Mercury and uranium mineralization in the Clarno and John Day Formations, Bear Creek Butte area, Crook County, Oregon

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INTRODUCTION

Occurrences of the precious metals mercury and uranium have been reported from the Eocene to Oligocene Clarno Formation in the Ochoco and Blue Mountains; however, the metallogeny of this complex sequence of volcanic and volcaniclastic rocks is largely unknown. Prior to this study, the geology of the precious-metal mining districts was described by Brooks and Ramp (1968), mercury occurrences were described by Brooks (1963), and uranium occurrences were reported by Schafer (1956) for rocks of the Clarno Formation and the lower portion of the John Day Formation.

Hydrothermally altered rocks of the Clarno and John Day Formations are exposed in the Bear Creek Butte area, southwestern Crook County, Oregon (Figure 1). Prospecting for mercury began in this area during the late 1920's, and recorded production from the Platner and Oronogo Mines was 30 flasks. Brooks (1963), however, estimated production of about 45 flasks from the main producing mine, the Platner Mine. Schafer (1956) reported uranium exploration was primarily during the summer of 1955.

Mercury is one of the recognized pathfinder elements in exploration for gold in epithermal deposits. This association and the development of the McLaughlin Mine, one of the largest U.S. gold mines, at the site of the Manhattan mercury mine in northern California (Mining Engineering, 1986; Burnett, 1986) has resulted in evaluation of the precious-metal potential of mercury properties within Oregon. Several features associated with volcanic-hosted epithermal precious-metal deposits are present at Bear Creek Butte and indicate similarities to models developed by Buchanan (1981), Fournier (1983), and Berger and Eimon (1983) and as summarized by Tooker (1985).

STRATIGRAPHY OF THE BEAR CREEK BUTTE AREA

The rocks at Bear Creek Butte were assigned to the Eocene to lower Oligocene Clarno Formation by Lowry (1940). Wilkening (1986) recognized two sequences of rocks separated by an erosional unconformity, as indicated on the geologic map (Figure 2) and in the composite stratigraphic column in Figures 2 and 3.

Lower sequence of the Clarno Formation

The lower of these two sequences (Figure 2) is composed of basaltic andesite lava flows and intercalated mudflows and volcaniclastic sediments. Based on flow banding, topography, and the thickness and dip direction of lava flows, a volcanic center is inferred to underlie the northeast quarter of the area shown in Figure 2, where the flow section is at least 200 m thick.

Phyric flows are more abundant than weakly phyric flows. Clinopyroxene and plagioclase phenocrysts comprise 15 to 25 percent of the phyric flows and occur in a felty groundmass of plagioclase laths. The less phyric flows form cliffs and ledges and contain up to 10 percent of 2-mm-long plagioclase phenocrysts in a plagioclase-rich felty groundmass. Chemical compositions of these flows are presented in Table 1.

The mudflows contain carbonized wood fragments and subangular to subrounded cobbles to boulders of andesite in a matrix of sand and mud. The channel walls and irregular floors are exposed for some flows. The volcaniclastic sediments exhibit crude to well-developed bedding and cross-bedding and contain sparse leaf fossils that have been described by Mote (1940). Clasts include andesite lithic fragments, plagioclase crystals, and sparse quartz grains.

The lower sequence was eroded and deeply weathered to a dark-red, clay-rich zone prior to eruption of the upper sequence. This zone is thickest (up to 3 m) and best exposed in the south-central part of the area shown in Figure 2.

Upper sequence of the Clarno Formation

The upper sequence is a bimodal volcanic suite that includes basalt flows and the rhyolite flows that form two prominent buttes, Bear Creek and Taylor Buttes (Figure 2). The rhyolite flows display well-developed flow layering and contain up to 10 percent euhedral to subhedral plagioclase phenocrysts. Irregularly shaped, sparse
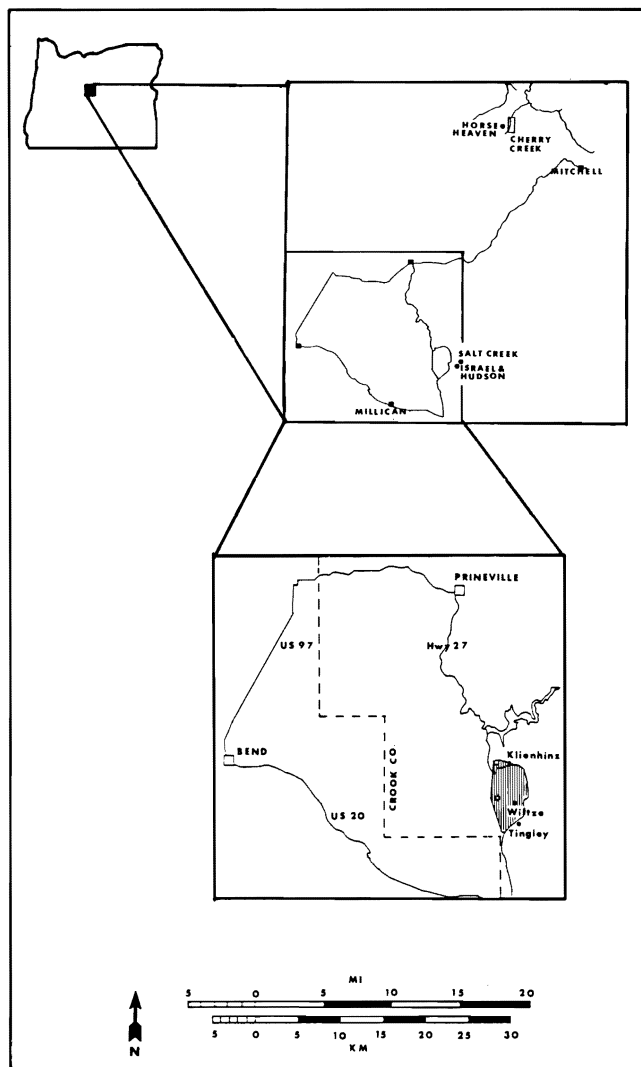

Figure 1. Location map for the Bear Creek Butte area in southwestern Crook County, Oregon.
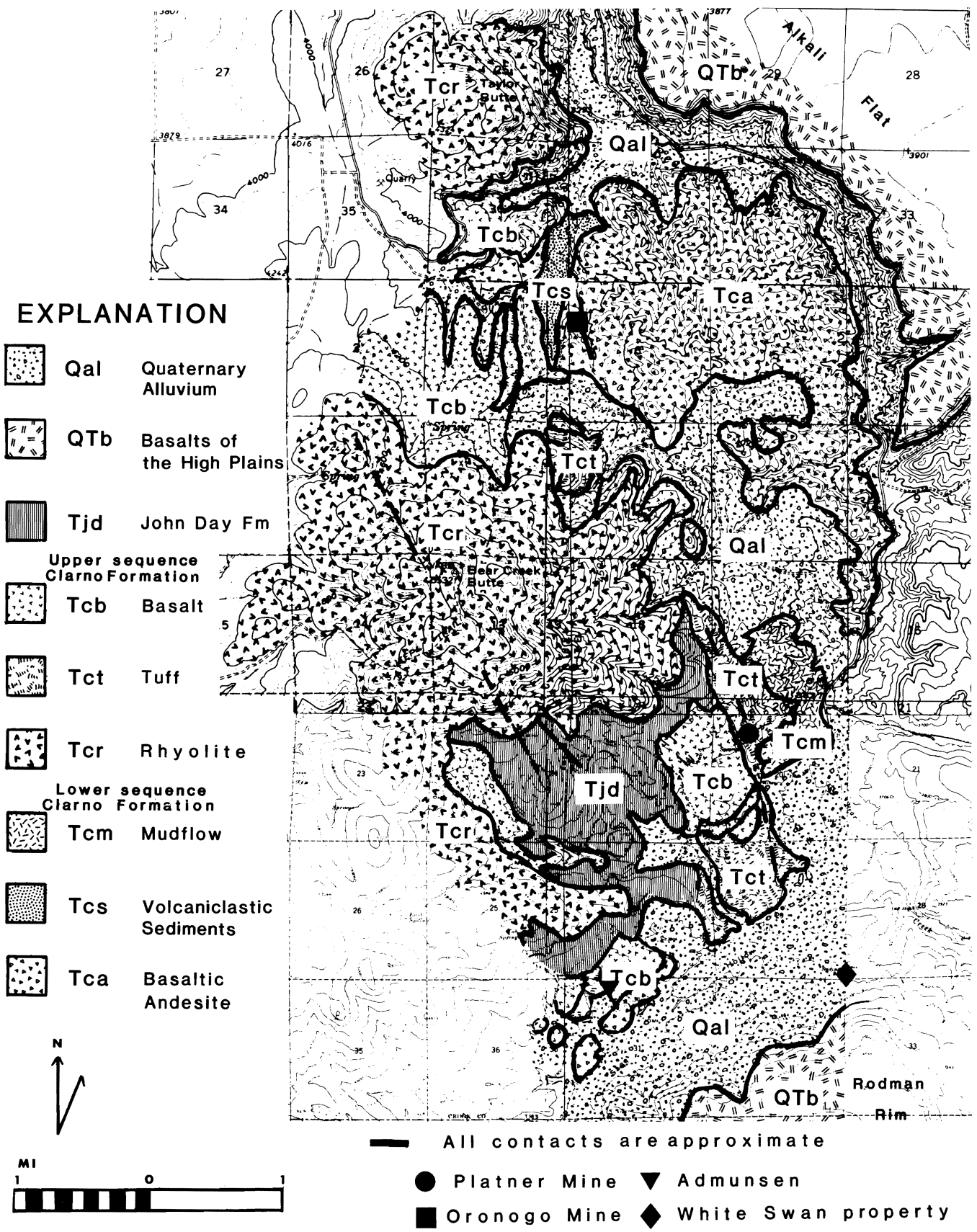
EXPLANATION

Qal — Quaternary Alluvium

QTb — Basalts of the High Plains

Tjd — John Day Fm

Upper sequence Clarno Formation

Tcb — Basalt

Tct — Tuff

Tcr — Rhyolite

Lower sequence Clarno Formation

Tcm — Mudflow

Tcs — Volcaniclastic Sediments

Tca — Basaltic Andesite

N

MI
1   0   1

All contacts are approximate

● Platner Mine   ▼ Admunsen

■ Oronogo Mine   ◆ White Swan property

Figure 2. Generalized geologic map of the Bear Creek Butte area.

Table 1. Major-element geochemistry of basaltic andesites from the lower sequence of the Clarno Formation.

Major element oxide (Wt %)	Sample number 133	160	170	263	425	588	717	540
SiO_2	50.16	58.11	55.61	56.24	57.71	61.49	62.61	66.94
Al_2O_3	16.39	18.39	18.37	18.93	18.38	17.60	17.94	16.04
TiO_2	0.98	1.05	0.98	1.15	1.03	1.01	1.30	0.95
Fe_2O_3	4.43	3.06	3.66	3.72	3.43	2.89	2.73	2.85
FeO	5.08	3.51	4.19	4.26	3.93	3.31	3.12	3.26
MgO	9.13	2.96	5.35	2.30	3.02	2.44	0.28	0.42
MnO	0.17	0.09	0.16	0.12	0.09	0.10	0.06	0.23
CaO	10.59	7.56	8.39	9.11	7.21	5.69	6.79	4.48
K_2O	0.44	1.23	0.30	0.27	1.03	1.25	1.50	1.17
Na_2O	2.41	3.75	2.82	3.61	3.89	3.98	3.36	3.40
P_2O_5	0.21	0.27	0.18	0.30	0.29	0.26	0.31	0.27
Total	99.99	99.98	100.01	100.01	100.01	100.02	100.00	100.01

Sample locations: BCB-133 - SE, SE, NW, S. 7, T. 18 S., R. 17 E.: BCB-160 - NW, SE, SW, S. 8, T. 18 S., R. 17 E.: BCB-170 - SW, SW, SW, S. 31, T. 17 S., R. 17 E.: BCB-263 - NE, SE, NE, S. 6, T. 18 S., R. 17 E.: BCB-425 - SW, NW, NW, S. 9, T. 18 S., R. 17 E.: BCB-588 - SW, SW, SW, S. 36, T. 17 S., R. 16 E.: BCB-717 - SW, SE, NE, S. 20, T. 18 S., R. 17 E.: BCB-540 - SE, NE, SW, S. 36, T. 17 S., R. 16 E.

Major element concentrations determined by X-ray fluorescence at Washington State University, Department of Geology, Dr. Peter Hooper. Trace element and rare earth element concentrations determined by instrumental neutron activation are available upon request.

Table 2. Major-element geochemistry for samples from the upper sequence of the Clarno Formation.

Major element oxide (Wt %)	Sample number 45	63	112	143	385	84	325	655	195
SiO_2	75.38	72.70	75.25	80.19	76.61	49.94	48.78	49.09	56.41
Al_2O_3	13.46	13.77	14.01	10.54	13.54	16.10	17.05	20.73	18.03
TiO_2	0.29	0.31	0.24	0.23	0.25	2.42	2.62	1.88	1.04
Fe_2O_3	1.16	1.40	0.87	0.80	0.58	5.81	6.06	4.78	3.48
FeO	1.33	1.61	1.00	0.92	0.66	6.66	6.94	5.47	3.99
MgO	0.16	0.29	0.05	0.01	0.14	5.73	4.43	3.93	4.16
MnO	0.02	0.07	0.01	0.05	N.D.	0.16	0.24	0.16	0.14
CaO	0.72	1.03	0.16	0.19	0.28	8.94	8.87	9.60	6.72
K_2O	3.82	6.30	3.93	3.97	4.12	0.71	0.94	0.57	1.89
Na_2O	3.60	2.46	4.36	3.01	3.79	3.13	3.65	3.47	3.60
P_2O_5	0.06	0.06	0.12	0.08	0.03	0.40	0.41	0.31	0.53
Total	100.00	100.00	100.00	99.99	100.00	100.00	99.99	99.99	99.99

Sample locations: BCB-45 - NW, NW, SE, S. 13, T. 18 S., R. 16 E.: BCB-63 - SW, SE, SE, S. 13, T. 18 S., R. 16 E.: BCB-112 - SW, NE, NW, S. 25, T. 17 S., R. 16 E.: BCB-143 - NE, SE, SE, S. 12, T. 18 S., R. 16 E.: BCB-385 - NE, NW, SE, S. 25, T. 18 S., R 16 E.: BCB-84 - NW, SW, SE, S. 36, T. 17 S., R. 16 E.: BCB-325 - NW, NW, NE, S. 30, T. 18 S., R. 17 E.: BCB-655 - NW, NW, SW, S. 20, T. 18 S., R. 17 E.: BCB-195 - SW, NE, NE, S. 31, T. 18 S, R. 17 E.

Major element oxides determined by X-ray fluorescence at Washington State University, Department of Geology. Trace element concentrations determined by instrumental neutron activation are available upon request.

vesicles are encrusted with iron oxides and are locally filled with quartz. Basalt flows and rhyolite tuffs are exposed on the lower flanks of the buttes. The basalt flows form iron-stained, low, fractured, knobby outcrops. Some low-volume flows contain plagioclase and traces of olivine in glomerocrysts within a felty groundmass of very fine-grained plagioclase laths and interstitial pyroxene. Other basalts, contain laths of plagioclase and up to 10 percent opaques, clinopyroxene, and intersitial olivine.

Two felsic tuffs, a welded tuff and a lithic tuff, cap ridges near Taylor and Bear Creek Buttes. The welded tuff is glassy and vesicular and contains sparse lithic clasts. Glass shards and small pumice clasts in a devitrified matrix are noted in thin sections. The lithic tuff is rich in lithic fragments and pumice clasts. Round lithic clasts of rhyolite that are similar to the rhyolite of Bear Creek Butte occur in the tuff. Table 2 contains geochemical analyses of the flows of the upper sequence of the Clarno Formation.

Along the lower slopes of Rodman Rim are outcroppings of vesicular, plagioclase-phyric, pyroxene-bearing andesite with red scoriaceous flow tops. These rocks underlie the basalts exposed in Rodman Rim and are believed to overlie the rhyolite of the upper sequence of the Clarno Formation. The composition of this unit is contained in the last column in Table 2. The rocks are similar to those described by Waters and others (1951) that overlie the rhyolites of their upper sequence of the Clarno Formation in the Horse Heaven mining area.

John Day Formation

An outlier of the Oligocene John Day Formation crops out southeast of Bear Creek Butte (Figure 2). The John Day Formation rests with angular discordance on the upper sequence and the dark red paleosol that mantles the andesites of the lower sequence. The John Day Formation here consists of three members. The lowest is a 10-m-thick, dark-reddish tuffaceous claystone and siltstone. The middle member is a pale-green tuffaceous claystone and siltstone. The tuffaceous sediments are capped by a welded ash-flow unit that is 3 to 6 m thick.

Basalts of the High Lava Plains

The cliffs and ledges of Rodman Rim (Figure 2) are formed by outcrops of vesicular basalts that underlie this part of the High Lava Plains. Alkali Flat (Figure 2) is formed by younger basalt flows that were erupted from a cinder cone located 8 km to the east. These basalts occupy a valley cut through the basalts that crop out along Rodman Rim.

HYDROTHERMAL ALTERATION

Three types of hydrothermal alteration have been defined, based on time of formation, alteration assemblage, and trace-element geochemistry. These types include (1) fumarolic alteration, (2) alteration associated with mercury prospects, and (3) alteration associated with uranium prospects. Zones of isolated, bleached, and vuggy fumarolic alteration are found on the slopes of rhyolite domes that form Taylor and Bear Creek Buttes and will not be discussed further.

Alteration of mercury prospects

Hydrothermal alteration associated with mercury prospects is located along northwest- and north-northwest-trending fault zones. The Oronogo and Platner Mines and the Admunsen Claims (Figure 2) are located in the areas of greatest hydrothermal alteration. Brooks (1963) described the geology of the Salt Creek, Hudson, and Israel Prospects located east of the study area, and their general characteristics are summarized in Table 3.

The hydrothermal alteration at mercury prospects in the Bear Creek Butte area has been divided by Wilkening (1986) into zones of strong, moderate, and weak alteration, based on the hydrothermal alteration mineralogy and preservation of primary rock textures.

The zones of strong alteration are centered around faults and form crude ellipses that are elongated along strike of the faults. Silicification in these zones varies in width from 3 m at the Oronogo Mine to more than 10 m at the Platner Mine. Abundant narrow quartz veinlets and silica flooding characterize the zone. Cinnabar occurs in the fine quartz veinlets that cut the silicified rocks. Fine-grained quartz has replaced all primary minerals, but iron oxides outline the primary mineral textures.

Hydrothermal breccias are restricted to the zones of strong alteration. These breccias consist of subangular to subrounded rock fragments ranging up to 0.25 m in diameter. The breccias have been sealed by very fine-grained quartz, and fragments display evidence of multiple episodes of brecciation. The breccias occur at the Platner Mine and Admunsen Claim along fault zones and are spatially associated with mafic intrusions.

The Platner Mine (Figure 4) is centered in the largest area of hydrothermal alteration. A lithic-rich tuff and glomeroporphyritic basalt flow of the upper sequence and a mafic intrusion comprise the lithologies affected by hydrothermal alteration. The zone of strong hydrothermal alteration is centered along faults trending N. 0° -15° W. and dipping 75° -85° to the west. Offset is not pronounced along these faults, but slickensides with variable but gentle plunge indicate late strike-slip motion. In the zone of silica flooding, the felsic tuff and mafic intrusion are replaced by fine-grained quartz and iron oxide. These materials have been brecciated and occur as fragments within a hydrothermal breccia. The breccia fragments also include previously brecciated tuff fragments. Younger cinnabar-bearing quartz veins cut the breccia. Similar patterns of alteration occur at the Admunsen Claim.

At the Oronogo Mine, the zone of strong alteration is restricted to narrow, <3-m-wide, elongate zones paralleling the strike of faults that cut lower sequence porphyritic andesite flows. Hydrothermal breccias and mafic intrusions are absent. Quartz veins vary from cockscomb growth along the vein walls to subhedral quartz grains that completely fill the veins. These veins rarely exceed 2 cm in width and host cinnabar mineralization.

The transition away from the silicified zone to the zone of moderate hydrothermal alteration is gradational as the ratio of clay to quartz increases. Moderate alteration is characterized by argillic alteration. Kaolinite is the most common clay; montmorillonite is associated with kaolinite at the Admunsen Claim. Clay minerals
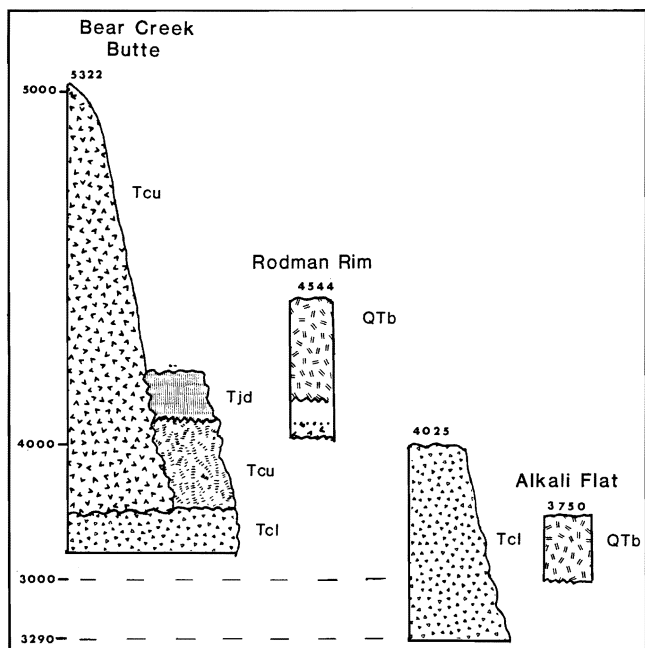
Figure 3. Generalized stratigraphic columns for various sections within the Bear Creek Butte area. Columns are indicated by elevation. Tcu=upper sequence of the Clarno Formation; Tcl=lower sequence of the Clarno Formation; other symbols same as in Figure 2.

replace much of the host rocks, leaving relic primary textures. At the Platner and Oronogo Mines, argillic alteration is more widespread in the hanging wall than in the footwall of controlling faults. Quartz veinlets are common, and, at the Platner Mine and Admunsen Claim, calcite forms stringers. Fine-grained limonite and hematite occur with clays and as fracture coatings.

The zone of weak alteration forms an irregular halo around the periphery of the zone of moderate alteration. The alteration is propylitic and contains chlorite, pyrite, carbonate, and clay minerals partially to totally replacing primary silicate minerals. In tuffs, pumice clasts and matrix are altered in patches, whereas less permeable lithic fragments are unaffected by alteration. Iron oxide coats fracture surfaces and, in thin sections, forms irregular masses and blebs. Locally the iron oxide pseudomorphs replace pyrite. Calcite is the most common carbonate, locally replacing the groundmass of the host rocks and occurring as fine stringers in felsic tuffs near the Admunsen Claim. Clay minerals cloud the groundmass and rim plagioclase phenocrysts in basaltic andesites at the Oronogo Mine.

Geochemical analysis of the alteration zones was performed using instrumental neutron activation analysis (INAA); selected data are included in Table 4. Bulk samples were collected along the strike

of the fault zone to the north and south of the Platner Mine. In the area of the mine, grab samples were collected along three traverses run perpendicular to the fault trend. Arsenic and antimony concentrations decrease toward the south, away from the mine, and antimony concentrations gradually decrease away from the mine to the north. Mercury is irregularly distributed along the controlling structure and attains highest concentrations south of the Platner Mine.

The concentrations of arsenic, antimony, and mercury are lower at the Admunsen Claim. At the Oronogo Mine, concentrations of arsenic and antimony are low, whereas mercury concentrations are the highest encountered in this study.

Alteration of uranium prospects

The hydrothermal alteration zones associated with uranium prospects occur along northwest-trending ridges south of Bear Creek Butte and are controlled by northwest-trending faults. The host rocks are tuffs of the John Day Formation and rhyolites of the upper sequence of the Clarno Formation. The alteration zones are similar to those encountered at mercury prospects.

Geochemistry of the prospects indicates anomalous uranium concentrations six to ten times over background, with a high concentration of 59 ppm recorded in one sample. Arsenic and molybdenum concentrations are anomalous, but concentrations of antimony are generally very low (Table 5).

J. Gray of the Oregon Department of Geology and Mineral Industries sampled the area that bounds the study to the east. In one prospect, the White Swan property (Allen, 1939; Table 3), two samples of jasperoid float and a dump sample were collected. The data for these samples are contained in Table 6. The White Swan property lies along the extension of the northwest-trending uranium-bearing fault within the study area. The samples are relatively enriched in base metals but are also anomalous in uranium, molybdenum, and arsenic. Antimony is of low concentration. Data for other sites sampled by Gray are also presented in Table 6.

DISCUSSION
Stratigraphic relations

The stratigraphy of the Clarno Formation in the Bear Creek Butte area is similar to that described by other workers (Waters and others, 1951; Oles and Enlows, 1971; Noblett, 1981) in other areas of central Oregon.

Oles and Enlows (1971) described the stratigraphy of the Clarno Formation near Mitchell (Figure 1) in central Oregon and recognized two dissimilar sequences of rocks separated by an angular unconformity. The lower Clarno, composed of volcanic breccias, andesite flows, and varicolored tuffaceous sediments, is separated from the upper Clarno by a thick saprolite. The upper Clarno includes andesite lava flows and mudflows that were deposited upon a deeply eroded surface and, in places, occur as intracanyon deposits. One of the youngest units within the upper Clarno is a rhyolite-welded ash-flow tuff that locally caps ridges in the Mitchell area. These younger units appear to be unaffected by the deformation that in-

Table 3. Description of prospects from east of the study area.

Prospect name	Location	Structure	Lithology	Alteration	Reference
White Swan	S½ sec. 28, T. 18 S. R. 17 E.	NE - SW	White tuff	Veinlets of crystalline gypsum, last 8 ft of 47-ft shaft in pyritized Blue clay	Allen, 1939, unpublished DOGAMI report
Salt Creek	sec.3 T.18 S. R. 17 E.	N.10°E. dike cut by N.50°W. fractures	Andesite cut by andesite dike	silicification	Brooks, 1963
Hudson	E½NE¼ sec.9, W½ sec. 10, T. 18 S., R.17 E.	N.10°E., dips 75°E	Andesite flow over lithic tuff	Silicification, carbonate veinlets	Brooks, 1963
Israel	NE¼ sec. 9 T.18 S., R.17 E.	NW faults N fault	Andesite	Clays, limonite, mild silicification and carbonatization	Brooks, 1963

fluenced the Cretaceous section and the lower Clarno Formation.

Noblett (1981) indicated that the upper portion of the Clarno Formation is volumetrically small and that a thick saprolite and angular unconformity separate it from the lower Clarno in the area of Cherry Creek (Figure 1). In that area, the upper Clarno Formation is composed of andesite flows and tuffs.

In the Horse Heaven mining district, Waters and others (1951) indicated a thick sequence of Clarno rocks that they divided into four units: andesite, tuffs and volcanic mudflows, tuffs, and rhyolitic tuff. A thick saprolite is developed on these units and separates them from a more nearly flat-lying sequence of lavas that unconformably overlie the four units. The upper sequence includes a "basaltic andesite" that is distinct from those andesites below the unconformity. These "basaltic andesites" contain numerous altered ferromagnesian phenocrysts, lack plagioclase phenocrysts, and were partially eroded before eruption of rhyolite flows, ash-flow tuffs, and tuffs. These deposits are locally buried beneath a younger set of unaltered, vesicular "augite andesites." These rocks contain plagioclase and augite phenocrysts and sparse xenocrysts of quartz. Swanson and Robinson (1968) assigned the "basaltic andesites," rhyolites, and "augite andesites" to the upper Clarno Formation. This was based on a radiometric age determination of 41.0 ± 1.2 m.y. for a porphyritic rhyolite flow at the Horse Heaven Mine.

The thickness of the Clarno Formation in the Bear Creek Butte area is not known, since the base is not exposed. The basaltic andesites, mudflows, and volcaniclastic sediments of the lower sequence are similar to those described by Waters and others (1951), Oles and Enlows (1971), and Noblett (1981) within the lower portion

Table 4. Selected geochemical data for mercury prospects in the Clarno Formation.

(1)	(2)	(3)	(4)

Oronogo mine area

Hg	6/9	0.1- 4.4	1.0 ppm
As	3/9	1.5- 3.9	2.3 ppm
Sb	8/9	6.7- 22.0	14.9 ppm

Admunsen claim

Hg	5/9	0.1- 2.4	0.6 ppm
As	8/9	1.0- 43.1	11.6 ppm
Sb	8/9	1.0- 56.0	29.4 ppm

Platner mine area

Hg	14/40	0.1- 1.0	0.3 ppm
As	33/40	1.1- 50.0	11.4 ppm
Sb	31/40	0.8-102.0	37.0 ppm

(1) Element of interest.
(2) Number of samples with element above background / total number of samples analyzed.
(3) Range of concentrations above background: background determined from fresh rocks from the altered unit.
(4) Average concentration of samples above background. Concentrations determined by instrumental neutron activation analysis. N.D.= not detected. Hg concentrations are normalized against an internal standard. As and Sb concentrations are given in ppm.

of the Clarno Formation. Although a thick weathered zone or saprolite is present, an angular unconformity between the lower sequence and the rocks included in the upper sequence at Bear Creek Butte does not appear to be present.

The lower sequence of the Clarno Formation ranges in chemical composition from basalt to dacite, with basaltic andesite the most abundant rock type. These rocks belong to the high-alumina calc-alkaline intermediate rock series, and data from this study are in general agreement with those obtained by Oles and Enlows (1971), Novitsky-Evans (1974), Huggins (1977), Owen (1977), and Rogers and Novitsky-Evans (1977a,b) for the lower Clarno Formation in the Mitchell area.

The rocks included in the upper sequence are a bimodal volcanic suite of subalkaline rhyolite and low-potassium, high-titanium basalt. Petrographically, this association is similar to the "basaltic andesite-rhyolite" suite described by Waters and others (1951) in the Horse Heaven mining area; however, at Bear Creek Butte, the basalts not only underlie but are interlayered with the felsic pyroclastic rocks erupted from Taylor and Bear Creek Buttes.

The augite andesites described by Waters and others (1951) may be similar to the unaltered, vesicular andesite sample BCB-195 (Table 2). However, in the Bear Creek Butte area, this andesite directly overlies the andesites of the lower sequence rather than the rhyolite-basalt suite of the upper sequence. The phenocryst content, lack of alteration, vesicular nature, and red scoriaceous flow-top rubble are similar in the rocks from the two areas.

The distance between the Bear Creek Butte area and those areas of the Clarno Formation that have been previously studied precludes correlations because of the laterally discontinuous nature of volcanic deposits. It may be stated that, at Bear Creek Butte, (1) the lower sequence is composed of lavas of basalt, andesite, and dacite composition; (2) deformation of the lower sequence prior to eruption of the upper sequence is not noted; (3) a thick weathered zone separates the upper and lower sequences and is believed to mark the same stratigraphic level as the one noted in the Mitchell-Horse Heaven mining areas; and (4) the upper sequence is composed of rhyolite and basalt flows and rhyolite tuffs.

Hydrothermal alteration

Mercury prospects: Temperature, pressure, rock type, permeability, fluid composition, and duration of activity are recognized as playing important roles in development of epithermal mineral deposits. The composition and temperature of hydrothermal solutions responsible for mineralization at Bear Creek Butte were not directly determined in this study. Based on the work of Roedder (1967), White and others (1971), Taylor (1974), Rose and Burt (1979), and Mariner and others (1983), it is believed that the mercury mineralization at Bear Creek Butte originated from hydrothermal fluids that were dilute alkali-chloride solutions of meteoric waters within a temperature range of 150°-300 °C.

Boiling of hydrothermal solutions is associated with several important processes including changes in pressure and temperature, hydrothermal brecciation, fractionation of volatile components into the vapor phase, and increasing salinity of the fluid phase. Self-sealing and local separation of carbon dioxide from the fluid lead to pressures greater than rock strength. This leads to rupture, boiling of solutions, and, under the correct conditions, hydrothermal brecciation. Repeated cycles in the same area concentrate metals and, given adequate time, result in the eventual formation of an ore deposit. Fluctuations in the level and thickness of the zone of boiling influence the volume of the mineralized zone and thus the tonnage of the deposit.

Blakestad and Stanley (1986) argued that only prograding geothermal systems possess the geochemical attributes capable of forming near-surface economic mineralization. Prograding systems are those with steep geothermal gradients associated with the rise of intrusions to shallow levels in the crust. Monotonic systems, those

characterized by static and low geothermal gradients, are not favorable for forming economic deposits.

Mercury, arsenic, and antimony are commonly associated with epithermal precious-metal deposits. Mercury is a volatile element that is readily transferred into the vapor phase when boiling occurs. To transport mercury, the hydrothermal solution must be reducing enough to keep mercury in solution as Hg^0_{aq} (Verakamps and Buseck, 1984). Upon boiling, mercury is carried in the vapor toward the surface as Hg^0_{vap}. Vapor transport results in formation of mercury halos as well as flux of mercury to the atmosphere. Cinnabar cannot occur in vapor-dominated systems and requires participation from an aqueous phase. Deposition of mercury as cinnabar requires turning Hg^0_{aq} into Hg^{++}. This conversion may occur in response to mixing with oxidizing or acidic water. The association of cinnabar + hematite ± pyrite indicates oxidized or sulfur-poor solutions.

Arsenic and antimony are commonly found in geothermal systems associated with mercury and in hot-spring precious-metal deposits. Christensen and others (1983) found that arsenic reflected the geometry of fluid-flow controlling structures at the Roosevelt Hot Springs Thermal Area, Utah. Somewhat higher concentrations were detected within the upper and more altered portions of wells. Antimony was found in low concentrations and was concentrated within a narrow zone in the upper levels of the geothermal system. These elevated concentrations were found to be largely coincident with silicification.

Evaluation of the potential for epithermal precious-metal mineralization involves recognition of those features in the rocks that indicate both the extent to which the aforementioned processes have been active and the distribution of elements of geochemical interest.

At Bear Creek Butte, hydrothermal alteration is structurally controlled, and the lateral extent of alteration is a function of the permeability of the host lithology. Where the host rocks are tuffs, as at the Platner Mine, the alteration zones are wide and extend up to 85 m from the controlling faults. At the Oronogo Mine, where the host rocks are andesite flows, the alteration is restricted to a narrow zone along the faults. Cinnabar occurs in quartz veins cutting silicified rocks in the zones of strong alteration.

The hydrothermal system that formed the mercury prospects at Bear Creek Butte was driven by mafic intrusions. As these intrusions rose along fault zones, the ground water was heated. Probably separation of CO_2 from the fluid and local trapping of this gas allowed lithostatic pressure and tensile strength of the rocks to be exceeded. This allowed rupture of the rocks, violent decompression, and development of hydrothermal breccias. Boiling of the solutions may have fractionated some mercury into the vapor phase to produce the geochemical anomaly in the altered zone. The final emplacement of the dikes was followed by continued hydrothermal activity, as sulfur-poor fluids carried mercury leached from the country rocks deep within the system toward the surface to become mixed with near-surface, cool, and oxidized water, that precipitated mercury as cinnabar in chalcedony and quartz veins in silicified breccias. The kaolin and quartz alteration and pseudomorphic replacement

of pyrite suggest that the prospects may be near the paleosurface that existed at the time of alteration.

The lack of detectable gold by INAA (detection limit of 0.05 ppm) in the alteration zone and veins is disappointing; however, if gold were deposited at the zone of boiling associated with development of hydrothermal brecciation, a precious-metal zone might occur at a deeper level than the rocks exposed at the present erosion surface.

Uranium prospects: The uranium prospects at Bear Creek Butte are characterized by the geochemical association of uranium and molybdenum in hydrothermally altered felsic tuffs. Analogous settings are the uranium deposits in the Lakeview uranium district, Oregon, where the host rocks are peraluminous rhyolites and tuffs that Castor and Berry (1981) tentatively correlated with the John Day Formation. At Lakeview, secondary mineralization occurs along limonitized and/or silicified shear zones in bleached ash-flow tuffs. This alteration mineralogy is similar to that found in the prospects at Bear Creek Butte. The source of uranium is believed to be the tuffs of the John Day Formation, with deposition occurring within structural sites where oxidized solutions became reduced and allowed deposition of uranium and molybdenum (Zielinski, 1981).

This environment of deposition is distinct from the oxidizing conditions required for deposition of mercury in the mercury prospects. The fault trend at the uranium prospects also differs from the controlling fault trends in the mercury prospects, which are more north-northwest to northwest. From these data, it is interpreted that the uranium was not deposited within the same system that formed the mercury deposits.

TIMING OF MINERALIZATION

The timing of mineralization of the two systems is not certain. The mercury system, which may be as old as the Eocene or early Oligocene, developed during volcanism that deposited the upper sequence of the Clarno Formation. An upper age on mineralization can be set only as the age of the younger plateau basalts, since nowhere in the study area does the alteration cut rocks of the John Day Formation allowing a more precise bracketing of the age of alteration. The uranium-system alteration is within the John Day Formation and is not related to Clarno volcanism. The controlling northwest fault coincides with a lineation in the plateau basalts of Rodman Rim that is visible on Landsat imagery. Thus the uranium mineralization may have developed as recently as late Miocene or Pliocene.

CONCLUSIONS

1. The Clarno Formation in the Bear Creek Butte area is composed of a lower sequence of basalt, andesite, and dacite flows, mudflows, and volcaniclastic sediments and an upper sequence of basalt-rhyolite and younger andesite. The two volcanic sequences are separated by a paleosol.

2. The basalt-rhyolite association of the upper sequence of the Clarno Formation at Bear Creek Butte is similar to that at the Horse Heaven mining area.

3. Mercury mineralization as cinnabar is hosted in quartz veinlets cutting silicified hydrothermal breccias that developed ahead of basaltic intrusions. The present erosion level in these deposits is believed to be near the paleosurface at the time of mineralization. Precious metals may occur at deeper levels in the system but were not detected by surface geochemical sampling.

4. Uranium mineralization is minor and developed under differing conditions from the spatially associated mercury mineralization. Uranium occurs in the tuffs of the John Day Formation and may have developed during the late Miocene or Pliocene.

Table 5. Selected geochemical data for uranium prospects in the John Day Formation.

Sample Number	As	Sb	U	Th	Mo
CA-M	2.2	0.9	5.3	5.2	N.D.
190	2.7	0.3	4.9	19.1	N.D.
191	3.7	0.3	4.6	18.7	N.D.
193	92.3	N.D.	43.0	7.5	1.0
194	153.7	N.D.	28.0	14.6	1.2
194B	7.9	0.3	6.4	17.6	N.D.
196B	15.8	N.D.	59.0	12.2	1.1

Mo concentrations are normalized against sample 193. Mercury concentrations were below detection limits for instrumental neutron activation analysis. N.D. = not detected.

Table 6. Geochemical data for samples collected by J. Gray, Oregon Department of Geology and Mineral Industries, 1984.

Trace element in ppm	388	389R01	Sample number 389R02	390R01	391R01	391R02	392R01	393R01
Au	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Ag	0.16	0.15	0.13	0.12	0.21	0.14	0.13	0.14
As	9	15	3	12	29	10	19	3
Hg	0.53	0.20	0.11	0.52	0.30	0.10	0.30	0.06
Cu	12	7	11	12	8	12	14	51
Pb	40	15	10	4	6	9	15	4
Zn	139	133	193	52	65	135	68	58
Mo	3.2	3.5	4.8	6.4	3.9	3.1	17.1	1.7

Sample locations: 388R01 - NE, SW, NE, S. 35, T. 17 S., R. 16 E.: 389R01 - NW, NW, SW, S. 36, T. 17 S., R. 16 E.: 390R01 - NW, NW, NE, S. 36, T. 17 S., R. 16 E.: 391R01 - NE, SW, NE, S. 36, T. 17 S., R. 16 E.: 391R02 - NW, NW, NE, S. 36, T. 17 S., R. 16 E.: 392R01 - SW, SW, NW, S. 28, T. 18 S., R. 17 E.: 393R01 - SW, SW, SW, S. 28, T. 18 S., R. 17 E.

Figure 4. Abandoned workings of the Platner Mine. Silicified hydrothermal breccias and narrow basalt dikes form the ridge crest.

by the first author. An early draft of the manuscript was reviewed by Jerry Gray and Edward Taylor. Their comments have helped to improve the paper.

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Geologist Board accepts new structure

The Oregon Board of Geologist Examiners has tentatively approved the transfer of its administration from the former Department of Commerce to "independent state agency" status. This change was provided for in Senate Bill 1034, passed by the Oregon Legislature and signed by the Governor in July.

The Geologist Board's budget for the biennium 1987-89 will remain unchanged, according to Dr. Allen F. Agnew, Chairman. Because the work load of the Geologist Board does not require a full-time administrator, it was decided that the Geologist Board should contract for its administrative services with the staff of the Board of Engineering Examiners.

Agnew reported to the Geologist Board that he had met with Edward B. Graham, Executive Secretary of the Board of Engineering Examiners, to work out the details of the transfer of administrative services. Graham is a registered Land Surveyor in the State of Oregon, through the Board of Engineering Examiners.

The new arrangement, the Geologist Board agreed, should provide economic services and convenience for both boards. Further information is available from Administrator Graham or Judy Holan, Room 403, Labor and Industries Building, Salem, OR 97310, phone (503) 378-4180.

The Geologist Board has scheduled its next examination for potential registrants for October 30-31.

—Board of Geologist Examiners news release

Oregon DEQ announces open position

The Oregon Department of Environmental Quality (DEQ) is seeking to fill the following position:

Hydrogeologist (Geologist 4) position, compensation $2,483-$3,158 per month, with the State of Oregon, Department of Environmental Quality, in Portland. The position is with the Solid Waste Program of the Hazardous and Solid Waste Division.

The Hydrogeologist serves as the program's expert in determining the accuracy and adequacy of reports, normally submitted by consultants, that describe hydrologic conditions below solid waste facilities; a further responsibility of the position is the monitoring of programs developed to detect contamination.

DEQ is an equal opportunity employer. For further information, contact the DEQ personnel office, 811 SW 6th Avenue, Portland, OR 97204, phone (503) 229-5110. □

Plan for scientific drilling in the Cascades released

Broad outlines of a program for scientific drilling for the Cascade Range (PSDC) in Oregon, Washington, and California and a detailed plan for the first phase of this comprehensive scientific investigation have been published by the Oregon Department of Geology and Mineral Industries (DOGAMI) in a new open-file report.

The report, DOGAMI Open-File Report O-86-3, is entitled *Investigation of the Thermal Regime and Geologic History of the Cascade Volcanic Arc: First Phase of a Program for Scientific Drilling in the Cascade Range*. It was prepared for the U.S. Department of Energy by DOGAMI geologist George R. Priest with contributions by 23 other geologists from a variety of state and federal agencies and academic and private research institutions.

The 120-page report includes descriptions of the objectives and priorities of all three anticipated phases of the PSDC. For the first phase, it presents specific discussions of 11 tasks of implementation, as well as a management plan and a scheduling and budget plan. Drilling and extensive geologic and geophysical surveys are proposed for a representative segment of the volcanic arc in the vicinity of Santiam Pass and Breitenbush Hot Springs. The final phase would culminate in the drilling of an ultra-deep drill hole to depths of 7-10 km. The report contains new data on the Cascade Range and numerous illustrations, including geophysical models and generalized geologic maps. An extensive bibliography on Cascade research is also included.

The PSDC report is the result of nearly three years of planning by scientists from state and federal geological surveys, universities, and national laboratories. The PSDC plan was developed as part of the national Continental Scientific Drilling Program which is administered by the U.S. Department of Energy, the U.S. Geological Survey, and the National Science Foundation. The proposed studies are intended to serve as a framework for specific proposals for studies in the future.

The new report, Open-File Report O-86-3, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $9. Orders under $50 require prepayment. □
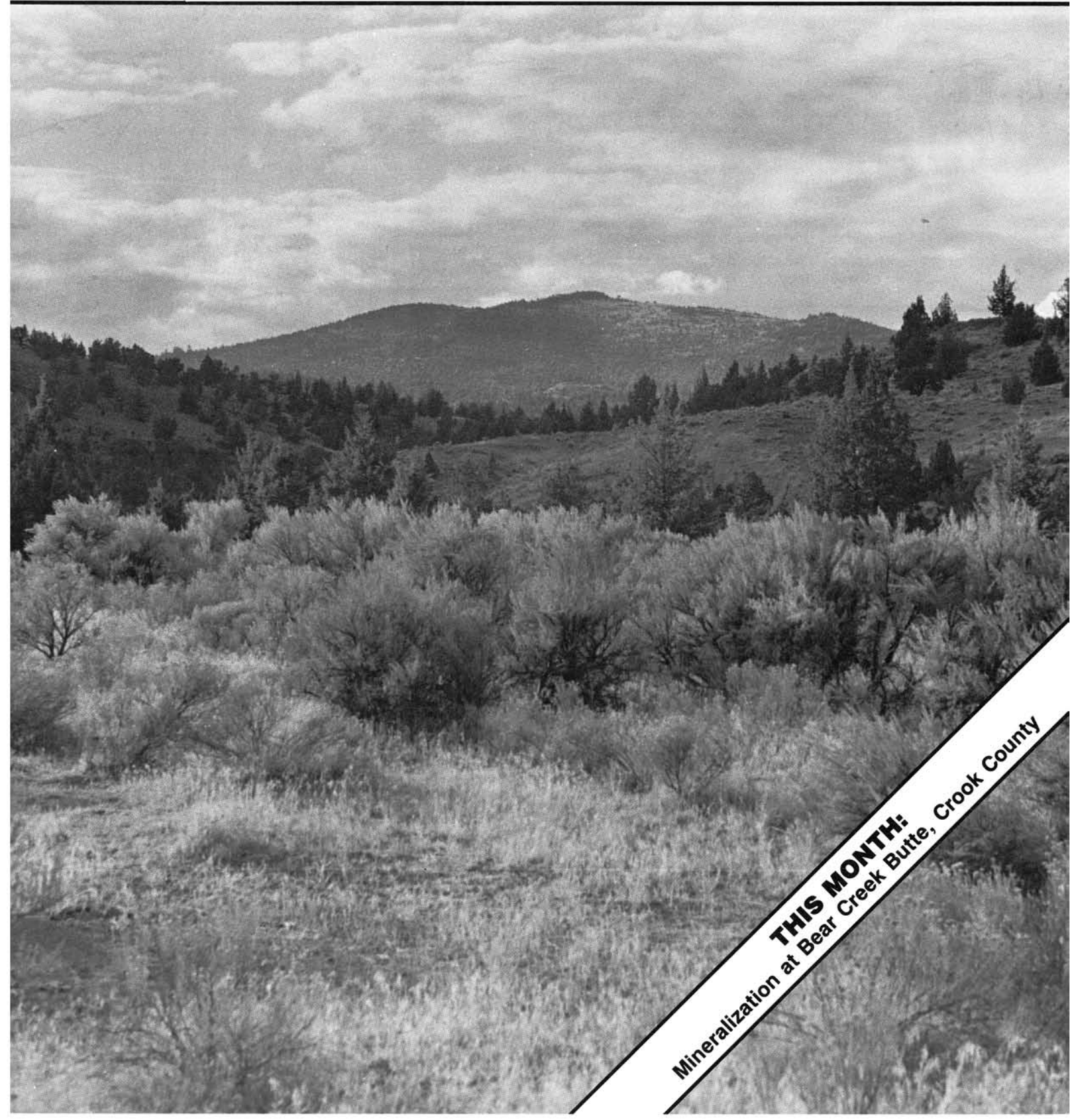
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THIS MONTH:
Mineralization at Bear Creek Butte, Crook County