USGS
science for a changing world

Preliminary Geologic map of the Skull Springs quadrangle, Malheur County, Oregon

by James G. Evans[1] and G.Benjamin Binger[2]

Open-File Report 99-331

1999

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

[1] U.S. Geological Survey, Spokane, Wash.
[2] Washington State University, Pullman, Wash.

INTRODUCTION

The Skull Springs quadrangle is located about 75 km southwest of the town of Vale, Malheur County, Oregon. The quadrangle can be reached from U.S. Highway 20 by a graded county road that goes south from the Harper turn-off on U.S. 20 (Figure 1). Numerous jeep trails provide access from the county road to most parts of the quadrangle.

Some of the formations of the quadrangle were originally named and described by Kittleman and others (1965). Kittleman and others (1967) produced a geologic map of the Owyhee region at the scale of 1:125,000. Later, Walker (1977) compiled a geologic map of eastern Oregon at the scale of 1:500,000 that incorporated earlier work, and Walker and MacLeod (1991) produced a geologic map of the State of Oregon at the scale of 1:500,000. The geology of the Skull Springs quadrangle was mapped at the scale of 1:24,000 in 1992 as part of a cooperative project between the Oregon Department of Geology and Mineral Industries and the U.S. Geological Survey. The geology was incorporated into the geologic map of the Mahogany Mountain 30 by 60 minute quadrangle (Ferns and others, 1993b) at the scale of 1:100,000.

The chemical classification of the volcanic rocks used in this report is based on the total alkali-silica diagram of Le Bas and others (1986). The correspondence between absolute ages and geologic ages is from Palmer (1983).

The rocks exposed in the Skull Springs quadrangle mostly comprise a flat-lying to gently dipping section of volcanic, pyroclastic and volcaniclastic rocks of late Tertiary age. The quadrangle is located along the western margin of the north-trending, 50 x 100 km, middle Miocene Oregon-Idaho graben (OIG; Ferns and others, 1993a,b). The western margin of the graben is generally placed where the stratigraphy changes abruptly from the early to middle Miocene, largely flood basalt-rhyolite volcanic rock association of the western horst to the middle to late Miocene sedimentary, pyroclastic, and silicic to mafic volcanic rocks of the graben (Ferns and others, 1993a,b). This structural and stratigraphic transition zone extends through the middle of the quadrangle (Figure 2).

STRATIGRAPHY

Horst

The oldest unit of the horst, the early to middle Miocene basalt of Malheur Gorge (map unit Tm; Evans, 1990a,b), is exposed along parts of Camp, Cottonwood, and Skull Creeks. The name "basalt of Malheur Gorge" as used here is equivalent to part of the "unnamed igneous complex" of Kittleman and others (1965). This thick sequence of tholeiitic basalt flows is petrologically, chronologically, and geochemically, equivalent to the Imnaha and Grande Ronde Basalt of the Columbia River Basalt Group (Binger, 1997). The basalt of Malheur Gorge, however, probably did not erupt from dike swarms similar to those that fed the Columbia River Basalt Group to the north. A vent for the basalt of Malheuer Gorge is located in the Jones Butte area, 10 km to the north-northwest (Evans, 1996). The unit in the Skull Springs quadrangle consists of fine-grained, sparsely phyric and aphyric mafic lava flows (Table 2), and generally resembles the upper part of the formation in the Malheur Gorge area. Four samples of the unit were analyzed for major oxides (Table 2); three samples range from basalt to basaltic andesite; one of the samples is altered (silicified, sample 468/46). The unit was dated at 16.8±1.2 Ma, 16.9±0.67 Ma, 17.9±1.76 Ma, 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 ages of the Imnaha, Picture Gorge, and Grande Ronde Basalts of the Columbia River Basalt Group (Baksi, 1989).

The middle Miocene Dinner Creek Welded Tuff (Greene and others, 1972; formerly the Dinner Creek Welded Ash-Flow Tuff of Kittleman and others, 1965; about 15 Ma, Fiebelkorn and others, 1983) typically overlies the basalt of Malheur Gorge to the north. In the Skull Springs quadrangle, however, the basalt of Malheur Gorge is mostly overlain by poorly lithified tuffaceous sandstone of map unit Tss (see below). In the southwestern corner of the quadrangle, the basalt of Malheur Gorge is overlain by a trachyandesite flow (map unit Tta; see below) and a tongue of OIG sedimentary and pyroclastic rocks of unit Tspo (see below). Sources of tuff and welded tuff beds in unit Tss were not identified. It is possible that some of these may be part of a distal facies of the Dinner Creek. The map unit is interpreted to be of middle Miocene age because of its position above the basalt of Malheur Gorge and below the middle Miocene Wildcat Creek Welded Ash-Flow Tuff (map unit Twc; see below).

The upper part of the sandstone (map unit Tss) contains a 3-m-thick welded tuff (map unit Twt_1) that weathers to prominent cliffs and resistent boulders. This welded tuff superficially resembles some of the uppermost Dinner Creek Welded Tuff in the Alder Creek quadrangle to the north, but is considered to be too high in the section to be Dinner Creek.

The Hunter Creek Basalt (map unit Th; Kittleman and others, 1965; Greene and others, 1972) overlies the Dinner Creek Welded Tuff over most of the horst to the north, but, in the Skull Springs quadrangle, lava flows similar to Hunter Creek flows were only seen in the OIG sequence. In this report, the Hunter Creek is discussed in conjunction with the OIG map units (see below).

The Littlefield Rhyolite (map unit Tl; Kittleman and others, 1965 typically overlies Hunter Creek Basalt to the north and is remarkable for its regional extent (1,100 km^2) and volume (100 km^3). In the Skull Springs quadrangle, the Littlefield is exposed along a 1 to 2 kilometer-wide zone trending north-south in the middle of the quadrangle, and along Skull Creek. Lees ($^{40}Ar/^{39}Ar$ method, 1994; Lees' samples KL-91-46, KL-91-47, and KL-92-258) dated Littlefield Rhyolite in the Namorf quadrangle (Ferns and O'Brien, 1992) 30 km to the north (Fig. 1) at 15.2±0.31, 16.3±0.87, and 16.8±0.4 Ma. The youngest date is most in accord with accepted radiometric dates of underlying volcanic rock units.

Tims Peak Basalt (map unit Ttp; Kittleman and others, 1965) overlies the Littlefield Rhyolite in the southwestern corner of the quadrangle. The unit is mapped as far north as the southwestern part of the Westfall Butte quadrangle (Figure 1), and is interpreted as olivine basalt flows that erupted during middle Miocene from a generally north-trending dike swarm that is largely covered by the flows (Evans, 1966; Evans and Binger, 1997). A possible north-northwest-trending dike of Tims Peak may intrude map unit Tspo in N1/2 sec. 21, T. 25 S., R. 40 E.. The dike interpretation is used in cross-section BB'.

The Wildcat Creek Welded Ash-Flow Tuff (map unit Tw; Kittleman and others, 1965) overlies the tuffaceous sandstone unit, Tss, and extends as far north as the Tims Peak quadrangle (Evans and Keith, 1966). Four samples of the welded tuff were analyzed for major oxides; one of them is rhyolite and two are trachydacite (samples 469, 31, and 56, Table 2). Splits of one sample (splits 466 and 37) were analyzed at both the USGS (analysis 466) and WSU (analysis 37); the USGS analysis suggests that the rock sample is trachyandesite; the WSU results suggest the rock is a rhyolite. The variation in all results may be due to variations in amounts and kinds of xenoliths in the welded tuff, especially the variable amounts of partly digested to undigested fragments of fine-grained hematite-rich basaltic xenoliths. Similar variability in composition in the Wildcat Creek is reported by Ferns and Williams (1993) in the Crowley quadrangle, 15 km to the southwest.

Unit Twt_2, the youngest welded ash-flow tuff, resembles a welded tuff unit mapped in the Little Black Canyon 7.5' quadrangle (map unit Twt, Evans and Binger, 1998b), 50 km to the north. The welded tuff overlies the Wildcat Creek Welded Ash-Flow Tuff in the northwestern corner of the Skull Springs quadrangle. Some exposures of the welded tuff in the adjacent Alder Creek (Evans and Binger, 1998a) and Shumway Reservoir (Evans, unpub. mapping, 1991) quadrangles are overlain by the middle Miocene Shumway Ranch Basalt (Kittleman and others, 1965), and underlain by middle Miocene map units, indicating that the welded tuff is middle Miocene.

A dacite flow unit (map unit Tdf) that may have filled a paleovalley eroded into the Wildcat Creek Welded Ash-flow Tuff and the sandstone unit Tss forms a ridge that trends northeastward from a possible vent source in the adjacent Star Creek Reservoir quadrangle (Figure 1; Evans and Rytuba, unpub. mapping, 1992). Based on stratigraphic relations in the Star Creek Reservoir quadrangle, 1992), the flow direction is northeastward. Age of the dacite flow may be middle or late Miocene.

A trachyandesite flow (map unit Tta) and paleovalley-fill of trachyandesite composition (map unit Ttv) are present in the southwestern corner of the quadrangle. Although they are compositionally similar, it is not clear whether the two trachyandesite units are from the same source. The paleovalley filled by trachyandesite is about 4 km long and the elevation of its base appears to decrease eastward by about 60 m. Because the horst may have been uplifted after eruption of the trachyandesite, the present eastward gradient may not be indicative of original flow direction. Inasmuch as trachyandesite was found in the late Miocene basalt of Cedar Mountain (map unit Tcmb;

see below) in the southeastern part of the quadrangle, the trachyandesite paleovalley-fill may have originated to the east and flowed westward. Depending on the stratigraphic relations of the trachyandesite unit, Ttv, and the basalt of Cedar Mountain, map unit Ttv, and by implication map unit Tta, may be late Miocene in age.

Oregon-Idaho Graben

The stratigraphic units of the Oregon-Idaho graben (OIG; Ferns and others, 1993a,b) include the rhyolite of Dry Creek, a basaltic andesite unit, and sedimentary and pyroclastic rocks. The rhyolite of Dry Creek(map unit Tr), informally named by Evans and Binger (1998a) for exposures in the Alder Creek quadrangle and more extensively exposed in the Rufino Butte quadrangle (Brooks, 1992b), is found in the northeastern corner of the Skull Springs quadrangle. In contrast to the Alder Creek quadrangle, this rhyolite is not the oldest of the OIG strata in the Skull Springs quadrangle. Sedimentary and pyroclastic strata included in map unit Tspo that are older than Littlefield Rhyolite and may be at least as old or older than Hunter Creek Basalt (see cross-section AA') are found in a tongue just west of the OIG. The stratigraphic relations between these middle Miocene beds and the other stratigraphic components of the OIG sequence are not clear because the sedimentary and pyroclastic rocks are poorly lithified and are buried by younger units such as the basalt of Cedar Mountain (map unit Tcmb) and the alluvial fan deposits (map unit QTf). As in other segments of the western margin of the OIG, the graben margin is blurred by intercalated sedimentary strata transported westward from the graben and volcanic rocks erupted from vents along or near the graben margin.

The oldest rocks exposed in the OIG section may be lava flows that resemble the Hunter Creek Basalt that is so common on the horst to the north (Evans, 1990a,b; Evans, 1996; Evans and Keith. 1996; Evans and Binger, 1997. 1998a,b). In the Westfall quadrangle (Figure 1), thick dikes of Hunter Creek and Hunter Creek flows are found west of the OIG margin (Brooks and O'Brien, 1992). Chemically, the Hunter Creek Basalt north of the Tims Peak quadrangle is typically an icelandite (Carmichael, 1974; typical Hunter Creek contains Al_2O_3=Fe_2O_3=14%), or a basaltic andesite according to the scheme of Le Bas and others (1986; Evans, 1990a,b). From the Tims Peak quadrangle south to the Skull Springs quadrangle (Evans and Keith, 1996, Evans and Binger, 1998b), however, the Hunter Creek is a basaltic andesite that contains more Al_2O_3 (17%) and much less Fe_2O_3 (6%) than the parts of the unit to the north. Four samples of the unit in the Skull Springs quadrangle include trachybasalt, basaltic trachyandesite, and basaltic andesite. A variety of magma types seem to occupy the Hunter Creek stratigraphic interval, with distinctive icelandite magma being more typical of the northern part of the horst section. Lees ($^{40}Ar/^{39}Ar$ method, 1994; Lees' samples HOR-9, KL-91-100, KL-91-102, KL-92-269, and KL-92-278) dated icelandite-type Hunter Creek at 15.0±0.73, 15.8±0.6, 15.9±0.26, 16.5±1.2, and 18.6±0.63 Ma. The youngest date is most in accord with stratigraphic and geochemical evidence (Evans and Binger, 1998b) that the Hunter Creek was erupted shortly after the eruption of the 15 Ma Dinner Creek Welded Tuff. It is not certain, however, that the more varied and iron-poor lavas in the Hunter-Creek interval conform to this model.

The basaltic andesite flows (map unit Tba) exposed in the southeastern part of the Alder Creek quadrangle along Dry Creek (map unit Tba, Evans and Binger, 1998a) and in the northeastern corner of the Skull Springs quadrangle correlate with the basaltic andesite in the Rufino Butte quadrangle (Brooks, 1992b; his unit Tdb), where it attains a thickness of 150 m and overlies rhyolite continuous with the rhyolite of Dry Creek (map unit Tr). The basaltic andesite flows are probably associated with extensional development of the OIG (Ferns and others, 1993b) and are of limited volume and extent. The chemical composition of the basaltic andesite in the Alder Creek quadrangle is assumed to be similar to the composition of the basaltic andesite in the Rufino Butte quadrangle (Brooks, 1992b; Evans and Binger, 1998a).

The sedimentary and pyroclastic rocks of the OIG, map unit Tspo, may be correlative with all or part of map unit Tss in the horst section. The coarse clasts (maximum 1 m) are unusual in the generally fine-grained sedimentary and pyroclastic rocks of the OIG. Their location close to the western margin of the graben suggests rapid uplift of the horst and associated subsidence and filling of the graben. Apparently, subsidence at times also included the horst, which acted as a platform within a regional subsidence regime during stages of graben development. Based on geophysical studies of Griscom and Halvorson (in Smith, 1994), the thickness of map unit Tspo may be of the order of 2 km. According to their model, the OIG is floored by a slab of basalt 1.8 km thick buried beneath as much as 2 km of relatively low-density graben-fill. It is not clear how thick a section of graben-fill is exposed in the Skull Springs quadrangle, but the Skull Springs section is likely to be mostly in the upper part of the OIG section.

An andesite flow (map unit Taf) overlies map units Th and Tba and part of map unit Tspo in the northeastern part of the quadrangle, and is overlain by flows of rhyolite of Dry Creek. The stratigraphic variation in the underlying beds suggests that substantial faulting, uplift, and erosion had occurred in the OIG section before the andesite flow was deposited.

The rhyolite of Dry Creek (Evans and Binger, 1998a) appears to have 3 flows in the Skull Springs quadrangle that are distinguished by stratigraphic relations with other units of the graben section. The oldest flow is shown in a narrow northwest-trending outcrop just south of the mouth of Cold Spring Creek in E1/2 sec. 24, T. 24 S., R. 40 E. Three samples of this flow were analyzed for major oxides (Table 2) and are rhyolite (sample 98) and high-silica rhyolite (samples 93 and 97). The younger flow is in NE1/4 sec. 24, about 12 m above the lowest flow. Two samples of the intermediate flow are rhyolite (sample 95) and high-silica rhyolite (sample 96). The youngest flow is in SE1/4 sec. 24 and NE1/4 sec. 25, T. 24 S., R. 40 E. above the andesite flow unit Taf exposed along Wildcat Creek and the faulted, intermediate-level rhyolite flow. The rhyolite flows along the northeast margin of the quadrangle are most likely part of the youngest flow. Five samples of the youngest flow were analyzed for major oxides and are trachydacite (samples 66 and 91), dacite (sample 71), and rhyolite (samples 87 and 92). Although the rhyolite of Dry Creek is overlain by map unit Tba in the Rufino Butte quadrangle to the northeast (Brooks, 1992b), the rhyolite in the Skull Springs quadrangle overlies the andesite flow (map unit Taf), which overlies unit Tba. Therefore, the rhyolite unit is diachronous, although the unit as a whole is middle Miocene.

A north-striking dike of basaltic andesite (map unit Tbi) intrudes map unit Tspo in sec. 24 in the northeastern corner of the quadrangle. It is not clear whether this dike is related to the basalt of Cedar Mountain. A 600-m-long, northeast-striking, steeply dipping dike exposed along the lower part of Cold Spring Creek appears from its similarity and proximity to the basalt of Cedar Mountain to be a feeder of those lava flows

The basalt of Cedar Mountain (map unit Tcmb) in the southeastern part of the quadrangle, is part of an extensive mafic to intermediate volcanic assemblage including the large shield volcano of Cedar Mountain, about 10 km to the southeast. The volcano lies on the northwest rim of the Iron Point caldera (Evans, 1991), which may be middle or late Miocene in age. Ten samples from the unit were analyzed for major oxides (Table 2) and range in composition from basalt to andesite. At least one sample is trachyandesite. Significant differences were obtained at USGS and WSU laboratories in analyses of splits of two samples (462, basaltic trachyandesite/19, trachyandesite and 470, trachyandesite/73, basaltic andesite). As mentioned above, the Cedar Mountain volcanic center may have been the source of trachyandesite map units Tta and Ttv. Hart and Mertzman (K-Ar method; 1982) dated a sample of the basalt of Cedar Mountain at 10.2 Ma, or late Miocene.

Post-tectonic Deposits

Alluvial fan deposits (map unit QTf) that preserve fan morphology are found in the east-central part of the quadrangle. They could be as old as late Miocene and (or) as young as Quaternary.

Older alluvium, map unit QTa, near the west-central margin of the quadrangle is a remnant of a Pliocene or Quaternary paleovalley.

Landslide deposits (map unit Qls) are commonly found where resistent rock types are underlain by poorly consolidated sedimentary and pyroclastic rock units, like Tspo and Tss. In the northwestern corner of the quadrangle, however, the dacite flow (map unit Tdf) that was originally emplaced in a paleovalley cut into Wildcat Creek Welded Ash-Flow Tuff and perhaps the sandstone unit Tss, now stands above the Wildcat Creek and sheds landslide deposits onto the welded tuff.

Alluvium (map unit Qa) is found along Skull, Wildcat, and Cold Spring Creeks , and a few unnamed creeks.

STRUCTURE

The quadrangle contains two different stratigraphic sections of flat-lying to gently dipping volcanic and sedimentary rocks. The section in the western part of the quadrangle consists of early to middle Miocene flood-basalt and associated rhyolitic to intermediate volcanic rocks. The section in the eastern part consists of middle to late Miocene rhyolitic to basaltic volcanic rocks and sedimentary rocks that were deposited in the 50 x 100 km middle Miocene Oregon-Idaho graben (OIG). The OIG formed as a result of regional east-west extension (Ferns and others, 1993a,b). The stratigraphic sections of the horst and graben are in contact along a north-northeast-striking fault zone that passes through the middle of the quadrangle.

The contact between the two sections roughly parallels the transition between the regionally relatively high subregional gravity potential characteristic of the OIG and the lower gravity potential of the horst (Griscom and Halvorson, in Smith, 1994; Figure 2; cross-section A-A'). The western margin of the OIG is shown in Figure 2 by a north-northeast-trending line of stippled hot-dogs. Although the graben generally shows relatively higher areomagnetic intensity than the horst, in the segment of the graben margin included in the Skull Springs quadrangle, an aeromagnetic ridge parallels the graben-horst boundary (Figure 3). The aeromagnetic high in the northern part of the adjacent Alder Creek quadrangle marks a dome of magnetic Littlefield Rhyolite that was emplaced along the graben-horst boundary. The aeromagnetic ridge in the Skull Springs quadrangle reflects a lobe of the rhyolite that flowed southward along a shallow depression or paleovalley along the graben-horst boundary.

Most faults in the quadrangle have northerly strikes that vary between north-northeast and north-northwest, but are generally subparallel to the western margin of the OIG. The complex stratigraphic relations of the map units in the OIG section indicate their deposition in a middle Miocene synextensional environment.

The north-northwest-trending line of stippled hot-dogs west of the quadrangle (Figures 2 and 3) marks the approximate western margin of the horst. West of that line is another graben and the associated Stockade Mountain silicic volcanic center (Walker and MacLeod, 1991). The graben may be part of the Juntura Basin of Shotwell (1963).

GEOCHEMISTRY

Fifty-four unaltered volcanic rocks and eight altered rocks were collected for analysis by James G. Evans; two samples were collected by Howard C. Brooks of the Oregon Department of Geology and Mineral Industries. Of the unaltered rocks, 14 were analyzed by the U.S. Geological Survey, Branch of Geochemistry (samples 458 to 471), for major oxides using wave-length dispersive x-ray fluorescence spectroscopy (Taggart and others, 1990) by D.F. Siems and J.S. Mee. Forty-five samples, including splits of 11 of the samples analyzed by the USGS, were analyzed for major oxides and 17 minor elements by x-ray spectroscopy (samples 5 to 98; Hooper and others, 1993) by G.B. Binger at the GeoAnalytical Laboratory, Washington State University, Pullman. Two samples that were collected by Howard C. Brooks were analyzed for major oxides and 12 minor elements by Bondar-Clegg (samples 330 and 331). The major-oxide analyses are shown in Table 2. The trace-element analyses are shown in Table 3.

The eight altered rocks (Table 4) were analyzed by the U.S. Geological Survey, Branch of Geochemistry, for 31 major and trace elements by the inductively coupled plasma atomic emission spectrometry method (Briggs, 1990) by D.L. Fey, and the data are reported in Table 5. However, the following elements are not included in Table 5 because they occur in uniformly low concentrations in all samples: silver, <2 parts per million (ppm); bismuth, <10 ppm; tin, <5 ppm; thallium, <40 ppm; and uranium, <100 ppm. The samples were analyzed for gold by the flame and graphite-furnace atomic absorption spectrophotometry method (O'Leary, 1990) and the results are shown in Table 5. Mercury was analyzed by the cold-vapor atomic absorption spectrophotometry method (O'Leary and others, 1990) and the results are shown in Table 5. The gold and mercury analyses were by B.H. Roushey and A.H. Love. Of the eight altered rock samples, 5 are altered sedimentary rocks from map units Tss and Tspo and 3 are altered rhyolite from map unit Tr.

The altered sedimentary rocks are high in hematite and (or) high in silica in the form of chalcedony. Iron content ranges from 1.2 to 36 weight-percent; the highest concentration was found in hematite-cemented siltstone (sample 364) in map unit Tss.

Samples 364, 365, and 366 generally contain the highest concentrations of elements commonly transporterd in hydrothermal systems, as well as relatively high concentrations of various metals and rare earths.

Elements	As	Au	Cu	Hg	Mn	Ni	V	Y	Zn
Sample No.									
364	190		120	0.13	1,300		1,600	130	280
365		0.002	190			44			140
366					1,200				120

The three samples are in the northwestern quadrant of the quadrangle; samples 364 and 365 are about 200 m west of north-striking faults; sample 366 is less than 30 m west of a northeast-striking fault.

The other altered rocks are located in NW1/4 sec. 24, T. 24 S., R. 40 E. and show few significant concentrations of elements. Lead and thorium, however, are greatest in the rhyolite samples (lead 16-18 ppm; thorium 10 ppm).

In summary, visibly altered volcanic or sedimentary rocks are not abundant in the quadrangle. Samples of hematite- and silica-cemented clastic rocks showed elevated metal and rare-earth concentrations as well as gold, mercury, and arsenic. These rocks could be related to paleohydrothermal systems circulating along faults related to formation of the OIG.

REFERENCES CITED

Baksi, A.K., 1989, Reevaluation of the timing and duration of extrusion of the Imnaha, Picture Gorge, and Grande Ronde Basalts of the Columbia River Basalt Group, *in* Reidel, S.P. and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 105-111.

Binger, G.B., 1997, The volcanic stratigraphy of the Juntura region, eastern Oregon: Pullman, Washington State University, master's thesis, 206 p.

Briggs, P.H., 1990, Elemental analysis of geological materials by inductively coupled plasma atomic emission spectrometry, *in* Arbogast, B.F., ed., Quality assurance manual for the Branch of Geochemistry: U.S. Geological Survey Open-File Report 90-668, p. 83-91.

Brooks, H.C., 1992a, Preliminary geologic map of the Copeland Reservoir quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-93-3, scale 1:24,000.

———, 1992b, Preliminary geologic map of the Rufino Butte quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Map O-92-17, scale 1:24,000.

Brooks, H.C. and O'Brien, J.P., 1992, Geology and mineral resources map of the Westfall quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-71, scale 1:24,000.

Carmichael, I.S.E., 1964, The petrology of Thingmuli, a Tertiary volcano in eastern Iceland: Journal of Petrology, v. 5, p., 435-460.

Evans, J.G., 1990a, Geology and mineral resources map of the Jonesboro quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-66, scale 1:24,000.

———, 1990b, Geology and mineral resources map of the South Mountain quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-67, scale 1:24,000.

———, 1991, Geologic map of the Lower Owyhee Wilderness Study Area, Malheur County, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-2167, scale 1:50,000.

———, 1996, Geologic map of the Monument Peak quadrangle, Malheur County, Oregon: U.S. Geological Survey Miscellaneous Field Study Map MF-2317, scale 1:24,000.

Evans, J.G. and Binger, G.B., 1997, Geologic map of the Westfall Butte quadrangle, Malheur County, Oregon: U.S. Geological Survey Open-File Report 97-491, scale 1:24,000.

———, 1998a, Geologic map of the Alder Creek quadrangle, Malheur County, Oregon: U.S. Geological Survey Open-File Report 98-484, scale 1:24,000.

———, 1998b, Geologic map of the Little Black Canyon quadrangle, Malheur County, Oregon: U.S. Geological Survey Open-File Report 98-493, scale 1:24,000.

Evans, J.G. and Keith, W.J., 1996, Geologic map of the Tims Peak quadrangle, Malheur County, Oregon: U.S. Geological Survey Miscellaneous Field Study Map MF-2316, scale 1:24,000.

Ferns, M.L., Brooks, H.C., Evans, J.G., and Cummings, M.L., 1993a, Geologic map of the Vale 30 x 60 minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-77, scale 1:100,000.

Ferns, M.L., Evans, J.G., and Cummings, M.L., 1993b, Geologic map of the Mahogany Mountain 30 x 60 minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-78, scale 1:100,000.

Ferns, M.L. and O'Brien, J.P., 1992, Geology and mineral resources of the Namorf quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-74, scale 1:24,000.

Ferns, M.L. and Williams, Christopher, 1993, Preliminary geologic map of the Crowley quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-93-4, scale 1:24,000.

Fiebelkorn, R.B., Walker, G.W., MacLeod, N.S., McKee, E.H., and Smith, J.G., 1983, Index to K-Ar determinations for the State of Oregon: Isochron/West, no. 37, p.3-60.

Greene, R.C., Walker, G.W., and Corcoran, R.E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geological Survey Miscellaneous Investigations Map I-680, scale 1:250,000.

Hart, W.K. and Mertzman, A.S., 1982, K-Ar ages of basalts from south-central and southeastern Oregon: Isochron/West, no. 33, p.23-26.

Hooper, P.R., Johnson, D.M., and Conrey, R.M., 1993, Major and trace element analyses of rocks and minerals by automated X-ray spectrometry: Pullman, Washington State University, Geology Department, Open-File Report, 36 p.

Kittleman, L.R., Green, A.R., Haddock, G.H., Hagood. A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1967, Geologic map of the Owyhee region, Malheur County, Oregon: Eugene, University of Oregon Museum of Natural History Bulletin 8, scale 1:125,000.

Kittleman, L.R., Green, A.R., Hagood, A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1965, Cenozoic stratigraphy of the Owyhee region, southeastern Oregon: University of Oregon Museum of Natural History Bulletin 1, 45 p.

Le Bas, M.J., LeMaitre, R.W., Streckeisen, A. and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, pt. 3, p. 745-750.

Lees, K.R., 1994, Magmatic and tectonic changes through time in the Neogene volcanic rocks of the Vale area, Oregon, northwestern USA: Milton-Keynes, United Kingdom, The Open University, Ph.D. dissertation, 284 p.

O'Leary, R.M., 1990, Determination of gold in samples of rock, soil, stream sediment, and heavy mineral concentrates by flame and graphite furnace atomic absorption spectrophotometry following dissolution by HB and Br_2, *in* Arbogast, B.F., ed., Quality assurance manual for the Branch of Geochemistry: U.S. Geological Survey Open-File Report 90-668, p. 46-51.

O'Leary, R.M., Crock, J.G., and Kennedy, K.R., 1990, Determination of mercury in geological materials by continuous flow cold vapor atomic absorption spectrophotometry, *in* Arbogast, B.F., ed., Quality assurance manual for the Branch of Geochemistry: U.S. Geological Survey Open-File Report 90-668, p. 60-67.

Palmer, A.R., 1983, The Decade of North American Geology 1983 geologic time scale: Geology, v. 11, no. 9, p. 503-504.

Shotwell, J.A., 1963, Miocene mammalian faunas of southeastern Oregon: University of Oregon Museum of Natural History Bulletin, v. 14, p. 1-67.

Smith, C.L., 1994, Quantitative mineral resource assessment of BLM's Malheur, Jordan, and Andrews Resource Areas, southeastern Oregon: U.S. Geological Survey Administrative Report to the Bureau of Land Management, 297 p.

Taggert, J.E., Jr., Bartel, Ardith, and Siems, D.F., 1990, High-precision major element analysis of rocks and minerals by wave-length dispersive x-ray fluorescence spectroscopy, *in* Arbogast, B.F., ed., Quality assurance manual for the Branch of Geochemistry, USGS: U.S. Geological Survey Open-File Report 90-668, p. 166-172.

Walker, G.W., 1977, Geologic map of Oregon east of the 121st meridian: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-902, scale 1:500,000.

Walker, G.W. and MacLeod, N.S., 1991, Geologic map of Oregon: U.S. Geological Survey Map, scale 1:500,000.

Table 1. Locations, lithologies, and map units of unaltered volcanic rock. Numbers in parentheses are splits of samples analyzed at USGS and WSU.

Sample No.	Map unit	Lithology	Location
458(5)	Tl	rhyolite	NW1/4 sec 23, T. 24 S., R. 40 E.
459(8)	Tbcm	basaltic andesite	NW1/4 sec 26, T. 24 S., R. 40 E.
460	Tl	rhyolite	NW1/4 sec 21, T. 25 S., R. 40 E.
461(14)	Ttp	basalt	same
462(19)	Tbcm	basaltic andesite	SE1/4 sec 16, T. 25 S., R. 40 E.
463(26)	Tm	basaltic trachyandesite	Near ctr sec 20, T. 25 S., R. 40 E.
464(28)	Tm	basaltic trachyandesite	NE1/4 sec 9, T. 24 S., R. 40 E.
465(36)	Twt_1	welded tuff(rhyolite)	NE1/4 sec 30, T. 24 S., R. 40 E.
466(37)	Twc	welded tuff(trachyandesite)	same
467(44)	Tta	trachyandesite	SE1/4 sec 19, T. 25 S., R. 40 E.
468	Tm?	altered basalt	SW1/4 sec 19, T. 25 S., R. 40 E.
469	Twc	welded tuff(trachydacite)	SE1/4 sec 16, T. 24 S., R. 40 E.
470(73)	Tbcm	trachyandesite	NW1/4 sec 31, T. 24 S., R. 41 E.
471(83)	Th	trachybasalt	NW1/4 sec 24, T. 24 S., R. 40 E.
5(458)	Tl	rhyolite	same as 458
6	Tl	rhyolite	SW1/4 sec. 23, T. 24 S., R. 40 E.
8(459)	Tbcm	basaltic andesite	NW1/4 sec. 26, T. 24 S., R. 40 E.
9	Tbcm	basaltic andesite	Near center sec. 35, T. 24 S., R. 40 E.
11	Tbcm	trachyandesite	Near SE corner sec. 14, T. 25 S., R. 40 E.
14(461)	Ttp	basalt	NW1/4 sec. 21, T. 25 S., R. 40 E.
16	Ttv	trachyandesite	S1/2 sec. 21, T. 25 S., R. 40 E.
19(462)	Tbcm	trachyandesite	Near SE corner sec. 16, T. 25 S., R. 40 E.
20	Tbcm	andesite	W1/2 sec. 10, T. 25 S., R. 40 E.
23	Twt_1	welded tuff(rhyolite)	N1/2 sec 8, T. 25 S., R. 40 E.
25	in Tss	welded tuff(rhyolite)	S1/2 sec 17, T. 25 S., R. 40 E.
26(463)	Tm	basaltic andesite	Near center. sec. 20, T. 25 S., R. 40 E.
28(464)	Tm	basaltic andesite	NE1/4 sec. 9, T. 24 S., R. 40 E.
31	Twc	welded tuff(rhyolite)	NE1/4 sec 8, T. 24 S., R. 40 E.
32	Twt_2	welded tuff(rhyolite)	Near ctr sec 8, T. 24 S., R. 40 E.
33	Tdf	dacite	SE1/4 sec. 7, T. 24 S., R. 40 E.
36(465)	Twt_1	welded tuff(rhyolite)	NW1/4 sec. 30, T. 24 S., R. 40 E.
37(466)	Tw	welded tuff(rhyolite)	same
42	Twt_1	welded tuff(trachydacite)	NE1/4 sec. 24, T. 25 S., R. 39 E.
43	Twc	welded tuff(rhyolite)	NE1/4 sec 24, T. 25 S., R. 39 E.
44(467)	Tta	trachyandesite	SE1/4 sec. 19, T. 25 S., R. 40 E.
46	Tm	altered basalt	SW1/4 sec. 19, T. 25 S., R. 40 E.
48	Tm	basalt	Near NE corner sec. 12, T. 25 S., R. 39 E.
53	Tm	basaltic andesite	SW1/4 sec 16, T. 24 S., R. 40 E.
56	Twc	welded tuff (trachydacite)	NE1/4 sec. 28, T. 24 S., R. 40 E.
57	in Tspo	tuff(trachydacite)	SW1/4 sec. 22, T. 24 S., R. 40 E.
60	Twt_1	welded tuff(high-silica rhyolite)	SE1/4 sec. 29, T. 24 S., R. 40 E.
61	Twt_1	welded tuff(high-silica rhyolite)	Near NE cor sec 32, T. 24 S., R. 40 E.
65	Tbcm	basalt	W1/2 sec. 36, T. 24 S., R. 40 E.
66	Tr	trachydacite	S1/3 sec 25, T. 24 S., R. 40 E.
71	Tr	dacite	Near NW cor sec 24, T. 25 S., R. 41 E.
72	Tbcm	basalt	NE1/4 sec. 25, T. 24 S., R. 40 E.
73(470)	Tbcm	basaltic andesite	NW1/4 sec 31, T. 24 S., R. 41 E.
76	Tbcm	basaltic andesite	N1/2 sec. 35, T. 24 S., R. 40 E.
77	Taf	andesite	NW1/4 sec. 13, T. 24 S., R. 40 E.
78	Taf	andesite	SE1/4 sec 13, T. 24 S., R. 40 E.

Table 1 (continued)

Sample No.	Map unit	lithology	Location
81	Tr	rhyolite	NE1/4 sec. 24, T. 24 S., R. 40 E.
83(471)	Th	basaltic trachyandesite	NW1/4 sec. 24, T. 24 S., R. 40 E.
84	Th	basalt trachyandesite	SW1/4 sec 13, T. 24 S., R. 40 E.
85	Taf?	basaltic andesite	NW1/4 sec. 24, T. 24 S.,. R. 50 E.
87	Tr	rhyolite	Near ctr. sec. 24, T. 24 S., R. 40 E.
88	Tbi	basaltic andesite	NE1/4 sec 24, T. 24 S., R. 40 E.
89	in Tspo	andesite?	same
90	Th	basaltic andesite	NE1/4 sec 11, T. 24 S., R. 40 E.
91	Tr	trachydacite	SW1/4 sec. 7, T. 24 S., R. 41 E.
92	Tr	rhyolite	NW1/4 sec. 7, T. 24 S., R. 41 E.
93	Tr	high-silica rhyolite	NE1/4 sec. 24, T. 24 S., R. 40 E.
95	Tr	rhyolite	NE1/4 sec 24, T. 25 S., R. 40 E.
96	Tr	high-silica rhyolite	same
97	Tr	high-silica rhyolite	same
98	Tr	rhyolite	same
330	Tm	basalt	NW1/4 sec. 5. T. 25 S., R. 40 E.
331	Twc	welded tuff (rhyolite)	E1/2 sec. 5, T. 25S., R. 40 E.

Table 2. Major oxide analyses of volcanic rock samples listed in Table 1. Results are given in weight-percent and are normalized on a volatile-free basis. Total iron is given as Fe_2O_3 in analyses 458 to 471, 330, and 331,and as FeO in samples 5 to 98A. Numbers in parentheses are splits of samples that were analyzed both at the USGS and WSU.

Sample No.	458	459(8)	460	461(14)	462(19)	463(26)	464(28)	465(36)	466(37)	467(44)	468(46)
Map unit	Tl	Tbcm	Tl	Ttp	Tbcm	Tm	Tm	Twt_1	Twc	Tta	Tm(alt)
Rock name	rhyolite	basaltic andesite	rhyolite	basalt	basaltic trachy-andesite	basaltic andesite	basaltic andesite	rhyolite	trachy-andesite	trachy-andesite	
Oxides											
SiO_2	72.55	54.18	73.24	51.52	56.66	54.92	52.64	75.02	60.09	60.01	72.55
Al_2O_3	12.79	16.75	12.55	17.95	16.41	16.15	13.54	12.58	14.84	14.37	13.20
Fe_2O_3	5.04	9.23	3.82	9.91	8.93	10.26	14.70	2.52	9.65	10.19	3.43
MgO	0.10	5.09	0.21	4.96	3.27	4.39	4.09	0.44	1.74	1.87	0.22
CaO	0.61	8.22	0.92	10.02	6.64	7.10	7.70	0.68	4.77	4.78	0.54
Na2O	4.16	3.28	4.15	3.13	3.70	3.49	3.09	2.58	3.98	3.94	3.78
K2O	2.23	1.44	4.40	0.87	2.18	1.54	1.26	5.82	2.54	2.55	5.77
TiO_2	0.43	1.20	0.56	1.07	1.45	1.24	2.27	0.20	1.76	1.65	0.33
P_2O_5	0.06	0.46	0.11	0.40	0.61	0.74	0.49	0.09	0.49	0.45	0.06
MnO	0.03	0.15	0.04	0.17	0.15	0.17	0.22	0.07	0.14	0.19	0.12

Table 2 (continued)

Sample No.	469	470	471	5	6	8(459)	9	11	14(461)	16	19(462)
Map unit	Tw	Tbcm	Th?	Tl	Tl	Tbcm	Tbcm	Tbcm	Ttp	Ttv	Tbcm
Rock name	trachy-dacite	trachy-andesite	trachy-basalt	rhyolite	rhyolite	basaltic andesite	basaltic andesite	trachy-andesite	basalt	trachy-andesite	trachy-andesite
Oxides											
SiO_2	66.93	60.08	51.17	73.26	72.51	54.79	57.26	57.23	51.91	61.21	57.33
Al_2O_3	13.41	16.71	16.79	13.07	12.52	16.81	16.74	16.60	17.77	16.74	16.51
Fe_2O_3 (FeO)	6.66	7.32	11.30	3.73	4.14	8.06	7.40	7.88	8.92	6.29	7.90
MgO	1.04	2.26	5.00	0.07	0.24	5.22	3.27	3.24	5.49	1.90	3.31
CaO	2.30	5.69	7.97	0.61	0.69	8.36	7.08	6.80	10.36	5.38	6.66
Na_2O	4.62	4.06	3.49	4.49	4.24	3.52	3.98	4.17	3.15	4.45	3.92
K_2O	3.48	2.32	1.53	4.30	4.10	1.45	2.08	1.88	0.79	2.46	2.16
TiO2	1.02	1.06	1.87	0.417	0.408	1.217	1.461	1.460	1.110	1.091	1.471
P_2O_5	0.38	0.39	0.71	0.041	0.81	0.443	0.586	0.61	0.326	0.385	0.597
MnO	0.16	0.11	0.17	0.025	0.34	0.142	0.134	0.142	0.173	0.090	0.144

Sample No.	20	23	25	26	28	31	32	33	36(465)	37(466)	42
Map unit	Tbcm	Twt_1	in Tss	Tm	Tm	Twc	Twt_2	Tdf	Twt_1	Twc	Twt_1
Rock name	andesite	rhyolite	rhyolite	basaltic andesite	basaltic andesite	rhyolite	rhyolite	dacite	rhyolite	rhyolite	trachy-dacite
Oxides											
SiO_2	57.18	74.89	75.69	55.51	53.65	75.20	75.90	66.62	75.97	73.15	68.92
Al_2O_3	16.39	13.15	13.33	16.39	13.68	12.93	11.51	13.55	12.25	13.19	13.65
FeO	7.99	2.36	2.00	8.82	12.89	2.09	2.83	5.74	2.08	3.16	5.71
MgO	3.26	0.67	0.09	4.51	4.18	0.69	0.23	1.90	0.44	0.18	0.59
CaO	6.89	0.87	0.46	7.25	7.83	0.94	0.23	3.57	0.49	0.53	1.44
Na_2O	3.93	3.19	2.66	3.74	3.32	2.69	3.25	3.28	3.06	3.91	4.76
K_2O	2.13	4.50	5.53	1.59	1.30	5.20	5.75	3.78	5.46	5.41	3.62
TiO_2	1.460	0.200	0.175	1.288	2.453	0.190	0.203	1.207	0.170	0.311	0.871
P_2O_5	0.62	0.123	0.026	0.74	0.472	0.031	0.024	0.274	0.026	0.043	0.276
MnO	0.148	0.049	0.040	0.159	0.225	0.045	0.064	0.091	0.056	0.119	0.169

Sample No.	43	44	46(468)	48	53	56	57	60	61	65	66
Map unit	Twt_1	Tta	Tm(alt)	Tm	Tbcm	Twc	in Tspo	Twt_1	Twt_1	Tbcm	Tr
Rock name	rhyolite	trachy-andesite		basalt	basaltic andesite	trachy-dacite	trachy-dacite	high-silica rhyolite	high-silica rhyolite	basalt	trachy-dacite
Oxides											
SiO_2	71.63	60.45	72.76	49.35	53.72	61.78	62.99	77.73	77.25	48.55	68.20
Al_2O_3	13.55	14.42	13.25	14.78	13.84	13.80	13.90	12.16	12.41	16.36	14.92
FeO	3.73	9.05	3.19	13.99	13.18	8.36	8.67	0.90	1.09	11.76	3.96
MgO	0.36	2.07	0.38	5.13	4.14	1.39	1.29	0.16	0.11	6.04	0.97
CaO	0.74	5.04	0.56	9.89	7.69	3.81	3.51	0.35	0.24	9.46	2.92
Na_2O	5.02	4.17	4.02	3.01	3.12	4.46	4.60	4.78	4.68	3.40	4.03
K_2O	4.12	2.45	5.35	0.56	1.38	3.89	2.85	3.69	4.00	0.93	3.96
TiO_2	0.550	1.753	0.322	2.68	2.288	1.660	1.496	0.168	0.158	2.468	0.824
P_2O_5	0.142	0.413	0.047	0.397	0.435	0.76	0.505	0.038	0.048	0.84	0.131
MnO	0.152	0.183	0.115	0.228	0.217	0.127	0.199	0.015	0.010	0.194	0.080

Table 2 (continued)

Sample No.	71	72	73	76	77	78	81	83	84	85	87
Map unit	Tr	Tbcm	Tbcm	Tbcm	Taf	Taf	Tr	Th	Th	Taf	Tr
Rock name	dacite	basalt	basaltic andesite	basaltic andesite	andesite	andesite	rhyolite	basaltic trachy-andesite	basaltic trachy-andesite	basaltic andesite	rhyolite
Oxides											
SiO_2	63.39	48.96	56.98	56.93	60.44	60.41	75.94	51.95	54.69	54.94	69.70
Al_2O_3	15.45	16.27	17.10	16.85	15.75	15.72	12.55	16.78	16.76	17.01	14.26
FeO	5.88	11.88	7.03	7.86	6.31	6.16	1.49	9.96	7.63	7.75	3.71
MgO	2.09	5.76	4.21	3.11	3.61	3.57	0.35	5.15	5.56	5.02	0.91
CaO	4.71	9.21	7.55	7.14	5.92	6.15	0.49	8.09	8.33	8.42	2.14
Na_2O	4.03	3.49	3.67	3.87	3.70	3.61	4.53	3.72	3.75	3.67	4.44
K_2O	2.95	0.99	1.80	2.01	2.80	2.76	4.37	1.56	1.47	1.37	4.00
TiO_2	1.194	2.431	1.159	1.489	1.044	1.133	0.210	1.935	1.206	1.237	0.691
P_2O_5	0.221	0.80	0.358	0.60	0.316	0.356	0.049	0.68	0.451	0.448	0.116
MnO	0.085	0.216	0.140	0.135	0.119	0.121	0.019	0.171	0.150	0.143	0.045

Sample No.	88	89	90	91	92	93	95	96	97	98
Map unit	Tbi	in Tspo	Th	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Rock name	basaltic andesite	andesite	basaltic andesite	trachy-dacite	rhyolite	high-silica rhyolite	rhyolite	high-silica rhyolite	high-silica rhyolite	rhyolite
Oxides										
SiO_2	54.93	58.32	55.42	61.92	72.32	77.95	74.53	81.45	78.39	74.75
Al_2O_3	17.02	18.11	17.45	15.37	14.08	11.78	13.62	9.67	11.56	13.67
FeO	7.63	9.53	6.94	5.93	1.93	1.14	1.78	0.99	0.93	1.39
MgO	5.22	1.74	4.71	3.06	0.42	0.20	0.34	0.30	0.33	0.00
CaO	8.38	5.96	8.88	5.29	1.58	0.21	1.39	0.26	0.26	0.45
Na_2O	3.64	3.20	3.47	4.02	4.30	4.21	1.99	3.06	4.27	4.30
K_2O	1.37	1.70	1.30	2.99	4.74	4.22	6.01	4.05	4.02	5.15
TiO_2	1.221	0.973	1.257	1.024	0.358	0.200	0.226	0.150	0.190	0.219
P_2O_5	0.452	0.342	0.454	0.292	0.228	0.071	0.031	0.039	0.033	0.033
MnO	0.147	0.130	0.114	0.107	0.042	0.028	0.074	0.031	0.013	0.036

Sample No.	330	331
Map unit	Tm	Twc
Rock name	basalt	rhyolite
Oxides		
SiO_2	50.77	74.22
Al_2O_3	15.39	12.39
Fe_2O_3	12.64	2.98
MgO	4.50	0.34
CaO	8.38	0.52
Na_2O	3.22	4.93
K_2O	1.62	4.08
TiO_2	2.263	0.390
P_2O_5	1.009	0.093
MnO	0.214	0.062

Table 3. Selected trace element compositions of volcanic rock samples 5 to 98, 330, and 331. Results are given in ppm.

Sample No.	5	6	8	9	11	14	16	19	20	23	25
Map unit	Tl	Tl	Tbcm	Tbcm	Tbcm	Ttp	Ttv	Tbcm	Tbcm	Twt_1	in Tss
Elements											
Ni	11	5	71	16	13	71	10	11	13	12	12
Cr	0	2	107	29	27	44	3	18	25	5	0
Sc	7	3	26	24	19	31	16	26	22	4	3
V	27	18	224	190	201	277	159	199	198	26	5
Ba	1,768	1,793	832	906	995	429	988	868	2,762	1,257	1,339
Rb	118	121	18	31	31	9	45	34	36	72	80
Sr	133	140	514	540	530	388	483	521	624	35	33
Zr	496	514	140	206	204	95	207	205	208	402	416
Y	80	69	25	31	36	27	27	30	32	90	83
Nb	40	41.4	8.4	18.2	17.7	6.2	13.9	17.5	28.3	18.6	28.6
Ga	27	27	18	19	20	18	20	21	20	23	25
Cu	4	0	64	46	31	120	40	38	38	13	6
Zn	146	145	85	96	95	95	86	99	96	154	125
Pb	11	18	4	7	2	4	7	8	7	16	16
La	57	57	24	36	29	16	32	34	35	49	40
Ce	117	99	28	71	69	1	52	63	46	104	101
Th	13	11	0	3	0	0	3	3	2	10	10

Sample No.	26	28	31	32	33	36	37	42	43	44	46
Map unit	Tm	Tm	Twc	Twt_2	Tdf	Twt_1	Twc	Twt_1	Twc	Tm	Tm
Elements											
Ni	94	9	12	14	23	9	7	10	16	3	13
Cr	189	20	3	0	51	6	2	9	7	2	2
Sc	18	35	4	0	12	2	7	12	5	23	8
V	170	386	7	10	114	16	4	74	46	142	13
Ba	1,170	588	1,257	14	406	1,382	1,051	1,067	976	836	1,051
Rb	42	41	79	145	92	80	97	77	90	61	96
Sr	428	313	42	13	176	32	38	153	84	319	38
Zr	146	182	408	1,144	134	388	411	349	381	236	412
Y	32	43	87	161	34	88	69	66	57	46	70
Nb	13.1	14.6	27.1	97	20.4	27.3	32.3	27.1	29.2	19.6	31.4
Ga	19	25	20	30	18	24	22	22	21	22	20
Cu	39	126	8	6	14	0	0	10	14	35	6
Zn	86	122	146	257	78	134	125	120	109	120	124
Pb	8	1	16	35	11	15	15	9	6	7	14
La	12	14	46	107	43	50	67	41	44	26	45
Ce	38	57	99	236	69	112	100	85	115	45	107
Th	3	3	7	15	9	7	8	6	8	8	8

Table 3 (continued)

Sample No.	48	53	56	57	60	61	65	66	71	72	73
Map unit	Tm	Tm	Twc	in Tspo	Twt_1	Twt_1	Tbcm	Tr	Tr	Tbcm	Tbcm
Elements											
Ni	47	2	9	6	13	10	61	14	27	66	48
Cr	156	20	24	20	0	0	112	22	41	2,676	60
Sc	40	38	19	17	2	0	26	11	19	24	24
V	387	405	188	169	0	19	287	72	139	313	190
Ba	310	719	1,288	947	1,530	1,457	789	913	1,033	1,027	791
Rb	9	34	58	57	77	71	8	87	66	9	29
Sr	315	320	318	255	32	28	535	178	242	551	47[illegible]
Zr	186	178	267	288	395	362	169	270	240	167	170
Y	47	42	56	58	107	86	35	37	36	37	24
Nb	12.5	12.3	20.6	23.5	28.0	26.7	18.5	22.3	20.9	19.9	12.5
Ga	21	24	21	23	22	23	17	17	17	17	20
Cu	257	112	17	21	1	5	33	11	17	37	58
Zn	124	121	159	128	136	117	124	60	81	176	79
Pb	4	6	10	9	13	12	2	10	11	3	5
La	8	16	34	22	46	55	27	50	33	20	25
Ce	47	40	64	76	90	111	66	74	60	50	53
Th	0	3	5	5	7	9	1	9	8	0	1

Sample No.	76	77	78	81	83	84	85	88	89	90	91
Map unit	Tbcm	Tbcm	Tba	Tr	Th	Th	Taf?	Tbi	in Tspo	Th	Tr
Elements											
Ni	16	46	30	11	46	71	72	70	31	86	35
Cr	30	90	79	0	84	105	112	104	10	109	71
Sc	22	18	23	0	24	27	27	28	24	31	16
V	197	148	179	11	234	223	225	223	148	221	149
Ba	1,731	1,162	1,615	950	832	861	898	1,001	2,573	932	7[illegible]
Rb	31	60	63	110	14	19	16	18	28	19	74
Sr	609	327	325	36	565	502	521	514	310	542	273
Zr	210	196	198	337	183	139	140	138	143	144	20[illegible]
Y	33	31	31	65	33	22	23	23	38	24	30
Nb	19.1	13.5	14.4	29.8	15.7	10.4	9.4	10.4	7.4	10.0	14.3
Ga	20	19	20	18	19	18	19	20	21	22	16
Cu	26	40	44	0	44	59	60	55	94	54	38
Zn	93	63	69	64	114	84	83	83	99	83	63
Pb	5	5	8	14	6	4	2	5	5	8	8
La	29	17	14	50	32	22	23	22	41	8	20
Ce	57	55	49	121	59	41	43	39	60	36	56
Th	4	6	6	10	0	2	0	0	2	1	5

Table 3 (continued)

Sample No.	92	93	95	96	97	98	330	331
Map unit	Tr	Tr	Tr	Tr	Tr	Tr	Tm	Twc
Elements								
Ni	10	7	11	9	9	10	0	0
Cr	4	4	1	3	2	4	41	21
Sc	8	1	7	0	22	0	0	0
V	22	17	9	17	3	18	0	0
Ba	1,182	623	803	507	640	777	1,080	1,130
Rb	133	100	251	80	97	109	32	89
Sr	136	19	436	24	21	25	447	42
Zr	279	299	364	225	290	342	272	423
Y	34	47	59	37	52	52	31	66
Nb	17.8	28.0	31.4	20.1	27.2	29.7	37.0	37.0
Ga	16	20	17	21	18	21		
Cu	1	0	3	0	1	6		
Zn	29	45	85	42	47	65		
Pb	13	14	18	13	16	16		
La	45	53	57	53	63	45		
Ce	53	104	117	87	101	98		
Th	10	8	11	6	7	11		

Table 4. Descriptions, map units, and locations of altered rock samples.

Sample No.	Map unit	Lithology	Location
364	Tss	silicified sandstone	SE1/4 sec. 30, T. 24 S., R. 40 E.
365	Tss	argillically altered sandstone	Near center sec. 16, T. 24 S., R. 40 E.
366	Tspo	silicified sandstone	NE1/4 sec. 28, T. 24 S., R. 40 E.
367	Tspo	silicified sandstone	NE1/4 sec. 24, T. 24 S., T. 40 E.
368	Tr	rhyolite	same
369	Tspo	silicified siltstone	same
370	Tr	rhyolite	same
371	Tr	rhyolite	same

Table 5. Major- and minor-element analyses of samples listed in Table 4. Results for Al, Ca, Fe, K, Mg, Na, P, and Ti are given as weight-percent. Other elements are in ppm.

Sample No.	364	365	366	367	368	369	370	371
Map unit	Tss	Tss	Tspo	Tspo	Tr	Tspo	Tr	Tr
Elements								
Al	0.88	8.5	6.2	2.2	5.5	3.1	5.5	6.0
Ca	0.81	2.0	2.7	0.34	0.25	1.2	0.50	0.20
Fe	36	9.9	8.9	1.7	1.1	1.2	1.0	1.1
K	0.09	0.11	0.87	2.1	4.3	1.4	4.	3.35
Mg	0.17	0.83	1.1	0.39	0.10	0.47	0.12	0.04
Na	0.04	0.19	0.70	0.19	1.9	0.10	1.7	2.9
P	0.53	0.21	0.21	0.01	0.02	0.006	0.15	0.01
Ti	0.06	1.2	1.2	0.14	0.12	0.10	0.11	0.12
As	190	<10	<10	<10	<10	<10	<10	<10
Au	N0.002	0.002	N0.002	N0.002	N0.002	N0.002	N0.002	N0.002
Ba	500	67	950	200	580	370	530	680
Be	13	2	2	<1	3	3	2	3
Cd	3	<2	<2	<2	<2	<2	<2	<2
Ce	65	13	53	22	89	91	81	93
Co	25	33	23	7	1	2	1	1
Cr	48	110	10	6	2	1	<1	<1
Cu	120	190	38	6	4	4	4	3
Eu	2	3	2	<2	<2	<2	<2	<2
Ga	20	20	19	27	26	25	30	18
Hg	0.13	N0.02	0.02	0.04	0.02	0.05	0.05	0.02
Ho	5	<4	<4	<4	<4	<4	<4	<4
La	65	27	31	12	49	52	43	53
Li	<2	14	12	77	24	17	18	10
Mn	1,300	380	1,200	380	310	330	260	120
Nb	<4	6	11	<4	17	10	15	20
Nd	63	40	36	12	40	43	35	43
Ni	14	44	8	4	<2	<2	<2	<2
Pb	10	<4	5	6	18	8	16	17
Sc	3	41	28	4	3	3	3	3
Sr	58	120	280	150	44	630	35	23
Th	<4	<4	5	<4	10	8	10	10
V	1,600	230	82	17	10	25	17	14
Y	130	42	44	14	43	49	38	38
Yb	17	4	5	1	5	6	4	4
Zn	280	120	140	27	53	52	52	48