7.5' quadrangle, Evans, 1990a).

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Table 1. Locations of unaltered rock samples.

Sample No.	Map unit	Location
721	Twt	Near Center sec. 25, T. 18 S., R. 40 E.
722	Tbp	SE1/4 sec. 24, T. 19 S., R. 39 E.
723	Th	Near Allotment 3 Res., NE1/4 sec. 12, T. 18 S., R. 40 E.
724	Th	Near SE corner sec. 12, T. 18 S., R. 40 E.
725	Tl	NE 1/4 sec. 25, T.19 S., R. 40 E.
10	Th	NW1/4 sec. 14, T. 19 S., R. 40 E.
21	Tbp	Near center sec. 18, T. 19 S., R. 40 E.
47	in Tst	SW1/4 sec. 19, T. 18 S., R. 40 E.
53	Tbp	SE1/4 sec. 8, T. 19 S., R. 40 E.
54	Th	NE1/4 sec. 7, T. 19 S., R. 40 E.
55	Tbp	SE1/4 sec. 7, T. 19 S., R. 40 E.
63	Th	N1/2 sec. 36, T. 18 S., R. 40 E.
82	Th	W1/2 sec. 26, T. 18 S., R. 40 E.

Table 2. Major oxide analyses of rock samples listed in table 1.

[Normalized on a volatile-free basis. Samples 721 to 725 were analyzed by X-ray spectroscopy by the U.S. Geological Survey and total iron is reported as Fe_2O_3. Samples 10 to 82 were analyzed by X-ray fluorescence at the WSU GeoAnalytical Laboratory and total iron is reported as FeO.]

Sample no.	721	722	723	724	725
Map unit	Twt	Tbp	Th	Th	Tl
Rock name	rhyolite	basalt	basaltic andesite	basaltic andesite	rhyolite
SiO_2	74.99	50.86	55.73	55.83	73.19
Al_2O_3	11.42	23.20	13.86	13.60	12.96
Fe_2O_3	3.34	3.97	12.34	13.10	3.66
MgO	0.44	3.64	3.17	2.80	<0.10
CaO	0.82	14.59	6.91	6.54	1.01
Na_2O	2.43	2.49	3.02	3.12	3.34
K_2O	5.89	0.21	1.95	1.91	5.30
TiO_2	0.22	0.78	2.31	2.34	0.42
P_2O_5	0.35	0.17	0.51	0.56	0.06
MnO	0.06	0.09	0.20	0.20	0.06

Sample No.	10	21	47	53	54	55	63	82
Map unit	Th	Tbp	in Tst	Tbp	Th	Tbp	Th	Th
Rock name	basaltic andesite	basalt	basaltic andesite	basalt	basaltic andesite	basalt	basaltic andesite	basaltic andesite
SiO_2	56.93	51.88	52.54	49.41	56.02	51.27	55.83	56.52
Al_2O_3	13.94	21.45	14.04	17.85	13.57	19.26	13.37	13.57
FeO	10.34	4.31	11.95	8.25	11.81	6.80	12.55	12.03
MgO	3.31	4.13	3.56	8.42	3.35	5.88	3.18	2.94
CaO	7.18	14.10	8.84	12.32	6.92	12.79	6.85	6.65
Na_2O	3.07	2.71	2.88	2.36	3.40	2.53	3.12	3.17
K_2O	2.10	0.26	1.51	0.21	1.91	0.25	2.11	2.08
TiO_2	2.399	0.912	3.71	0.860	2.349	0.915	2.328	2.362
P_2O_5	0.486	0.173	0.79	0.170	0.457	0.184	0.450	0.480
MnO	0.24	0.090	0.182	0.144	0.199	0.113	0.202	0.191

Table 3. Major- and trace-element analyses of unaltered rock samples listed in table 1.

[Concentrations of Al, Ca, Fe, K, Mg, Na, P, and Ti in samples 721 to 725 are in weight-percent; concentrations of other elements in these samples are in parts per million (ppm). Samples were analyzed by inductively coupled plasma atomic emission spectroscopy by the U.S. Geological Survey. Samples 10 to 82 were analyzed for 17 trace-elements by X-ray fluorescence at the WSU GeoAnalytical Laboratory. "<" followed by a number means that the element was found in concentrations below the lower confidence limit.]

Sample no.	721	722	723	724	725
Elements					
Al	5.6	13	7.4	7.1	6.5
Ca	0.59	10	4.8	4.5	0.74
Fe	2.3	2.7	8.5	9.0	2.6
K	4.5	0.19	1.7	1.6	4.2
Mg	0.28	2.2	1.9	1.7	0.05
Na	1.7	2.0	2.4	2.4	2.4
P	0.16	0.08	0.17	0.20	0.03
Ti	0.12	0.51	1.3	1.3	0.26
Ba	160	130	980	1000	2000
Be	6	<1	1	1	4
Ce	220	5	57	59	140
Co	2	25	39	34	<1
Cr	<1	370	11	4	<1
Cu	11	42	9	18	6
Eu	<2	<2	2	2	3
Ga	32	18	26	26	26
Ho	5	<4	<4	<4	<4
La	110	5	35	37	78
Li	33	4	10	10	15
Mn	460	670	1,500	1,500	470
Mo	3	<2	<2	<2	<2
Nb	63	<4	8	9	30
Nd	110	14	40	44	75
Ni	3	80	5	3	<2
Pb	29	<4	7	8	22
Sc	<2	42	32	31	7
Sr	25	260	360	340	150
Th	18	<4	9	9	16
V	11	230	370	320	<2
Y	170	19	40	47	91
Yb	19	2	4	4	10
Zn	250	37	140	140	160

Sample no.	10	21	47	53	54	55	63	82
Element								
Ni	0	91	0	146	0	168	0	13
Cr	21	310	25	276	25	262	15	0
Sc	26	42	33	45	30	36	29	5
V	368	275	445	248	367	261	375	4
Ba	1,508	132	695	113	864	138	801	1,247
Rb	54	3	33	4	45	4	49	61
Sr	376	244	335	214	319	224	322	31
Zr	211	54	220	50	201	54	203	323
Y	46	23	51	20	41	23	42	74
Nb	17.3	4.0	20.3	3.7	18.1	3.4	15.9	22.6
Ga	22	16	22	13	22	16	23	16
Cu	2	71	7	100	0	102	4	1
Zn	137	57	153	62	131	61	136	97
Pb	9	1	3	1	10	0	7	10
La	24	20	30	0	29	0	22	44
Ce	57	28	69	10	65	1	46	78
Th	6	1	5	0	5	1	4	5

Table 4. Descriptions and locations of altered rock samples.

Sample No.	Description	Location
654	Orange brown jasperoid	SE1/4 sec. 19, T. 19 S., R. 39 E.
655	Brown sandstone	SE1/4 sec. 34, T. 18 S., R. 40 E.
656	Multicolored chalcedony	Near Black Canyon Res., NW1/4 sec. 23, T. 19 S., R. 40 E.
657	Hematitic welded tuff	W1/2 sec. 23, T. 19 S., R. 40 E.
658	Siliceous hot spring deposit	NE1/4 sec. 20, T. 19 S., R. 40 E.
659	Multicolored chalcedony	Near center sec. 18, T. 19 S., R. 40 E.
660	Silicified sediment	NE1/4 sec. 18, T. 19 S., R. 40 E.
661	Quartz vein	Near center sec. 24, T. 19 S., R. 40 E.
662	Brown chalcedony	NE1/4 sec. 13, T. 19 S., R. 40 E.
663	Green and orange chalcedony	NE1/4 sec. 1, T. 19 S., R. 40 E.
664	Brown and green chalcedony	Near Annies Res., SE1/4 sec. 21, T. 19 S., R. 40 E.
665	Hematite and chalcedony	Near NW corner sec. 22, T. 19 S., R. 40 E.
666	Silicified sediment	Near line between secs. 12 and 13, T. 19 S., R. 40 E.
667	Green chalcedony	Near center sec. 30, T. 19 S., R. 40 E.
668	Hematite-cemented sandstone	SE1/4 sec. 34, T. 18 S., R. 40 E.
669	Silicified siltstone	NE1/4 sec. 16, T. 19 S., R. 40 E.
670	Silicified breccia	SW1/4 sec. 10, T. 19 S., R. 40 E.
671	Silicified sandstone	Near Black Canyon Res., NW1/4 sec. 23, T. 19 S., R. 40 E.
266	Brown and green chalcedony	NE1/4 sec. 27, T. 19, S., R. 40 E.

Table 5. Major- and trace-elements analyses of altered rock samples.

[The rock samples were analyzed by inductively coupled atomic emission spectrophotometry by the USGS. Concentrations of Al, Ca, Fe, K, Mg, Na, P, and Ti are given in weight-percent. Concentrations of other elements are in ppm. "N" followed by a number means that mercury (Hg) was not found at the 0.02 ppm lower limit of detection. "<" followed by a number means that the element was present in concentrations less than the lower confidence limit.]

Sample no.	654	655	656	657	658	659	660	661	662
Elements									
Al	0.05	7.4	0.20	6.0	0.17	0.21	0.86	0.05	0.11
Ca	0.05	2.4	0.09	4.2	0.06	0.14	0.37	0.05	0.12
Fe	2.6	7.3	7.7	8.7	1.9	6.5	5.1	0.98	3.2
K	0.03	0.62	0.04	0.30	0.05	0.06	0.07	0.05	0.06
Na	0.02	0.93	0.11	1.6	0.08	0.13	0.44	0.03	0.12
Na	0.01	0.92	0.01	0.49	0.01	0.01	0.03	0.01	0.007
P	0.02	0.14	0.03	0.22	0.01	0.02	<0.005	0.01	<0.005
Ti	<0.005	0.7	0.02	1.6	0.01	0.01	0.06	<0.005	0.005
As	20	110	28	<10	49	49	<10	<10	<10
Ba	47	510	34	670	30	140	49	640	60
Be	<1	2	2	1	<1	1	1	<1	<1
Ce	<4	77	<4	49	<4	<4	5	<4	<4
Co	2	20	6	35	6	17	2	1	<1
Cr	1	190	2	26	1	5	2	<1	<1
Cu	2	34	4	24	2	52	4	2	3
Eu	<2	<2	<2	2	<2	<2	<2	<2	<2
Ga	<4	17	<4	19	<4	<4	4	<4	<4
Hg	N0.02	0.04	0.02	0.02	N0.02	N0.02	0.02	N0.02	N0.02
La	<2	94	<2	25	<2	3	3	<2	2
Li	<2	8	6	8	6	8	3	<2	9
Mn	120	380	380	1,200	340	400	54	40	34
Mo	<2	8	<2	<2	<2	<2	<2	<2	<2
Nb	<4	7	<4	12	<4	<4	<4	<4	<4
Nd	<4	20	<4	29	<4	<4	<4	<4	<4
Ni	<2	61	<2	16	<2	85	2	<2	<2
Pb	<4	4	<4	<4	<4	<4	<4	<4	<4
Sc	<2	27	<2	31	<2	<2	2	<2	<2
Sr	5	410	9	280	5	10	25	16	9
Ta	<40	<40	<40	<40	<40	<40	<40	<40	<40
V	42	310	220	240	110	230	140	31	41
Y	<2	51	7	34	2	5	5	<2	3
Yb	<1	6	1	3	<1	1	<1	<1	<1
Zn	2	120	3	110	12	30	25	2	11

Table 5. Major- and trace-elements analysis of altered rock samples—Continued.

Sample no.	663	664	665	666	667	668	669	670	671	266
Element										
Al	0.33	0.50	0.50	0.25	0.73	4.3	0.97	1.3	6.1	2.7
Ca	0.12	0.26	0.21	0.30	0.23	0.61	0.27	0.50	3.3	0.24
Fe	2.0	10	30	4.8	3.1	16	3.1	6.0	9.2	2.6
K	0.08	-.04	0.05	0.06	0.03	2.4	0.09	0.11	0.37	1.2
Mg	0.15	0.18	0.23	0.12	0.20	0.12	0.21	0.31	1.6	0.18
Na	0.01	0.02	0.007	0.01	0.01	0.84	0.01	0.05	0.54	1.4
P	<0.005	0.02	0.07	0.04	<0.005	0.13	0.02	0.02	0.20	0.01
Ti	0.04	0.03	0.03	0.04	0.02	0.13	0.05	0.11	1.6	0.06
As	20	110	110	<10	<10	780	120	160	<10	25
Ba	110	160	120	61	72	950	290	670	740	980
Be	<1	1	2	4	<1	4	<1	2	1	2
Ce	4	5	9	<4	<4	76	18	12	55	47
Co	3	7	44	3	2	13	79	10	34	2
Cr	<1	2	<1	<1	<1	17	2	8	19	20
Cu	4	24	3	5	7	120	6	10	26	4
Eu	<2	<2	<2	<2	<2	<2	<2	<2	2	<2
Ga	<4	<4	5	<4	<4	12	<4	<4	19	8
Hg	0.02	N0.02	0.02	0.02	N0.02	0.03	0.02	0.02	N0.02	<0.02
La	<2	6	5	2	<2	34	16	10	25	25
Li	36	6	3	<2	7	4	<2	<2	9	8
Mn	510	300	1700	290	160	450	900	590	1,300	59
Mo	<2	3	9	<2	<2	27	<2	2	<2	<2
Nb	<4	<4	<4	<4	<4	13	<4	<4	14	12
Nd	<4	4	<4	<4	<4	38	14	9	29	24
Ni	2	5	7	2	<2	29	9	6	13	2
Pb	<4	<4	<4	<4	<4	13	5	<4	4	7
Sc	<2	10	14	<2	7	5	3	4	32	2
Sr	9	22	21	19	16	70	25	42	270	33
Ta	<40	<40	50	< 40	<40	<40	<40	<40	<40	<40
V	84	710	490	66	58	280	210	240	250	560
Y	<2	8	15	3	<2	58	20	12	34	34
Yb	<1	2	4	<1	<1	8	2	2	4	4
Zn	14	130	41	10	15	180	38	32	120	65