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GEOLOGIC MAP OF THE WEST FALL BUTTE QUADRANGLE, MALHEUR COUNTY, OREGON

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INTRODUCTION

The Westfall Butte 7.5' quadrangle, Malheur County, Oregon, is about 10 km west of the town of Westfall and about 12 km north of U.S. Highway 20 in Malheur Gorge (Fig. 1). Principal access to the quadrangle is from a dirt road north of Highway 20 along Pole Creek.

Some of the formations in the quadrangle were 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). Geologic mapping of the Westfall Butte quadrangle at the scale of 1:24,000 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 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 quadrangle mostly comprise a flat-lying to gently-dipping section of volcanic, pyroclastic, and sedimentary rocks of late Tertiary age. The Dinner Creek Welded Tuff (Tdc), Hunter Creek Basalt (Th), and the older ignimbrite member of the Westfall Butte Volcanics (Toig) contain rare fragments of chert and argillite, some with recrystallized radiolaria tests that suggest the presence at depth of Mesozoic and (or) Paleozoic accreted rocks, possibly part of the Baker terrane of Silberling and others (1987). The basalt of Malheur Gorge (Tm), the oldest exposed rock unit, contains inclusions of rhyolitic welded tuff entrained in basaltic welded tuff (Evans, 1990a,b) that suggest the presence of silicic pyroclastic rocks under the basalt. The Tertiary rocks in the quadrangle are part of a north-trending horst about 85 km long that forms the western margin of the 50-km-wide Oregon-Idaho graben (OIG) of Ferns and others (1993). The bulk of the volcanic rocks described in this report represent the pre-OIG volcanic stratigraphy of the region and subsequent local middle Miocene volcanism and sedimentation that was contemporaneoous with development and evolution of the OIG.

GEOLOGY

The basalt of Malheur Gorge (Tm), the oldest exposed rock unit, is a sequence of tholeiitic basalt and basaltic andesite flows that is at least 600 m thick south of the quadrangle (Evans, 1990a). The name "basalt of Malheur Gorge" as used here is equivalent to the "unnamed igneous complex" of Kittleman and others (1965). This thick sequence of tholeiitic basalt flows is petrologically, geochemically, and stratigraphically equivalent to the Imnaha and Grande Ronde Basalts (G.B. Binger, unpub. data, 1996). The unit extends 85 km south of Westfall Butte, but is buried by younger rocks north of the butte. The principal vent for the basalt is located in the Jones Butte area, 30 km to the south (Evans, 1996). Parts of the unit were 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 Dinner Creek Welded Tuff (Tdc; Greene and others, 1972; formerly the Dinner Creek Welded Ash-Flow Tuff of Kittleman and others, 1965) the basalt of Malheur Gorge and is clearly distinguished in the field by cliffs 6 to 100 m high formed by the central strongly welded part of the formation. The less strongly welded parts of the formation above and below the cliffs are usually buried by debris from the overlying Hunter Creek Basalt (see below). Average composition of the Dinner Creek is alkali rhyolite (Haddock, 1967; Evans, 1990a, Table 1; Table 1, this report, samples 732, 118A, 118B). The formation ranges in thickness from 12 to as much as 120 m in the northern part of the quadrangle where the base of the formation is not exposed. 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 20 km west-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 appears to increase greatly 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 from a few percent to as much as 50 percent. A possible Dinner Creek vent to the north would be buried by younger rocks. K-Ar radiometric ages of the Dinner Creek in Malheur County are 15.3±0.4 and 14.7±0.4 (Fiebelkorn and others, 1983). The older age is from Dinner Creek on the south side of Malheur Gorge near the Malheur River in sec. 26, T. 20 S., R. 39 E. (Evans, 1990a). The other dated sample was taken from the Dinner Creek in the western part of Malheur Gorge. A date listed for the Dinner Creek in Baker County may not be from the Dinner Creek ash-flow sheet and is not considered here. Based on these radiometric ages, the age of the Dinner Creek is about 15 Ma, or middle Miocene.

The Hunter Creek Basalt (Th; Kittleman and others, 1965; Greene and others, 1972) overlies the Dinner Creek Welded Tuff. 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; Evans, 1990a,b). The Hunter Creek Basalt appears to thin south of Westfall Butte and is absent over the Dinner Creek north of Westfall Butte, most likely because the flows did not reach that area. In general, the Hunter Creek Basalt appears to be absent from the area northwest of a northeast-trending line that passes roughly through Westfall Butte and that could be a fault obscured by younger rocks and younger faulting. Possible vents for the Hunter Creek flows were mapped by Brooks and O'Brien (1992) in the Westfall quadrangle, 10 km to the east. 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 a basaltic andesite composition like that of the Hunter Creek Basalt, suggesting mingling between rhyolite and andesite magmas prior to eruption. In sec. 34 and 35, T. 12 S., R. 39 E. in the Westfall Butte quadrangle , 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, probably 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 sedimentary and tuffaceous rocks unit (Tst) overlies Hunter Creek Basalt north of Westfall Butte and is present in thin isolated patches across the eastern part of the quadrangle. The bulk of the unit lies north of a poorly defined northwest-trending zone that passes through the northern part of the Westfall Butte quadrangle, and is a segment of the Adrian fault zone (AFZ) of Ferns and others (1993). The unit Tst consists largely of pyroclastic and slightly reworked silicic volcaniclastic material, including lahars from a nearby source, possibly from the Westfall Butte volcanic center.

The oldest unit of the Westfall Butte Volcanics, the older rhyolitic ignimbrite (Toig), is exposed on the north, west, and east flanks of Westfall Butte, overlies unit Tst, and appears to pinch out just south of the butte (cross-section A-A'). The ignimbrite, may be part of a valley-fill sequence, the vent for which was not identified and could be buried. Outcrops of the older ignimbrite in S1/2 sec. 25, T. 18 S., R. 38 E. contain lapilli as much as 2 cm long and blocks as much as 1 m long of basalt and devitrified welded tuff resembling Dinner Creek Welded Tuff and may be part of a basalt and hydrovolcanic complex that is better exposed to the west. The older ignimbrite unit may be a near-vent facies, and may have erupted from a vent to the west in the adjacent De Armond Mountain 7.5' quadrangle (M.L. Cummings, Portland State University, unpub. mapping, 1996). Rhyolite flows (Trf1) locally overlie the older ignimbrite and are, in turn, covered by flows from the basaltic andesite, andesite, and dacite flows unit (Tbad). The vents of units Trf1 and Tbad were not identified.

Subsequently, a small, north-trending basin formed and accumulated as much as 150 m of sedimentary and tuffaceous rocks in the Kelsay Butte area (unit Tsk; cross-section B-B'). The stratigraphic relations in the northwestern part of the quadrangle indicate that unit Tsk was deposited over unit Tbad. The alignment of the sedimentary basin with the north-trending rhyolite dike (Tri) to the north, a likely feeder for at least some of the rhyolite flows and ignimbrites, suggests that subsidence accompanied or preceded eruption of the rhyolite. Apparent dropstones of basalt in part of the unit Tsk, possibly ballistic ejecta, suggest that some eruptions were contemporaneous with deposition.

The first volcanic unit clearly related to renewed volcanic activity at Westfall Butte is the younger ignimbrite unit (Tyig) that overlies the sedimentary and tuffaceous rocks of unit Tsk in the Kelsay Butte area. Later eruptions from an unidentified source resulted in emplacement of the laminated welded tuff unit, Twt. Dacite flows (Tdf), mapped locally, probably erupted from a small vent (Tdi) about 1.5 km south-southwest of Westfall Butte.

Other pyroclastic rocks, that may have erupted from the Westfall Butte volcanic center, were mapped in the northern part of the adjacent Little Black Canyon 7.5' quadrangle (Evans, unpub. mapping, 1990; Ferns and others, 1993). Volcanism at Westfall Butte may also have contributed tuff to middle Miocene parts of the Bully Creek Formation to the east (Brooks and O'Brien, 1992; Evans, unpub. mapping, 1990, Little Black Canyon 7.5' quadrangle; this report, cross-section A-A').

Sometime after the volcanism at Westfall Butte ceased, lacustrine sedimentation dominated the area, as indicated by the Bully Creek Formation and the pillow-basalt breccia unit, Tpb. The olivine basalt flows of the Tims Peak Basalt (Ttp) flowed over the marginal parts of the lake basin forming pillow-basalt breccia (Tpb), and possibly some invasive flows and intrusive sills of the basalt may have caused local phreatic explosions. No single vent was found for the Tims Peak Basalt, but dikes cut the pillow-basalt breccia and suggest that the Tims Peak Basalt erupted from a dike swarm that may be largely covered by the basalt flows. The pillow-basalt breccia in the southwest corner of the Westfall Butte quadrangle may have been connected to the same lacustrine environment as the pillow-basalt breccia in the South Mountain quadrangle (Evans, 1990b) and in the Tims Peak quadrangle (Evans and Keith,1996), both of which may have been marginal to a middle Miocene Bully Creek Lake. Flows of the Tims Peak Basalt transgress onto the younger ignimbrite, Tyig, and may have protected part of the middle Miocene Westfall Butte Volcanics from erosion. Lees (1994) dated a sample of Tims Peak Basalt at 13.4±3.56 Ma ($^{40}Ar/^{39}Ar$ method; Lees' sample KL-92-273). The date has a large percentage error; the mean, however, fits an estimate of the age of the Tims Peak Basalt between 15 and 13 Ma (older than 15 Ma unit Td and younger than 12.4 Ma Shumway Ranch Basalt; Fiebelkorn and others, 1983).

The basalt porphyry unit (Tbp) forms a thin (3 m) resistant cap on erosional remnants of the unit Tst in the southeastern part of the quadrangle. Field evidence in the Little Black Canyon 7.5' quadrangle to the east (Evans, unpub. mapping, 1990) shows that the basalt is a sill or invasive flow that affected the lower, middle Miocene part of the Bully Creek Formation, and produced phreatomagmatic explosions. The basalt is a high alumina basalt like the Tims Peak Basalt, and it could be a sill or invasive flow fed by the dike swarm that fed the Tims Peak Basalt flows.

Alluvial fan deposits (Tf) of estimated Miocene and (or) Pliocene age have retained their alluvial fan morphology and appear to postdate most of the faulting. The lapilli tuff found in the unit indicates that silicic volcanism in the region was contemporaneous with deposition.

Quaternary landslide deposits (Qls) occur in the Westfall Butte Volcanics, the largest one on the east side of Westfall Butte covers about 1 km2.

Alluvium (Qa) is assumed to be largely Quaternary. An exposure of alluvium in a stream bank in NW 1/4 sec. 17, T. 19 S., R. 39 E., however, shows the offset of a 15 to 30 cm-thick white ash bed by as much as 15 cm suggesting either that some of the alluvium is older than Quaternary, or that minor faulting occurred in the Quaternary. The uppermost 1 m of alluvium there is not cut by the fault. It is possible that the alluvium ranges in age from late Pliocene to Holocene. However, until more evidence is available to constrain the age, the alluvium is assumed to be Quaternary.

In summary, the dominantly Miocene rocks exposed in the quadrangle rest on substrates of probable Triassic and (or) Paleozoic accreted terrane and early Miocene or older silicic volcanic rocks. The oldest Tertiary rocks exposed comprise an early Miocene flood-basalt sequence that is virtually identical to the Columbia River Basalt Group to the north. Rapid subsidence of the north-trending, 50-km-wide OIG to the east followed eruption during middle Miocene of a welded tuff from a vent estimated to be north of Westfall Butte and eruption of basaltic andesite flows from north-trending vents located about 10 km to the east along the western margin of the OIG. Subsequently, relatively minor eruptions occurred in the vicinity of Westfall Butte. The last volcanic activity recorded in the quadrangle is eruption of relatively small-volume, high-alumina basalt flows from a north-trending dike swarm along the western margin of a lake that transgressed the horst west of the OIG. The volcanism in the Westfall Butte area, the development of the lake along the western margin of the OIG, and the eruptions of the high-alumina basalts are in part contemporaneous. Subsequently, the area underwent erosion and deposition that produced alluvial fan deposits in late Miocene or Pliocene, and alluvium along segments of existing stream channels in the Quaternary.

STRUCTURE

The quadrangle is located at the northern end of a horst that extends 85 km to the south and forms the west wall of the Oregon-Idaho graben (OIG; Ferns and others, 1993). The section south of Westfall Butte is made up largely of the volcanic sequence that includes the basalt of Malheur Gorge (Tm), the Dinner Creek Welded Tuff (Tdc), and the Hunter Creek Basalt (unit Th), all of which are widespread in the horst. Exposures of the basalt of Malheur Gorge and Hunter Creek Basalt seem to end abruptly and the Dinner Creek to thicken abruptly along a northeast-trending line that passes through the Westfall Butte area. The exact nature of this abrupt stratigraphic change is not clear, but it may be a fault that was significant in defining the topography prior to or during the eruption of the Dinner Creek Welded Tuff and the Hunter Creek Basalt and could be part of a caldera margin. The basalt of Malheur Gorge is assumed to underlie the Dinner Creek in the northwestern part of the quadrangle, as shown on cross-section AA', although the rocks underlying the Dinner Creek there are not exposed. The isostatic gravity map of Griscom and Halvorson (1994) shows a gravity high over much of the quadrangle south of Westfall Butte and a gradient decreasing to the north approximately coinciding with the northeast trending zone of stratigraphic change (Fig. 2). The thinning of the Hunter Creek along the northeast-trending stratigraphic boundary could be due to a rise in paleo-elevation at the caldera rim or a mounding of the top of the Dinner Creek outflow sheet in a moat basin near the rim. The Westfall Butte Volcanics may be a marginal late stage event in the caldera-forming process during which the Dinner Creek was emplaced. Cummings (unpub. mapping, 1996), in mapping areas west and northwest of the Westfall Butte quadrangle, suggests that the northeast-trending structure that passes under Westfall Butte is a regional structure that is larger than a caldera. This hypothesis is based on his observations that the volcanic rocks exposed west and northwest of the Westfall Butte quadrangle appear to bear no relation to volcanic rocks in the Westfall Butte quadrangle. Griscom and Halvorson (unpub. regional K/Th aerorad data, 1995) suggest that the northeast-trending structure is an important crustal boundary, although they do not suggest its character.

The Adrian fault zone (AFZ) of Ferns and others (1993a, Fig. 1) trends west-northwest across the northern part of the Westfall Butte quadrangle. The AFZ truncates some of the northerly -trending faults and is cut by some of them north of Westfall Butte. The AFZ appears to coincide with a weak west-northwest-trending trough in the gravity data (Fig. 2). The older middle Miocene volcanic sequence that includes the basalt of Malheur Gorge through Hunter Creek Basalt was downdropped to the northeast of the AFZ. The intersecting fault relations suggest largely contemporaneous movement on the two sets of faults, with faults of the northerly trending set continuing to be active after the AFZ became inactive. One of the north-northeast-trending faults in the northwest corner of the map juxtaposes units Tsk and Tyig and is covered by Ttp, indicating a middle Miocene age for the fault. Several faults that strike north, northeast, and east are covered by the alluvial fan deposits (Tf); these relations indicate probable cessation of significant faulting by late Miocene or Pliocene.

As discussed above in the section on the age of the alluvium (Qa) some of the latest fault movement in the quadrangle, possibly late Pliocene or Pleistocene, occurred along a fault that cuts alluvium in the west-central part of the quadrangle. The amount of slip (about 15 cm) is insignificant compared to the more obvious mappable offsets of geologic units. In general, the field evidence suggests tectonic quiescence of the area since late middle Miocene.

The aeromagnetic data of Griscom and Halvorson (1994, Fig. 3) show relatively high magnetic intensity probably associated with the presence of the basalt of Malheur Gorge and Hunter Creek Basalt. The aeromagnetic low southwest of Westfall Butte corresponds generally with the large north-trending rhyolite dike. The north-northwest-trending ridge of high aeromagnetic intensity in the southwest corner of the quadrangle may reflect the dike swarm that fed the Tims Peak Basalt flows. The north-trending aeromagnetic ridge northwest of the quadrangle is part of the boundary between two aeromagnetic surveys and may be ignored.

GEOCHEMISTRY

Twenty-nine samples of unaltered volcanic rocks (Table 1) and 11 samples of altered rocks (Table 4) were collected by J.G. Evans during field mapping. Seven of the unaltered rock samples were analyzed for major elements by X-ray spectroscopy (Taggert and others, 1990) by J.S. Mee and D.F. Siems of the USGS Branch of Geochemistry. Seventeen of the unaltered rock samples were analyzed for major elements by X-ray fluorescence by G.B. Binger at the GeoAnalytical Laboratory of Washington State University, Pullman. The results of these analyses, shown in Table 2, are normalized on a volatile-free basis. The samples analyzed by the USGS express total iron as Fe_2O_3; the samples analyzed at WSU express total iron as FeO. These analyses are discussed below.

The unaltered rock samples 726 to 732 were analyzed for major and trace elements (Tables 2 and 3) by inductively coupled plasma atomic emission spectrometry (ICP; Briggs, 1990) by B.H. Roushey and P.L. Hageman of the USGS Branch of Geochemistry. Lower limits of detection are implied in the ICP analyses of Table 3 by numbers preceded by the symbols "N" (element not detected at the concentration indicated) and "<" (element detected but in lower concentrations than the minimum confidence level indicated). Some of the elements listed in the ICP suite are not included because these elements occur in uniformly lower-than-confidence-level 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); europium (Eu), <2 ppm; holmium (Ho), <4 ppm; molybdenum (Mo), < 2 ppm; tin (Sn), < 5 ppm; tantalum (Ta), < 40 ppm; and uranium (U), < 100 ppm.

The unaltered rock samples 20 to 139 were analyzed for major oxides and 17 trace elements by X-ray fluorescence (Hooper and others, 1993) by G.B. Binger, WSU. These results are shown in Table 3.

The unaltered rocks are relatively rich in barium (680 to 2,534 ppm); 24 of the samples contain more than 1,000 ppm barium, the highest is from a sample (22) of rhyolite from the younger rhyolite flows unit Trf2. Lead content ranges from <4 to 23 ppm, the highest is from a sample (726) of perlitic glass from the younger ignimbrite unit Tyig. Copper ranges from 5 to 150 ppm, the highest is from a sample (730) of basaltic andesite in the map unit Tbad. Zinc ranges from 37 to 150 ppm, the highest is from a sample (732) of Dinner Creek Welded Tuff. These concentrations of barium, copper, lead, and zinc are not unusual in unaltered volcanic rocks (see discussions in Brobst and Pratt, 1973). The absence of detectable concentrations of arsenic, molybdenum, and tin, possible markers of alteration, in the unaltered rock samples 726 to 732 corroborates the field judgment that samples 726 through 732 are unaltered. A different suite of minor elements was analyzed in samples 20 to 139; this trace-element suite does not include elements that might be strong indicators of rock alteration. Sample 118B, however, contains 81.05 percent SiO_2 (Table 2) and is most likely a silicified part of the Dinner Creek Welded Tuff. This alteration could have occurred during post-emplacement degassing and devitrification of the strongly welded part of the unit and may not, by itself, be indicative of locally significant hydrothermal mineralizing processes.

The altered rocks, described in Table 4, were analyzed for major and trace elements by inductively coupled plasma atomic emission spectrometry (ICP; Briggs, 1990). 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 P.L. Hageman of the USGS Branch of Geochemistry. The results of these analyses are shown on Table 5. Some of the elements are not included in Table 5 because they occur in uniformly lower-than-confidence-level concentrations in all the samples. These elements are: Ag; Au, none detected at 0.05 ppm; Bi; Cd; Eu; Ho; Ta; and U.

Measurable concentrations of arsenic, mercury, molybdenum, tin, and unusually high concentrations of iron oxide are considered indications of possibly significant rock alteration in this study. In the field, the indicators that led to selection of the altered samples were conspicuously large concentrations of iron oxide and (or) large concentrations of silica, as in veins, nodules or replacement zones.

Seven of the altered rock samples (629-632, 634, 636, and 637) contain measurable concentrations of the elements arsenic, mercury, molybdenum, and tin and tend to be associated with relatively elevated concentrations of other elements. The quartz and jasper found as float on Hunter Creek Basalt (unit Th; 627 and 628) and two of the samples of silicified Dinner Creek Welded Tuff (unit Tdc; 633 and 635) had no remarkable concentrations of minor elements. Three of the seven significantly altered rock samples are from the rhyolitic Dinner Creek Welded Tuff (632, 634, and 637), confirm the apparent altered character of parts of the unit, and suggest that arsenic, mercury, molybdenum, and tin may occur at high background levels in the unit. Two of the significantly altered samples (630 and 636) are from hematite-enriched siltstone beds in the unit Tst, emphasizing the importance of permeability in localizing zones of enrichment near volcanic centers. Such zones, however, may be peripheral to significant mineralization. Staatz and Olson (1973) estimate thorium crustal abundance in the 6 to 13 ppm range, which encompasses the range of thorium concentrations found in the altered rock samples. The highest concentration of cerium (110 ppm) occurs in one of the hematitic siltstones (630), but its significance is not known.

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Table 1. Locations of unaltered rock samples

Sample no.	Composition	Map unit	T/R/S
726	rhyolite	Tyig	SE 1/4 sec. 7, T. 19 S., R.39 E.
727	rhyolite	Trf_2	Near center. sec. 8, T. 19 S., R. 39.E
728	dacite	Tdf	SW 1/4 sec. 29, T. 18 S., R. 39 E
729	rhyolite	Tri	S. 1/2 sec. 29, T. 18 S., R. 39 E.
730	basaltic andesite	Tbad	Near NE corner sec. 20, T. 18 S., R. 39 E.
731	andesite	Tbad	NW 1/4 sec. 4, T. 19 S., R. 39 E.
732	rhyolite	Tdc	NE 1/4 sec. 20, T. 18 S., R. 39 E.
20	rhyolite	Tyig	SE 1/4 sec. 7, T. 19 S., R. 39 E.
22	rhyolite	Trf_2	W 1/2 sec. 8, T. 19 S., R. 39 E.
32	rhyolite	Tyig	NW 1/4 sec. 7, T. 19 S., R. 39 E.
45	andesite	Tbad	NW 1/4 sec. 32, T. 18 S., R. 39 E.
59	dacite	Tbad	NE 1/4 sec. 5, T. 19 S., R. 39 E.
85	dacite	Tdi	SE 1/4 sec. 5, T. 19 S., R. 39 E.
92C	dacite	Toig	S1/2 sec. 25, T. 18 S., R. 38 E.
97	basaltic andesite	Tbad	N 1/2 sec. 23, T. 18 S., R. 39 E.
101	andesite	Tbad	NE 1/4 sec. 29, R. 18 S., R. 39 E.
104	basaltic andesite	Tbad	SW 1/4 sec. 25, R. 18 S., R. 39 E.
105	dacite	Tbad	NW 1/4 sec. 25, R. 18 S., R. 39 E.
111	basaltic andesite	Tbad	N 1/2 sec. 4, T. 19 S. R. 39 E.
112	basaltic andesite	Tbad	N 1/2 sec. 4, T. 19 S., R. 39 E.
118	rhyolite	Tdc	E 1/2 sec. 3, T. 19 S., R. 39 E.
118A	rhyolite	Tdc	E 1/2 sec. 3, T. 19 S., R. 39 E.
124A	rhyolite	Twt	Near SW cor. sec. 4, T. 19 S., R. 39 E.
126	dacite	Tdi	On line between secs. 4 + 5, T. 19 S., R. 39 E.
128	andesite	Tbad	SE 1/4 sec. 29, T. 18 S., R. 39 E.
129B	rhyolite	Toig	NE1/4 sec. 29, T. 18 S., R. 39 E.
134	rhyolite	Toig	SE1/4 sec. 28, T. 18 S., R. 39 E.
137	rhyolite	Toig	SW1/4 sec. 34, T. 18 S., R. 39 E.
139	basaltic andesite	Tbad	NW 1/4 sec. 34, T. 18 S., R. 39 E.

Table 2. Major -element analyses. Normalized on a volatile-free basis. Samples 726 to 732 were analyzed by X-ray spectroscopy by the U.S. Geological Survey and total iron is reported as Fe_2O_3. Samples 20 to139 were analyzed at the WSU GeoAnalytical Laboratory and total iron is reported as FeO.

Sample no.	726	727	728	729	730	731	732
Map unit	Tyig	Trf_2	Tdf	Tri	Tbad	Tbad	Tdc
Rock name	rhyolite	rhyolite	dacite	rhyolite	basaltic andesite	andesite	rhyolite
SiO_2	75.42	72.49	65.29	71.28	54.87	59.30	76.25
Al_2O_3	14.13	15.16	15.97	15.06	18.89	16.24	11.51
Fe_2O_3	1.04	2.74	5.88	2.84	6.05	8.90	3.56
MgO	<0.10	0.22	0.87	0.36	3.96	2.68	0.12
CaO	1.17	1.79	4.54	2.81	11.26	6.49	0.53
Na_2O	3.64	3.56	3.74	3.91	2.78	3.36	4.13
K_2O	4.45	3.61	2.46	3.11	0.99	1.75	3.59
TiO_2	0.06	0.29	0.81	0.42	0.87	0.87	0.21
P_2O_5	<0.05	0.08	0.37	0.16	0.20	0.27	0.07
MnO	0.08	0.05	0.07	0.04	0.12	0.14	0.03

Sample no.	20	22	32	45	59	85	92C	97	101	104	105
Map unit	Tyig	Trf_2	Tyig	Tbad	Tbad	Tdi	Tbad	Tbad	Tbad	Tbad	Tbad
Rock name	rhyolite	rhyolite	rhyolite	andesite	dacite	dacite	basaltic andesite	basaltic andesite	andesite	basaltic andesite	dacite
SiO_2	75.23	74.88	75.29	57.97	66.48	67.27	52.62	56.31	61.41	56.47	63.59
Al_2O_3	14.26	14.07	14.01	16.43	16.06	15.32	16.02	17.12	16.41	16.35	15.90
FeO	0.86	1.25	0.82	7.28	5.43	4.86	9.33	7.11	7.68	8.32	6.04
MgO	0.02	0.03	0.00	4.57	0.26	0.91	8.53	4.83	2.05	5.00	1.80
CaO	1.30	1.39	1.25	7.87	4.18	3.85	9.15	9.29	5.96	8.42	5.41
Na_2O	3.47	3.87	3.73	3.03	4.09	4.08	2.22	3.06	3.52	3.04	3.72
K_2O	4.73	4.32	4.77	1.75	2.39	2.67	0.65	1.19	1.74	1.26	2.30
TiO_2	0.039	0.089	0.036	0.775	0.764	0.684	0.994	0.787	0.851	0.811	0.809
P_2O_5	0.021	0.044	0.021	0.177	0.296	0.281	0.322	0.166	0.284	0.171	0.326
MnO	0.068	0.048	0.080	0.139	0.040	0.080	0.155	0.141	0.102	0.149	0.108

Sample no.	111	112	118A	118B	124A	126	128	129B	134	137	139
Map unit	Tbad	Tbad	Tdc	Tdc	Twt	Tdi	Tbad	Toig	Toig	Trf_1	Tbad
Rock name	dacite	basaltic andesite	rhyolite	high-silica rhyolite	rhyolite	dacite	andesite	rhyolite	rhyolite	rhyolite	basaltic andesite
SiO_2	71.00	55.90	78.70	81.05	70.70	68.07	62.65	70.64	72.48	76.19	55.83
Al_2O_3	14.60	16.57	11.25	10.23	15.20	15.53	16.08	15.30	14.63	13.47	16.99
FeO	3.31	8.81	1.64	1.28	3.39	4.44	6.52	3.24	2.48	3.84	9.37
MgO	0.46	4.89	0.00	0.00	0.41	0.69	2.18	0.51	0.46	0.63	4.34
CaO	2.98	8.35	0.31	0.29	2.42	3.55	5.51	2.80	2.45	3.68	7.93
Na_2O	4.04	3.10	4.44	3.94	3.68	3.95	3.77	3.79	3.82	4.03	3.21
K_2O	2.91	1.24	3.45	3.03	3.27	2.76	2.09	2.95	3.21	2.78	1.09
TiO_2	0.471	0.820	0.152	0.141	0.509	0.663	0.810	0.470	0.309	0.584	0.882
P_2O_5	0.166	0.170	0.032	0.024	0.357	0.265	0.285	0.234	0.101	0.217	0.203
MnO	0.061	0.156	0.023	0.018	0.064	0.079	0.096	0.068	0.062	0.053	0.160

Table 3. Major- and trace-element analyses of unaltered rock samples. Concentrations of Al, Ca, Fe, K, Mg, Na, P, and Ti are in weight-percent; concentrations of other elements are in parts per million (ppm). Samples 726 to 732 were analyzed by inductively coupled plasma atomic emission spectrometry by the U.S. Geological Survey. Samples 20 to 139 were analyzed for 17 trace-elements by X-ray fluorescence at the WSU GeoAnalytical Laboratory.

Sample no.	726	727	728	729	730	731	732
Map unit Element	Tyig	Trf_2	Tdf	Tri	Tbad	Tbad	Tdc
Al	7.3	7.5	8.2	7.8	10.0	8.5	6.1
Ca	0.88	1.3	3.2	2.1	7.8	4.5	0.39
Fe	0.74	1.8	4.0	2.0	4.1	6.0	2.5
K	3.7	2.9	2.0	2.6	0.86	1.5	2.9
Mg	0.05	0.14	0.54	0.23	2.3	1.6	0.08
Na	2.7	2.6	2.7	2.9	2.2	2.5	2.9
P	0.01	0.03	0.16	0.07	0.08	0.12	0.03
Ti	0.03	0.12	0.49	0.26	0.55	0.54	0.13
Ba	2,300	2,100	1,800	2,100	680	1,300	1,400
Be	2	1	1	1	<1	<1	2
Ce	31	73	73	87	24	51	99
Co	<1	3	13	4	26	30	1
Cr	3	2	2	1	49	4	3
Cu	7	18	40	14	150	66	5
Ga	16	16	18	17	20	19	20
La	19	76	45	52	16	34	56
Li	23	6	5	13	8	12	13
Mn	590	360	470	260	890	1,000	150
Nb	9	5	7	7	<4	5	18
Nd	14	53	36	36	19	31	55
Ni	<2	4	5	3	47	25	3
Pb	23	19	11	16	<4	6	14
Sc	3	5	15	7	40	40	4
Sr	150	230	330	300	260	260	43
Th	4	6	5	8	<4	<4	7
V	<2	14	110	28	260	260	19
Y	23	22	27	21	26	26	87
Yb	2	2	3	3	3	3	9
Zn	37	56	68	56	79	75	150

Table 3. (continued)

Sample no.	20	22	32	45	59	85	92C	97	101	104	105
Map unit	Tyig	Trf_2	Tyig	Tbas	Tbad	Tdi	Toig	Tbad	Tbad	Tbad	Tbad
Element											
Ni	9	10	8	70	6	5	200	58	16	64	8
Cr	2	3	2	28	0	1	322	26	7	19	6
Sc	1	3	11	28	17	13	27	38	22	29	18
V	0	13	0	195	82	70	214	196	171	216	141
Ba	2,330	2,534	2,320	1,528	1,953	2,049	240	795	1,453	879	1,616
Rb	78	74	79	25	33	44	11	17	28	19	36
Sr	150	174	146	297	319	312	235	242	293	239	307
Zr	67	95	65	93	183	190	77	92	136	96	151
Y	22	21	23	29	40	30	26	24	24	26	28
Nb	12.0	12.2	12.3	5.9	8.9	9.4	4.8	5.0	7.3	5.3	8.2
Ga	14	15	16	17	17	17	14	18	18	17	20
Cu	11	13	5	99	20	35	108	115	17	131	46
Zn	38	36	35	70	80	72	82	76	74	76	76
Pb	17	19	16	4	9	7	2	2	7	6	8
La	14	28	11	21	60	51	1	22	22	29	31
Ce	0	30	13	32	73	56	27	29	40	27	37
Th	4	6	5	2	5	4	3	1	3	3	2

Sample no.	111	112	118A	118B	124A	126	128	129B	134	137	139
Map unit	Tbad	Tbad	Tdc	Tdc	Twt	Tdi	Tbad	Toig	Toig	Toig	Tbad
Element											
Ni	8	61	12	13	2	4	14	12	6	9	47
Cr	3	15	3	0	2	2	7	1	0	5	11
Sc	7	33	5	5	7	14	21	8	8	11	32
V	36	212	12	4	38	54	158	43	22	78	104
Ba	2,088	819	1,349	1,247	2,138	2,085	1,456	2,068	2,021	2,027	1,153
Rb	51	19	71	61	54	46	34	51	58	51	7
Sr	273	236	28	31	244	288	298	268	268	294	263
Zr	187	96	362	323	181	195	145	180	193	177	110
Y	22	24	79	74	20	33	25	25	21	22	26
Nb	9.2	5.8	24.7	22.6	10.9	10.1	7.9	8.9	10.6	9.1	6.2
Ga	14	16	22	16	14	16	18	16	14	18	16
Cu	29	129	5	1	23	22	42	29	9	34	131
Zn	60	75	122	97	60	70	72	56	45	55	86
Pb	8	4	11	10	12	8	6	14	10	9	5
La	34	12	52	44	34	59	29	42	40	45	20
Ce	63	35	104	78	39	57	37	64	76	56	40
Th	8	0	5	5	6	4	3	5	10	6	2

Table 4. Descriptions and locations of altered rock samples

Sample no.	Description	Location
627	Quartz vein, float in area of unit Th	N 1/2 sec. 30, T.19 S., R. 39 E.
628	Yellow-brown jasper, float in unit Th	NW 1/4 sec. 18, T. 19 S., R. 39. E
629	Rhyolitic glass breccia with cinnabarnear base of unit Tyig	SE 1/4 sec. 7, T. 19 S., R. 39 E.
630	Hematitic siltstone	SE 1/4 sec. 32, R.18 S., R. 39 E.
631	Yellow-brown limonite replacement of unit Tbad	SE 1/4 sec. 32, R. 18 S., R. 39 E.
632	Brown and yellow-green jasper in Tdc	SE 1/4 sec. 28, T. 19 S., R. 39 E.
633	Brown jasper nodule in unit Tdc	Line between secs. 26 + 27, T. 19 S., R. 39 E.
634	Brown jasper in unit Tdc	SE 1/4, sec. 38, R. 19 S., R. 39 E.
635	Yellow-brown laminated jasper from base of unit Tbad	NW 1/4 sec. 19, R. 18 S., R. 39 E.
636	Hematitic siltstone, unit Tst	SW 1/4 sec. 21, T. 18 S., R. 39 E.
637	Weathered and oxidized welded tuff, unit Tdc	Near center. sec. 9, T. 19 S., R. 39 E.

Table 5. Major- and trace-element analyses of altered rock samples. Concentrations of Al, Ca, Fe, K, Mg, Na, P, and Ti are given in weight percent. Concentrations of the other elements are in ppm. "N" followed by a number means that mercury (Hg) was not found at the 0.02 ppm, the lower confidence limit. "<" followed by a number means that the element was detected but in concentrations less than the minimum confidence level indicated

Sample no.	627	628	629	630	631	632	633	634	635	636	637
Element											
Al	0.38	0.40	7.1	13	8.5	0.43	0.25	3.9	0.17	7.2	7.9
Ca	0.06	0.17	0.87	0.45	3.8	0.11	0.6	0.19	0.09	1.2	1.2
Fe	0.92	2.0	0.72	8.1	7.5	2.9	1.3	2.7	1.7	10	4.0
K	0.06	0.04	3.5	0.42	0.99	0.15	0.02	1.8	0.03	0.87	1.6
Mg	0.04	0.10	0.24	0.29	1.4	0.05	0.04	0.09	0.05	0.37	0.43
Na	0.03	0.01	2.1	0.28	1.7	0.17	0.008	1.9	0.01	0.82	1.7
P	0.01	<0.005	0.02	0.12	0.07	0.01	0.008	0.009	<0.005	0.09	0.04
Ti	0.04	0.02	0.03	1.0	0.56	0.01	0.02	0.07	0.01	0.54	0.43
As	<10	<10	<10	10	32	23	<10	<10	<10	120	<10
Ba	44	18	2,100	800	1,100	300	69	1,300	160	680	870
Be	<1	1	3	3	1	1	<1	2	<1	4	3
Ce	4	<4	2	110	29	7	<4	27	<4	39	95
Co	3	<1	2	33	21	<1	<1	2	10	22	10
Cr	2	<1	<1	43	130	4	2	2	5	28	10
Cu	3	2	19	5	83	6	2	9	15	45	25
Ga	<4	<4	15	33	20	<4	<4	15	<4	18	25
Hg	N0.02	N0.02	0.02	0.06	0.03	N0.02	N0.02	0.02	N0.02	0.03	0.02
La	5	<2	17	52	17	3	<2	15	<2	26	55
Li	<2	<2	32	28	7	<2	<2	13	<2	26	36
Mn	140	24	610	960	670	50	34	200	36	210	730
Mo	<2	<2	<2	<2	3	<2	<2	2	<2	4	<2
Nb	<4	<4	10	23	7	<4	<4	12	<4	12	18
Nd	<4	<4	13	44	12	<4	<4	13	<4	27	56
Ni	<2	<2	<2	27	51	<2	<2	<2	65	34	9
Pb	<4	<4	22	23	6	<4	<4	14	<4	8	44
Sc	<2	7	3	25	26	<2	<2	3	<2	18	13
Sn	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	7
Sr	6	14	150	68	260	13	6	31	9	160	130
Th	<4	<4	5	11	<4	<4	<4	<4	<4	<4	8
V	33	120	2	170	190	140	65	80	16	290	78
Y	<2	<2	22	41	15	3	<2	15	<2	49	90
Yb	<1	<1	2	4	2	<1	<1	2	<1	7	11
Zn	8	<2	37	130	67	55	17	120	21	130	170