UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

ZEOLITE-CLAY MINERAL ZONATION OF VOLCANICLASTIC SEDIMENTS WITHIN THE McDERMITT CALDERA COMPLEX OF NEVADA AND OREGON

By

Richard K. Glanzman and James J. Rytuba;
U.S. Geological Survey, Denver, Colorado 80225;
and Menlo Park, California 94025

OPEN-FILE REPORT 79-1668

1979

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

ZEOLITE-CLAY MINERAL ZONATION OF VOLCANICLASTIC SEDIMENTS WITHIN THE McDERMITT CALDERA COMPLEX OF NEVADA AND OREGON

By

Richard K. Glanzman and James J. Rytuba;

U.S. Geological Survey, Denver, Colorado 80225;

and Menlo Park, California 94025

OPEN-FILE REPORT 79-1668

1979

Table of Contents

Illustrations

ZEOLITE-CLAY MINERAL ZONATION OF VOLCANICLASTIC SEDIMENTS WITHIN THE MCDERMITT CALDERA COMPLEX OF NEVADA AND OREGON

By

Richard K. Glanzman and James J. Rytuba

U.S. Geological Survey, Denver, Colorado 80225;
and Menlo Park, California 94025

ABSTRACT

Volcaniclastic sediments deposited in the moat of the collapsed McDermitt caldera complex have been altered chiefly to zeolites and potassium feldspar. The original rhyolitic and peralkaline ash-flow tuffs are included in conglomerates at the caldera rims and grade into a lacustrine series near the center of the collapse. The tuffs show a lateral zeolitic alteration from almost fresh glass to clinoptilolite, clinoptilolite-mordenite, and erionite; to analcime-potassium feldspar; and finally to potassium feldspar. Vertical zonation is in approximately the same order. Clay minerals in associated mudstones, on the other hand, show little lateral variation but a distinct vertical zonation, having a basal dioctahedral smectite, a medial trioctahedral smectite, and an upper dioctahedral smectite. The medial trioctahedral smectite is enriched in lithium (as much as 6,800 ppm Li).

Hydrothermal alteration of the volcaniclastic sediments, forming both mercury and uranium deposits, caused a distinct zeolite and clay-mineral zonation within the general lateral zonation. The center of alteration is generally potassium feldspar, commonly associated with alunite. Potassium feldspar grades laterally and vertically to either clinoptilolite or clinoptilolite-mordenite, generally associated with gypsum. This zone then grades vertically and laterally into fresh glass. The clay minerals are a dioctahedral smectite, a mixed-layer clay mineral, and a 7-A clay mineral. The mixed-layer and 7-A clay minerals are associated with the potassium feldspar-alunite zone of alteration, and the dioctahedral smectite is associated with clinoptilolite. This mineralogical zonation may be an exploration guide for mercury and uranium mineralization in the caldera complex environment..

INTRODUCTION

The McDermitt caldera complex, a Miocene collapse structure along the Nevada-Oregon border in the Great Basin physiographic province, is among the largest known caldera complexes. The largest producing mercury mine in North America occurs within the complex along with other significant deposits of mercury, uranium, and lithium (Rytuba, 1977; Rytuba and Glanzman, 1978; Glanzman and others, 1978). Mercury is produced from hydrothermally altered volcaniclastic sediments in the McDermitt mine on the eastern side of the caldera complex. The Bretz and Opalite mines (once mercury producers also) are both in hydrothermally altered volcaniclastic sediments in the northern interior of the complex. A significant new uranium discovery has been described as occurring in the altered volcaniclastic sediments in the Bretz mine area. The uranium content in the sediments increases with the degree of alteration at both the Bretz and Opalite mines. Lithium occurs in a trioctahedral smectite clay within the north and west interior of the caldera complex. The lithium content also increases with the degree of alteration in the order--glass, clinoptilolite, analcime, potassium feldspar.

Recent studies of alteration zones of the caldera-fill volcaniclastic sediments in the McDermitt caldera complex illustrate a zonation that is similar but distinct from zonation in other areas. The Lake Tecopa lacustrine sediments of Pleistocene age in southern California (Sheppard and Gude, 1968), the Big Sandy Formation lacustrine sediments of Pliocene age in western Arizona (Sheppard and Gude, 1973), and the pyroclastic rocks of Neogene age in Japan (Utada, 1971) are similar to the McDermitt deposits in that the general order of alteration zones is from partially altered glass to clinoptilolite to analcime to feldspar with the dominant clay mineral being montmorillonite. The McDermitt sediments differ, however, in associated zeolites and type of feldspar. The McDermitt sediments either do not contain or do not contain enough phillipsite or chabazite to register on whole rock X-ray diffractometer patterns of representative rock samples from discrete rock units. These two zeolites are common in all three of the other zonation sequences. Potassium feldspar is common in the McDermitt sediments, the Lake Tecopa beds, and the Big Sandy Formation. However, albite and (or) albitized plagioclase (with or without an intervening laumontite zone) follows the analcime zone in pyroclastic rocks of Japan (Utada, 1971; Iijima and Utada, 1972), indicating a sodic alteration of tuffaceous sandstones rather than potassic alteration.

The zonation shown by pyroclastic rock in Japan may be a result of its island-arc setting with sediments derived primarily from a sodium-rich oceanic crust. The fluids that altered the sediments are probably also mostly oceanic in origin. McDermitt sediments (as well as those of the Big Sandy and Lake Tecopa) have a continental setting with volcaniclastic sediments derived from a magma mainly of continental crust or largely enriched with continental crust. The chemical composition of the fluids altering the sediments would be largely derived from meteoric water in contact with the sediments.

The similarities between the mineralogic zonation of the McDermitt sediments and these other areas indicates a distinct pattern of geochemical alteration of tuffaceous sediments. This pattern of mineralogic zonation will be useful as an exploration guide to identify areas of hydrothermal alteration that can result in uranium, mercury, lithium and other hydrothermal ore deposits. Continuing work on the geochemistry and clay mineralogy associated with both diagenetic and hydrothermal alteration in the caldera environment should provide a framework for comparison regardless of environment.

GEOLOGIC SETTING

The present north-south boundary length of the McDermitt caldera complex is 45 km and the east-west boundary width is 35 km. Volcaniclastic sediments form a ring within the collapsed moat of the caldera complex (Figure 1). The base

of the complex is basalt, andesite, and dacite flows of Cenozoic age that were deposited on granodiorite of Mesozoic age. The mafic and intermediate lavas were erupted 24 to 18 m.y. ago and were soon followed by five peralkaline rhyolite ash flows. Each of the ash-flow tuff units represent a specific caldera within the complex.

The volcaniclastic sediments were deposited after the formation of the caldera complex. An andesite flow interstratified with the sediments has a Potassium-argon age date of 16.4 + 1.2 m.y., which indicated that deposition of the sediments occurred shortly after caldera formation. Resurgent domes intrude each of the calderas. Further geologic mapping and age dating of the resurgent domes of the calderas are needed to determine the sequence of caldera events and more closely relate the volcaniclastic sediments to these events.

The volcaniclastic sediments are thickest over the ring fracture zones of the collapsed calderas and they thin toward the central resurgent domes. The sediments may aggregate as much as 200 m in thickness, but over most of their occurrence they average about 80 m. Post-depositional alteration is both diagenetic and hydrothermal.

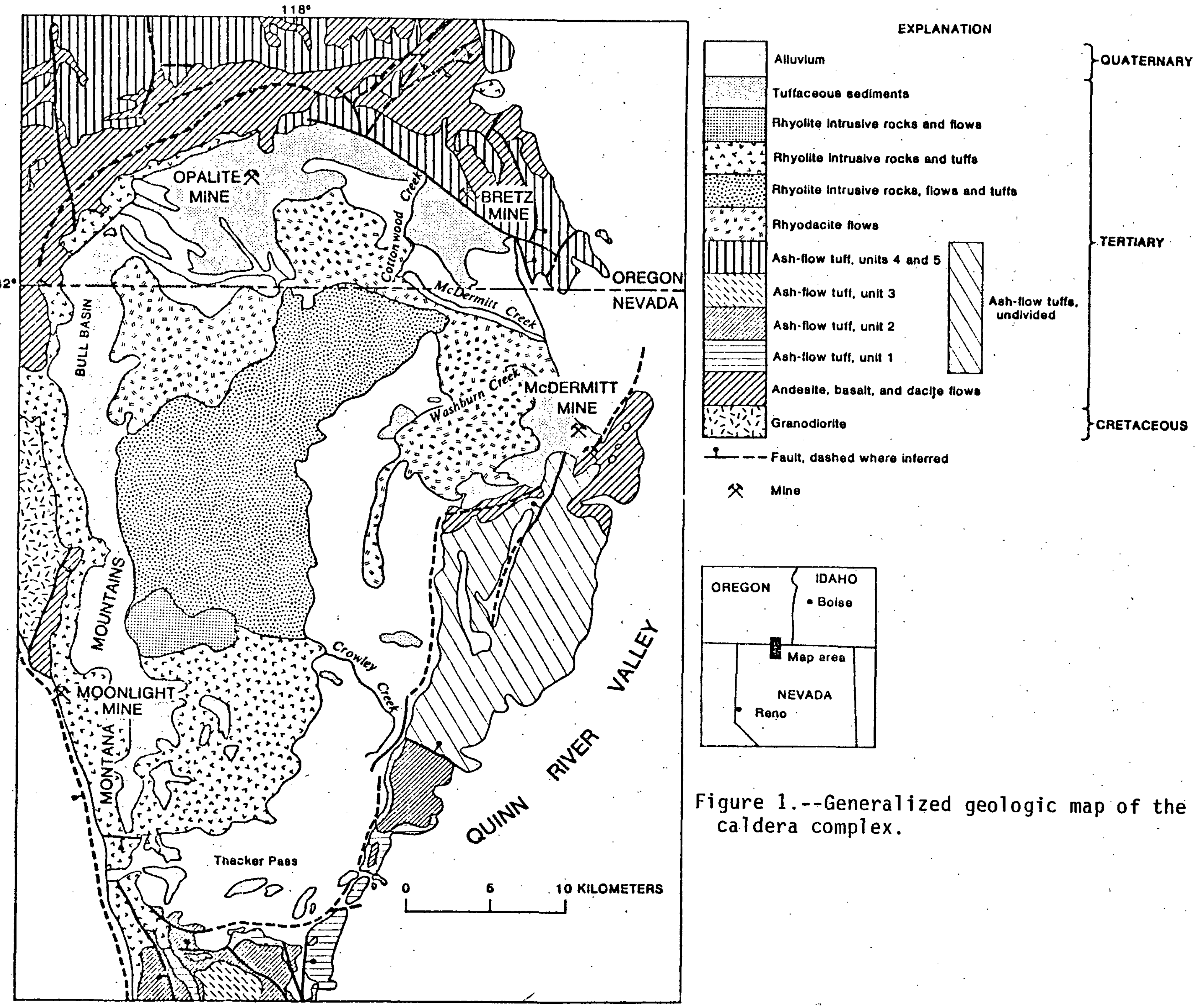

Figure 1.--Generalized geologic map of the McDermitt caldera complex.

Intrusion of the rhyolite ring domes and related intrusions into ring-fracture zones undoubtedly had a significant effect on the alteration of the sediments. Reconstruction of the Miocene surface indicates that the presently exposed intrusions were emplaced 100 to 800 m beneath the Miocene surface; however, a few may have intruded to the surface to form extrusive domes. The domes and intrusions in the western ring-fracture zones were emplaced 14.6 to 13.5 m.y. ago, representing the last stage of rhyolitic volcanism in the complex. Sediments along the western fracture zones are the most altered.

Subsequent to alteration, the sediments on the north and west of the complex were tilted 12° east and deeply eroded during the Pliocene. This part of the caldera is the present-day topographic high for the volcaniclastic sediments and therefore receives enough moisture to support vegetative cover. The cover is distinctive between the tuffaceous sandstone and mudstone units. This difference is particularly evident on aerial photographs allowing the distribution of the mudstone to be easily mapped. The present-day topographic high for the volcaniclastic sediments is in the Montana Mountains area, and is 2,220 to 2,300 m above sea level. In contrast, the Bull Basin section is at about 2,000 m, the Opalite and Bretz mine areas are 1,600 m, and the McDermitt mine is about 1,400 m above sea level. The erosion is a particularly important event because 25 to 40 percent of the lithium-enriched clays, originally associated with the altered tuffaceous sediments, are now interbedded with fluvial sediment in the Quinn River Valley adjacent to the caldera complex.

STRATIGRAPHY OF VOLCANICLASTIC SEDIMENTS

The McDermitt volcaniclastic sediments are divisible into three distinct stratigraphic units. About the lower one-third of the section is a tuffaceous sandstone with minor interbedded mudstone and is largely composed of potassium feldspar and zeolites. The zeolite associated with the potassium feldspar depends on lateral position in the caldera and is erionite, clinoptilolite, or analcime. The medial third of the section is a mudstone with minor amounts of tuffaceous sandstone. The upper third of the volcaniclastic sediments is a tuffaceous sandstone altered to potassium feldspar with minor mudstone interbeds. This upper unit contains a petrified wood horizon that is persistent throughout the area of outcrop. Pliocene-Pleistocene and Holocene erosion has removed most of this unit and part of the medial mudstone from the northwest side of the caldera complex.

ALTERATION

The glass to zeolite alteration shown at the top of Figure 2 schematically depicts the combined hydrothermal but largely diagenetic alteration of the three stratigraphic units from the Bretz area to the Montana Mountains. The tuffaceous sandstone which overlies volcanic flows and intrusives is generally composed of potassium-feldspar with subordinate zeolites. The medial mudstone generally contains only zeolites and clay with interbedded primary oolites on the western side of the caldera complex. The upper tuffaceous sandstone contains essentially equal amounts of zeolites and potassium-feldspar. Smectite is by far the dominant clay mineral group. Lithium-poor dioctahedral smectites form an envelope around the lithium-rich trioctahedral smectites that occur only in the mudstone. Calcite is ubiquitous, generally in the form of a cementing matrix, nodules, and veins. Aragonite occurs in the Bretz area as invertebrate fossil skeletons along with fish skeletons, leaves, and carbonaceous debris. Dolomite occurs in the mudstone of the Bull Basin and Montana Mountains areas. Silica in the least altered tuffaceous sediments is in the form of cristobalite with very little quartz. Quartz increases with the degree of alteration so that in the most altered tuffaceous sediments it is abundant and cristobalite is a minor constituent. Cristobalite crystallinity increases toward centers of hydrothermal alteration as indicated by its _d_(101) spacing. Nearly amorphous or poorly crystalline cristobalite has a _d_ spacing near 4.12 A. Cristobalite in the clinoptilotite-mordenite zone has a _d_ spacing between 4.08 and 4.09 A. Well-crystallized cristobalite has a _d_ spacing of 4.04 A. Cristobalite in the potassium-feldspar zone, intimately associated with ore minerals, has a _d_ spacing of 4.06 A. The lower tuffaceous sandstone contains silicified laminar-bedded layers. The medial mudstone contains opaline to chalcedonic silica nodules and lenses near the contact with the upper tuffaceous sandstone. The upper tuffaceous sandstone contains a persistent petrified-wood horizon. The lower and upper tuffaceous sandstones are oxidized. The mudstone is generally in a reduced state containing pyrite in the Montana Mountains. Almost the entire section is oxidized in the Opalite area as a result of the hydrothermal alteration that formed the mercury deposit.

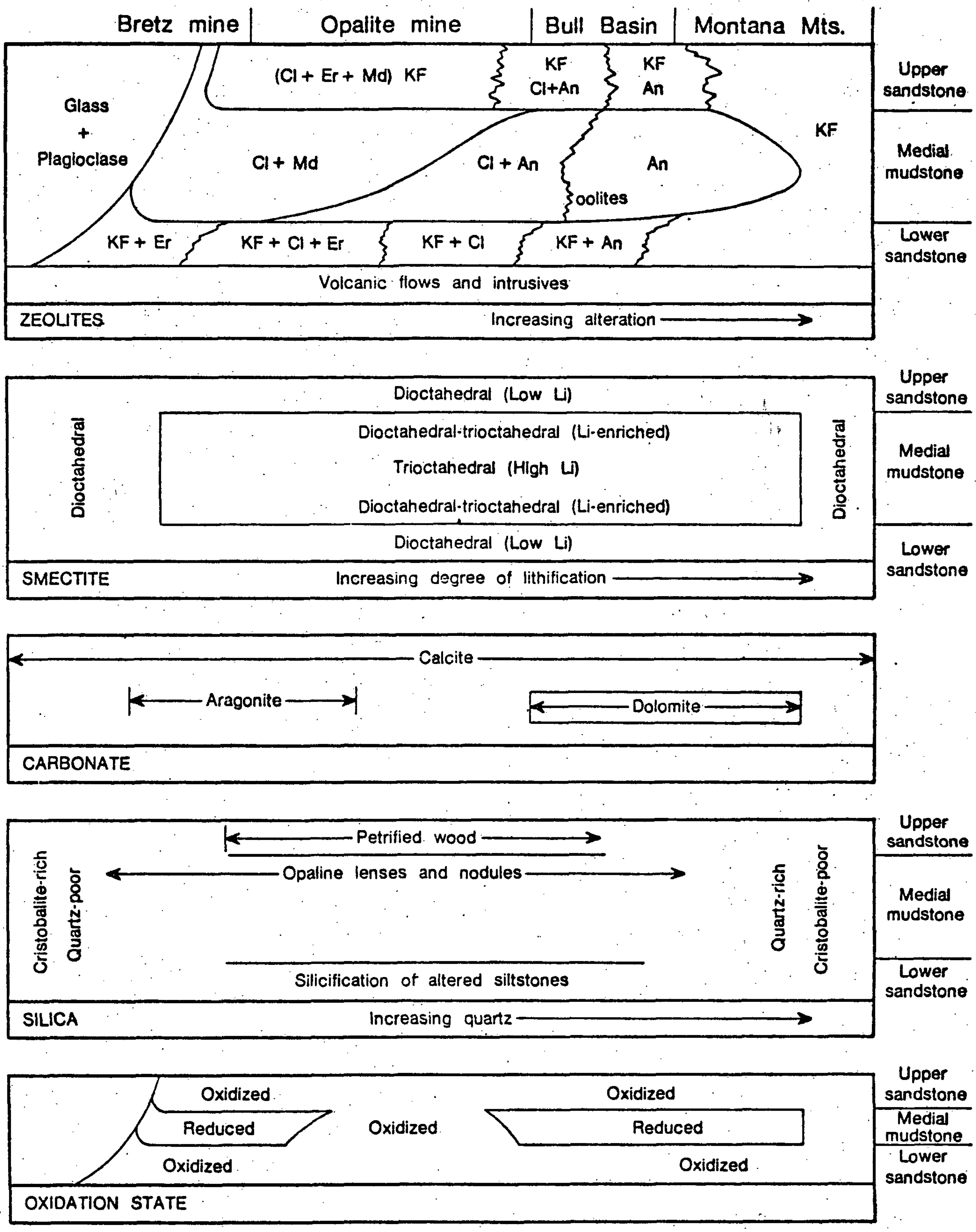

Figure 2.--Relationships between zeolites, smectite, carbonates, silica phases, and the oxidation state of the altered tuffaceous sediments of the McDermitt caldera complex. (Cl, clinoptilolite; Md, mordenite; Er, erionite; An, analcime; and K F, potassium-feldspar. Neither the vertical or horizontal relationships are to scale).

The volcaniclastic sediments are zoned in the order glass, clinoptilolite, analcime, potassium-feldspar in a counterclockwise manner around the caldera complex, beginning with glass in the southeastern part of the complex. Scattered outcrops of very fresh appearing glass occur along a 3.0-5-km-wide alluvial-covered belt on the extreme southeastern side of the complex. These sediments are some of the least altered of the volcaniclastic sediments, but the sediments in the glass zone also contain a dioctahedral smectite, plagioclase, and calcite. The section is not well enough exposed to determine the thickness or the extent of alteration in this belt from the southernmost boundary in eastern Thacker Pass to McDermitt Creek. From the scattered outcrops, it is very probable that the alluvial cover is thin and that glassy sediments may be continuous throughout the belt. If the sediments have not been as eroded as the northern and western sides of the complex, a thickness of as much as 200 m may be attained. Zeolitic sediments occur in the southeastern part of the complex along the upper portions of Crowley Creek. Although outcrops are sparse; the sediments are probably the same type as those found on Washburn Creek and share characteristics with those of the McDermitt mine.

Five sites of hydrothermal alteration have been identified in the McDermitt caldera complex--the McDermitt mine, Bretz mine, a small point source 2 km south of the Bretz mine, Opalite mine, and an area near the boundary between Bull Basin and the Montana Mountains. Hydrothermal alteration at four of the sites has imposed a more advanced zeolite zone on an earlier zone of the general diagenetic zonation skipping one or more zones from the sequence. The McDermitt mine site is the best example of the most easily identified hydrothermal site. Alteration from the glass zone to the potassium-feldspar zone occurs within about 4 km. Alteration in the Bretz area was very intense. Sediments are altered from the glass-clinoptilolite-erionite zone to potassium-feldspar in less than a kilometer. The Opalite mine alteration is very broad and more general than at the other sites. Alteration of the sediments at the Opalite mine from clinoptilolite-potassium-feldspar to potassium-feldspar skips only the analcime zone. The site, near the analcime-potassium-feldspar and potassium-feldspar zones, occurs within the potassium-feldspar zone itself and therefore is not identifiable by this criteria. The change in oxidation state of the sediments, amount of silicification, degree of crystallinity of cristobalite, clay mineralogy, and trace-element distribution define it as a site of hydrothermal alteration.

At each deposit the sediments are oxidized. The intensity of the oxidation varies with the proximity to the hydrothermal center. The coarse-grained tuffaceous sediments at the core of the altered area are strongly silicified into a gray opaline mass in which some of the original tuffaceous material is barely discernable. The tuffaceous sediments above the opalite are altered to potassium-feldspar. The siltstones in the sediments are altered to a dioctahedral smectite, mixed-layer 15-A and 10-A clay minerals, and 15-A and 7-A clay minerals. The 7-A clay mineral is closer to the deposit than the other clay minerals and occurs alone at the deposit. Pyrite and alunite are also present within or very near the mercury mineralization. Lithium is generally less than 0.01 percent.

The potassium feldspar zone grades vertically and laterally into a clinoptilolite-potassium feldspar zone with or without mordenite. Clay minerals in this zone are generally dioctahedral smectites at the base and near the deposit with mixed dioctahedral-trioctahedral smectites above and on the periphery of the deposit. Gypsum and calcite are the accessory minerals in this zone. Lithium contents range from 0.04 to 0.1 percent but may be as high as 0.2 percent. This clinoptilolite-potassium feldspar zone is present in the hydrothermal alteration of both the glass and the diagenetically altered clinoptilolite zones. Hydrothermal alteration of the analcime-potassium feldspar zone has the same oxidation characteristics, clay mineralogy, accessory minerals, and lithium content.

Zones peripheral to the above hydrothermally altered zones are characterized by white or green mudstone in the clinoptilolite zones and a green mudstone in the analcime-potassium feldspar zone. The clay mineral is a trioctahedral smectite in both zones. The smectite is light to dark brown and gel-like or laminar bedded with a bentonitic weathering habit in the clinoptilolite zones. The lithium content ranges from 0.2 to 0.4 percent. The smectite in the analcime-potassium feldspar and the potassium feldspar zone of the Montana Mountains is a well-indurated green claystone with a porcellanitic to waxy luster in a fresh sample. The lithium smectite is probably diagenetic but the smectite in the potassium feldspar zone and perhaps part of the analcime-potassium feldspar zone has been hydrothermally altered to an as yet undetermined extent. The lithium content is 0.3 to 0.7 percent.

McDERMITT MINE AREA

The volcaniclastic sediments are essentially altered to clinoptilolite, clinoptilolite-erionite, and clinoptilolite-mordenite from upper Crowley Creek north to Washburn Creek and east to the McDermitt mercury mine. Each of the clinoptilolite zones generally contains potassium feldspar. The Washburn Creek section, however, contains lithium-enriched trioctahedral smectite and dolomite. In contrast, the clinoptilolite section on the periphery of the McDermitt mine contains lithium-poor dioctahedral smectite and calcite (Figure 3).

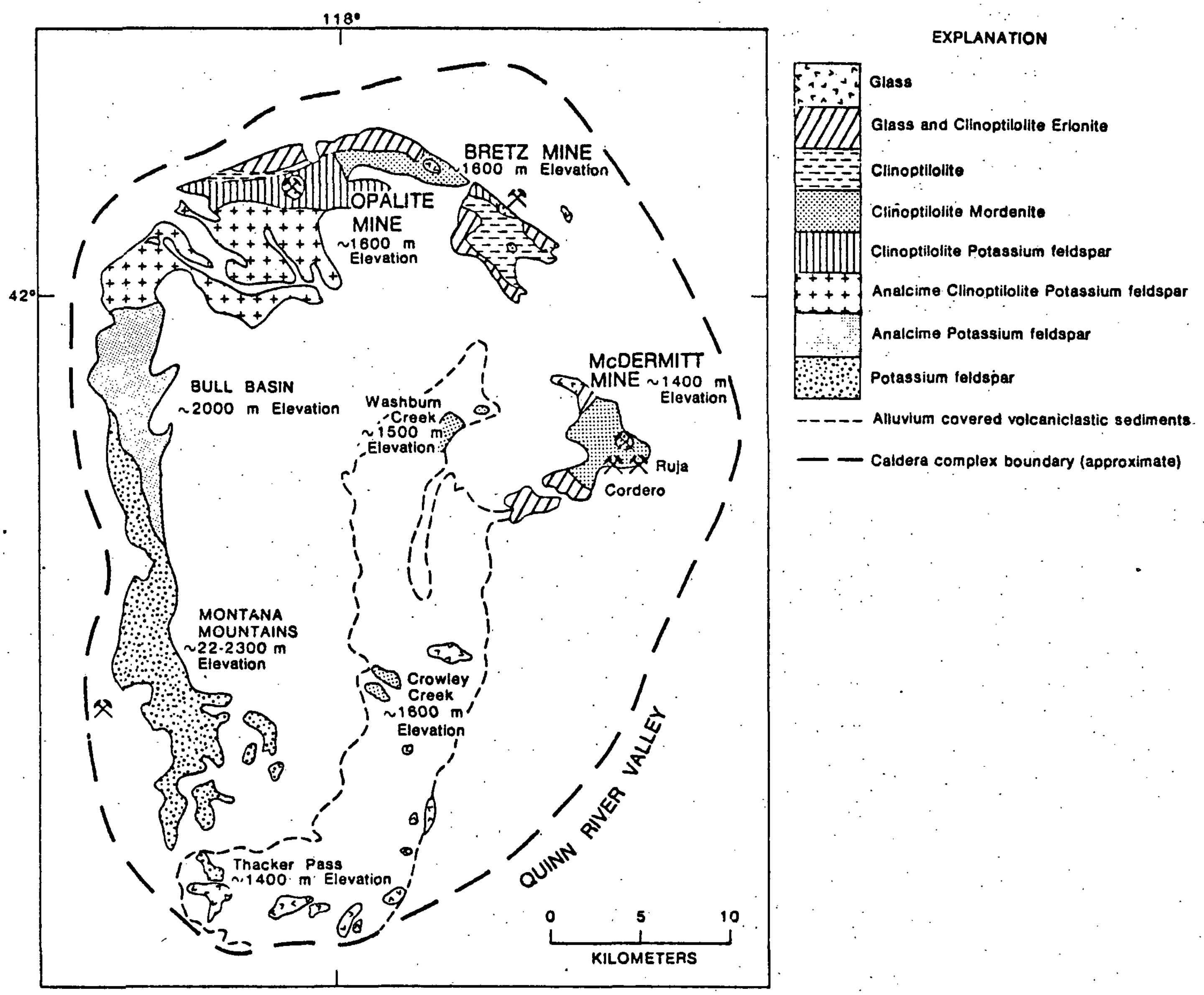

Figure 3.--Alteration zones in the altered tuffaceous sediments in the McDermitt caldera complex.

The alteration around the McDermitt mine is typical of the northern end of the caldera (Figure 4). The clinoptilolite-erionite zone is at the more erionite than clinoptilolite in discrete coarse-textured tuffaceous sandstone. Clinoptilolite increases in abundance until it is dominant, and mordenite is associated with it. Clinoptilolite forms discrete beds but no layers of mordenite alone have been discovered. Most of the clinoptilolite-mordenite zone that surrounds the McDermitt mine has a thin alluvial cover. Much of the zone on the periphery of the mine is partially altered glass and mordenite. Cristobalite, smectite, potassium feldspar, and calcite are associated with all clinoptilolite combinations. Gypsum becomes more abundant as the mine area is approached. Below the clinoptilolite-mordenite layer in the mine pit, potassium feldspar is the dominant mineralogy. Cristobalite, alunite, and a variety of clay minerals are adjacent mineral facies with the mercury-rich potassium feldspar altered sediments. Both well-crystallized (sharp 001 peak) 7-A and 15-A clay minerals are present and irregularly distributed in the clay horizons in the pit area. A few mixed-layered 10-A and 15-A clay minerals also occur but may be dehydrated halloysite-montmorillonite rather than illite-montmorillonite. Work is continuing on the clay mineralogy of the pit area. The smectites are all dioctahedral.

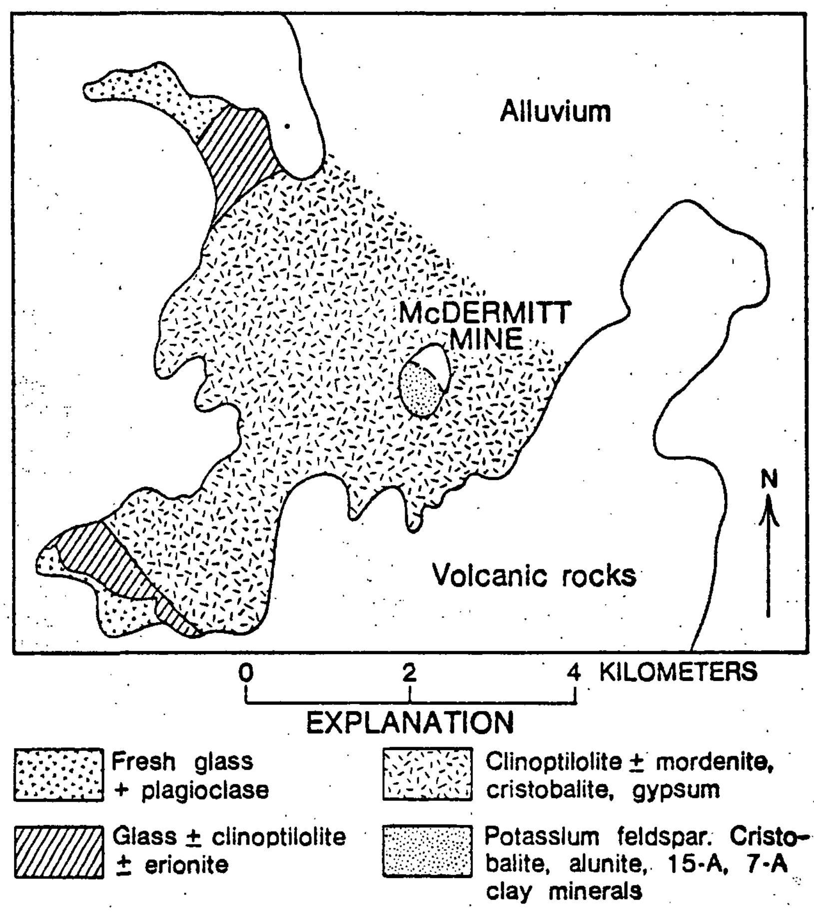

Figure 4.--Alterations zones in tuffaceous sediments near the McDermitt mine.

An outcrop of almost unaltered glass-zone sediments, occurring 2.4 km due east of the Bretz mining area, suggests that the zone of altered glass is present on the north side of the McDermitt mine and that the clinoptilolite alteration may be at least partially hydrothermal at both the Bretz and McDermitt mining areas. The glass has a fresh appearance. Cinders are easily identified in the upper part of the exposure. Plagioclase, calcite, dioctahedral smectite, and quartz are all associated with the glass. The lithium content is as high as 300 ppm but is more commonly 40-100 ppm.

Bretz Mine Area

Alteration of sediments at the Bretz mining area is similar to the McDermitt mine area, but oxidation of the sediments and pyrite around the mine area is much stronger and more evident. The zoning of the alteration is the same--clinoptilolite-erionite at the volcanic rock-sediment boundary, clinoptilolite, clinoptilolite-mordenite, and finally potassium feldspar at the mine.

A section was measured along Cottonwood Creek, which forms the western boundary of the sediment outcrop near Bretz and illustrates the vertical zonation of the alteration (Figure 3).

Alteration of the sediments is linearly concentrated along the ring fracture and decreases toward the center of the caldera complex. Almost unaltered glass is exposed both east and west of the mine. Another center of alteration, although much smaller, is south of the Bretz mine shown by the potassium feldspar zone on Figure 3.

The base of the volcaniclastic sediments has a very irregular surface because of predepositional, depositional, and post-depositional events outlined above in the geologic setting. The sediments in the Bretz and Opalite areas are deposited on a very vesicular, deeply altered basaltic andesite. The color of the sediments is in sharp contrast to the dark dull red of the basaltic andesite. The lower tuffaceous sandstone is light to dark brown, the medial mudstone is white and green, and the upper tuffaceous sandstone is light brown and pale yellow.

The lower tuffaceous sandstone is about 19 m thick and is composed of a repetitive lithologic three unit series. The first lithologic unit in the series is a coarse-textured pale-brown to white clinoptilolite, feldspar, and cristobalite-rich tuff. The tuff has a variable thickness but is as much as

1 m thick. The second lithologic unit is laminar bedded, brown, cristobalite-rich clay 4-6 cm thick that may be silicified (dark reddish brown) and may contain feldspar but little clinoptilolite. The second lithologic unit is commonly interbedded with the third unit of very thin bedded (2 mm), light-brown, clinoptilolite-feldspar-rich clay 2-4 cm thick. The mineralogy and lithium content of the measured section is shown on Figure 5. The graphs for individual minerals are based on the height of the major peak for that mineral measured on an X-ray diffractometer pattern of a powdered rock sample. The clay mineral of this lower tuffaceous sandstone is a dioctahedral smectite with less than 0.02 percent lithium. Just below the base of the medial mudstone unit (19 m), the clay is a mixture of dioctahedral and triotahedral smectite; calcite is consistently present, as is quartz but in very low abundance, and lithium increases to 0.05 percent and more.

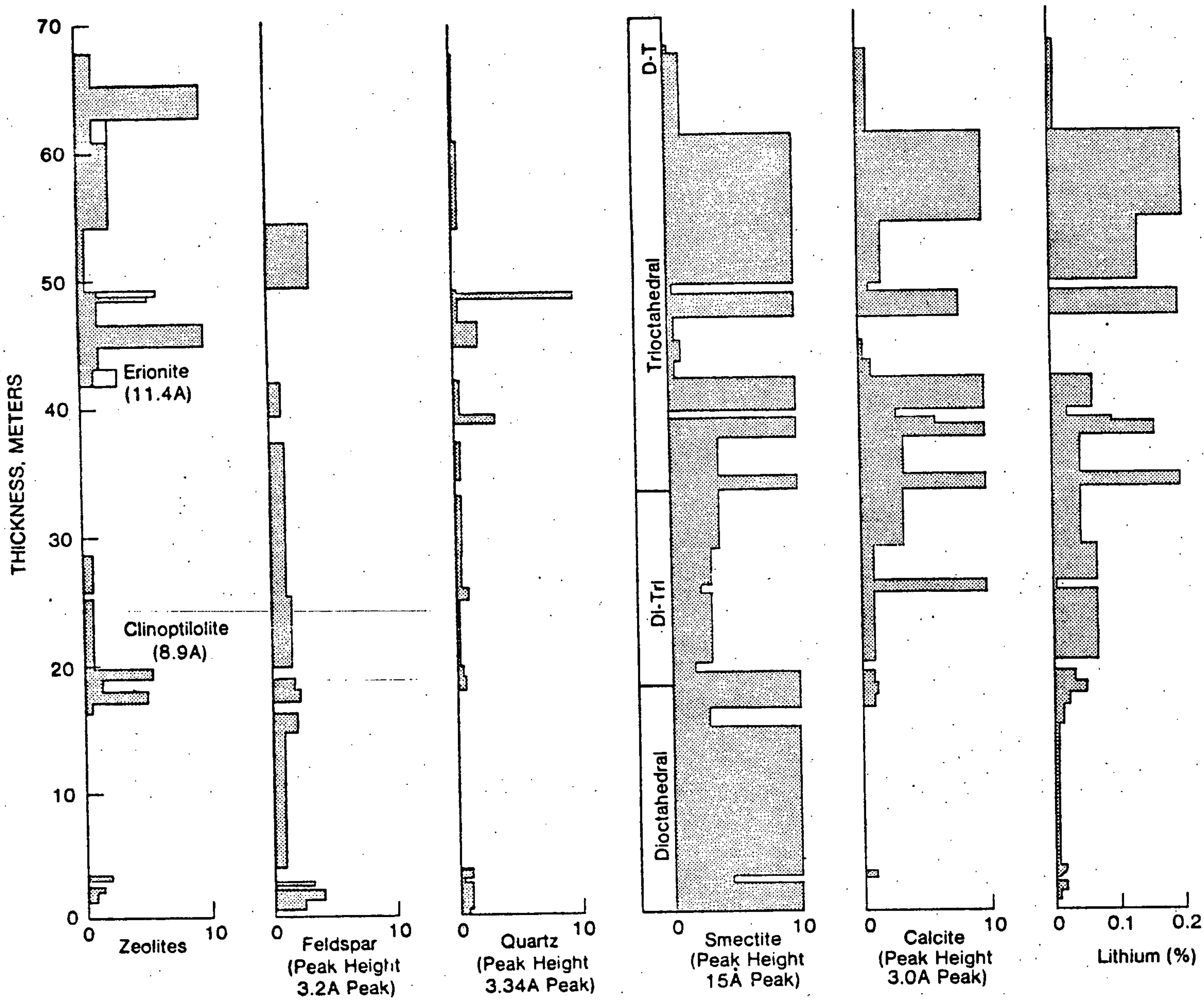

Figure 5.--Relationships between zeolites, potassium feldspar, quartz, smectite, calcite, and the lithium content in the altered tuffaceous sediments in a measured section near the Bretz Mine. (The horizontal scale for each mineral is based on the height of the indicated peak on an X-ray diffractometer pattern. Cu K radiation).

The medial mudstone extends from 19 m to almost 61 m in this section. The mudstone is dominantly white where altered and brown in the upper part. It contains two interbedded green clinoptilolite, clinoptilolite-erionite, or clinoptilolite-mordenite tuffaceous sandstones. The central part of the mudstone is a trioctahedral smectite containing as much as 0.21 percent lithium. Calcite is abundant as a cementing material, as nodules, and as veins. Aragonitic ostracod tests, mollusc and gastropod shells as well as fish skeletons, leaves, and carbonaceous debris are abundant in the mudstone. Massive white, brown, gray, and black ledges (0.3 m) and nodules (1 m across) of opaline silica mark the uppermost part of the mudstone. The mudstone persists a few meters above the opaline silica ledges and nodules.

The upper tuffaceous sandstone begins at about 61 m on the measured section (Figure 5). The measured section was terminated at 68 m because of extensive slumping along a fault. The upper tuffaceous sandstone is 10 to 30 m thick. The sandstone is coarse-grained, massive-bedded, light-brown, clinoptilolite, clinoptilolite-mordenite, or clinoptilolite-erionite (particularly near the volcanic-rock boundary), and potassium feldspar with a few thin interspersed beds of dioctahedral smectite and mixed-layer clay. A horizon containing petrified wood is present in the upper sandstone.

Opalite Mine Area

There is little unaltered glass in the Opalite area. Alteration of the sediments in the Opalite mercury mine area on the northwest side of the caldera complex shows the same zones and vertical section as those at the Bretz mine. An erionite-rich clinoptilolite zone begins at the volcanic-rock wall of the caldera. Erionite decreases with distance from the rock sediment boundary toward the center of the caldera until only clinoptilolite or clinoptilolite-mordenite zones are present. Potassium feldspar is present in all three of the clinoptilolite zones but increases in abundance toward the Opalite mine site where it no longer contains an associated zeolite (Figure 3). The potassium feldspar is enriched around the Opalite mine in an east-west zone parallel to the other three clinoptilolite zones, forming a distinct alteration zone of potassium feldspar associated with clinoptilolite. Clinoptilolite is altered to analcime that forms the analcime-clinoptilolite-potassium feldspar zone south of the Opalite mine. The alteration is essentially complete just a few kilometers south of the Nevada-Oregon State line. This is a transition zone between the clinoptilolite-potassium feldspar and the analcime-potassium feldspar zone. Heulandite was expected to occur with analcime instead of clinoptilolite by analogy with other areas (Utada, 1971), but the temperature test indicated that heulandite was present in only one bed. The bed is a dark-brown tuffaceous siltstone interbedded with clinoptilolite and analcime at the extreme eastern tip of the analcime-clinoptilolite-potassium feldspar zone south of McDermitt Creek in the NW 1/4 of Sec. 3, T. 47 N., R. 35 E.

The vertical section of the Opalite area sediments is essentially the same as that of the Bretz area--a lower tuffaceous sandstone on a very vesicular volcanic-rock base with a medial mudstone containing an opaline silica horizon near its contact with an upper tuffaceous sandstone that contains the petrified-wood horizon. The color of the Opalite section is a uniform light and dark brown even though the green beds are present in the mudstones. The sediments seem uniformly oxidized, perhaps as a result of the hydrothermal alteration at the Opalite mine.

The Opalite mine has a core of gray opaline silica that gives the mine its name. The mine has a large potassium feldspar alteration zone surrounding the opalite core. The clay beds on the periphery of the mine, interbedded with the potassium feldspar, are either a dioctahedral smectite, a mixed dioctahedral-trioctahedral smectite, or a mixed layer 15-A and 10-A clay. The clay minerals in the clinoptilolite-potassium feldspar zone are generally a dioctahedral-trioctahedral smectite even in the mudstone. There are few trioctahedral smectites. The lithium-enriched smectites are commonly mixed structural types, and the highest lithium content in the area is only 0.25 percent. The clay mineral in both the lower and upper tuffaceous sandstones is a dioctahedral smectite. In addition to the petrified wood horizon in the upper tuffaceous sandstone, the only identified interbedded layer of siliceous limestone in the sediments occurs in the extreme southern outcrop of the analcime-clinoptilolite-potassium feldspar zone. Calcite is abundant and gypsum is common in the mudstone but only as nodules, lenses, and veins.

Erosion has removed most of the upper tuffaceous sandstone in the upper reaches McDermitt Creek. Part to all of the mudstone has been removed along the northeast side of the analcime-clinoptilolite-potassium feldspar alteration zone. Oolite beds crop out in the mudstone along and near the contact with the volcanic extrusives of the central resurgent domes. The oolite beds extend from this zone and at least partially through the analcime-potassium feldspar zone in Bull Basin.

Bull Basin

Alteration of volcaniclastic sediments in Bull Basin, west of Disaster Peak, has progressed to the formation of an analcime-potassium feldspar zone. The sediments intertongue with gravels and conglomerates derived from terrain outside the caldera and from erosion of the caldera walls on the west side of the zone. Erosion of the zone on the north end of its outcrop, about 3 km east of Disaster Peak, has cut through most of the section and this intertonguing is best exposed. The gravels extend from the caldera walls east to at least half way across the outcrop at the base of the middle green mudstone unit in the zone.

The medial mudstone is better indurated than in the preceding alteration zones. The color is a brighter green on a weathered surface in sharp contrast to the interbedded light-brown potassium feldspar altered tuffaceous sandstone. Oolite beds are also interbedded in the mudstone, particularly along the eastern side of the zone. The lithium content increases in this zone to as much as 0.4 percent. Dolomite is part of the mineralogy of the homogeneous-appearing mudstone. Calcite is still abundant but in the form of nodules and veins. The mudstone unit is present in scattered poorly outcropping patches in the topographic transition between Bull Basin and the Montana Mountains.

The wedge-shaped facies of potassium feldspar that extends north from the Montana Mountains along the west side of Bull Basin includes a hydrothermally altered area similar to Bretz and Opalite but perhaps not as intensely altered because of a more remote intrusive. The basal units of the tuffaceous sediments are exposed in the creek cut in Sec. 3, T. 46 N., R. 34 E. The basal unit is much like that of the Bretz section with silicified laminar-bedded cyclic lithologic units alternating with potassium feldspar altered tuffaceous sandstone. The mudstones that overlie and form the medial part of the section are oxidized to dark brown. The lithium content in the mudstones of this area decreases to approximately 0.25 percent. Dolomite and some analcime are present in the mudstones. The smectites are a mixture of dioctahedral and trioctahedral structural types, and a mixed-layer 15-A and 10-A clay mineral appears in the section. Most of the mudstone and all of the upper tuffaceous sandstone have been removed by erosion. All three units are present in the Montana Mountains section.

Montana Mountains

Altered sediments in the Montana Mountains part of the caldera complex are poorly exposed. Road cuts and two bulldozer trenches expose the medial mudstone unit at the surface. Cuttings from a drill hole in unsurveyed T. 45 N., R. 34 E. enabled the determination of the mineralogy of the altered sediments shown on Figure 6. The almost-80-m-thick section can be separated again into three zones--a lower potassium feldspar-rich reddish tuffaceous sediment, a medial green mudstone, and an upper brown potassium feldspar altered tuffaceous sandstone. There are significant differences in the alteration of these sediments from that of the Bretz section.

Figure 6.--Relationship between zeolites, potassium feldspar, quartz, smectite, calcite, dolomite, and the lithium content in the altered tuffaceous sediments in drill-hole cuttings from the Montana Mountains. (The horizontal scale for each mineral is based on the height of the indicated peak on an X-ray diffractometer pattern. Cu K radiation).

The lower tuffaceous sandstone is interbedded with lenses of gravel that contain clasts of volcanic rock which were deposited on an altered rhyolite flow.

The medial mudstone is probably the same unit as in the other areas, but it is quite well indurated. It is brilliant light green on the weathered surface and dark green, almost porcelaneous to waxy, on a fresh surface. The unit is a lithium-enriched trioctahedral smectite containing as much as 0.68 percent lithium and also contains pyrite. Pyrite occurs as nodules of cubic crystals as much as a centimeter in diameter. The individual crystals are almost 3 mm on a face. Chemical weathering of near-surface exposures of this medial mudstone has removed the pyrite, filled the crystal cast with gypsum, and coated the crystal-cast walls with brown iron oxide. An opaline silica-rich unit also occurs in the mudstone in the same relative stratigraphic position as it does in the other areas. The structure of the smectite changes gradually from dioctahedral in the lower tuffaceous sandstone, to a dioctahedral-trioctahedral mixture, to trioctahedral in the medial mudstone, and then back through a dioctahedral-trioctahedral mixture to dioctahedral in the upper tuffaceous sandstone. Calcite and dolomite correlate fairly well with the lithium and smectite distribution. The feldspar and quartz have an inverse relationship to the lithium, smectite, calcite, and dolomite. The section is very quartz-rich compared to the quartz-poor Bretz section. Quartz is lowest where both clinoptilolite and analcime occur in the lower part of the section and in the mudstone section. Analcime, although low, appears in both the lower tuffaceous sandstone and medial mudstone. The occurrence of clinoptilolite with analcime this far south in the caldera fill is surprising. The occurrence of clinoptilolite suggests that the alteration occurred from the top down leaving this only partly altered remnant when the rest of the clinoptilolite was altered to analcime. Work is continuing in the area on the mineralogy of other drill-hole cuttings and the lithium-rich trioctahedral smectite.

South of the Montana Mountains on the western side of Thacker Pass, the sediments are altered to light brown and white potassium feldspar and quartz. A few beds of dark-brown, low-lithium, dioctahedral smectite, mixed dioctahedral-trioctahedral smectite, and one trioctahedral smectite bed are interbedded in the tuffaceous sandstone. A piece of petrified wood was collected from the surface of one outcrop. Exact correlation in this highly faulted part of the caldera is not possible at this time, but it appears to be an area in which the most altered and least altered sediments intertongue. Preliminary gravity work indicates that this area may contain the thickest section of volcaniclastic sediments. The glass zone may simply be a relatively unaltered upper part of the section similar to the area west of the Bretz section that overlies the complete three-unit sequence. If a complete sequence is proven by drilling, it will be the sixth area of hydrothermal alteration and probably will be mineralized.

SUMMARY

The zonation of the zeolite and clay minerals resulting from diagenetic alteration of the volcaniclastic sediments within the collapsed moat of the McDermitt caldera complex agrees, in general, with the zonation described in the Lake Tecopa lacustrine beds of Pleistocene age (Sheppard and Gude, 1968), tuffaceous rocks of the Big Sandy Formation of Pliocene age (Sheppard and Gude, 1973), and zones I, II, and III of the pyroclastic rocks of Neogene age in Japan (Utada, 1971). Zones I, II, and III correspond to the glass, clinoptilolite, and analcime zones, respectively.

Five sites of hydrothermal alteration are imposed on the diagenetic zonation sequence-the McDermitt mine, Bretz mine, a point source 2 km south of the Bretz mine, Opalite mine, and near the boundary between the Bull Basin and the Montana Mountains. Four are identified by zeolite zonation, and all five can be identified by mineral zonation, oxidation state of the sediments, amount of silicification, degree of crystallinity of cristobalite, clay mineralogy, lithium content, and other trace element distribution. These criteria should be generally applicable to other areas of hydrothermal alteration of volcanogenic sediments with possible mineral potential, regardless of whether the sediments were deposited in a caldera or in a basin.

REFERENCES CITED

Glanzman, R. K., Rytuba, J. J., and McCarthy, J. H., Jr., 1978, Lithium in the McDermitt caldera, Nevada and Oregon: Energy, v. 3, no. 3, p. 347-353.

Iijima, A., and Utada, M., 1972, A critical review on the occurrence of zeolites in sedimentary rocks in Japan: Japanese Journal of Geology and Geography, v. 62, no. 1-4, p. 61-84.

Rytuba, J. J., 1977, Uranium content of tuffaceous sediments and opalite mercury deposits within the McDermitt caldera, Oregon-Nevada: Geological Society of America Abstract with Programs, v. 9, no. 4, p. 492.

Rytuba, J. J., and Glanzman, R. K., 1978, Relation of mercury, uranium, and lithium deposits to the McDermitt caldera complex, Nevada-Oregon: U.S. Geological Survey Open-File report 78-926, 19 p.

Sheppard, R. A., and Gude, A. J., 3d, 1968, Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California: U.S. Geological Survey Professional Paper 597, 38 p.

______1973, Zeolites and associated authigenic silicate minerals in tuffaceous rocks of the Big Sandy Formation, Mohave County, Arizona: U.S. Geological Survey Professional Paper 830, 36 p.

Utada, M., 1971, Zeolitic zoning of the Neogene pyroclastic rocks in Japan: Earth Science and Astronomy, University of Tokyo, v. 21, no. 2, p. 189-221.