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Geologic map of the Shumway Reservoir quadrangle, Malheur County, Oregon

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INTRODUCTION

The Shumway Reservoir quadrangle is located about 65 km southwest of the town of Vale, Malheur County, Oregon (Figure 1). 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, or from the county road (Shumway Grade) south from U.S. 20 at Juntura. Numerous jeep trails provide easy access from the county road to most parts of the quadrangle.

The formations of the quadrangle were originally named and described by Kittleman and others (1965). A reconnaissance geologic map (scale 1:63,360) that includes the quadrangle was made by Hagood (1963) as part of a study of the Monument Peak area. Hagood'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 geology of the Shumway Reservoir quadrangle was mapped at the scale of 1:24,000 in 1991 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 Vale 30 by 60 minute quadrangle (Ferns and others, 1993) 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 quadrangle is located along the western margin of the horst that borders the north-trending, 50 x 100 km, middle Miocene Oregon-Idaho graben (OIG; Ferns and others, 1993). The horst lies between the OIG and a north-northwest-trending graben that may be part of the Juntura Basin of Shotwell (1963). Based on abrupt stratigraphic changes from the largely sedimentary, pyroclastic, and silicic to mafic volcanic rocks of the graben to the largely flood basalt-rhyolite volcanic rock association of the horst, the eastern margin of the horst is found about 8 km to the east in the Alder Creek quadrangle (Evans and Binger,1998a).

STRATIGRAPHY

The rocks exposed in the Shumway Reservoir quadrangle comprise a flat-lying to gently dipping section of volcanic, pyroclastic and volcaniclastic rocks of late Tertiary age. The oldest rock unit inferred to underlie the area is the basalt of Malheur Gorge (Evans, 1990a,b; formerly "unknown igneous complex" of Kittleman and others, 1965). This unit is shown on the cross sections where it is labelled "Tm". The unit consists of a flood-basalt sequence that is as much as 1 km thick.

The oldest exposed unit of the horst, the middle Miocene Dinner Creek Welded Tuff (map unit Td; Greene and others, 1972; formerly the Dinner Creek Welded Ash-Flow Tuff of Kittleman and others, 1965), is exposed along Cottonwood Creek in sec. 12, T. 23 S., R. 39 E. The Dinner Creek overlies the basalt of Malheur Gorge in quadrangles to the east and north, and is distinguished in the Shumway Reservoir quadrangle by cliffs as much as 5 m high formed by the strongly welded uppermost part of the formation. The less strongly welded and unwelded parts of the formation below the cliffs consist of generally white bedded tuff like the lower Dinner Creek to the east in the Alder Creek quadrangle (Evans and Binger, 1998a). Although the bulk of the formation here is not welded, no new formational name is proposed. As much as 36 m of the formation is exposed along Cottonwood Creek in the northeastern part of the quadrangle. The unit is as much as 80 m thick to the east in the adjoining Alder Creek quadrangle. The Dinner Creek in the Shumway Reservoir and Alder Creek quadrangles differs from Dinner Creek to the north which has a persistent central strongly welded member and lapilli tuff of variable thickness above and below the welded tuff. To the north, in the Monument Peak area (Evans, 1996) and along parts of Malheur Gorge (Evans, 1990b), the lapilli tuff is absent and the welded tuff is 3 to 6 m thick, or is absent. Average composition of the Dinner Creek is alkali rhyolite (Haddock, 1967; Evans, 1990a, Table 1). Based on his estimate of the increase in thickness of the Dinner Creek to the west-northwest, Haddock (1967) suggested that the vent from which the tuff was erupted is at Castle Rock, about 55 km northwest of the quadrangle. However, recent mapping (M.L. Cummings, Portland State University, unpub. mapping, 1996) indicates that Castle Rock is not a vent. The thickness of the Dinner Creek in the Westfall Butte quadrangle (Evans and Binger, 1997) about 40 km to the north appears to increase greatly (as much as 120 m thick) to the north of Westfall Butte and suggests a vent source in that direction. A northerly provenance of the unit is further suggested by the northerly increase in lithic fragments in the strongly welded part of the formation near Westfall Butte from a few percent at most south of the butte to as much as 50 percent near the butte. A possible Dinner Creek vent north of Westfall Butte would be largely buried by younger rocks. K-Ar radiometric ages of the Dinner Creek in Malheur Gorge are 15.3±0.4 and 14.7±0.4 Ma (Fiebelkorn and others, 1983). Based on these radiometric ages, the age of the Dinner Creek is about 15 Ma, or middle Miocene.

The Hunter Creek Basalt (map unit Th; Kittleman and others, 1965; Greene and others, 1972) overlies the Dinner Creek Welded Tuff. The Hunter Creek is black, generally aphyric, and contains rare sedimentary interbeds. Chemically, the Hunter Creek Basalt north of the quadrangle is an icelandite (Carmichael, 1964; typical Hunter Creek contains Al_2O_3=Fe_2O_3=14%), or a basaltic andesite (Le Bas and others, 1986; Evans, 1990a,b). The basaltic andesite that occupies the stratigraphic position of the Hunter Creek and is continuous with Hunter Creek mapped in the adjacent Alder Creek quadrangle to the east, (samples O, Table 2, Evans and Binger,1998a) and in the Skull Springs quadrangle to the southeast (Evans, unpub. data, 1992) are not icelandite. Although more analyses are needed to substantiate this difference in composition of the basaltic andesites, the existing samples suggest that there are at least two magma sources for lava flows in the Hunter Creek interval, although their field appearances are virtually identical. Given the narrow range of acceptable radiometric ages of volcanic rock units in the area, the occurrence of icelandite and basaltic andesite in the same stratigraphic interval, sandwiched between Dinner Creek Welded Tuff and Littlefield Rhyolite, indicates penecontemporaneity of the two Hunter Creek magma types. Two lines of evidence strongly suggest that, although the Hunter Creek Basalt is younger than Dinner Creek based on its stratigraphic position over the Dinner Creek, the flows erupted relatively soon after the Dinner Creek Welded Tuff was emplaced. A lens of black vitrophyre in the Dinner Creek in the Jonesboro quadrangle (Evans, 1990a, Table 1) has an icelandite composition like that of the icelandite magma type of the Hunter Creek Basalt, suggesting mingling between rhyolite and icelandite magmas prior to eruption. In sec. 34 and 35, T. 12 S., R. 39 E. in the Westfall Butte quadrangle (Evans and Binger, 1997), the dominantly rhyolitic tuff of the Dinner Creek grades to andesitic tuff just below the Hunter Creek flows. 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, very close in age to the Dinner Creek. 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 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 the hypothesis that the Hunter Creek was erupted shortly after the eruption of the Dinner Creek Welded Tuff.

The Littlefield Rhyolite (map unit Tlr; Kittleman and others, 1965; sample 179, Table 2) overlies Hunter Creek Basalt and is remarkable for its regional extent (1,100 km^2) and volume (100 km^3). The unit is generally about 90 m thick where it is part of a flat-lying stratigraphic sequence in the northeastern part of the quadrangle. Stratigraphic relations and relatively abrupt changes in thickness of the rhyolite in the Tims Peak and Alder Creek quadrangles (Evans and Keith, 1996; Evans and Binger, 1998b) suggest that the Littlefield Rhyolite erupted from a series of vents along the western margin of the OIG. 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) 20 km to the north-northeast at 15.2±0.31, 16.3±0.87, and 16.8±0.4 Ma. The youngest date is most in accord with radiometric dates of underlying map units.

Tims Peak Basalt is present near the northwest corner of the quadrangle and in the southwest part of the quadrangle. The basalt is a high-alumina olivine tholeiite to the north (Evans, 1990a,b, 1996) where it overlies a north-trending feeder dike swarm that erupted into a lake and produced basalt-pillow breccia.

The tuffaceous sandstone (map unit Tts), and sandstone (map unit Tss) units overlie Littlefield Rhyolite and are differentiated in the field by the volcanic rock units that overlies them. Tuffaceous sandstone is overlain by the trachyandesite flow (map unit Tta), and is differentiable only in a small area in the east-central part of the quadrangle where trachyandesite is present. The unit is as much as 40 m thick in E1/2 sec. 26, T. 23 S., R. 39 E. Unit Tts is stratigraphically equivalent to map unit Tts in the Alder Creek quadrangle (Evans and Binger, 1998a) to the east where it is seen to overlie Littlefield Rhyolite and to map unit Ts_1 in the Monument Peak quadrangle (Evans, 1996) to the north.

The sandstone unit, Tss, is overlain by the Wildcat Creek Welded Ash-Flow Tuff (map unit Tw). The sandstone unit includes the older tuffaceous sandstone (map unit Tts) over most of the quadrangle where the trachyandesite is not present to separate the two units. The sandstone varies in thickness from 30 to 75 m in the quadrangle. Unit Tss is stratigraphically equivalent to map unit Tss in the Alder Creek quadrangle (Evans and Binger, 1998a) to the east and to map unit Ts_2 in the Monument Peak quadrangle (Evans, 1996) to the north.

The trachyandesite flow (map unit Tta) in the west-central part of the adjacent Alder Creek quadrangle underlies Wildcat Creek Welded Ash-Flow Tuff (map unit Tw) and the sedimentary and pyroclastic rocks unit (map unit Tsp) and overlies tuffaceous sandstone (map unit Tts). The outcrops of this unit are limited to a few fault blocks. The unit represents a small volume lava flow, the vent of which has not been identified. Although thin sections of samples from the unit look like ordinary basalt, two samples of the unit from the Alder Creek quadrangle that were analyzed for major oxides are trachyandesite (Evans and Binger, 1998a).

The Wildcat Creek Welded Ash-Flow Tuff (map unit Tw; Kittleman and others, 1965) overlies the sandstone (map unit Tss). Because of its varied appearance, three samples of the welded tuff from the Shumway Reservoir quadrangle (samples 174, 734, and 737, Table 2), and seven samples in the Alder Creek quadrangle (Evans and Binger, 1998a) were analyzed for major oxides. Nine of the samples are rhyolitic, including the three samples from the Shumway Reservoir quadrangle. One of the samples from the Alder Creek quadrangle is dacitic. Some of the lithologic and geochemical variation of the welded tuff may be due to the variable amount of partly digested to undigested xenoliths of fine-grained hematite-rich basalt or basaltic andesite. The unit is as much as 145 m thick in sec. 10, T. 23 S., T. 39 E.; other exposures more than 100 m thick are found in the central part of the quadrangle. These may be an especially thick part of the deposit that filled a local depression or graben. Typical thickness of the unit over the northern and eastern parts of the Shumway Reservoir and adjacent quadrangles is about 30 m or less. The vent of the Wildcat Creek has not been identified.

The sedimentary and pyroclastic rocks unit (map unit Tsp) overlies the Wildcat Creek Welded Ash-Flow Tuff and is overlain by the unnamed welded tuff unit, Twt, and Shumway Ranch Basalt (map unit Tsr). The unit varies in thickness from as little as 6 m in the southwestern part of the quadrangle to 135 m, no base exposed, in the west-central part northwest of Shumway Ranch where a major north-northeast-trending graben is inferred from regional geologic relations. The unit is stratigraphically equivalent to map unit Tsp in the Alder Creek quadrangle (Evans and Binger, 1998a) and to map unit Ts_3 in the Monument Peak quadrangle (Evans, 1996)

Unit Twt, the youngest welded ash-flow tuff, resembles a welded tuff mapped as far north as the Little Black Canyon 7.5′ quadrangle (Evans and Binger, 1998b) 40 km to the north-northeast and is commonly 3 to 6 m thick over most of its extent. The unusual 40 m thickness of the unit in sections 29, 30, and 32, T. 23 S., R. 39 E. suggests that it may have filled a topographic depression. In the Shumway Reservoir quadrangle the welded tuff overlies the sedimentary and pyroclastic rocks unit (map unit Tsp) and underlies the middle Miocene Shumway Ranch Basalt (map unit Tsr) This ash-flow may have been erupted from a vent at or near the Westfall Butte volcanic center 50 km to the north (Evans and Binger, 1997). The presence of partly digested mafic volcanic fragments much like in the Wildcat Creek Ash-Flow Tuff argues for a relatively close vent source for Twt, but no appropriate vent has yet been identified. A middle Miocene age of Twt in the quadrangle can be inferred from stratigraphic relations (middle Miocene Shumway Ranch Basalt over Twt) in NE1/4 sec. 11, T. 24 S., R. 39 E. and in secs. 29 and 32 , T. 23 S., R. 39 E. The outcrop pattern of Twt which seems largely independent of the exposures of Tsr may be a result of the synextensional deposition of the two units over a surface broken by generally north-trending horsts and grabens.

The Shumway Ranch Basalt (Kittleman and others, 1965; see unit description) was named for outcrops near Shumway Ranch in the western part of the quadrangle (type locality in S1/2 sec. 30, T.23 S., R. 39 E.). Eight samples of the unit were analyzed for major oxides and include trachybasalt, basaltic andesite, and basaltic trachyandesite (Samples 738, 739, 142, 146, 150, 172, 193, and 203, Table 2). A sample of the unit from Red Butte in the Alder Creek quadrangle was dated at 12.4±0.5 Ma (K-Ar method; Fiebelkorn and others, 1983). The unit is continuous to the south in the Star Creek Reservoir quadrangle where a sample from the The Monuments was dated at 13.4±0.6 Ma (K-Ar method; Monument Rock Basalt in Fiebelkorn and others, 1983).

Alluvial fan deposits (map unit QTf) are found mostly in the southern part of the quadrangle; they are probably remnants of more extensive deposits. These deposits are similar to alluvial fan deposits in adjacent quadrangles and hint at extensive local uplift and erosion in late Teriary and (or) Quaternary. They could be as old as late Miocene or as young as Quaternary.

Landslide deposits (map unit Qls) are found mostly along north-trending faults, especially where basalt or welded tuff overlies poorly lithified sedimentary rocks.

Alluvium (map unit Qa) is found along, creeks. The most extensive alluvium is found along Granite Creek and other tributaries to the Easterday Reservoir.

METAMORPHISM AND (OR) HYDROTHERMAL ALTERATION

The Shumway Reservoir quadrangle is immediately west of the Alder Creek quadrangle in which most of the map units from the early to middle Miocene basalt of Malheur Gorge to the Tertiary or Quaternary alluvial fan deposits show evidence of low-grade metamorphism and (or) hydrothermal alteration in thin section (Evans and Binger, 1998a). These two processes of mineralogical change may not be easily differentiated where metamorphic neomineralization is incipient. The basalt of Malheur Gorge is not exposed in the Shumway Reservoir quadrangle, and the Dinner Creek Welded Tuff, the oldest map unit, as well as the other two welded tuffs do not show obvious metamorphic or hydrothermal effects.

In the Shumway Reservoir quadrangle, indications of hydrothermal activity such as veins and cement of chalcedony, manganese oxide (?), and hematite in hand specimen, and formation of sericite and muscovite seen in thin section strongly suggest that hydrothermal fluids effected the sedimentary and unwelded pyroclastic units as young as the alluvial fan deposits (unit QTf). Although mafic minerals are partly altered to biotite as high up in the section as the Shumway Ranch Basalt in the Alder Creek quadrangle, this kind of alteration was not observed in the Shumway Ranch Basalt in the Shumway Reservoir quadrangle. One intrusion suspected of affecting the older rocks of the Alder Creek quadrangle is a possible feeder for the Littlefield Rhyolite flows and a related dome in the central part of that quadrangle. This intrusion, however, could not have supplied the heat required to cause thermal metamorphism or hydrothermal alteration in map units younger than the Littlefield Rhyolite including unit Tts and younger. Thermal effects on rocks younger than Littlefield Rhyolite may have been caused by paleohydrothermal systems along the western margin of the OIG, the western margin of the horst west of the OIG, and connecting faults, or by systems related to the late Miocene silicic volcanism and late Miocene to Quaternary basaltic volcanism to the southwest in the Crowley area (Evans and Rytuba, unpub. mapping, 1992, Star Creek Reservoir 7.5" quadrangle; Ferns and Williams, 1993; Ferns and others, 1993b). Evidence of paleohydrothermal activity possibly as late as Quaternary was found to the north in the southern part of the Monument Peak quadrangle (Evans, 1996).

STRUCTURE

Dips and strikes are not shown on the map because the attitudes of the map units are horizontal to gently dipping, and therefore difficult to measure accurately in the field. In addition measurable attitudes are difficult or impossible to find for most of the units either because the rock is internally massive, such as Shumway Ranch Basalt (unit Tsr), or is poorly exposed, such as the several poorly lithified sedimentary and unwelded pyroclastic rock units, or because blocks of resistent tuff and basalt have slumped. In general, the contacts of the rock units on the geologic map provide the best estimates of their attitudes which can be calculated from the geologic map.

The older part of the stratigraphic section from Dinner Creek Welded Tuff to Littlefield Rhyolite in the quadrangle is like so much of the block west of the OIG that extends from Little Black Canyon quadrangle to the north-northeast (Figure 1; Evans and Binger, 1997b) south to the Skull Springs quadrangle to the southeast (Evans , unpub. mapping, 1992). The Littlefield Rhyolite, which is the youngest of the subregional volcanic rock units, is exposed as far west as E1/2 sec. 6, T. 23 S., R. 39 E., about 2 km from the west boundary of the Shumway Reservoir quadrangle. From these outcrops it is impossible to determine whether the map units that are found under the Littlefield Rhyolite elsewhere to the east and north, including the thick flood basalt sequence of the basalt of Malheur Gorge (Evans, 1990a,b) are present at depth in the quadrangle, but they are assumed to be present in the cross-sections AA′ and BB′.

Evidence of middle Miocene faulting is shown in NE1/4 sec. 22, T. 23 S., R. 39 E. where a fault cuts the lower contact of Littlefield Rhyolite, but not its upper contact. A sliver of Littlefield Rhyolite was apparently uplifted and eroded before deposition of the overlying sandstone (unit Tss). Subsequent faults nearby cut the lower contact of the sandstone unit, but not the overlying Wildcat Creek Welded Ash-Flow Tuff. It is possible that many of the faults on the map developed in middle Miocene and were active during late Miocene extensional faulting.

The irregular stratigraphy across the southern half of the quadrangle from Wildcat Creek Welded Ash-flow Tuff (Twt) to the alluvial fan deposits (QTf) suggests that these map units were deposited during tectonism in which the numerous minor fault blocks were uplifted, eroded, slightly tilted, and downdropped in an irregular pattern that included reversal of relative movement along some of the faults such as in the northeastern part of the quadrangle. These stratigraphic variations are especially evident on cross-section AA′. The alluvial fan deposits represent a period of deposition of sediment derived from uplift and erosion of the local volcanic, sedimentary, and hydrothermally altered rocks. Erosion surfaces were generally not deeply dissected and unconformities are not well marked by strong discordances in attitudes or obvious paleorelief, although changes in thicknesses of map units suggest that paleotopography consisted of gently rolling hills. Present day erosion of the alluvial fan deposits is a result of regional uplift and relative lowering of erosional base level.

A recently compiled gravity survey of eastern Oregon (Griscom and Halvorson in Smith, 1994) that includes the Shumway Reservoir quadrangle suggests that the quadrangle is part of a large, generally north-trending region of low density with the gradients plunging toward the southwestern corner of the quadrangle (Figure 2). The area of low density may reflect the presence of a buried basin, graben, or possibly a caldera. The western end of cross-section AA′ is drawn to reflect the presence of a graben to the west of the horst.

The magnetic map (Figure 3), also from recently compiled surveys (Griscom and Halvorson in Smith, 1994), shows that the quadrangle is at the northern end of an area of very low magnetic intensity that would be consistent with the model of a north-trending basin or graben or a volcanic center that includes a caldera that extends into the southern part of the quadrangle, or a body of magnetic rock that is reversely polarized. Considering the coincidence of the magnetic low with part of the gravity low, the basin hypothesis seems more reasonable. The magnetic pattern would also be consistent with a generally southward dipping block of kilometer-thick basalt of Malheur Gorge capped by Dinner Creek Welded Tuff through Littlefield Rhyolite. Cross-section BB′ is drawn to reflect an estimated 300 m, north-to-south decrease in elevation of the top of the basalt of Malheur Gorge. The relatively high magnetic intensity in the northeastern part of the quadrangle may be related to the magnetic Littlefield Rhyolite flows that extend for about 15 km west of the proposed vent, dome, and flow complex aligned along the western margin of the OIG in the Alder Creek quadrangle (Evans and Binger, 1998a). The north-northeast-trending line of stippled hotdogs in the eastern part of the adjacent Alder Creek quadrangle is the approximate location of the horst west of the OIG (Figures 2 and 3) based on surficial geology.

The north-northwest-trending line of stippled hotdogs in the western part of the Shumway Reservoir quadrangle marks the approximate western margin of the horst. West of that line is another graben and associated Stockade Mountain silicic volcanic center (Walker and MacLeod, 1991). The graben may be part of the Juntura Basin of Shotwell (1963), which may be part of a northwestward continuation of the Miocene northern Nevada rift (Griscom and Halvorson in Smith, 1994; Stewart and others, 1975; Zoback and Thompson, 1978; Zoback and others, 1994).

GEOCHEMISTRY

Fifteen unaltered volcanic rocks and seven altered rocks were collected by James G. Evans for analysis. Of the unaltered rocks, five were analyzed by the U.S. Geological Survey for major elements using wave-length dispersive x-ray fluorescence spectroscopy (Samples 734 and 736 to 739, Table 2; Taggart and others, 1990) and for minor elements by inductively coupled plasma atomic emission spectrometry (Table 3; Briggs, 1990); 10 samples (142, 146, 150, 152, 157, 172, 174, 193, and 203, Table 2) were analyzed for major oxides and 8 of these (samples 142, 146, 150, 157, 172, 179, 193, and 203, Table 3) for minor elements by x-ray spectroscometry (Hooper and others, 1990) by G.B. Binger at the GeoAnalytical Laboratory, Washington State University, Pullman.

Samples 734 and 736 to 739 were analyzed for 31 major and trace elements, including the following trace elements, which were not found at the lower limits of detection indicated in parentheses and are not shown in Table 3: silver (<2 ppm), arsenic, (<10 ppm), gold (<8 ppm), bismuth (<10 ppm), cadmium (<2 ppm), tin (<5 ppm), and uranium (<100 ppm). The 8 samples analyzed by G.B. Binger were analyzed for 17 minor elements (Table 3).

The altered rocks (Table 4) were analyzed by the U.S. Geological Survey for 31 major and trace elements by the inductively coupled plasma atomic emission spectrometry method (Briggs, 1990), and the data are reported in Table 5. However, the following elements are not included in Table 5 because they occur in concentrations below the lower confidence limit in all samples: silver, bismuth, cadmium, holmium (<4 ppm), molybdenum (<2 ppm), tin, and uranium. The samples were analyzed for gold by the flame and graphite-furnace atomic absorption spectrophotometry method (O'Leary, 1990), but no gold was detected at the lower limit of detection of 0.002 ppm. 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 altered rocks have disseminated brown (iron) and black (manganese) oxides, and (or) veins as much as 3 mm wide that are relatively high in hematite and (or) high in silica in the form of chalcedony and opal veins. Extent of the veining and dissemination of oxides in sedimentary hosts is not known because these rocks weather easily to soil. However, the occurrences of obviously mineralized rock are few. The oxidized basalt (sample 651; map unit Th) is restricted to a single exposure along Cottonwood Creek near faults. Iron content ranges from 0.08 to 9 weight-percent (Table 5); the highest concentration was found in hematite-cemented siltstone (sample 650) in map unit Tsp. For comparison, concentrations of iron in unaltered rocks varied from 2.2 to 8.0 weight-percent (Table 3); the higher concentrations are in Shumway Ranch Basalt. Therefore, the 3.8 to 9.0 percent in the altered rocks derived from predominantly siliceous protoliths is unusual. The one sample of oxidized Hunter Creek Basalt (sample 651) contains 7.1 wt-percent Fe (Table 5), which is within the range for that lithology.

The significance of trace element concentrations in the altered rocks is revealed by comparison with concentrations of the same elements in the unaltered rocks and to crustal abundances. Arsenic from 10 to 46 ppm in samples 650-652 is most likely an effect of hydrothermal fluids, as it is absent (<10 ppm) in unaltered rocks (Table 2). Mercury was found in all the altered rocks and ranged from 0.02 to

0.07 ppm. The unaltered rocks were not analyzed for mercury, so it is not known how their mercury concentration compares with the altered rocks. However, the mercury concentrations of the altered rocks are similar to crustal abundance (Bailey and others, 1973), and so are not considered to be indicative of significant enrichment. Manganese concentrations greater than 1,300 ppm (maximum in unaltered rocks) appear to reflect hydrothermal veining in siltstone and sandstone of map units Tss (sample 652, 3,400 ppm Mn) and QTf (sample 653, 2,200 ppm Mn). The chalcedony of sample 650 also has a vanadium concentration higher than crustal abundance (Fischer, 1973; 150 ppm vs. 440 ppm); unaltered rocks contain as much as 220 ppm (Table 3).

Compared to their concentrations in unaltered volcanic rocks, the concentrations of Cr, Cu, and Zn in altered rocks are not remarkable. However, concentrations of these elements (Cr as high as 43 ppm; Cu as high as 39 ppm, Zn as high as 140 ppm) in the hydrothermally effected, largely silicic sedimentary and pyroclastic rocks, whose protoliths would be expected to show low metal cocentrations, are suggestive of slight enrichment of these elements, probably by hydrothermal fluids.

Sample 650, which is especially enriched in so many trace elements, was taken from a locality within a a few hundred meters of the estimated trace of the western boundary of the horst. Its location suggests that the fault zone defining this margin of the horst has been permeable to hydrothermal fluids. The mineralization is most likely associated directly or indirectly with east-west, middle to late Miocene extension.

In summary, arsenic is the only trace element that can be definitely attributed to hydrothermal activity in the quadrangle. It is suspected, however, that the relatively high metal values (Cr, Cu, Mn, and Zn) in the hematite-cemented sedimentary rocks of map units Tss, Tsp, and Qtf) are from hydrothermal activity. Although unaltered-looking sedimentary rocks from these map units were not analyzed, their lack of hematite and silica cement is expected to correlate with relatively low concentrations of metals.

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Table 1. Locations of unaltered rock samples

Sample No.	Map unit	Location
734	Tw	NW1/4 sec. 22, T. 23 S., R. 39 E.
736	Twt	NW1/4 sec. 29, T. 23 S., R. 39 E.
737	Tw	W1/2 sec. 8, T. 23 S., R. 39 E.
738	Tsr	S1/2 sec. 3, T. 23 S., R. 39 E.
739	Tsr	SE1/4 sec. 15, T. 23 S., R. 39 E.
142	Tsr	Near center sec. 26, T. 23 S. R. 39 E.
146	Tsr	SE1/4 sec. 36, T. 23 S., R. 39 E.
150	Tsr	NE1/4 sec. 4, T. 24 S., R. 39 E.
152	Twt	NE1/4 sec. 33, T. 23 S., R. 39 E.
157	Twt	On line between secs. 29 and 30, T. 23 S., R. 39 E.
172	Tsr	SE1/4 sec. 10, T. 23 S., R. 39 E.
174	Tw	N1/2 sec. 10, T. 23 S., R. 39 E.
179	Tl	NW1/4 sec. 9, T. 23 S., R. 39 E.
193	Tsr	Near NW corner sec. 16, T. 23 S. R. 39 E.
203	Tsr	SW1/4 sec. 34, T. 22 S., R. 39 E.

Table 2. Major oxide analyses of rock samples listed in table 1. Normalized on a volatile-free basis. Samples 734 to 739 were analyzed by X-ray spectroscopy by the U.S. Geological Survey and total iron is reported as Fe2O3. Samples 142 to203 were analyzed at WSU GeoAnalytical Laboratory and total iron is reported as FeO.

Sample No.	734	736	737	738	739
Map unit	Tw	Twt	Tw	Tsr	Tsr
Rock name	rhyolite	rhyolite	rhyolite	trachybasalt	basalt
Oxides					
SiO_2	73.45	76.05	69.35	51.45	50.93
Al_2O_3	13.24	10.98	13.37	16.37	16.51
Fe_2O_3	3.09	3.25	5.11	11.83	11.87
MgO	0.12	<0.10	0.77	4.78	4.94
CaO	0.33	0.23	1.84	7.83	8.00
Na_2O	4.95	3.81	3.72	3.33	3.36
K_2O	4.38	5.38	4.81	1.71	1.51
TiO_2	0.33	0.23	0.67	1.81	1.97
P_2O_5	0.06	<0.05	0.20	0.71	0.72
MnO	0.04	0.06	0.15	0.18	0.18

Sample No.	142	146	150	152	157	172	174	179	193	203
Map unit	Tsr	Tsr	Tsr	Twc	Twt	Tsr	Twc	Tl	Tsr	Tsr
Rock name	basaltic andesite	basaltic andesite	trachybasalt	rhyolite	rhyolite	trachybasalt	rhyolite	rhyolite	basaltic trachyandesite	basaltic trachyandesite
Oxides										
SiO_2	52.08	52.05	51.90	76.08	76.22	51.95	73.92	73.36	52.94	53.21
Al_2O_3	18.34	16.42	16.97	10.85	11.19	16.44	12.93	12.47	17.15	17.20
FeO	9.45	10.65	10.36	2.63	2.68	10.49	2.99	4.32	8.91	8.76
MgO	4.33	4.69	4.73	0.20	0.11	5.08	0.29	0.20	4.83	4.48
CaO	9.06	7.90	8.14	0.58	0.33	7.98	0.27	0.68	8.04	8.29
Na_2O	3.50	3.73	3.48	4.67	3.66	3.73	4.95	4.31	3.64	3.65
K_2O	0.99	1.61	1.54	4.68	5.45	1.51	4.17	4.14	1.76	1.75
TiO_2	1.564	2.007	1.989	0.196	0.213	1.950	0.369	0.378	1.864	1.877
P_2O_5	0.546	0.75	0.73	0.064	0.083	0.70	0.085	0.068	0.69	0.587
MnO	0.130	0.192	0.169	0.064	0.065	0.170	0.027	0.070	0.171	0.198

Table 3. Major-and minor-element analyses of unaltered rock samples listed in table1. Concentrations of Al, Ca, Fe, K, Mg, Na, P, and Ti in samples 734 through 739 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 142 to203 were analyzed for 17 trace-elements by X-ray fluorescence at the WSU GeoAnalytical Laboratory; results of these analyses are also in ppm.

Sample No.	734	736	737	738	739
Map unit	Tw	Twt	Tw	Tsr	Tsr
Element					
Al	6.3	5.5	6.8	8.5	8.7
Ca	0.26	0.17	1.3	5.3	5.5
Fe	2.2	2.3	3.5	7.8	8.0
K	3.6	4.2	3.8	1.4	1.3
Mg	0.08	0.06	0.47	2.7	2.8
Na	3.6	2.7	2.7	2.5	2.6
P	0.02	0.007	0.08	0.30	0.31
Ti	0.21	0.13	0.42	1.1	1.2
Ba	970	58	900	800	840
Be	3	7	3	1	1
Ce	57	210	100	58	60
Co	<1	<1	6	36	38
Cr	7	<1	11	110	110
Cu	5	11	15	53	36
Eu	<2	<2	<2	2	2
Ga	24	30	23	21	22
Ho	<4	4	<4	<4	<4
La	28	110	52	35	36
Li	16	41	14	8	10
Mn	230	460	1,200	1,300	1,300
Mo	<2	4	<2	<2	<2
Nb	22	69	22	12	12
Nd	35	110	49	40	43
Ni	<2	<2	6	56	54
Pb	13	29	15	4	5
Sc	6	<2	12	23	24
Sr	40	10	110	580	590
Th	6	16	9	<4	<4
V	14	3	52	200	220
Y	31	160	63	30	33
Yb	4	18	8	3	3
Zn	120	250	130	110	120

Table 3 (continued)

Sample No.	142	146	150	157	172	179	193	203
Map unit	Tsr	Tsr	Tsr	Twt	Tsr	Tl	Tsr	Tsr
Element								
Ni	42	36	38	15	42	9	41	44
Cr	112	74	89	0	95	2	80	64
Sc	24	24	22	0	28	5	31	26
V	225	237	237	1	229	22	233	225
Ba	2,039	1,066	1,310	70	1,048	1,829	971	883
Rb	9	14	16	140	14	115	20	22
Sr	632	600	647	12	572	131	581	550
Zr	164	194	186	1,059	189	484	185	184
Y	29	37	35	143	34	83	32	32
Nb	14.1	17.0	15.4	93	16.8	38	16.1	14.1
Ga	21	24	23	28	25	27	21	25
Cu	47	31	41	6	34	2	45	38
Zn	96	119	124	240	117	154	115	113
Pb	3	8	5	32	6	16	6	6
La	24	37	30	88	24	78	35	27
Ce	41	50	46	239	51	110	37	41
Th	1	1	1	17	2	14	2	0

Table 4. Locations and descriptions of altered rock samples

Sample No.	Description (map unit)	Location
647	Hematite veins in poorly lithified mudstone (Tsp)	SW1/4 sec. 2, T. 24 S., R. 39 E.
648	Tuff cemented by chalcedony (Tsp)	Near NW corner sec 4, T. 24 S., R. 39 E.
649	White chalcedony veins (Tsp)	SE1/4 sec. 28, T. 23 S., R. 39 E.
650	White chalcedony (Tsp)	Near center sec. 5, T. 24 S., R. 39 E.
651	Oxidized basalt (Th)	NE1/4 sec. 10, T. 23 S., R. 39 E.
652	Siltstone with brown and black oxides (Tss)	SW1/4 sec. 14, T. 23 S., R. 39 E.
653	Sandstone cemented by chalcedony and black oxide (QTf)	SE1/4 sec. 22, T. 23 S., R. 39 E.

Table 5. Major- and trace-element analyses of altered rock samples listed in table 4. Concentrations of Al, Ca, Fe, K, Mg, Na, P, and Ti are given in weight-percent. Concentrations of other elements are in ppm. "<" followed by a number means that the element was present in concentrations less than the lower confidence limit indicated.

Sample No.	647	648	649	650	651	652	653
Map unit	Tsp	Tsp	Tsp	Tsp	Th	Tss	QTf
Element							
Al	7.5	8.0	0.12	9.8	6.8	7.3	6.9
Ca	0.87	1.1	5.2	0.93	1.6	0.94	1.1
Fe	7.0	3.6	0.08	9.0	7.1	8.1	3.8
K	0.36	1.3	0.02	0.57	2.3	1.1	1.2
Mg	0.50	0.51	0.61	0.91	0.21	0.40	0.44
Na	0.42	1.0	0.02	0.26	2.8	0.88	1.5
P	0.02	0.04	0.01	0.03	0.17	0.04	0.02
Ti	0.60	0.46	0.007	1.4	0.73	0.57	0.58
As	<10	<10	<10	46	10	20	<10
Ba	350	1,000	180	770	1,300	1,300	2,600
Be	2	2	<1	4	2	5	2
Ce	13	65	<4	82	76	83	210
Co	12	6	1	22	8	50	39
Cr	31	22	<1	43	<1	36	40
Cu	34	18	13	39	7	28	25
Eu	<2	<2	<2	<2	3	<2	2
Ga	17	21	<4	30	25	22	20
Hg	0.03	0.05	0.04	0.07	0.02	0.05	0.03
La	8	35	<2	38	44	31	71
Li	26	14	<2	71	6	30	21
Mn	190	550	19	920	1,100	3,400	2,200
Nb	12	15	<4	32	19	25	16
Nd	5	30	<4	34	41	24	73
Ni	15	12	3	37	7	16	41
Pb	11	16	<4	16	12	27	14
Sc	15	14	<2	23	23	10	12
Sr	110	170	140	120	280	170	240
Th	6	9	<4	12	8	15	7
V	150	49	9	420	55	220	130
Y	11	35	3	33	39	45	59
Yb	2	4	<1	4	4	5	6
Zn	96	69	2	140	140	79	77