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RELATION OF MERCURY, URANIUM, AND LITHIUM DEPOSITS
TO THE MCDERMITT CALDERA COMPLEX, NEVADA-OREGON

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Abstract

The McDermitt caldera complex, located along the Nevada-Oregon border, is a Miocene collapse structure 45 kilometer in diameter. Large-volume rhyolitic and peralkaline ash-flow tuffs were erupted from 17.9 to 15.8 m.y. ago, leading to the formation of overlapping and nested calderas. Emplacement of rhyolitic ring domes, located primarily along the western margin of the calderas, represents the last phase of volcanic activity.

The complex is the site of large deposits of mercury, an ore deposit and several occurrences of uranium, and widespread occurrences of lithium. Mercury deposits at Cordero, McDermitt, Bretz, Ruja, and Opalite occur along ring fractures in sedimentary rocks that fill the calderas. Near the deposits the rocks are altered to zeolites and within the ore zones to potassium feldspar and silicate minerals. Although the mercury deposits contain anomalous concentrations of uranium, the most important uranium occurrences are restricted to rhyolitic ring domes emplaced along the western margin of the calderas.

Lithium occurrences are located in tuffaceous rocks that are altered to zeolites and potassium feldspar. Concentrations of lithium ranging from 0.1 to 0.68 percent are associated with the clay mineral hectorite. The rhyolitic rocks erupted from the McDermitt caldera complex are enriched in mercury, uranium, and lithium and are likely source rocks for these elements in the ore deposits. Tuffaceous caldera fill-sediment averages 0.29 ppm mercury, 22 ppm uranium, and 236 ppm lithium; large-volume ash-flow tuffs contain up to 0.26 ppm mercury, 20 ppm uranium, and 300 ppm lithium.

Introduction

The McDermitt caldera complex in the Great Basin province of the western United States is a Miocene collapse structure consisting of nested and overlapping calderas. The calderas occur along the Nevada-Oregon border (Fig. 1) and occupy the Trout Creek, Double-H, and Montana Mountains. Important deposits and occurrences of mercury, uranium, and lithium occur within the complex, including the largest producing mercury deposit in North America. The size of the caldera complex, 45 km in north-south diameter and 35 km east-west, and its large volume of pyroclastic material 1,100 km³, place it among the largest known cauldron complexes.

Geology

The caldera complex is developed on a terrane of Mesozoic granodiorite and Cenozoic basalt, andesite, and dacite flows. The mafic and intermediate lavas were erupted 24 to 18 m.y. ago and have a total thickness in excess of 420 m in the northern part of the complex (Fig. 2). Rocks of equivalent age in the south are dominantly dacite and andesite with a total thickness greater than 150 m. Reconstruction of the Miocene surface in relation to eruption of flows at the end of volcanic activity shows that a structural depression existed in the area now occupied by the complex. This depression may have formed because of the large volume of erupted magma; within this basin local deposits of clastic and tuffaceous rocks accumulated.

Explosive rhyolitic volcanism began with eruption of a large-volume ash-flow tuff sheet (Fig. 2, unit 1). The sheet is a simple cooling unit with a maximum thickness of 230 m in the Double-H Mountains. To the north the unit thins to 70 m in the vicinity of Hoppin Peaks and is absent in the Oregon portion of the complex. The sheet consists of black basal vitrophyre, 1.5 m

thick, with well-developed eutaxitic texture that grades upward into a densely welded, vapor-phase-altered tuff composed of alkali feldspar, cristobalite, and soda amphibole. Vapor-phase crystallization has given the unit a granophyric texture and destroyed nearly all the original fragmental texture of the tuff. Secondary flowage features are common in both the vitrophyre and the zone of vapor-phase alteration; flow foliation, lineation, and folds are common.

Table 1 Chemical analysis of the unit (Table 1) shows that total alkalis exceeds aluminum and that the rock is peralkaline. The molecular ratio of alkalis to aluminum is 1.1, and total iron as FeO-plus-MnO is 2.55 percent, typical of comendites. Excess sodium is revealed by the presence of soda amphibole in the zone of vapor-phase alteration.

During a hiatus in volcanic activity, tuffaceous sedimentary rock as thick as one meter was deposited on the locally eroded top of unit 1. Volcanic activity resumed with deposition of several small-volume ash-flow tuffs having a combined thickness of 9 m, followed by eruption of a large-volume ash-flow tuff that cooled as a single unit (Fig. 2, unit 2). The ash-flow tuff has a maximum thickness of 210 m in the Double-H Mountains, a thickness of 55 m near Hoppin Peaks, and is absent in the northern part of the caldera complex.

The basal vitrophyre of unit 2 is 3 m thick and characterized by green, black, and purple bands. The remainder of the unit consists of densely welded, vapor-phase-altered tuff composed of alkali feldspar, soda amphibole, and cristobalite in a granophyric texture. Secondary flowage features also are common in this unit which exhibits flow folds well developed in the basal vitrophyre. As in unit 1, chemical analysis indicates that unit 2 is a comendite, with a molecular ratio of total alkalis to aluminum equaling 1.1 and total iron as FeO-plus-MnO at 2.74 percent. The areal distribution of

units 1 and 2 is very similar, suggesting that both were erupted from vents in the southern part of the caldera complex.

The third large ash-flow tuff (Fig. 2, unit 3) erupted 17.9 m.y. ago, immediately after unit 2 cooled. The ash-flow tuff is a simple cooling unit with a black basal vitrophyre, 3 m thick, that is characterized by abundant alkali-feldspar phenocrysts and an upper zone of brown, densely welded, crystal-rich tuff. In a few localities of the Double-H Mountains a vapor-phase zone is exposed that consists of a gray-green rock composed of alkali feldspar, cristobalite, and soda amphibole in a granophyric texture. Chemical analysis of the vitrophyre (Table 1) indicates that it is peraluminous; however, its large water content suggests that the rock may have been subjected to alkali leaching and that sodium has been depleted. Lipman (1965, 1969) and Noble (1970), for example, have shown that rhyolitic glasses are susceptible to ground-water leaching of sodium and potassium. The mineralogy of the vapor-phase zone indicates a peralkaline rhyolite; chemical analysis would designate it a comendite if sodium and potassium are significantly depleted.

Two large-volume ash-flow tuffs, units 4 and 5, with ages of 15.8 m.y. occur in the northern part of the caldera complex and in small areas north of Hoppin Peaks. The tuffs are simple cooling units with a combined thickness in excess of 120 m on the northern rim of the complex and 10 m north of Hoppin Peaks. The distribution of both units 4 and 5 is similar and indicates that the source of the tuffs was in the northern part of the complex. Unit 4 is a gray crystal-rich tuff that is usually unwelded where less than 5 m thick. Thicker sections, locally up to 30 m, have an unwelded base, grading upward into a densely welded zone of overlying black vitrophyre. Above the vitrophyre the unit is a vapor-phase-altered tuff consisting of alkali

feldspar, cristobalite, and soda amphibole. The mineralogy and gray-green color of the rock suggest that it is peralkaline rhyolite. Unit 5 caps the top of the Trout Creek Mountains and has an exposed thickness of 90 m, but its original thickness is unknown because the upper part has been eroded. To the south, the unit thins to a few meters near Hoppin Peaks, where it occupies Miocene stream channels developed on the andesite basement.

The base of unit 5 is characterized by a brick-red crystal-rich tuff, unwelded at the base and grading upward into a black vitrophyre 2 m thick. The rest of the unit consists of densely welded, vapor-phase-altered tuff composed of alkali feldspar, cristobalite, and soda amphibole in a granophyric texture. Locally densely welded, brown crystal-rich tuff is interstratified with greenish-gray tuff in the vapor-phase-altered zone. The mineralogy and color of this unit, which are similar to those of the other tuffs, suggest that it too is peralkaline.

Eruption of each large-volume ash-flow tuff formed a collapse caldera, and later resurgence gave rise to a central resurgent dome within each caldera.

Fig. 3 Parts of five ring-fracture zones (Fig. 3) indicate that the calderas are complexly overlapping and partly nested within each other. The best preserved caldera is located in the extreme southern part of the complex and is here informally named the Calavera caldera; it has a diameter of 18 km and is nearly circular. The northern scarp of the Double-H Mountains defines the southern ring-fracture zone of the Calavera caldera. Large-scale landsliding along the original caldera rims has developed an irregular topographic edge about half a kilometer south of the original ring fracture. The eastern and northern border of the caldera are coincident with Crowley Creek, and the northwest ring fracture extends the length of Calavera Canyon. The entire western margin of the caldera has been displaced below the Kings River Valley

by a large Basin and Range fault bordering the west side of the Montana Mountains. A resurgent dome occupies the southeastern part of the mountains.

Another well-preserved caldera found in the northernmost portion of the complex was originally defined by Walker and Repenning (1965) to coincide with the southern scarp of the Trout Creek Mountains; further mapping has shown that this caldera is 27 km in diameter and oval in shape. The western margin extends along the scarp defined by Disaster Peak and the adjacent hills, and the southern margin coincides with the upper part of Crowley Creek. Southeastern segments of the ring fracture likely extend through Long Canyon; extensive landsliding has displaced the original rim by 1 km north of the ring-fracture zone. A central resurgent dome occupies Long Ridge; for which the caldera is informally named.

In the northeast part of the complex is a less well preserved circular caldera, 21 km in diameter; its southern and eastern segments are defined by the northeastern scarp of the range of which Hoppin Peaks are a part. The northeastern part of the ring fracture extends through the extreme southern part of the Trout Creek Mountains, where landsliding and normal faults have modified its original topographic expression. The western part of the caldera is obscured by younger volcanic deposits. A resurgent dome is present in the topographic high between McDermitt and Washburn Creeks; the caldera is informally named the Washburn caldera.

A poorly preserved collapse structure, 21 km in diameter and informally named the Jordan Meadow caldera, occurs in the central portion of the complex. Only the eastern and western segments of the ring fracture are preserved; its eastern segment extends along the western scarp of the Hoppin Peaks range. To the south the ring fracture is cut off by the Calavera caldera, and to the north it is covered by younger volcanic rocks. The western part of the ring

fracture is on the southern side of Horse Creek Canyon; to the south of the ring fracture terminates against a normal fault, and to the north it is cut off by the Long Ridge caldera. A well-preserved resurgent dome occupies the topographic high of Jordan Meadow Mountain. A poorly exposed, unnamed caldera coincides with the southern ring fracture of the Calavera caldera and extend eastward into the Quinn River Valley, where it is covered by alluvium. The rest of the ring fracture has been obscured by more recent faulting, and its location is uncertain.

Chronologic development of the five calderas and their relations to the five large-volume ash-flow tuffs have not yet been determined. Further dating of the resurgent domes should accurately date each collapse event and provide a correlation with the ash-flow tuffs.

Sedimentary rocks, consisting of tuffaceous sandstone, siltstone, and shale fill the moat portions of the calderas. Near the caldera ring-fracture zones are alluvial fans composed of coarse pebble conglomerates. The rocks are thickest (more than 100 m) in parts of moats nearest the ring-fracture zones. An andesite flow interstratified with the rocks has a K-Ar age of 16.4 ± 1.2 m.y. and indicates that most of the rocks were deposited shortly after formation of the calderas. The rocks are more deeply eroded in the northern and western part of the complex because of a 12° regional tilting of the Trout Creek-Montana-Double-H block to the southeast. Uplift and tilting on an eastward-trending fault that forms the southern scarp of the Montana Mountains have also resulted in deeper erosion of the rocks on the western margin of the complex.

Unaltered vitric sedimentary rocks suitable for chemical analysis are found in the extreme northeast part of the Long Ridge caldera and in the southern part of the Calavera caldera. Chemical analysis of the glass shows that it contains up to 8 percent water; because of the high water content, the analysis in Table 1 has been recalculated water free. Assuming no alkali leaching occurred, the tuffs are peraluminous rhyolites. Throughout the rest of the complex, the tuffs have altered to zeolite assemblages owing to diagenesis and hydrothermal activity (Rytuba, Glanzman, and McCarthy, 1977; Glanzman, Rytuba, and McCarthy, 1978). The observed zeolites include: erionite, clinoptilolite, mordenite, and analcime; authigenic potassium feldspar is also an important alteration product.

Mercury Deposits

Five economic deposits and several occurrences of mercury lie within the caldera complex. The Opalite, Bretz, and McDermitt deposits occur in moat-filling tuffaceous sedimentary rocks, and the Cordero and Ruja deposits are localized in volcanic rocks near the ring-fracture zone. The McDermitt deposit is the only deposit being mined and is presently the largest mercury deposit in North America, with reserves estimated to be 300,000 flasks. The McDermitt, Cordero, and Ruja deposits are located along and adjacent to the southeastern ring-fracture zone of the Washburn caldera, the Opalite deposit along the projected trace of the northwestern ring-fracture zone, and the Bretz deposit along and adjacent to the northeast ring-fracture zone of the Long Ridge caldera (Fig. 3). Cinnabar is the main ore mineral in all the deposits, and in the McDermitt deposit corderoite, $\text{Hg}_3\text{S}_2\text{Cl}_2$, is also abundant. Other mercury and antimony minerals include mosesite, kleinite, calomel, montroydite, stibnite, and tripuhyite. Gangue minerals associated with the ore include quartz, cristobalite, potassium feldspar, clinoptilolite,

mordenite, alunite, kaolinite, and montmorillonite; anomalous associated trace elements include As, Mo, Be, Sb, and U.

Tuffaceous sedimentary rocks surrounding the McDermitt deposit show three distinct zones of alteration, which extend laterally from the deposit

Fig. 4 (Fig. 4). At distances greater than 4 km away, the rocks are unaltered and consist of water-laid vitric tuffs. Extending from the fresh glass zone to the deposit is a narrow transitional zone of glass + clinoptilolite + erionite and a large inner zone of clinoptilolite and mordenite. In the ore zone potassium feldspar and smectite clays are the predominant alteration products

Fig. 5 (Fig. 5). Local beds of alunite and kaolinite occur immediately above the ore horizon.

Cristobalite is present in all the alteration zones, its crystallinity varying with distance from the McDermitt deposit. The crystallinity is determined by its $d(101)$ spacing: Completely crystalline cristobalite has a value of 4.04\AA ; nearly uncrystalline cristobalite, 4.12\AA . Around the McDermitt deposit the cristobalite decreases in crystallinity systematically away from the center. Cristobalite from the potassium feldspar zone, where it is intimately associated with the ore minerals, has $d(101)$ spacing of 4.06\AA , which indicates a high degree of crystallinity. In the clinoptilolite + mordenite zone spacing ranges from 4.08 to 4.09\AA ; the higher values occur further from the deposit. Spacing ranges from 4.10 to 4.11\AA in the glass + clinoptilolite + erionite zone, and the silica is completely noncrystalline in the unaltered vitric zone. This progressive decrease in crystallinity is similar to that reported by Murata and Larson (1975) for cristobalite in Monterey shale; they related decrease in crystallinity to a decrease in strata burial depth and a decrease in temperature. The decrease in crystallinity around the McDermitt deposit has resulted from a decreasing temperature away

from the deposit; a thermal gradient extends laterally from the deposit into the country rocks for a distance of 4 km. Homogenization of fluid inclusions in quartz indicates a maximum temperature of 200°C at the core of the deposit, where the cristobalite is most crystalline. Because of the thermal gradient, zeolite alteration zones formed around the deposit, and the size of the alteration aureole defines the maximum extent to which reactive hydrothermal fluids penetrated into the country rocks.

A similar type of alteration pattern surrounds the Opalite and Bretz deposits and indicates that, in plan view, the hydrothermal cells were circular and had a maximum temperature at the core of the deposit.

Uranium Deposits

Deposits and occurrences of uranium in the caldera complex occur in two environments: rhyolite ring domes and intrusive bodies, and mercury deposits within the tuffaceous sedimentary rocks. Uranium concentrations within the rhyolite domes and intrusions are the most economically significant.

The Moonlight mine and several uranium occurrences are located in rhyolite domes and near surface-intrusive plugs emplaced along the western ring-fracture zone of the Jordan Meadow and Calavera calderas (Fig. 2). The intrusions and domes, exposed along the western scarp of the Montana and Double-H Mountains, are porphyritic rhyolites that contain 10-20 percent phenocrysts of quartz, albite, and potassium feldspar in a groundmass of glass. In the core of the intrusive rocks and in the vicinity of the ore deposits the groundmass is devitrified and consists of spherulites of quartz, potassium feldspar, and riebeckite. Chemical analysis of a vitrophyre from one of the rhyolite domes indicates that it is peraluminous rhyolite (Table 1), although widespread occurrence of riebeckite in many of the domes and intrusions indicates that some, perhaps most, are peralkaline rhyolite.

A small number of K-Ar dates demonstrate that the domes and intrusions in the western ring-fracture zones were emplaced from 14.6 to 13.5 m.y. ago and thus represent the last stage of rhyolitic volcanism in the complex. Other undated rhyolite domes were emplaced along the northern ring-fracture zone of the Long Ridge and Washburn calderas; the intrusions and domes were emplaced after most of the caldera fill-sediment was deposited. Reconstruction of the Miocene surface indicates that the presently exposed intrusions were emplaced from 100 to 800 m below the Miocene surface and that some of the intrusive rocks surfaced to form extrusive domes. Contacts of the intrusions with the country rock are sharp, and evidence for forceful emplacement of the rhyolites is common.

Intrusions and domes associated with the uranium deposits are altered to potassium feldspar, quartz, and pyrite. Potassium feldspar partly replaces plagioclase phenocrysts and large portions of the groundmass; veinlets of quartz and potassium feldspar are also present. Country rocks adjacent to the intrusions and tuffaceous sedimentary rocks above the intrusions are also altered to this assemblage. Local argillic alteration to nontronite occurs on fractures and in the groundmass.

In Moonlight mine, ore occurs along the brecciated contact of the intrusion and the caldera wallrocks and includes both granodiorite and andesite. The ore mineral is pitchblende, and gangue minerals are pyrite, quartz, and fluorite; in the oxidized portion of the deposit autunite and hematite are present. Anomalous concentrations of molybdenum, beryllium, and mercury are present in and outside the ore zone. Fluid inclusions in quartz associated with the pitchblende indicate a deposition temperature of 330°C, and stratigraphic evidence indicates that the deposit formed at a shallow depth of about 800 m.

The Moonlight mine and associated occurrences are very similar to deposits described by Smirnov (1977) as "molybdenum-uranium deposits in subvolcanic intrusions." In deposits in the U.S.S.R., the intrusive necks of extrusive alaskite and rhyolite domes are mineralized with veins and stockworks of pitchblende and lesser amounts of jordisite, pyrargyrite, and cinnabar. The intrusive rocks occur along high-angle fault zones, which may be caldera-related fractures, and the ore tends to occur near the fractured and brecciated margins of the intrusives. Widespread potassic alteration is unlike that at the Moonlight mine because sericite rather than potassium feldspar occurs with the pyrite and quartz. The deposits are considered to have formed at shallow depths of 300 to 500 m and over a temperature interval of 120-200°C.

The second type of uranium occurrence within the caldera complex consists of local concentrations in the mercury deposits. Anomalous concentrations of uranium occur within the Bretz, Opalite, and McDermitt deposits; up to several hundred ppm uranium is associated with brecciated opalite and altered sedimentary rocks containing goethite and (or) pyrite. Zeolitized country rocks adjacent to the Opalite mercury deposit are depleted in uranium content as compared to the unaltered tuffaceous sedimentary rocks (Fig. 6). In the zone of potassium feldspar alteration the uranium content is higher and reaches its highest concentration in the sulfide-bearing opalite (Rytuba, 1977). Radioactivity measurements of the Opalite deposit show that readings as high as several thousand counts per second occur over some parts; in comparison, the unaltered and unmineralized sedimentary rocks average 160 counts per second. The presence of anomalous concentrations of uranium in the opalite-type mercury deposits indicates that radioactivity surveys are a potential exploration method here and may be applicable elsewhere.

Fig. 6

The occurrence of opalite-type mineralization in tuffaceous sedimentary rocks overlying the rhyolite intrusion that contains the Moonlight deposit suggests that the mineralization of uranium and that of mercury are related, mercury being concentrated at or near the surface and uranium concentrated mostly at deeper levels. Similar trace-element suites (Be, Mo, As, and Sb) associated with the opalite-type mercury and uranium deposits also support this concept.

Lithium Occurrences

Economic concentrations of lithium occur within the tuffaceous moat-filling sedimentary rocks of the caldera complex. As much as 0.68 percent Li is present in the rocks in the form of hectorite and some other, but as yet uncharacterized, lithium-bearing mineral (Glanzman, Rytuba, and McCarthy, 1978). High lithium concentrations occur in lacustrine beds within the tuffaceous sedimentary rocks and are the highest reported concentrations of lithium for this type of environment.

Distribution of lithium within the caldera complex is closely related to the zeolite alteration zones developed in the tuffaceous sedimentary rocks. Analysis of unaltered rocks indicates that the original lithium content of the sediment averaged 230 ppm, higher than normal for average rhyolitic rocks (approximately 50 ppm). During zeolitization of the rocks lithium was depleted in the alteration zones of erionite, clinoptilolite, and mordenite and concentrated in the alteration zones of analcime and potassium feldspar. Rocks altered to erionite have an average lithium content of 160 ppm, and those altered to clinoptilolite and mordenite average 100 ppm. Locally, however, hectorite is interbedded with clinoptilolite.

The largest areas and highest concentrations of lithium occur in the western parts of the Long Ridge, Jordan Meadow, and Calavera calderas. The tuffaceous sedimentary rocks in this area routinely contain greater than 0.3 percent lithium over large stratigraphic intervals and constitute a major economic reserve of lithium. The rocks are altered to potassium feldspar, analcime, and quartz. Pyrite is ubiquitous. Petrography of the rocks shows that potassium feldspar pseudomorphically replaces analcime and that the rock was initially altered to analcime and then further to potassium feldspar. The high correlation coefficient, 0.65, of lithium with analcime-containing samples indicates that lithium was concentrated during the stage of analcime alteration; the rocks were subsequently converted to potassium feldspar because of thermal fluids generated during the emplacement of rhyolitic domes and intrusive bodies along the ring-fracture zone.

Relation of the Caldera Complex to the Ore Deposits

Unaltered rhyolitic rocks associated with the caldera complex are anomalously high in the same elements that occur in economic concentrations within the complex: Hg, U, and Li. The large-volume ash-flow tuffs contain from 0.25 to 0.65 ppm Hg; the rhyolite domes, intrusions, and sedimentary rocks, somewhat higher concentrations (Table 1). These concentrations are from one to two orders of magnitude above those reported in average rhyolite (Ozerova, 1976b), indicating that igneous formation of the McDermitt rhyolite was also an effective process for concentrating mercury. Volcanic country rocks adjacent to large mercury deposits in the U.S.S.R. (Ozerova, 1976a) and in Spain also contain anomalously high levels of the element for as far as several hundred kilometers from the deposits; as in the McDermitt environment, these large volumes of mercury-enriched rock were generated prior to the

formation of the deposits. Thus, initial concentration of mercury in the country rocks is likely an important prerequisite for the development of large mercury deposits.

Rhyolite rocks erupted from the McDermitt complex provide a source for the mercury. Hydrothermal systems along the ring-fracture zones of the calderas apparently removed mercury from the country rocks at depth and reconcentrated it in the near-surface environment. The size of the alteration aureoles around the mercury deposits indicates that large volumes of rock were penetrated by the hydrothermal system. Laboratory experiments reacting McDermitt rhyolite with various hydrothermal solutions at 200°C (unpub. data) indicate that nearly all the mercury partitions into the fluid phase to constitute a potential ore-forming solution.

The rhyolitic rocks in the caldera are similarly enriched in lithium to about an order of magnitude above average rhyolite (Table 1). Lithium is highly soluble and readily leached from rhyolitic glasses by ground waters (Zielinski, 1977) and by hydrothermal solutions (unpub. experimental data); the processes of low-temperature alteration of the tuffaceous sedimentary rocks to zeolites and of hydrothermal alteration of the ash-flow tuffs and sediments during formation of the mercury and uranium deposits would leach large amounts of lithium from the previously abnormally rich country rocks. Because the caldera complex provided a closed basin, these lithium-enriched solutions concentrated in the lowest part of the basin and were subsequently incorporated into lithium-bearing clay.

Although the uranium content of the rhyolitic rocks is also anomalously high, the enrichment factor for uranium relative to normal rhyolite is not so great as that for lithium and mercury (Table 1). The uranium deposits are closely associated with the rhyolite ring domes and intrusions, and this close

spatial relation indicates a genetic relationship to the intrusive rocks. The original uranium content of the mineralized intrusions and domes cannot be determined because of hydrothermal alteration of the rhyolite. Unhydrated vitrophyre from the margin of an unmineralized dome contains as much as 100 ppm uranium; if this uranium content characterizes the mineralized domes as well, then the last stage of volcanic activity generated rhyolite more highly enriched in uranium than the earlier stages (Table 1). Hydrothermal cells developed during cooling of the rhyolite intrusions would have reconcentrated the uranium, especially in the more permeable fractured rocks near the contacts of the intrusives. Localization of the mercury deposits along ring-fracture zones suggests that late-stage emplacement of the ring domes and intrusive bodies also provided a heat source for the hydrothermal systems that formed the deposits.

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Table 1. Chemical analyses of large-volume ash-flow tuff sheets,
rhyolite dome, and tuffaceous sandstone

[Minor elements in parts per million; all others in percent. N = not detected; -- = not analyzed. Analysts: F. Brown, Z. A. Hamlin, and Karen Duvall.]

	Basal vitrophyres of <u>large-volume ash-flow tuffs</u>			Intrusive dome <u>vitrophyre</u>	Vitric tuffaceous <u>sandstone</u>
Unit No. ---	<u>1</u>	<u>2</u>	<u>3</u>		
Field No. --	JR75-50	JR75-44	JR75-60	JR76-48	JR75-4A
Major elements					
SiO ₂	74.8	74.7	67.9	68.9	74.8
Al ₂ O ₃	11.0	11.0	12.7	11.9	12.6
Fe ₂ O ₃	2.0	1.1	1.7	3.6	2.7
FeO	.72	1.7	2.4	1.1	--
MgO	.06	.01	.16	.20	.4
CaO	.17	.23	1.1	.40	.8
Na ₂ O	4.3	4.3	3.5	3.6	2.8
K ₂ O	4.7	4.7	5.5	5.2	5.4
H ₂ O ⁺	.4	.38	2.3	3.9	--
H ₂ O ⁻	.20	.07	.56	.1	--
TiO ₂	.11	.23	.41	.37	.3
P ₂ O ₅	.05	.05	.12	.02	.04
MnO	.03	.05	.09	.07	.08
CO ₂	<u>.06</u>	<u>.04</u>	<u>.06</u>	<u>.04</u>	<u>--</u>
Total	99	99	99	99	100

Minor elements

Ag -----	N	.7	N	N	N
As -----	N	10	N	15	10
B -----	100	100	70	70	N
Ba -----	70	30	1000	300	700
Be -----	5	5	3	N	3
Ce -----	200	150	150	N	N
Cu -----	7	7	7	15	5
Cr -----	30	30	20	15	20
Ga -----	30	30	30	N	--
Hg -----	.25	.65	.26	1	.5
La -----	100	70	50	30	70
Li -----	300	300	--	30	320
Mo -----	5	7	5	10	--
Nb -----	20	20	10	10	30
Ni -----	N	N	N	3	N
Nd -----	70	70	50	N	N
Pb -----	70	50	50	30	30
Sb -----	N	N	N	10	2
Sc -----	N	N	7	7	N
Sn -----	10	7	7	5	N
Sr -----	15	3	70	20	N
U -----	3	20	N	20	20
V -----	N	N	7	N	--
Y -----	100	100	70	50	30
Yb -----	15	15	10	N	--
Zn -----	150	100	100	70	N
Zr -----	700	700	500	500	300



Figure 1.--Location of McDermitt caldera.

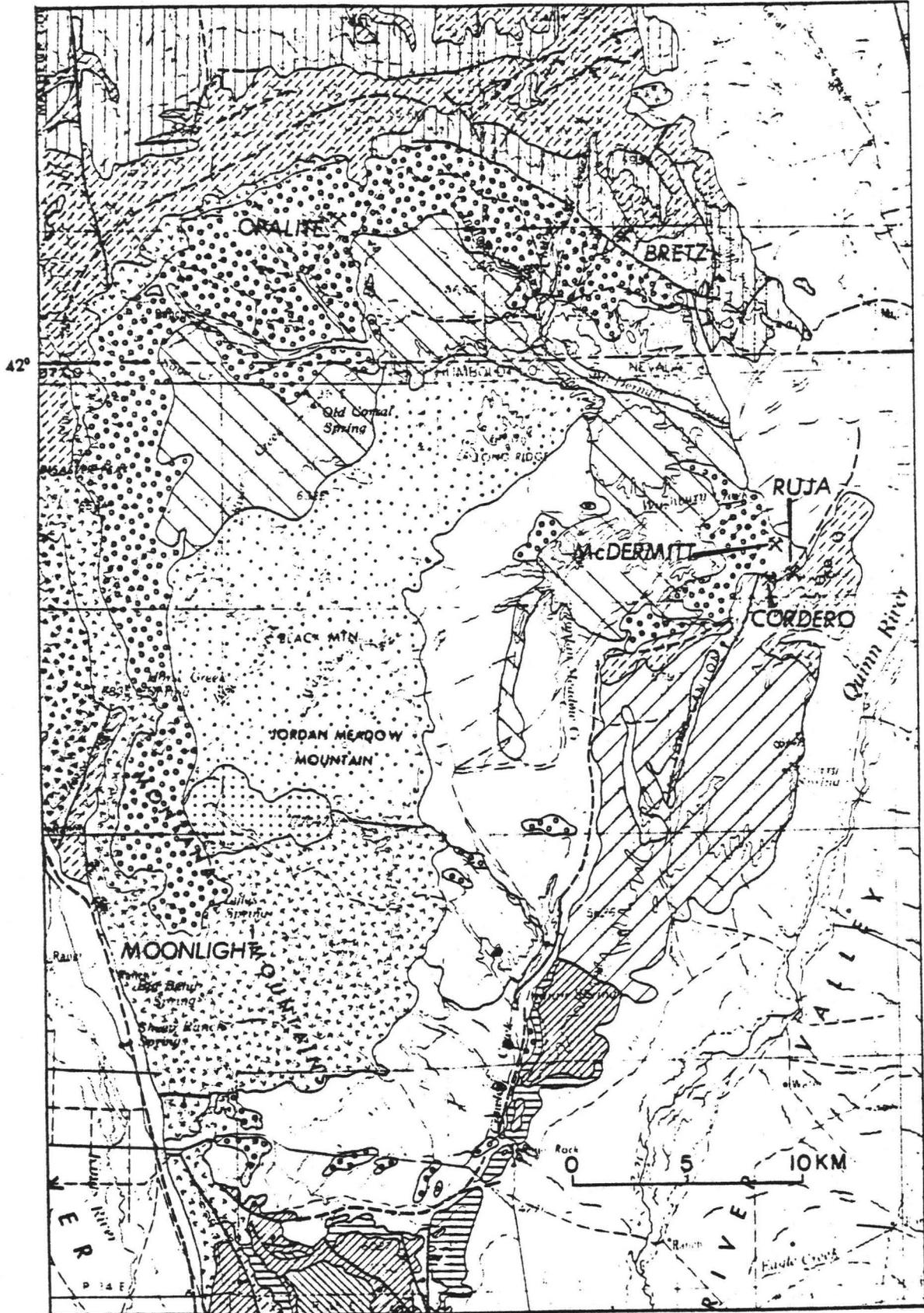


Figure 2.--Generalized geologic map of the McDermitt caldera complex.

EXPLANATION

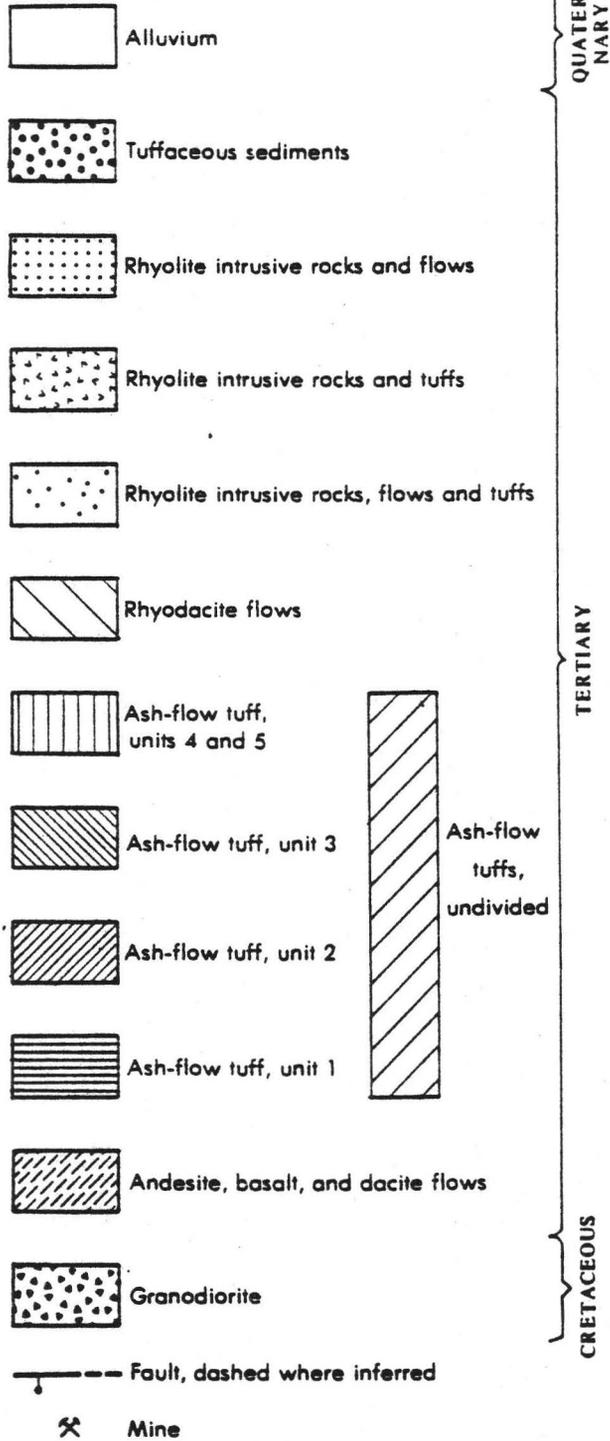
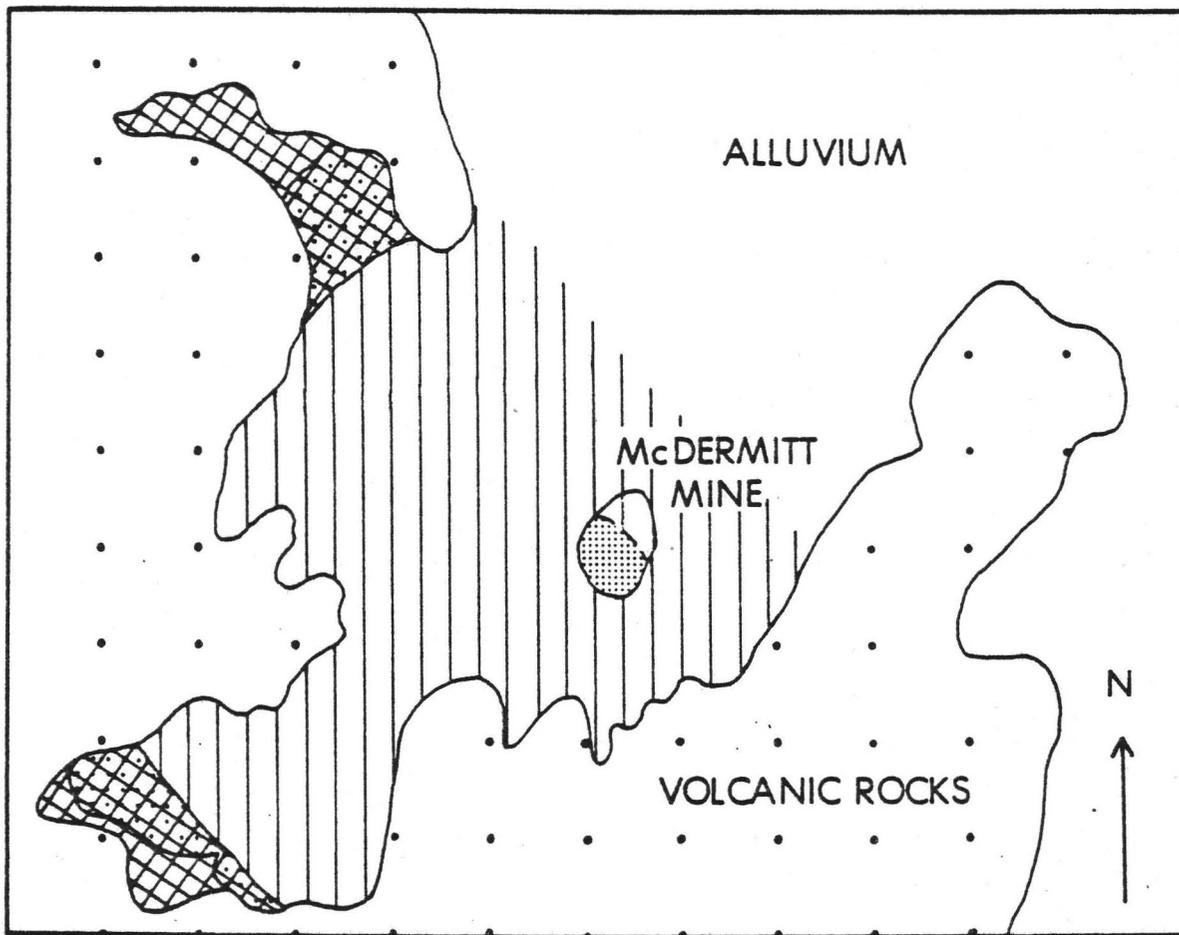
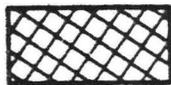


Figure 2

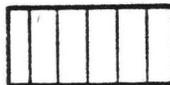


EXPLANATION

Alteration zones in sedimentary rocks



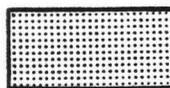
Fresh glass



Clinoptilolite ± mordenite



Glass ± clinoptilolite
± erionite



Potassium feldspar

0 2 KILOMETERS

Figure 4.--Alteration zones in tuffaceous sediments near the McDermitt deposit.



Figure 5.--Potassium feldspar and cordierite from the McDermitt deposit.

Montmorillonite coats the feldspar and cordierite.

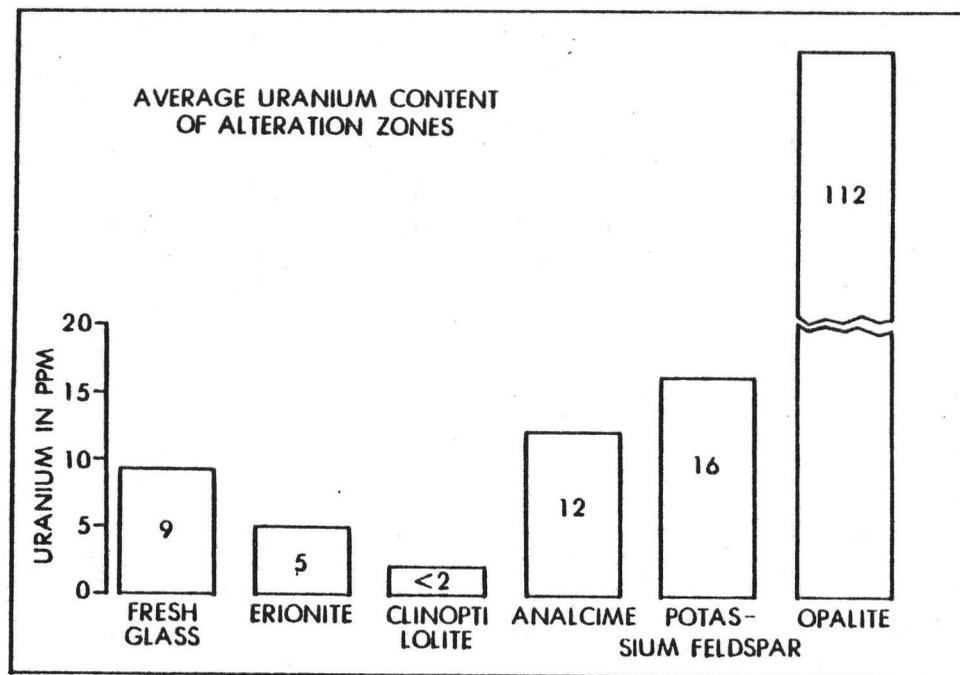


Figure 6.--Average uranium content of unaltered and altered tuffaceous sediments.