University of Nevada

Reno

Geology, Alteration, and Mineralization in the Pyroclastic and Sedimentary Deposits of the Bretz-Aurora Basin, McDermitt Caldera, Nevada-Oregon

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

by

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Miocene to Pliocene age sediments in the Bretz-Aurora basin, 16 miles west of McDermitt, Nevada, form as a series of blanketing phreatomagmatic and plinian, ash and lapilli, subaerial and subaqueous deposits.

Epithermal mercury associated with uranium, forms the center of an irregular zonational pattern in the lower 24.4m (80 ft.) of the stratigraphic section. A zonational sequence; mercury/silica-dioctahedral smectite (aluminum-rich)-pyrite-uranium/calcium carbonate-amorphous silica/minor uranium, progresses away from the center of the mineralizing system. The minerals and their distribution suggest a highly alkaline mineralizing solution with a pH greater than 9. A gradual decrease in pH and differences in solubility of each component created the zonational pattern.
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INTRODUCTION

The Bretz Mercury Mine is 380 highway kilometers (260 miles) northeast of Reno, Nevada and approximately 23 kilometers (16 miles) west-northwest of McDermitt, Nevada, on the Oregon side of the McDermitt caldera complex (Figure 1). The area of study covers seven and a half square kilometers (five square miles) to the west, south and southeast of the Bretz Mercury Mine, in T.41S., R41E. and T.40S., R41E. Access to the area is good along an east-west gravel county road, except in periods of heavy snow. The terrain is relatively flat in the study area, allowing two-wheel drive access, but within two miles the relief can reach 914m (3,000 ft.). The area is uninhabited and presently leased from the Bureau of Land Management for cattle grazing.

The McDermitt caldera complex is in a transition zone between the Columbia River plateau province on the north and the basin and range province on the south (Willden, 1964). There is a broad plateau held up by relatively flat lying rocks that is interrupted by rather broad valleys and assumes the appearance of the basin and range province (Willden, 1964). The McDermitt caldera complex has locally disrupted the basin and range faulting.

The climate is semi-arid with normal annual precipitation in the range of 13-25cm (5-10 inches) (Visher, 1954). About one-half of this falls in the winter, generally less than 2.5cm (1 inch) falls in summer months (Visher, 1954).
Vegetation is sparse in the low-lying areas and increases with increasing elevation. Several types of sagebrush are ubiquitous, along with juniper (Juniperus utahensis) and cottonwood (Populus fremontii) near streams in canyons and along springs in higher elevations. Most of the entire area is part of the United States Bureau of Land Management's Sonoran Desert Ecosystem Reserve. In preparation for the seeding of the area, the Bureau of Land Management killed 531 acres of sagebrush in the spring of 1968 and in the fall of 1969 created wheat over the same area (written communication, F. Hodge, U.S.B.L.M., 1980). Construction of a cross-field system completed the seeding project by the end of the previous year (written communication, F. Hodge, U.S.B.L.M., 1980).

Figure 1. Index map to study area.
The area is characterized by hot summers and cold winters (Willden, 1964). The normal daily maximum temperature is 32.2-35°C (90-95°F) during the last half of July (Visher, 1954), although a temperature as high as 37.8°C (100°F) is not uncommon (Willden, 1964). The normal daily minimum temperature in the middle of January is about -9.4°C (15°F) (Visher, 1954), but temperatures as low as -28.9°C (-20°F) and lower have been observed (Willden, 1964).

Vegetation is sparse in the low-lying areas, but increases with increasing elevation. Several species of sagebrush are ubiquitous, along with juniper (juniperus utahensis) and cottonwood (populous fremontii) near streams, in canyons, and along springs in higher elevations. Most of the study area is part of a United States Bureau of Land Management seeding project. In preparation for the seeding the Bureau of Land Management killed 2631 acres of sagebrush in the spring of 1968 and in the fall of the same year planted crested wheat over the same area (written communication, F. Hodge, U.S.B.L.M., 1980). Construction of a watering system completed the seeding project by the end of the year (written communication, F. Hodge, U.S.B.-L.M., 1980).

PREVIOUS WORK

The earliest geologic reports pertaining to the caldera complex were by Schuette (1933), Yates (1942), and Bailey and Phoenix (1944) describing the Opalite quick-
silver district. Taylor and Powers (1955), and Sharp (1955, 1956) wrote descriptions of the Moonlight and Granite Point uranium properties on the western edge of the caldera.

Walker and Repenning (1965) were the first to publish a regional geologic map, at a reconnaissance level, of the Adel Quadrangle, Lake, Harney and Malheur counties, at 1:250,000. Fisk, (1968) wrote a description of the Cordero Mercury Mine. Greene (1972) initiated the idea of a caldera complex and published a map of the region. McKee (1976) discussed the relationship between the caldera structure and the mercury mineralization. Rytuba and others (1976-1980) have published nine papers to date, on the geology, alteration, uranium, mercury, and lithium occurrences. Glanzman (1978, 1979) co-authored papers with Rytuba, dealing with the "lake beds" or "moat sediments."

Some of Rytuba's descriptions in his earlier published work did not agree with observations by Wallace and Roper (1980), geologists for Cordex Exploration Company and Placer-Amex, Inc., respectively. As a result, Wallace and Roper co-authored two papers on the Aurora and Bretz Uranium Mineralization. Drill hole interpretations assisted Wallace and Roper in proposing ideas differing from Rytuba's original concepts of the uranium deposits and geology of the adjacent areas.

Wallace, and others (1980) recognized icelandite and aenigmatite-bearing pantellerite in the caldera complex. The recognition of the unusual rock types and Glanzman's
(1978, 1979) work were used as a guide to lithologic descriptions, alteration, and stratigraphy of the sediments. Publications by Wallace and Roper (1980) gave insight to mineralization in the volcanics for possible application to mineralization in the sediments.

Cordex Exploration Company, Placer-Amex, Inc., and Locke Jacobs' work in the area since 1978, includes geologic mapping, drilling, sampling, and geophysics. Access to their information aided the completion of this study.

METHOD OF INVESTIGATION AND ANALYTICAL TECHNIQUES

In the early fall of 1978 a small section of sediments near the Bretz Mine was mapped at a scale of 1:4800 without the use of aerial photographs. The majority of field work and analytical analysis was later completed in the summer and fall of 1980. The area was mapped on a topographic map at a scale of 1:4800 with 3m (10 ft.) contour intervals and later transferred to a map at a scale of 1:12,000. Color aerial photographs at a scale of 1:9600 aided the mapping for most of the area. Areas not covered by color photographs were mapped with the aid of black and white aerial photographs at a 1:12,000 scale. For clarity and less cluttering the final map was drafted using 15.2 m (50 ft.) contour intervals.

Every tuff unit differing in field appearance was sampled for petrographic analysis. A total of 18 thin
sections and two polished sections were studied to determine compositional variations. Some mineral identification was aided by standard x-ray diffraction techniques. Ten of the 18 thin section samples were analyzed for major elements, on pressed powder self-supporting discs, by x-ray fluorescence methods similar to that described by Hutchison (1974), employing a Siemens Kristalloflex IV Generator and a Universal Sequential Spectrometer (SRS-1).

All clay samples were kindly analyzed by the R. T. Vanderbilt Company, (a clay exploration and development company). Each sample's colloidal suspension was analyzed for the percent yield, colloidal viscosity, and acid-salt stability. Clay color was determined and given a numerical value from 1-100 (the higher the value the lighter the color). The colloidal fraction of each sample was analyzed through the use of x-ray diffraction for smectite, cristobalite, kaolinite, orthoclase, erionite, clinoptilolite, calcite, and others, such as gypsum, quartz, and mica. The crude samples were also analyzed for the same minerals using similar procedures.

Tests on the potential hectorites included viscosity, acid compatibility, salt compatibility, acid demand, and specific resistance. Variations of salt content, percent solids, NaOH, and NaCl tested other specific properties of the potential hectorites. Procedures and results are compiled in the appendix. Samples containing hectorites were analyzed for arsenic, lead, lithium, sodium, and potassium.
The arsenic and lead values were obtained from crude samples, while lithium, sodium, and potassium contents were from the colloidal fraction.

Mercury in rock chip samples was kindly analyzed by Placer-Amex Inc., at the McDermitt Mercury Mine assay lab. The equipment produces reliable results and has sensitivity to parts per billion (ppb).

Uranium concentrations were determined from the results of several tests. To test for disequilibrium, the radiometric assays, determined by the "closed can" method, (cf. Bailey and Childers, 1977) were compared to chemical assays of the same material, in both core and drill cuttings. If the chemical assay value was less than the closed can assay value, the uranium was considered out of equilibrium, which was the case for most of the oxidized samples. This proved the gamma ray probe logs as inaccurately high for determining uranium concentrations. The uranium had been leached from the rock, but the less soluble radioactive daughter products remained behind.

Unoxidized samples resulted in chemical assay values equal to, or greater than the closed can assay values for the unoxidized samples. The gamma-ray probe log gave accurate or slightly lower results.

From these results, the uranium content in all oxidized material was determined by chemical assay methods and the unoxidized material was evaluated with gamma ray probe logs. The method for evaluation, using standard
techniques, is described as the "area-under-curve method" by the Atomic Energy Commission (Hallenburg, 1973).

This study focuses on the pyroclastic and sedimentary deposits within the Grants-Aztec basin, which are described in detail. The volcanoes that underlie the deposits are discussed briefly below to provide insight into relationships between these two major divisions.

Miocene ash-flows, lavas, and domes of the Judgesett caldera sequence surround and underlie Tertiary sediments (Rytuba, 1976). A Cretaceous quartz monzodiorite is the oldest unit and crops out on the western end of the caldera complex in the Xinger River Valley (Rytuba, 1976).

VOLCANICS

The Miocene volcanics in the area of study (Plate 1) are divided into two series by Wallace and Rogers (1980): (1) the Grants series and (2) the Aztec series. Wallace describes the Grants series volcanics as the footwall of an outflow sequence. The oldest rock in the sequence is a quartz-rich rhyolite ash-flow tuff (T1t), this rock crops out at the northeast corner of the geologic map (Plate 3). The unit is overlain by a calcicrime-rich rhyolite ash-flow tuff (T2t). Highly contorted secondary flow features are characteristic of this unit, and in most places, a nitrophyrus-lies at the top of the unit. Above the unit lies a complex sequence of thin basalt and andesite lavas (100-
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Miocene ash-flows, lavas, and domes of the McDermitt caldera sequence surround and underlie Tertiary sediments (Rytuba, 1976). A Cretaceous quartz monzonite is the oldest unit and crops out on the western end of the caldera complex in the Kings River Valley (Rytuba, 1976).

**VOLCANICS**

The Miocene volcanics in the area of study (Plate 1) are divided into two series by Wallace and Roper (1980); (1) the Bretz series and (2) the Aurora series. Wallace describes the Bretz series volcanics as the footwall or outflow sequence. The oldest rock in the sequence is a quartz-rich rhyolite ash-flow tuff ($Tt_1$). This rock crops out at the northeast corner of the geologic map (Plate 1). The unit is overlain by a sanidine-rich rhyolite ash flow tuff ($Tt_2$). Highly contorted secondary flow features are characteristic of this unit, and in most places, a vitrophyre lies at the top of the unit. Above the unit lies a complex sequence of thin basalt and andesite lavas (ice-
landites?) with a feldspar rich vitrophyre at the base of the Tlb unit. The vitrophyre sometimes merges with the Tt₂ basal vitrophyre. Unconformably above the Tlb is a phenocryst poor rhyolite ash-flow tuff with common secondary flowage features and breccia (Trt). Devitrification spherulites are prominent in the upper portions and in most places the unit has a basal vitrophyre. Near the base of the unit an aenigmatite-bearing pantellerite has been recognized and described by Wallace and others (1980). Landslide debris is common within the unit.

The Aurora Series from Wallace and Roper refers to the rocks within the caldera's ring fracture or the hanging wall sequence (Plate 1). The oldest unit is thought to be the Trt mentioned in the Bretz sequence, a crystal poor rhyolite ash-flow tuff. Above it lies a sanidine rich vesicular rhyolite (Tmc). The rhyolite crops out at the southern end of the geologic map, near McDermitt Creek. A younger rhyolite (Tar) forming domes and small flows intrudes the Tmc unit and other units. The top of the Aurora series and the youngest volcanic lava flows in the caldera (14.2 m.y. ± .2 m.y. (Rytuba, 1980)) are the Aurora Series Lavas (Ta) described by Wallace and others (1980) as an icelandite. The tops of the icelandite flows are very vesicular with a rare alkali feldspar phenocryst. The more dense forms contain variable amounts of phenocrystic plagioclase, clinopyroxene, Fe-Ti oxides, and in some rocks, olivine in a glassy, pilotaxitic, or hyalopilotaxitic ground mass (Wallace and
PYROCLASTICS AND SEDIMENTARY DEPOSITS

The Bretz-Aurora Basin is filled primarily with pyroclastic deposits. Sediments (limestones and shales) are interbedded with some pyroclastics. The distinction of sediments from pyroclastics are discussed in their appropriate map units.

The depositional contact between the pyroclastics and the volcanic flows is very sharp and conformable. There are no signs of reworking or soil layers separating the pyroclastics from the volcanic flows. The pyroclastics blanket the basin as subaerial and subaqueous ash beds. As a result the same normal depositional sequence is encountered overlying ash-flows (Trt), icelandite (Ta), rhyolite domes (Tar), and rhyolite flows (Tmc).

Presently active slump and landslide movement is observed above the Bretz Mine pits, suggesting similar occurrences during sedimentation. Near the ring fracture zone landslides and slumps disrupted the normal sedimentary sequence of the central portion of the basin. From drill hole data, none of the slides or coarse breccia/conglomerate zones were continuous over a large enough area to be separated as a map unit.

The deposits are divided into six units for mapping purposes. Each mapping unit can be divided into many other separate units (Plate 2a and b) but only in certain others, 1980).
areas of the basin where outcrop is good.

The grouping of map units was determined by outcrop, composition, thickness characteristics, and easily recognizable float, which in many cases was the only available means of rock identification. The restricted movement of float chips in the flat topography permits the use of float chip mapping techniques.

The sedimentary stratigraphic section in the Bretz Basin is over 210m (700 ft.) thick along the first drainage to the east of Cottonwood Canyon (Plate 2a and 2b). The measured thickness and actual thickness of the sediments in drill hole intersections correspond closely to each other.

Compositional variations (Figure 2) have been noted throughout the stratigraphic section and will be discussed separately for each map unit. All mineral percentages and grain sizes have been visually estimated. As standard procedure, microscopic measurements will be given in millimeters.

Tbt

The Tbt map unit can be divided into a maximum of four separate eruptive ash units grading from coarse at the base to fine at the top. All four units are classified by particle size as a volcanic ash with some lapilli (Fisher, 1961).

Tbt has a total maximum thickness of 6.1m (20 feet), in the measured section, but on the average it is 1 to 1.5m
Figure 2. Plot of Fe as Fe$_2$O$_3$ against SiO$_2$ for eruptive ash units occurring as sediments in the Bretz-Aurora basin. Field of comendites based on eleven analyses from Noble and Parker (1975), Green (1976), and Rytuba and Glanzman (1979). Comendites and icelandite taken from Wallace and others (1980).
Figure 3a. Outcrop of Tbt map unit in the measured section.

Figure 3b. Photomicrograph of Tbt ash shards(s), lapilli (l), and a small bright white plagioclase (An 60-65) fragment(p). Width of field 3.38 mm. Transmitted plane-polarized light.
(3-5 feet) thick forming poor outcrop (Figure 3a). It has been recognized at both ends of the basin (Plate 1), but drill holes throughout the basin prove its irregularity in distribution and thickness. Its irregularity without a meaningful pattern suggests a localized source, possibly the same as responsible for the Aurora Lava flows.

The basal unit is a very poorly sorted pumice fragment ash with lapilli up to 1cm long elongated parallel to the bedding. Most of the lapilli are flat and vesicular (Figure 3b), characteristic of basaltic ash of a magmatic subaerial deposit (Heiken, 1972). Vapor phase minerals are a minor constituent in the cavities and pumice fragments.

The overlying eruptive unit is coarse with a 0.7mm grain size and less than one percent lapilli. Vapor phase minerals are present as a minor constituent in pumice cavities, as in the unit below. The top of the unit abruptly changes to a very fine grained, less than 0.05mm grain size, blocky ash.

The next eruptive unit contains more glass and no lapilli. The glass shards are thicker, the sorting is moderate, and vapor phase mineralogy is the same as the unit it overlies. The upper part of the unit is composed of very fine ash, as in the tops of beds below it.

The upper part of the map unit is composed of black volcanic glass as coarse shards and as one to two millimeter scoriaceous grains. This unit grades into fine
laminated beds, less than 1mm thick, composed of glass shards. The shape and size of the shards suggest a magmatic subaerial eruptive environment (Heiken, 1972).

X-ray fluorescense indicates the ash is compositionally similar to the underlying icelandite described by Wallace, and others (1980) (Figure 2, 10). Microscopically the ash units average 95 to 99 percent volcanic glass and 1 to 3 percent plagioclase fragments (An 60-65) ranging from 0.05mm to 0.2mm with well developed carlsbad-albite twinning.

**Tss**

The Tss map unit is a series of thin, rhythmic, eruptive units of comenditic to low silica rhyolitic ash (Figure 2, 01, 04, 05) (Figure 4a).

The majority of the map unit contains a repetition of less than 1 meter (3 feet), silica poor rhyolitic eruptive units (Figure 2, 01, 04). Some are poorly sorted, but all have normal gradational sequences. The tops of the eruptive units have very thin laminated bedding (Figure 4b and 4c). As a result of mineralizing solutions, the tops of each individual eruptive unit can be accentuated by amorphous hyaloclastic silica flooding and pyrite as seen in the measured stratigraphic section (Figure 4a) and in Figure 4c.

The base of the map unit is a 2.8m (8.5 foot) thick well sorted potassium feldspar and glass ash with an
Figure 4a. Outcrop of Tss map unit in measured section. Silica rich resistant beds accentuate the tops of eruptive units.

Figure 4b. Hand sample of very fine laminated tops of Tss eruptive units.
Figure 4c. Photomicrograph of very fine laminated tops of eruptive units with hyaloclastic silica (white oval shapes). Pyrite (black) accentuates bedding. Width of field 3.38 mm. Transmitted plane-polarized light.

Figure 4d. Photomicrograph of coarse blocky vesiculated ash(s) and feldspar fragments(f) of the Tss map unit. Width of field 3.38 mm. Transmitted plane-polarized light.
average grain size of 0.5mm (Figure 4d). Its chemical composition plots at the edge of the comendite field (Figure 2, 05) which is a compositional equivalent of the rhyolite flows mapped by Wallace. The comendite ash contains 5 to 7 percent subhedral to anhedral, slightly mottled potassium feldspar fragments (Figure 4d).

The fairly constant thickness and repetition of each ash unit along with the blocky vesiculated nature of the ash grains (Figure 4d) suggests the volatile-rich phreatomagmatic eruptive environment (Heiken, 1972). Organic debris is encountered at the tops of some eruptive cycles (Plate 2a), and is indicative of a swampy or lacustrine environment with minor vegetation. Near the edge of the basin, at the Bretz Mine, fossil leaf imprints are common also suggesting a swamp or near shore environment.

**Tmt**

The Tmt map unit is distinguishable in outcrop by its thicker massive ash units. A 15.2 meter (50 foot) thick rhyodacitic volcanic ash unit lies at the base of the map unit (Figure 2, 08) (Figure 5a, b, c). In outcrop the basal portion of the rhyodacitic ash unit is very poorly sorted with angular lithics and nonwelded pumice up to 2.5cm in size. Most pumice fragments have devitrified leaving a vuggy appearance in outcrop. The upper 12.8 meters (42 feet) of this unit is very fine bedded to laminated (Figure 5a), forming a distinguishable outcrop by its lack of vege-
Figure 5a. Outcrop of finely laminated Tmt occurring at the top of the lowest eruptive unit within the map unit.

Figure 5b. Hand sample of rhyodacitic ash at the base of the Tmt map unit. Note lack of orientation or elongation of the pumice and lithic fragments.
native cover. The upper part of the ash unit has broken fragments up to 3 mm in size, forming vertical impact raps in the thin laminations. The unit is characteristic of a plinian ash deposit described by Sheridan and Opoku (1976), but lacks a basal surge deposit. Basal surges are commonly not present in ash deposits in subsequent environments (Oral communication by Morton, 1990). The mineralogical composition and the lack of vitrification of the ash deposits are given in Morton (1990).

Figure 5c. Photomicrograph of rhyodacitic ash shown in Figure 5b. Note cluster of euhedral plagioclase. Width of field 3.38 mm. Transmitted light, crossed nicols.

The mineralogy suggests a transition from rhyolitic to andesitic ash. Criteria of this transition are: (1) the large mottled phenocrysts of potassium feldspar (2) the presence of euhedral augite and (3) euhedral and sub-
tative cover. The upper part of the ash unit has pumice fragments up to 2mm in size, forming vertical impact sags in the thin laminations. The unit is characteristic of a plinian ash deposit described by Sheridan and Updike (1975), but lacks a basal surge deposit. Basal surges are commonly not present in ash deposits in subaqueous environments (Oral communication, Morton, 1980). The vertical impact sags and the lack of a base surge suggest a plinian eruption deposited in a subaqueous environment (Oral communication, Morton, 1980).

The eruptive unit at the base of the Tmt (Figure 5b, and 5c) is trimodal. Lapilli size (10mm) pumice fragments are evenly distributed in a glassy ash with grains less than 0.01mm. Crystals and lithic fragments averaging 0.5mm form the third mode and comprise 5-10% of the rock. Most abundant of the crystals are subhedral plagioclase feldspars (An 30-35), with an An content increasing towards the center of the crystal. The plagioclase forms as polycrystalline aggregates randomly distributed in the tuff. Mottled polycrystalline potassium feldspar grains are less common than the plagioclase feldspar and are up to 1mm in size. Euhedral augite crystals, of nearly the same size as the plagioclase, form less than one percent of the rock.

The mineralogy suggests a transition from rhyolitic to andesitic ash. Criteria of this transition are; (1) the large mottled phenocrysts of potassium feldspar (2) the presence of euhedral augite and (3) euhedral and sub-
hedral plagioclase feldspars.

Above the thick tuff lies a series of limey ostracod-rich ash beds (Figure 6). The ash has been diagenetically devitrified and partially replaced by calcite (Figure 6). Some subhedral calcite crystals are up to .15mm long, and are commonly found in vugs formed by ostracod shells (Figure 6).

Immediately above the limey ash in the measured stratigraphic section lie two black amorphous silica beds. They are less than 10cm (2 inches) thick and are separated by 15.2cm (6 inch) bed of very fine ash. The silica beds are a very good marker horizon because of its unique float (Figure 7). The pattern formed on the surface of the beds is typical of patterns formed from the dehydration of opaline matter, as contraction spheroids (Taliaferro, 1934) (Gross, 1972).

A series of variable thickness 7.6cm to 3 meters (3 inches to 10 feet) subaqueous rhyodacitic ash deposits overlie the silica beds (Figure 2, 07) (Figure 8). The series is 30.5-45 meters (100-150 feet) thick, with increasing thickness towards the former center of the basin. Some beds in the series have reverse graded bedding, but most have a normal grading sequence and contain many of the characteristics of ash deposits described by Sheridan and Updike (1975) except for the presence of basal surge deposits.

The eruptive units have occasional anhedral plagio-
Figure 6. Photomicrograph of ostracod-rich ash in the Tmt map unit. Width of field 3.38 mm. Transmitted plane-polarized light.

Figure 7. Hand sample of contraction spheroids in the middle of the Tmt map unit.
clay, feldspar (An 50-53). The majority of the ash is 
well sorted non-orien-ted glass shards and pumice fragments 
with an average size of 0.30 to 0.60 mm. Such ash deposits 
are more common to phreatomagmatic and magmatic than to 
phreatomagmatic eruptions (Heiken, 1972). The moderate 
amount of organics and the presence of fresh water exca-
ved fossils at the contact indicate an aquatic deposition.

The unit is composed of (Figure 9c) except for a 
solidated ash member and a normal grade and is compa-
ned with one to one and one half percent organics. 
Figure 8. Outcrop of massive rhyodacitic ash in the middle 
of the Tmt map unit in the measured section. 
thickness of the unit suggested a phreatomagmatic eruption, 
but the vesiculated glass shards and scoriaceous ash sug-
gest a magmatic plinian eruption (Heiken, 1972) (Williams 
and McBirney, 1979) (Figure 9c). From the overlying and 
underlying ash beds, fossils, and organic material, a 
subaqueous environment of deposition is inevitable.

This unit is composed of transported sediments, ash
class feldspars (An 50-55). The majority of the ash is well sorted non-oriented glass shard and pumice fragments with an average size of 0.50 to 0.60mm. Such shard structures are more common to plinian and magmatic than to phreatomagmatic eruptions (Heiken, 1972). The moderate amount of organics and the presence of fresh water ostracod fossils suggest a subaqueous environment of deposition.

The upper 12 meters (40 feet) of the Tmt map unit is composed of thinner unconsolidated rhyolitic ash beds (figure 2, 02), similar to the ash in the Tss map unit, except for the shard form and its unique blue gray unconsolidated ash outcrop (Figure 9a, b, c). Each unit has a normal gradational well sorted sedimentation sequence, and is composed of glass shards and scoriaceous ash (Figure 9a and c) with an average grain size of 0.5mm. Less than one percent of the ash is crystalline, as monocrystalline anhedral quartz.

The source is questionable. The repetitiveness and thickness of the units suggest a phreatomagmatic eruption, but the vesiculated glass shards and scoriaceous ash suggest a magmatic plinian eruption (Heiken, 1972) (Williams and McBirney, 1979) (Figure 9c). From the overlying and underlying ash beds, fossils, and organic material, a subaqueous environment of deposition is inevitable.

This unit is composed of transported sediments, ash
Figure 9a. Outcrop of thin rhyolitic ash units at the top of the Tmt map unit in the measured section.

Figure 9b. Hand sample of rock described in Figure 9a. Ash is unconsolidated and well sorted.
Figure 9c. Photomicrograph of Figure 9b. The ash is entirely composed of glass. Width of field 3.38 mm. Transmitted plane-polarized light.
deposits, and thin 5-15cm (2-6 inches) interbedded lime-
stones (Figure 10). The map unit is highly variable in
thickness. On the surface it is distinguishable by the
absence of thin laminated chips and the presence of thin
beds of fossiliferous limestone.

The base of the unit is composed of very thin bedded
calcareous shales. The shale bedding is not uniform in
thickness and is interbedded with thin beds, 7.6cm to 1m
(3 inches to 3 feet) of volcanic subaqueous rhyolitic ash
(Figure 10). The shales are composed of a mixture of re-
worked underlying volcanic ash of rhyodacitic to rhyolitic
composition, some have a carbonate cement while others are
slightly siliceous. Organics and carbon from vegetation
are common.

The middle and upper part of the unit is composed of
limestones and limey shales interbedded with thicker less
frequent volcanic ash beds up to 1.3m (4 feet) thick. At
the base of the unit lies a 5cm (2 feet) limestone bed with
prominent load cast features (Krumbein and Sloss, 1963)
(Figure 11) (Plate 2b). The bed is slightly fossiliferous,
with gastropods, vorticifex sp. V. concavus and planorbis
sp. df. P. utahensis (oral communication, J. R. Firby,
1980).

Above the load cast bed lies a series of rhyolitic vol-
canic ash beds interbedded with slightly fossiliferous
limestones, calcareous claystones, and limestone nodules.
Some ash beds have a calcareous mud cement, poor sorting
Figure 10. Outcrop of Tus map unit in the measured section. Note change in lithology between massive eruptive units (a) interbedded with shales (s).

Figure 11. Load casts in thin bed of fossiliferous limestone in the middle of the Tus map unit.
and irregular bedding common to turbidity transport (Krumbein and Sloss, 1963).

Near the top of the unit lies a 15.2cm (6 inch) black fossiliferous limestone. The bed can be traced from one edge of the basin to the other. The bed contains fresh water gastropods, vorticifex sp. of V. concavus, planorbis sp. of P. utahensis, lymnaea sp., and gyraulus sp. (oral communication, J. R. Firby, 1980) (Figure 12 a, b, and c). Pelecypod, sphaerium sp. and ostracods are also common in this bed (oral communication, J. R. Firby, 1980). The fossils suggest a fresh water permanent lake body during late Miocene to early Pliocene, probably Clarendonian (oral communication, J. R. Firby, 1980).

The top of the Tus map unit is composed of a series of shales, formed from reworked ash, and slightly thicker poorly sorted, rhyodacitic ash units, up to 3m (10 feet). Some of the ash is bimodal with up to 10% subhedral orthoclase feldspars, showing varying degrees of mottling. Both the feldspar grains and pumice fragments are up to .85mm in size. The grains in between the crystals and pumice are not more than .1mm and are composed of glass and devitrified glass. Subhedral to anhedral quartz may be present in up to 2% of the ash.

The ash particles are blocky and slightly vesicular which may be a composite of plinian and volatile-rich phreatomagmatic eruptions (Heiken, 1972). The thickness of the units suggests plinian eruptions (Williams and
Figure 12a. Fossiliferous limestone with gastropod, *gyraulus* sp. (oral comm., Firby, 1980)

Figure 12b. Fossiliferous limestone of Figure 12a with gastropod, *lymnaea* sp. (oral comm., Firby, 1980)
Figure 12c. Fossiliferous limestone of Figure 12a and b with ostracods, pelecypods, spaerium sp., gastropods, vorticifex sp. cf. V. concavus and ?planorbis sp. cf. P. utahensis (oral comm., Firby, 1980).
The Tus map unit formed synchronous with the movement of a major fault that bisects the basin (Plate 1, cross-section A-A' and B-B'). Sediments in this unit filled the deepest parts of the basin, forming transgression and overlap features on the underlying ash units (Plate 1, cross-section A-A') (Krumbein and Sloss, 1963).

Tut

The Tut map unit is composed of the youngest volcanic ash units in the Bretz-Aurora basin, with a range in composition from rhyodacitic to an iron rich dacite on the andesite side of the field (Figure 2, 03, 06). Maximum thickness of the unit is 61m (200 feet). Separate eruptive events have deposited up to 15.2m (50 foot) thick consecutive eruptive units (Plate 2b), which distinguishes the unit from all other map units (Figure 13a).

The sequence of eruptive units is composed of massive ash deposits that have filled and covered the previously existing basin. Slumping and turbidity flow features are common near beds with steep dips.

The middle of the map unit contains a layer of petrified wood logs 0.6m (2 feet) thick that lie parallel to the bedding. The wood shows signs of burning prior to burial, and much of the wood was charred after burial and replaced by silica. These features suggest the wood layer formed as a result of a lateral hot air blast prior to the depo-
Figure 13a. Outcrop of the iron rich ash flow in the Tut map unit. The base is finely laminated resembling a basal surge deposit. Above the base, the unit is very coarse with large lithics and air cavities, grading into a uniform fine grained ash flow.

Figure 13b. Photomicrograph of well developed axiolitic texture in a dacitic ash of the Tut map unit. Potassium feldspar in lower right corner. Width of field 3.38 mm. Transmitted plane-polarized light.
tion of a thick bed of ash (Williams and Condon 1970).

The wood horizon is overlain by a massive 11 ft. (3.4
ft.) thick dacitic plinian tuff with an average ash size
of 45 mm, less than 2% anhedral potassium feldspar (K. Weck
showing various stages of settling, and a trace of sanidine
(Figure 13b).

Above the dacitic plinian volcanic ash lies a dacitic
ash flow that the base of
laminated or
crossbedded
(Sheridan 1970). This
massive 3m
mound sequence
with 10% re-
fragments and
ice remains.

The top of the ash bed contains
shards, purple
plagioclase feldspar (An
30-35) form one percent of the ash flow and have a maximum
size of 2 mm. Honeycomb structures are common in the plagi-
class feldspar as partial replacement by volcanic glass
(Figure 13c).

Above it lies a 10m (30 feet) thick dacitic air fall
ash probably deposited during the same eruptive sequence.

Figure 13c. Photomicrograph of honeycomb structure in a
plagioclase feldspar of the iron-rich ash flow in the Tut map unit. Width of field 3.38 mm. Transmitted light, crossed nicols.
sition of a thick bed of ash (Williams and McBirney, 1979).

The wood horizon is overlain by a massive 21.3m (70 ft.) thick dacitic plinian tuff with an average shard size of 45mm, less than 5% anhedral potassium feldspars (.7mm) showing various stages of mottling, and a trace of sanidine (Figure 13b).

Above the dacitic plinian volcanic ash lies a dacitic ash flow tuff with a high iron content (Figure 13a). At the base of the unit lies a .6m (2 ft.) very fine grained laminated ash. Some areas have the appearance of being crossbedded resembling a base surge deposit (Figure 13a) (Sheridan and Updike, 1975). Above the fine beds lies a massive 3m (10 feet) thick unit with a normal graded bedding sequence. The base is poorly sorted and very coarse with 10% cobble sized (Fisher, 1961) well rounded lithic fragments and large air cavities. The percentage of lithics remains fairly constant to the top of the unit. At the top of the unit the ash is moderately sorted with glass shards, pumice, potassium feldspar fragments, mud and other debris, (logs and organics) with an average grain size of 5.7mm (Figure 13c). Subhedral plagioclase feldspars (An 30-35) form one percent of the ash flow and have a maximum size of 2mm. Honeycomb structures are common in the plagioclase feldspars as partial replacement by volcanic glass (Figure 13c).

Above it lies a 10m (30 feet) thick dacitic air fall ash probably deposited during the same eruptive sequence.
as the ash flow below it. The chemistry is very similar and it is much finer grained (.07-.1mm).

The change in thickness of the units from the other map units can be attributed to two factors: (1) eruptions are closer to the basin or (2) the eruptions have increased in magnitude.

The shard structure of the ash units suggests a plinian eruptive mechanism and the generally poor sorting indicates a subaerial environment of deposition (Heiken, 1972).

Poorly rounded volcanic gravels up to 15m (45 feet) have been deposited unconformably over the plinian and phreatomagmatic ash beds. In many areas the gravel has been eroded away, but it can be found throughout the basin in most instances above the Tut map unit. The gravel is made of rhyolite flow and ash-flow cobbles and boulders without bedding, sorting or cementation.

DISCUSSION

Jim Rytuba (1980) discussed a zone called the Ore-vada Rift (Figure 14). The McDermitt Caldera at the east edge of the rift system has the oldest rhyolitic volcanism (18.9 m.y.) (Rytuba, 1980). The icelandites in the McDermitt Caldera are dated at 14.2 \( + .2 \) m.y. (Rytuba, 1980), which is considered the maximum age of the volcanic ash sediments which overlie the dated "flows" in the Bretz-
Rytuba (1980) also proposed a schematic pre-eruption magma chamber configuration. He describes the magma chambers as being zoned from rhyolitic (peralkaline) on top to trachytic with increasing depth in the magma chamber (Figure 15). A similar pattern is observed in the sedimentary ash units with a reversal in the compositional sequence as expected. Three major eruptive chamber sequences have been distinguished but other minor sequences may be present. Each chamber sequence division will be presented, starting at the base of the stratigraphic column.

The base of the sedimentary stratigraphic column is composed of an ash of andesitic (icelandite?) composition, which would come from the bottom of the first magma chamber, if the chamber is highly zoned. Next in the stratigraphic section is a thick sequence 25mm (80 feet) of rhyolite phreatic and phreatomagmatic ash with high silica content that grades into rhyodacitic phreatomagmatic ash following a normal sequence according to Rytuba (1980). From the top of Tss to the middle of Tmt the composition of the tuff is rhyodacitic similar to the Tuff 3 eruptions in Figure 15 forming the second chamber sequence. The tuff composition again turns very silicic in the upper part of Tmt, from the eruption of a new chamber (Rytuba, 1980). The ash grades from rhyolite to rhyodacite to an iron rich dacitic ash flow approaching the composition of an icelandite at the top of the Tut map unit, indicating the bottom of a
Figure 14. Orevada Rift, taken from Rytuba (1980).
third magma chamber sequence corresponding to Tuff 3 of Figure 15.

The sedimentary stratigraphy fits the chamber configuration model proposed by Rytuba and contains two complete chamber eruptive sequences and the tail end of another chamber. The source of the sediments probably came from eruptions to the west from the progressively younger siliceous domes dated by McLeod and others (1976). The specific source dome cannot be determined but if only one magmatic segregation occurred in each dome, the source of the sediments would move progressively further for each compositional sequence. Using this interpretation, one can speculate that the ash of the third magma chamber sequence would be approximately 10.4 m.y. old, with Beatty Butte as its source (Figure 14), and the Tss map unit and three quarters of the Tmt map unit would be approximately 13.5 m.y. old and originated near Hawkes Valley, Oregon forming the second chamber. The large clasts at the top of the Tut map unit may have originated from a closer unknown source. It is unlikely that the ash flow traveled 150 km (93 miles).

Fossil evidence reaffirms the chamber sequence theory. Clarendonian age fossils 10 to 14 m.y. old (Clark, 1968) are found near the base of the sediments in the third chamber sequence, suggested by the chamber sequence theory to be 10.4 m.y. old.

Glanzman (1979), the only person who has published
Figure 15. Schematic pre-eruption magma chamber configuration (after Rytuba, 1980).

D = Depth to which magma chamber vented

0 5 10 20KM

Peralkaline, phenocryst poor magma

Trachytic-rhyolite, phenocryst rich
information dealing with the sediments, divides the sedimentary stratigraphic section into three parts; (1) lower tuffaceous sandstone (light to dark brown), (2) medial mudstone (white and green), and (3) upper tuffaceous sandstone (light brown and pale yellow). His lower tuffaceous sandstone is 19m (62 feet) thick, which corresponds with most of the Tss map unit. He separates each phase of an eruptive event into a separate lithologic unit, in his description of the map unit. Thin sections and outcrop show, as explained in the Tss section; (1) lack of abrasion on the grain surfaces, (2) well sorting, (3) normal graded bedding, and (4) repetitiveness of each eruptive unit, characteristic of volcanic ash deposits (Sheridan and Updike, 1975). A more representative term for this section should be a phreatomagmatic volcanic ash series deposited in a subaqueous environment, (Heiken, 1972), and not a tuffaceous sandstone.

Glanzman's medial mustone 42m (127 feet) thick corresponds with the lower half of the Tmt map unit. Most of his mudstone (white outcrop) unit is a massive plinian rhyodacitic ash deposit. No mud or reworking is noted in this unit. Large (lapilli sized) pumices are present at the base with smaller pumice fragments grading upwards in the unit. The green in the ash beds is a decomposition product of hornblende and augite producing glauconite (celadonite?) in the deepest part of water basins in accordance to the relative migration of iron and aluminum in water basins (Kraus, 1961) (Kosto, 1968). He describes the presence of
ostracods, mollusc, gastropod shells, fish skeletons, leaves, and carbonaceous debris. Only ostracods have been recognized by this writer in the section he has described. Molluscs, gastropods, and carbonaceous debris and possible fish skeletons have been identified more than 76m (250 feet) above this unit. Leaves and minor carbonaceous debris have been identified above and below his unit.

Glanzman’s upper tuffaceous sandstone is 10 to 30m (30-100 feet) thick. This corresponds to the upper half of the Tmt map unit, but his description fits the Tut map unit. He describes it as coarse grained, massively bedded, light brown, with zeolites and a petrified wood horizon. The only part of the stratigraphic section which contains petrified wood is in the middle of the Tut map unit. Glanzman’s description of a tuffaceous sandstone is actually a series of thick dacitic ash fall and ash flow units. The base of the dacitic ash flow could be mistaken for a tuffaceous sandstone because of the rounded lithics, but the majority of the ash has vesiculated pumice fragments and glass shard textures of plinian eruptive units.

The blanketing effect of the eruptive units allows application of this stratigraphic section in correlating other ash beds in basins within the caldera and in surrounding low lying areas outside the caldera walls. Ash deposits in the Owyhee Desert region have very similar characteristics.
Sediments fill a structure-controlled moat which follows the ring fracture zone of the McDermitt caldera complex. The ring fractures are outlined by Rytuba (1980) (Figure 14). The Bretz Mine (Plate 1) is located on the north edge of Rytuba's Longridge Caldera to the east of the intersection of the ring fracture with Rytuba's Washburn Caldera (Figure 14).

Most structures in the sediments are not exposed, because of the blanketing effect of the volcanic ash. Major structures can be noted by a sharp change in the dip angle of the sediments or by slump features in the bedding.

The north and northeastern edge of the basin is bounded by a caldera normal ring fracture fault(s). In most places it is not a clean breaking fault but rather a progressive series of down dropped blocks shown in cross-section A-A' by the flat terrace on the northeast end (Plate 1). Initial movement along the ring fracture occurred prior to sedimentation but later movement has cut the Tmt map unit and possibly the Trt map unit. Confusion arises where the ring fracture fault enters the Bretz Mine area (Plate 1). The ring fracture fault is bent southward at the Bretz Mine area and may join part of a fault which strikes parallel to the normal ring fracture fault, offsetting the Tut map unit. If the faults are the same, the ring fracture fault movement continued during the sedimentation process.
The bend in the ring fracture fault(s) is the result of a north-south striking normal fault horizontally separating the ring fracture 610m (2,000 feet) on the surface. From the dip of the bedding the fault dips more than 30° to the west. To the northwest of the offset the ring fracture continues with minor vertical offset (from drill hole data) along its original strike direction.

The south end of the basin is also fault controlled. The fault strikes parallel to the ring fracture fault and dips to the northeast. This fault displaces the Tus map unit as does the ring fracture fault.

The center of the basin is bisected by a normal fault striking nearly parallel to the two basin bounding faults and dipping irregularly to the northeast (Plate 1, cross-section A-A'). On the surface the fault is seen on the east side of the drainage of Cottonwood Creek 610 m (2,000 feet) southwest of the volcanic flow (Trt) and sediment contact. The same fault is exposed north of Tbt in the center of the basin and on the east end of the basin (Plate 1). The sediments are offset less to the west and more to the east where the fault offsets the Tus map unit (Plate 1, cross-section B-B'). The top of the Tut map unit is not offset by this fault.

The majority of the movement occurred during the deposition of the Tut map unit which is evident from the thickness of the Tut map unit to the northeast of the fault. A north-south normal fault intersects the bisecting basin
fault and dips to the west, the same direction as the north-south fault that offsets the ring fracture fault along the north edge of the basin. The fault has lifted the eastern block exposing the sediments to erosion (Plate 1, cross-section B-B'). The fault contact is very irregular which can be explained by doming effects and a low dip angle.

Toward the east end of the basin, near the ring fracture fault, the beds reverse their normal dip to the south. The beds strike nearly east-west and dip up to 45°N. No drill holes have intersected the trend proving a fault, but from the attitude of the beds it is interpreted as a covered fault (Plate 1, cross-section B-B'). The fault symbol on the geologic map in the volcanics, striking in the same direction as the bedding in the sediments, is a projection of where the fault should appear if it crosses the ring fracture fault into the volcanics. A breccia zone follows this trend into the volcanics.

The east end of the Bretz-Aurora basin is bounded by intrusive contacts of the Tar map unit and the west end of the basin represents a normal depositional contact with the underlying rock units.
ECONOMIC GEOLOGY

INTRODUCTION

Mining in the Opalite District began in 1926 at the Opalite Mercury Mine, in 1930 at the Bretz Mercury Mine, and in 1935 at the Cordero Mercury Mine (Figure 1). Production figures for the three mines are given in Table 1 (Speer, 1977).

In 1975 production began at the McDermitt Mercury Mine to the north of the Cordero Mine. Table 1 has the projected production and recovery for the McDermitt Mine announced by Placer Amex, Inc., in 1974. Currently its total production has increased, its yearly projected production of 20,000 flasks has been surpassed, and the average ore grade is slightly lower than the original announcement (oral communication, Roper, 1980).

The primary ore mineral for all non-operating mercury mines was cinnabar, but in the presently active McDermitt Mercury Mine a large portion of its ore is corderoite ($\text{Hg}_3\text{S}_2\text{Cl}_2$). Cinnabar and native mercury are also present (Sisselman, 1975). Further discussion of the mercury deposits will be limited to their relationships with the uranium occurrences in the sediments.

Uranium was initially discovered at the west end of the caldera complex, at the Moonlight Mine. Wildden (1964) contains a description of the mine by Taylor and Powers (1955):
### Table 1 Summary of production and history of mines in the Opalite district

<table>
<thead>
<tr>
<th>Mine</th>
<th>Date of Discovery</th>
<th>Dates of Production</th>
<th>Total Production (76 lb. flasks)</th>
<th>Recovery Lbs. Hg/Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bretz</td>
<td>1917</td>
<td>1930-1965</td>
<td>14,807</td>
<td>5.4</td>
</tr>
<tr>
<td>Opalite</td>
<td>1924</td>
<td>1926-1961</td>
<td>12,367</td>
<td>5.5</td>
</tr>
<tr>
<td>Cordero</td>
<td>1924</td>
<td>1935-1970</td>
<td>105,636&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.4</td>
</tr>
<tr>
<td>Ruja</td>
<td>1967</td>
<td>1968-1971</td>
<td>6,000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>?</td>
</tr>
<tr>
<td>McDermitt</td>
<td>1971</td>
<td>1975&lt;sup&gt;c&lt;/sup&gt;-?</td>
<td>394,737&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Includes production from Corderito mine and small surface pits.*

<sup>a</sup> Personal communication, R. Crofoot, 1974.

<sup>b</sup> Data based on exploration and engineering results. Announced by Placer Amex Inc. in April 1974.

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*Taken from Speer (1977).*
"The rocks exposed in the immediate vicinity of the Moonlight Mine...are intensely altered and silicified rhyolitic and latitic tuffs and flows. Three mappable rock units have been distinguished. The first is an acidic or intermediate ash tuff....The second is a rhyolite tuff which is light-colored on fresh surfaces but weathers brown from the oxidation of pyrite. The rock is intensely silicified and more or less brecciated, causing it to weather to vertical cliffs and craggy points. This rock is the host for the uranium minerals at the Moonlight Mine. The third rock unit is a rhyolite porphyry consisting of quartz, orthoclase or adularia, and abundant disseminated pyrite in a highly altered fine-grained groundmass....

"Quartz monzonite was noted only in the mine workings about 170 feet down the incline shaft. The rock is equigranular and contains about equal amounts of plagioclase and orthoclase with lesser amounts of quartz and augite...

"The major structure in the area...is a north-trending normal fault, exposed at the Moonlight Mine, and referred to as the Moonlight Fault. The fault dips from 45 to 54 degrees east near the surface, but the dip steepens to 60 degrees east in most of the main inclined shaft.... At most places in the shaft, the fault is a smooth plane overlain on the hanging wall by a zone of breccia that grades into unbroken rock away from the plane of movement. Fault gouge is well developed only where the quartz monzonite is adjacent to the fault.

"The ore minerals in the vein are autunite, torbernite, orange and yellow non-fluorescent uranium minerals collectively termed 'gummite,' and uraninite (?). The common gangue minerals are pyrite, fluorite, smoky quartz, iron oxides, and clays. The owners reported that carnotite had been identified in the ore but no carnotite was observed in the specimens collected."

Several cars of ore were shipped but the treatment and shipping charges exceeded the value of the ore (Willden, 1964).

Chevron has been working in the Moonlight Mine area for the past three years. They were the first company to explore for uranium in the caldera complex, during the exploration boom period of 1978-79 and initiated interest...
by many other companies.

The boom period started with a claim staking rush by an individual, Locke Jacobs, who flew a radiometric survey over the caldera and by Cordex Exploration Co. The first property Locke Jacobs staked, named the Aurora Prospect, was drilled and has been announced to contain 17 million tons of rock grading 0.05-0.06% U₃O₈ (Roper and Wallace, 1980). News of the discovery spread quickly and initiated interest from many more companies (oral communication, Locke Jacobs, 1980). The Aurora prospect is currently a joint venture between Placer-Amex Inc. and Locke Jacobs.

Some of the more active companies in the exploration for uranium throughout the caldera complex include: Energy Reserves, Western Nuclear, Energy Fuels, Anaconda, St. Joe Minerals Exploration, U. S. Steel, and many others. Exploration activity continues in 1980 but at a slower pace.

MINERAL DEPOSITS

General Description

Uranium mineralization in the Bretz-Aurora basin consists of flat tabular bodies, in most cases stratigraphically controlled (Roper and Wallace, 1980). In the Aurora ore zone a small percentage of the mineralization is in the sediments with the major portion in icelandite lava flows immediately below the contact between the sediments and the underlying volcanic flows (Roper and Wallace, 1980). The oxidized ore mineral is autunite \( \text{Ca(UO}_2\text{)}_2\text{(PO}_4\text{)}_2\cdot 8\text{-}12\text{H}_2\text{O} \)
and can only be seen in the sediments above the Aurora ice­
landite lava outcrop in the center of the basin (Plate 1).
Dioctahedral smectites, aragonite, limonite and gypsum are
the gangue minerals in the oxide zone (Figure 16). The
uranium in the unoxidized zone is associated with framboi­
dal pyrite and dioctahedral smectite. Molybdenum has been
reported but its location with respect to the ore bodies is
uncertain (oral communication, Wallace, 1980).

Both the Bretz and the Aurora uranium mineralization
lie near areas of anomalous mercury (Plate 1). The Bretz
Mine, a former mercury producer with an average grade of
5.4 pounds/ton (Table 1), is close to the Bretz uranium
mineralization. At the eastern edge of the Aurora mineral­
ized zone a mercury anomaly in the sediments assays up to
11 pounds/ton on outcrop samples (Plate 1).

The Bretz epithermal mercury mineralization, origi­
nally considered to lie in the sediments, has been proven
to lie mostly in the volcanics at the sediment contact
and in silicified landslide breccia (oral communication,
Wallace, 1980).

In both occurrences the mercury is in the form of
cinnabar. In the Bretz Mine pits stibnite, pyrite, and
marcasite have also been recognized.

Ore Mineralogy

In the volcanics the uranium occurs as open space
filling in vesicles of the vesicular to scoriaceous ice­
Figure 16. Altered Tss map unit above the uranium discovery location of the Aurora uranium prospect.
landite lava flow tops (Roper and Wallace, 1980). The identified uranium ore minerals are uraninite (pitchblende), coffinite, and uranophane forming very fine crystals and films on framboidal pyrite and ilmenite (Roper and Wallace, 1980).

In the pyroclastic deposits the mineralization is in thin laminated and massive ash. The ore minerals are too fine-grained for identification. The mineralogy is considered the same from the presence of framboidal pyrite and overlapping distribution patterns.

Distribution of Uranium

Surface radiometric survey anomalies are thin and follow attitudes in the bedding (Plate 1). Below the surface a drill hole may cross up to three sedimentary beds with anomalous uranium concentrations (Plate 1, cross-section A-A'). The highest uranium concentrations are found when two beds within 3m (10 feet) of each other are intersected. As the mineralized beds spread apart, more mineralized beds appear and the concentration of uranium gradually diminishes. No clear cut reasons can be given for this phenomena. It is possible that the solutions are following favorable permeable beds and dispersing down dip when other favorable beds are encountered. The variable distance of uranium concentrations above the volcanic flow contact supports this idea.
Alteration

All interpretations of alteration are through visual estimations of mineralogy in drill cuttings taken at five foot intervals. One hundred holes drilled by Cordex Exploration Company at the Bretz property and selected holes at the Aurora prospect were used to determine alteration patterns. In each hole the bottom 24.4m (80 feet) of the sediments were studied where available. The maximum footage available was used for holes that did not have 24.4m (80 feet) of sediments sampled above the volcanic flow contact. At each 1.5m (5 foot) interval a visual estimation was made of the percentage of carbonate, sulfides (pyrite and marcasite) and clay. For each drill hole the values for the intervals were averaged. A numerical value was given for the amount of silica in each interval from 0 to 3, with zero having no introduced silica and three being heavily silicified.

This is considered a valid determination of alteration patterns for the following reasons:

1. Phreatomagmatic eruptions blanket the basin at a nearly uniform thickness and chemical composition.

2. The bottom 24.4m (80 feet) of the sediments is composed of one major map unit of phreatomagmatic origin.

3. No sequences of calcium carbonate have been diagenetically formed in this ash horizon.
(4) The values are averaged totals for a 1.5m (5 foot) interval of the sediments.

(5) The values indicated are not absolute. They are relative and are presented to obtain patterns for interpretation.

(6) Over 130 holes determined the patterns except for the uranium, in which 500 holes were used.

(7) The highest concentrations of uranium are in the lower 24.4m (80 feet) of the stratigraphic section. Determination of the uranium content in the sediments has been discussed under the "Method of Investigation and Analytical Techniques" heading.

The proximity of the source areas to each other near the Bretz Mine dumps has destroyed original patterns. These patterns can best be recognized near the Bretz U shown in Figures 17 to 20 and northeast of Aurora U. Mineralization patterns near the Aurora U shown in Figures 17 to 20 are irregular due to oxidation of the sedimentary and pyroclastic deposits.

Clays

Complete results and methods of the clay analysis are found in the Appendix, and all sample locations are on the geologic map (Plate 1).

A high aluminum (up to 19 wt. % $\text{Al}_2\text{O}_3$) dioctahedral smectite is present in the Bretz-Aurora basin with up to 14 ppm acid soluble lead, 700 ppm acid soluble mercury,
and 440 ppm acid soluble arsenic. All metal values are much higher in the east side pits of the Bretz Mine than in the west side.

The clays have excellent to acceptable viscosity, high specific resistance, variable pH and with some treatment generally have good rheology (Appendix). The clays in the Aurora prospect area have very similar characteristics with the Bretz clay samples.

Glanzman and Rytuba (1979) reported the presence of a mixture of dioctahedral and trioctahedral smectites below the base of their medial mudstone unit (top of Tss unit Plate 2a). Only dioctahedral smectites have been identified from the analysis by R. T. Vanderbilt, below Glanzman's medial mudstone, which is a rhyolitic ash. High magnesium, lithium rich, trioctahedral smectites have been identified in the Tmt map unit or Glanzman's medial mudstone to the west of Cottonwood Creek. These clays lie in thin beds forming after rhyodacitic ash and characteristically have low aluminum (2-7 wt. % Al₂O₃), high magnesium (15-20 wt. % MgO), low iron (less than 1 wt. % Fe₂O₃), high lithium (up to 0.2% Li₂O), less than 15 ppm acid soluble arsenic, 4 ppm acid soluble lead, 4 ppm mercury, and one sample .07% boron concentration (Appendix). These clays have low stability to electrolytes, and generally have good rheology (Appendix). Their association with the uranium is suggested by Glanzman (anonymous, 1979).

The distribution of the dioctahedral smectites is
Figure 17. Distribution of dioctahedral smectites and uranium.
seen in Figure 17. In general, the clays are concentrated near the Bretz mercury pits and where the icelandite lavas have been brought to the surface by faulting and doming (?) at the Aurora Prospect. When compared with distribution of uranium in the sediments, the areas with lower clay content have the highest uranium content. In some instances the clay boundaries nearly outline the higher uranium concentrations, as seen near Bretz U., Aurora U., and east of Aurora U. in Figure 17.

Silica

The silica in the sediments is an amorphous hyalo-clastic type with an opaline appearance. The highest concentration of silica in the lower 24.4m (80 feet) of the sediments is on the western side of the highest clay concentrations (Figure 18). Where the clay concentration is lowest the silica content is generally highest but only near the mineralization. In both the Bretz and Aurora mineralization the highest concentrations of uranium are not at but are adjacent to the highest concentrations of silica which is most obvious at the Bretz U. of Figure 18.

When the two alteration types, silicification and argillization, are compared to the uranium concentrations, the uranium becomes sandwiched between the clay and the silica with both Bretz and Aurora prospects forming patterns of alteration that change from clay to uranium to silica in progression, from east to west.
Figure 18. Distribution of silica and uranium.

Opaline silica knobs are common as surface exposures. The silica knobs are associated with the ring fracture fault, or with intense shearing. The exact association has not been verified. The data suggest the knobs are almost totally opaline and contain anomalous concentrations of mercury and uranium. However, the concentrations of these elements within the knobs are less than those found in other areas. The ore on the south end contains up to 3,800 ppm copper and may be related to the opaline association. The data suggest that the process of precipitation of these elements may be related to the mineralization process.
Opaline silica knobs are common as surface exposures along certain trends (Plate 1). A series of opaline silica knobs trends nearly parallel to the ring fracture fault. The silica may be associated with the ring fracture fault or with intrusive rhyolite domes. The exact association has not been verified. To the east the knobs are almost totally opaline and are anomalously low in radioactivity, but contain more than 60 ppm of mercury. Towards the west, below the Bretz pits the knobs contain more carbonate than opal and the concentrations of mercury are slightly greater (up to 315 ppm). It was noted that the concentrations of mercury varied greatly within short distances on opaline outcrops. Two opaline outcrops to the east of the icelandite (Ta) outcrop (Plate 1) lie no more than 50m (150 feet) from each other. The opal on the south end contains 45 ppm and the opal on the north end contains over 3,000 ppm of mercury (Figure 19). In general, every massive opaline outcrop is anomalous in mercury and may be related to the period of mercury mineralization at the Bretz Mine.

Calcium carbonate

Calcium carbonate (calcite and aragonite) in the lower 24.4m (80 feet) of sediments is not evenly distributed and it does not increase or decrease with depth in the basin (Figure 19). For these reasons and because of its spotty nature it is suggested that calcium carbonate in the lower 24.4m (80 feet) is related to the mineralization process.
Figure 19. Distribution of calcium carbonate and uranium.

The presence of calcium carbonate is mapped by the distribution of uranium. However, the highest uranium concentrations are not always coincident with the highest calcium carbonate concentrations. Aurora mineralization patterns are not as prominent. Ground water flow and oxidation have altered the surface horizon. The original pattern of sulfo-siderite (pyrite and marcasite) overlies the uranium mineralization and the sediments, near the Bretz U. but many exceptions exist. The contour line is anomalously high in the southeastern quadrant of the map, indicating a high uranium concentration. In most cases the uranium content is closely associated with the iron oxide deposits, as seen in the southeastern quadrant of the map. The pattern of uranium concentration is not uniform, with some areas having higher concentrations than others. The data is also shown in Figure 20.
The presence of calcium carbonate conforms in shape to the pattern formed by the Bretz U. uranium and is very close to the higher uranium concentrations east of Aurora U.

Over the Aurora mineralization patterns are not as prominent. Acidic ground waters and oxidation where the mineralized sediments are near the surface have changed the original pattern.

Sulfides (pyrite and marcasite)

The sulfides (pyrite and marcasite) overlap slightly or are on the clay side of the uranium mineralization in the sediments, near the Bretz U. but many exceptions exist (Figure 20). The sulfide contour is anomalously high in a northwest-southeast zone on the south to southwest side of the highest uranium concentrations. In some cases the sulfide content is low at higher uranium concentrations and can also be low at low uranium concentrations.

Above the Aurora mineralization most of the sulfides have been oxidized leaving an obscured pattern. The high oxide concentration is interpreted as a formerly high sulfide content. The sulfides encountered in the Aurora zone increase in concentration to the west, away from the uranium mineralization.

Overall high sulfide content is encountered on both east and west sides of the highest uranium concentrations, as seen south and southeast of Bretz U. in Figure 20.
Figure 20. Distribution of sulfides and uranium.

In high silica rocks high uranium contents are found, while in sediments low values are indicated. From the stability of the Aurora Prospect (Plate 1), it is evident that any structural pattern would be influenced by the geologic设置.
Zeolites

Nearly all of the sediments have been subject to various stages of zeolitization, described by Glanzman and Rytuba (1979). Glanzman and Rytuba (1979) suggest a zonation of zeolites from clinoptilolite-erionite at the volcanic rock-sediment boundary, clinoptilolite, clinoptilolite-mordenite, and finally potassium feldspar at the Bretz Mine.

Zeolitization is dependent on the original rock chemistry (Beck, 1974). In high silica rocks high silica zeolites predominate and in low silica rocks low silica zeolites predominate (Beck, 1974). From the variations in chemical contents of the differing ash units, for example, in the vicinity of the Aurora Prospect (Plate 1), it is not likely that any zonational pattern would be meaningful when sampling surface outcrops across the stratigraphic section. According to the alteration series, Glanzman and Rytuba propose the highest silica content zeolites in the sediments nearest the Bretz pits and progressively lower away from the pits, mordenite having the highest silica content and erionite having the lowest silica content of the zeolites.

From the alteration patterns of the lower 24.4m (80 feet) of the sedimentary section the high silica content is furthest from the Bretz pits and the Aurora prospect which would form the opposite zeolite zonation pattern from what Glanzman and Rytuba suggest. Heulandite, a moderately low
silica content zeolite (Beck, 1979) similar to erionite, has been identified on the east side of the icelandite (Ta) outcrop in the center of the basin. The presence of heulandite in conjunction with the uranium mineralization does not fit into the zonational pattern presented by Glanzman and Rytuba.

Environments of Ore Deposition

The minerals, discussed in the alteration section and others, are associated with certain chemical environments and understanding of these environments is essential in determining mineralization processes.

The chemistry of the mercury mineralizing environment at the McDermitt Mercury Mine although not definite is described as precipitation from thermal, neutral to alkaline, sulfide-bearing aqueous solutions (Roper, 1976). This chemistry results from the analysis of similar small scale hot spring mercury mineralization solutions at Amadee Hot Springs, Amadee County, California; Boiling Springs, Valley County, Idaho; and at Cederville Hot Springs, Modoc County, California (Roper, 1976).

The mercury ore of the McDermitt Mine only differs from the Bretz mercury ore by the presence of corderoite, which is considered a secondary supergene mineral produced by in-situ alteration of cinnabar by an acidic, chlorine-rich ground water (Roper, 1976).

Other than having a slightly lower aluminum content,
the chemical composition of the dioctahedral smectite in
the McDermitt Mine is the same as the clays at the Bretz
Mercury Mine and is stable at neutral to acidic conditions
(Helgeson, 1969) (Appendix, sample 8-20).

Uranyl carbonate complexes greatly increase the mobi­
ity of uranium and solubility of uraninite; a point made
vividly clear by Figure 21 (Langmuir, 1978). The plot
shows that a rise in $P_{CO_2}$ from the atmos­pheric value of
$10^{-3.5}$ atm to a ground water value of $10^{-2}$ atm increases the
solubility of $UO_2^{2+}$ by more than 1000 times for $Eh$ values
above -.05 volts (Langmuir, 1978). Uranyl carbonate com­
plexes are commonly found in neutral to alkaline solutions
(Figure 22) similar to the solutions described by Roper
for the hot spring mercury mineralization.

The solubility of amorphous silica is little affected
by changes of pH in the range from 0-9, but increases
rapidly as the pH rises above 9 (Krauskopf, 1956). In
other words, silica is no more soluble in very dilute
alkali than acid solutions, contrary to common geologic
assumption (Krauskopf, 1956). The silicate ion is present
in solutions in appreciable amounts only at pH's over 9;
in more acid solutions the silicic acid is essentially un­
ionized (Krauskopf, 1956). Solubility is at least as high
in alkaline springs, but equilibrium is attained, in acid
solutions, at exceedingly slow rates (White and others,
1956).

The solubility of iron increases with increasing pH
Figure 21. The solubility of uraninite, UO$_2$(c), at pH=8 and 25°C as a function of Eh and P$_{CO_2}$. Also shown are the Eh values for some important redox reactions computed assuming: CH$_4$=CO$_2$, SO$_4$$_2^-$=HS$^-$, Fe$^{2+}$=10$^{-4}$M, and SO$_4$$_2^-$=10$^{-13}$M. Taken from Langmuir (1978).
Figure 22. Eh-pH diagram in the U-O_2-CO_2-H_2O system at 25°C for P_{CO_2}=10^{-2} atm, showing the stability fields of amorphous UO_2[UO_2(\text{am})], ideal uraninite [UO_2(c)], and U_4O_9(c). Solid-solution boundaries are drawn at 10^{-6}M (0.24 ppm) dissolved uranium species. Taken from Langmuir (1978).
at nearly equal rates. Its solubility is much lower than uranium as uraninite in alkaline environments (Harshman, 1974).

Sequence of Mineralization

The previous section demonstrates that mercury, uranium, iron, and silica are transported in alkaline solutions. The clay minerals and calcite discussed also develop in alkaline solutions. This geochemical evidence along with the alteration patterns suggest the same source for the uranium and the mercury deposits.

Solutions with a pH greater than 9 are suggested because of the large volume of silica in the alteration patterns, which suggests above normal concentrations of silica in the mineralizing solutions. This phenomenon can only occur at a pH greater than nine (Krauskopf, 1956). Solutions at this pH in a hot spring environment would put the mercury, silica, uranium, iron, and carbonate into solution. With decreasing pH and a normal precipitation sequence (Harshman, 1974), the following minerals would precipitate in sequence away from a hot spring center or other origin of mineralizing solutions: cinnabar/silica—smectites—sulfides (marcasite and pyrite)—uranium/carbonate. Cinnabar readily precipitates when the solution temperatures fall, or with dilution by ground water (Tunell, 1964), causing it to precipitate first. Once the pH of the solution decreased below 9, the silica would begin precipi-
tation at a slow rate. As the solutions gradually decrease in pH the iron would precipitate as pyrite and/or marcasite. The uranium is slightly more soluble than the marcasite/pyrite which results in precipitation near the pyrite and marcasite but further from the center of the mineralization. Immediately after the uranium precipitates, carbonate is released and would be available for the formation of calcium carbonate, which would immediately precipitate.

As the solutions continued moving through the sediments, the alkalinity along the same fluid channels would remain constant for a longer distance allowing the uranium to travel slightly further with minor leaching of the original uranium. Once the calcium carbonate has precipitated, the silica rich solutions become neutral. The introduced instability between the solution and its components enhances the potential for precipitation, increasing the silica content in the sediments with a gradual decrease in content furthest from the mineralizing source. This mineralization sequence has some similarities with the normal mineralization sequence for roll-type uranium ore deposits (eg. Harshman, 1974 and Granger, 1974). A difference between this occurrence and the typical roll-type uranium deposit is the absence of oxidation near uranium concentrations. This can be explained by reference to Figure 22. In this figure, solutions at a high pH can keep uranium in solution, without oxidation, and allow precipitation in the reducing environment. Another expla-
nation for this phenomenon is that oxidation did occur but has been inverted to a reducing environment with a rising water table. The present day water table lies above the uranium mineralization, which could mask any previous oxidation.

The following sequence of mineralization is proposed:

<table>
<thead>
<tr>
<th>Hypogene</th>
<th>Supergene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td></td>
</tr>
<tr>
<td>Cinnabar</td>
<td></td>
</tr>
<tr>
<td>Amorphous Silica</td>
<td></td>
</tr>
<tr>
<td>Uraninite? and others</td>
<td></td>
</tr>
<tr>
<td>Calcium Carbonate</td>
<td></td>
</tr>
<tr>
<td>Autunite</td>
<td></td>
</tr>
<tr>
<td>Limonite</td>
<td></td>
</tr>
</tbody>
</table>

This sequence is suggested from the following evidence;
(1) pyrite other than the framboidal type is common, (2) uranium coats the framboidal pyrite, (3) cinnabar is near the proposed sources of mineralization, (4) amorphous silica is furthest from the proposed sources of mineralization, (5) calcium carbonate is near or coincidental with the uranium mineralization, and (6) autunite and limonite have been identified only on surface exposures and oxidized sediments.

The sequence of mineralization was a continuous system of possibly more than one pulse with little change in the original solution.

The presence of pyrite on both sides of the highest
uranium concentration in the sediments is explained as being two types of pyrite. One type, frambooidal, is pre-ore and the other, a euhedral coarser crystalline pyrite formed during mineralization. This is a common phenomenon in roll-front uranium deposits (Goldhaber and Reynolds, 1979).

Age of Mineralization

The exact age of the mineralization has not been determined. The icelandite which underlies the sediments and which is the most favored host for the uranium has been dated at $14.2^{\pm} 2$ m.y. (Rytuba, 1980). This date then is the oldest possible age of mineralization.

The Tus map unit, from fossil evidence, is 10 to 14 m.y. old and mineralization is not encountered above this map unit. The age of mineralization is probably close to 10 m.y., but ranges between 14.2 and 10 m.y.
GEOLOGIC HISTORY AND SUMMARY

The Bretz basin is in a collapsed caldera structure (McKee, 1976). The basin, being a topographic low, began filling with water, forming a marshy environment. Vegetation in the marsh was sparse and very slow to progress. As the water deepened continuous volcanic activity began filling the basin with ash. The volcanic activity moved progressively westward along the Orevada Rift (Rytuba, 1980). The activity produced small rhythmic eruptions of phreatomagmatic ash that drifted eastward and gradually settled over a large area including the shallow aqueous Bretz basin.

After a series of eruptions, during which the Tss and Tmt map units were deposited, the basin started to change. Most of the change occurred in the center of the basin as a doming of the sediments to the south and southwest of the present day northeast-southwest striking fault. Movement along the fault zone accelerated during the deposition of the Tus map unit and the north side of the fault zone evolved into a deep basin.

The offset in the fault zone increased to nearly 100m (300 feet). The deep basin filled with a 135m (400 foot) sequence of lacustrine sediments characteristic of a fresh water permanent lake and ash beds, with only slight sedimentation to the south and southwest of the fault.

An increase in plinian eruptive activity deposited
much thicker sequences of ash. As the lake became shallower many trees began to grow forming trunks up to 1m (3 feet) in diameter. A plinian eruption toppled the trees with a hot air blast and buried the trees under a thick bed of ash. A series of ash beds, one with flowage features, completely covered the basin.

A period of volcanic quiescence followed and erosional processes commenced. The initial result was a covering of the ash deposits with a 10-15m (30-40 foot) section of volcanic gravel. Erosion cut through the gravels to the present topographic surface.

Sometime during the period of sedimentation, possibly in conjunction with the tectonic activity, hot spring activity provided mineralizing fluids for the mercury, uranium, and other elements. The solutions encountered the permeable vesicular flow-tops of the icelandite and spread into the sediments with a southwest regional dip, forming a depositional pattern.

The pattern away from the sources of mineralization is suggested as follows: cinnabar/silica-- clay (dioctahedral smectite)--pyrite-- uranium/calcium carbonate--silica (amorphous)/minor uranium. The pattern is very irregular, but is best recognized to the east of the Bretz pits.

The minerals present suggest very alkaline mineralizing solutions with a pH of greater than 9. The Mineralization pattern noticeable at both the Bretz and Aurora
prospects is considered a result of differing solubilities of each mineral complex.

The mineralization is similar to a roll-type uranium ore deposit, with the following exceptions: (1) there is no oxidation zone between close uranium peaks, (2) there is no abrupt change between mineralized and unmineralized sediments along bedding, and (3) no definite ore roll can be identified. For these reasons discussion of its similarity with other uranium deposits has not been attempted.

A paper written in German with an English abstract mentions the association of mercury with uranium in Permian volcanics at Konigsberg and at Lemberg (Dreyer, 1971). From the abstract the ore metals are similar but the environment is oxidized with secondary minerals as arsenates and phosphates (Dreyer, 1971). This mercury association as described can be useful in exploration of similar environments within caldera complexes.
REFERENCES CITED


McKee, E. H., 1976, Origin of the McDermitt caldera in Nevada and Oregon and related mercury deposits (Abs) Mining Eng., v. 27, no. 12, p. 70.


Rytuba, James, 1976, Geology and ore deposits of the McDermitt caldera, Nevada-Oregon, open-file report 76-535.

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.


Wallace, A. B., and Roper, M. W., 1980, Geology and uranium deposits along the northeastern margin of the McDermitt Caldera Complex, southern Malheur County, Oregon: Southwest Section American Association of Petroleum Geologists, Abstract with Program [in press].


INTRODUCTION

The samples were obtained from the McDermitt Caldera by Galli and a graduate student, C. Monkos. Bill Bradbury examined these by a screening procedure and based on his findings, certain ores which appeared to have some potential were examined by the Specialties Laboratory. The first four samples, A P P E N D I X, largely on x-ray examination for the presence of smectite and some indication of swelling in water were the following: 8-5, 8-6, 8-7, and 8-20 (McDermitt Mine).

Following this series, four additional samples were selected which were rated "Maybe" for smectite and showed no gelation. A fifth sample 8-16 was also selected which was rated as having smectite potential but did not show gelation. These samples were examined for potential by chemical treatment. (8-9, 8-12, 8-14, 8-16, and 8-18)

CONCLUSIONS

1. All of the initial four samples which were rated as having potential and gelled by the preliminary survey were found to have good viscosity with the exception of 8-20 which required chemical treatment.

2. Most of the last five samples which were rated "Maybe" for smectite content and did not gel by the preliminary survey were found to develop good gelling properties when chemically treated. One of these, 8-16, completely settled out when dispersed in water but formed a good gel structure when chemically treated.

3. The preliminary evaluation procedure developed by the Minerals group appears to be a good screening procedure described here.

4. Several of these ores have good potential. The Magnesium containing ores, 2-5, 8-5, and 8-7 have good gelling properties but lack in stability to electrolytes.

5. All of these ores lack the high brightness desired in VEEGUM products.
SPECIALTIES DEPARTMENT REPORT
Research and Development Division R. T. Vanderbilt
No. 2832

Smectite Exploration Samples (8-Series)

INTRODUCTION

The samples were obtained from the McDermitt Caldera by Galli and a graduate student, C. Ronkos. Bill Bradbury examined these by a screening procedure and based on his findings, certain ores which appeared to have some potential were examined by the Specialties Laboratory. The first four samples presented based largely on x-ray examination for the presence of Smectite and some indication of swelling in water were the following: 8-5, 8-6, 8-7, and 8-20 (McDermitt Mine).

Following this series, four additional samples were selected which were rated "Maybe" for smectite and showed no geletation. A fifth sample 8-16 was also selected which was rated as having smectite potential but did not show geletation. These samples were examined for potential by chemical treatment. (8-9, 8-12, 8-14, 8-16, and 8-8)

CONCLUSIONS

1. All of the initial four samples which were rated as having potential and gelled by the preliminary survey were found to have good viscosity with the exception of 8-20 which required chemical treatment.

2. Most of the last five samples which were rated "Maybe" for smectite content and did not gel by the preliminary survey were found to develop good gelling properties when chemically treated. One of these, 8-16, completely settled out when dispersed in water but formed a good gell structure when chemically treated.

3. The preliminary Evaluation procedure developed by the Minerals group appears to be a good screening procedure described here.

4. Several of these ores have good potential. The Magnesium containing ores, 8-5, 8-6, and 8-7 have good gelling properties but lack in stability to electrolytes.

5. All of these ores lack the high brightness desired in VEEGUM products.
DETAILS AND DISCUSSION

The first four samples were hydrated in a Waring Blender at 5% solids. The following results were obtained:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity @ 5%, cps</th>
<th>pH @ 5%</th>
<th>Acid compatibility</th>
<th>Acid Demand</th>
<th>Specific Resistance, ohms</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-5</td>
<td>14</td>
<td>8.2</td>
<td>2 ml 0.01N HCl</td>
<td>10.6</td>
<td>6664</td>
<td>Lt.Br.</td>
</tr>
<tr>
<td>8-6</td>
<td>380</td>
<td>7.3</td>
<td>3</td>
<td>3.0</td>
<td>6298</td>
<td>Lt. Br.</td>
</tr>
<tr>
<td>8-7</td>
<td>14</td>
<td>8.0</td>
<td>1</td>
<td>7.0</td>
<td>8160</td>
<td>Lt. Br.</td>
</tr>
<tr>
<td>8-20</td>
<td>3</td>
<td>8.5</td>
<td>6</td>
<td>1.8</td>
<td>9380</td>
<td>off white</td>
</tr>
</tbody>
</table>

It will be noted that all of these except 8-20 gave excellent to acceptable viscosity. 8-5, 8-6, and 8-7 had low stability to electrolytes. They also had high specific resistance, so it is possible the acid compatibility could be improved with chemical treatment.

150g of the ore was hydrated in 15,000 ml water for 8-5 and 8-20. 100g of ore in 10,000 ml water was used in the case of the others due to lack of sample. After standing overnight the colloidal fraction was decanted. Both colloidal fraction and residue were dried at 105°C. Results are as follows:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity @ 5%, cps</th>
<th>pH @ 5%</th>
<th>Acid compatibility</th>
<th>Acid demand</th>
<th>Specific Resistance, ohms</th>
<th>Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-5</td>
<td>210</td>
<td>8.6</td>
<td>1 ml 0.2N HCl</td>
<td>10.4</td>
<td>4535</td>
<td>46</td>
</tr>
<tr>
<td>8-6</td>
<td>740</td>
<td>8.4</td>
<td>1.5</td>
<td>2.4</td>
<td>5983</td>
<td>76</td>
</tr>
<tr>
<td>8-7</td>
<td>205</td>
<td>8.9</td>
<td>1</td>
<td>6.8</td>
<td>3975</td>
<td>32</td>
</tr>
<tr>
<td>8-20</td>
<td>5</td>
<td>9.4</td>
<td>3</td>
<td>2.8</td>
<td>5922</td>
<td>41</td>
</tr>
</tbody>
</table>

8-5, 8-6, and 8-7, which have the 060 x-ray peak at approximately 61° which identifies these as trioctahedral hectorites were quite low on stability to electrolytes.

8-20 did not develop a significant viscosity so the viscosity sample was treated with 1% salt on the basis of the solids. Results are as follows:
Initial viscosity, cps 5
Aged viscosity, cps 60
1% salt added, viscosity 500

It will be noted that this sample developed good viscosity with treatment. The acid and salt compatibility was checked and was still 3 and 6 as found initially.

The initial four samples selected by the Minerals Department all had good rheology with the use of some treatment. The three samples containing Magnesium, 8-5, 8-6, and 8-7 all were deficient in stability to electrolytes.

The next five samples selected for further investigation indicated "Maybe" for smectite content from x-ray examination and showed very little or no swelling in water based on the initial screening. They had low pHs and generally high resistivity. They could have potential by chemical treatment.

These samples were hydrated in a Waring Blender at 5% solids. The following results were obtained:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity @ 5%, cps</th>
<th>pH @ 5%</th>
<th>Acid Compatibility</th>
<th>Acid Demand (ml 0.01N HCl)</th>
<th>Specific Resistance (ohms)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-9</td>
<td>3</td>
<td>4.7</td>
<td>1</td>
<td>0.7</td>
<td>29760</td>
<td>Buff</td>
</tr>
<tr>
<td>8-12</td>
<td>4</td>
<td>5.5</td>
<td>5</td>
<td>0.5</td>
<td>16275</td>
<td>Buff</td>
</tr>
<tr>
<td>8-14</td>
<td>3</td>
<td>4.3</td>
<td>3</td>
<td>0.2</td>
<td>47430</td>
<td>Buff</td>
</tr>
<tr>
<td>8-16</td>
<td>31</td>
<td>4.1</td>
<td>0</td>
<td>0.2</td>
<td>2650</td>
<td>Buff</td>
</tr>
<tr>
<td>8-8</td>
<td>4</td>
<td>5.1</td>
<td>3</td>
<td>0.4</td>
<td>34410</td>
<td>Tan</td>
</tr>
</tbody>
</table>

Most of these samples were low viscosity, low pH and high resistivity. They, therefore, have potential for chemical treatment to enhance their properties.

They were hydrated at 1% solids in a Homomixer and allowed to stand overnight. The colloidal fraction was decanted. Both colloidal fraction and residue were dried at 105°C.

The following results were obtained:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity @ 5%, cps</th>
<th>pH @ 5%</th>
<th>Acid Compatibility</th>
<th>Acid Demand (ml 0.01N HCl)</th>
<th>Specific Resistance (ohms)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-9</td>
<td>3</td>
<td>4.7</td>
<td>1</td>
<td>0.7</td>
<td>29760</td>
<td>Buff</td>
</tr>
<tr>
<td>8-12</td>
<td>4</td>
<td>5.5</td>
<td>5</td>
<td>0.5</td>
<td>16275</td>
<td>Buff</td>
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<tr>
<td>8-14</td>
<td>3</td>
<td>4.3</td>
<td>3</td>
<td>0.2</td>
<td>47430</td>
<td>Buff</td>
</tr>
<tr>
<td>8-16</td>
<td>31</td>
<td>4.1</td>
<td>0</td>
<td>0.2</td>
<td>2650</td>
<td>Buff</td>
</tr>
<tr>
<td>8-8</td>
<td>4</td>
<td>5.1</td>
<td>3</td>
<td>0.4</td>
<td>34410</td>
<td>Tan</td>
</tr>
</tbody>
</table>
8-9  8-12  8-14  8-16  8-8

Viscosity @ 5%, cps  3  3  4  -  4
pH @ 5%  5.8  6.4  5.5  -  5.9
Acid compatibility  6  12  4  -  16
ml 0.01N HCl  
Specific Resistance, ohms  9936  4876  8464  -  11040
Color  Buff  Buff  Buff  Tan
Yield %  29  24  25  26
Acid Demand  0.9  1.1  0.9  -  0.9

8-16 settled completely after hydration at 1%, so no data could be obtained on the accepts. It was, therefore, dried at 105°C and rehydrated. 10% NaOH was added to bring the pH to 9.5-10.0 and 1% NaCl added. The crude ore now had the following viscosity:

8-16

Viscosity @ 5%, cps  155
pH  9.3

The remaining accepts samples were treated with NaOH to bring the pH to a range of 9.5-10.0 followed by the addition of 1% NaCl. The following amount of 10% NaOH to raise a 500 g. sample of 5% dispersion to the range of 9.5-10.0 pH was used:

8-9  8-12

Initial pH  6.1  6.8
10% NaOH added  1.9 ml to pH 9.9  0.8 ml to pH 9.7

8-14  8-16

Initial pH  6.1  treated as ore
10% NaOH added  2.6 ml to pH 9.7

8-8

Initial pH  6.3
10% NaOH added  1.25 ml to pH 9.8

Following this treatment the 5% gel sample was sheared for three minutes in a Waring Blender and properties determined. 8-14 was classified as a 1% solids dispersion and a separation of accepts and residue was made in the normal manner. It is included in the summary of the other treated accepts.
<table>
<thead>
<tr>
<th></th>
<th>8-9</th>
<th>8-12</th>
<th>8-14</th>
<th>8-16</th>
<th>8-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity @ 5%, cps</td>
<td>30</td>
<td>25</td>
<td>1100</td>
<td>600</td>
<td>19</td>
</tr>
<tr>
<td>pH @ 1%</td>
<td>8.4</td>
<td>8.2</td>
<td>9.2</td>
<td>9.3</td>
<td>8.7</td>
</tr>
<tr>
<td>Acid compatibility</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>ml 0.02N HCl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid Demand</td>
<td>2.6</td>
<td>1.9</td>
<td>3.3</td>
<td>2.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Specific Resistance, ohms</td>
<td>2708</td>
<td>2375</td>
<td>2470</td>
<td>2090</td>
<td>2850</td>
</tr>
</tbody>
</table>

We now have modified the rheology of these accepts samples so that they all could have potential. 8-16 which settled out completely initially, now has the colloidal accepts separating from the residue and forms a highly viscous material. 8-14 and 8-16 now have high gel structure accepts, when initially they were very thin suspension.

Acid compatibility has not been adversely affected in spite of the drop in specific resistance.

Acid demand is increased only slightly due to the addition of caustic.

These samples are off color, being tan to buff. As such, they probably do not have the potential for use in VEEGUM as if they were white. The fact, that we can change the rheology with chemical treatment does, however, increase our options with ores which do not have sufficient viscosity.
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>CaO</th>
<th>Fe₂O₃</th>
<th>Boron</th>
<th>Acid Soluble Arsenic</th>
<th>Acid Soluble Lead</th>
<th>Acid Soluble Mercury</th>
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</thead>
<tbody>
<tr>
<td>8-5</td>
<td>6.51%</td>
<td>15.2%</td>
<td>4.36%</td>
<td>1.33%</td>
<td>15.1 ppm.</td>
<td>3.75 ppm.</td>
<td>3.83, 4.00 ppm.</td>
<td></td>
</tr>
<tr>
<td>8-6</td>
<td>2.32%</td>
<td>19.0%</td>
<td>1.83%</td>
<td>0.89%</td>
<td>7.00 ppm.</td>
<td>-----</td>
<td>2.13, 2.28 ppm.</td>
<td></td>
</tr>
<tr>
<td>8-7</td>
<td>5.11%</td>
<td>15.2%</td>
<td>3.02%</td>
<td>0.41%</td>
<td>None Detected</td>
<td>5.62 ppm.</td>
<td>-----</td>
<td>2.90, 3.05 ppm.</td>
</tr>
<tr>
<td>8-8</td>
<td>17.0%</td>
<td>4.47%</td>
<td>1.26%</td>
<td>2.12%</td>
<td>&gt;440 ppm.</td>
<td>8.75 ppm.</td>
<td>258, 246 ppm.</td>
<td></td>
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<tr>
<td>8-9</td>
<td>15.1%</td>
<td>5.15%</td>
<td>1.10%</td>
<td>1.28%</td>
<td>&gt;440 ppm.</td>
<td>4.25 ppm.</td>
<td>736, 699 ppm.</td>
<td></td>
</tr>
<tr>
<td>8-12</td>
<td>16.2%</td>
<td>2.18%</td>
<td>1.26%</td>
<td>1.83%</td>
<td>&gt;220 ppm.</td>
<td>-----</td>
<td>12.3, 12.0 ppm.</td>
<td></td>
</tr>
<tr>
<td>8-14</td>
<td>19.4%</td>
<td>2.59%</td>
<td>1.10%</td>
<td>2.20%</td>
<td>13.5 ppm.</td>
<td>-----</td>
<td>-----</td>
<td>2.14, 1.94 ppm.</td>
</tr>
<tr>
<td>8-16</td>
<td>17.0%</td>
<td>2.73%</td>
<td>1.97%</td>
<td>2.02%</td>
<td>80.0 ppm.</td>
<td>4.50 ppm.</td>
<td>1.48, 1.35 ppm.</td>
<td></td>
</tr>
<tr>
<td>8-20</td>
<td>11.1%</td>
<td>1.67%</td>
<td>1.06%</td>
<td>1.76%</td>
<td>5.95 ppm.</td>
<td>14.3 ppm.</td>
<td>4.46, 4.53 ppm.</td>
<td></td>
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<tr>
<td>Lab No.</td>
<td>Field No.</td>
<td>% -37μ</td>
<td>E.G. Test Shift</td>
<td>Viscosity</td>
<td>pH 5%</td>
<td>(1% Solids) Specific Resistance T=25°C</td>
<td>060 Peak Shape/Height</td>
<td>G. E. Brightness</td>
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<td>-----------</td>
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<tr>
<td>GA-8-5’</td>
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<td>96</td>
<td>yes</td>
<td>3.5 cps</td>
<td>5.45</td>
<td>33°C</td>
<td>28,327</td>
<td>62.0° Brd-15</td>
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<tr>
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<td>yes</td>
<td>3.5 cps</td>
<td>5.40</td>
<td>31°C</td>
<td>32,387</td>
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<td>5.25</td>
<td>32°C</td>
<td>32,383</td>
<td>62.0° Brd-15</td>
</tr>
<tr>
<td>-11’</td>
<td>464532</td>
<td>95</td>
<td>no</td>
<td>4.6 cps</td>
<td>6.30</td>
<td>33°C</td>
<td>12,585</td>
<td>62.1° Brd-12</td>
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<tr>
<td>-12’</td>
<td>464533</td>
<td>99</td>
<td>yes</td>
<td>3.5 cps</td>
<td>6.10</td>
<td>33°C</td>
<td>12,585</td>
<td>62.1° Brd-11</td>
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<tr>
<td>-13</td>
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<td>3.0 cps</td>
<td>7.45</td>
<td>32.5°C</td>
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<td>-14’</td>
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<td>3.5 cps</td>
<td>5.00</td>
<td>32.2°C</td>
<td>37,730</td>
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<td>33.0°C</td>
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<td>61.8° Brd-14</td>
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<tr>
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<td>5.10</td>
<td>33.5°C</td>
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<td>61.4° Brd-14</td>
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<td>62.0° Brd-5</td>
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<td>-19’</td>
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<td>72</td>
<td>yes-tr</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>-20’</td>
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<td>94</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>61.8° Brd-9</td>
</tr>
</tbody>
</table>

1Submitted to Ben Carlson for final evaluation, bypassing Part II of the preliminary examination.
2Evaluation of smectite content via Part I indicates no smectite potential.
3Submitted to Ben Carlson after Parts I and II of the preliminary evaluation were concluded.
## EVALUATION OF SUBMITTED SMECTITE SAMPLES

### Physical Properties of Crude Ore

<table>
<thead>
<tr>
<th>Lab No.</th>
<th>Field No.</th>
<th>Location</th>
<th>Ethylene Glycol Test</th>
<th>Ethylene Glycol Shift</th>
<th>Raw Color</th>
<th>060 Peak Location</th>
<th>060 Peak Shape/Height</th>
<th>001 Peak Location</th>
<th>001 Peak Shape/Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-5</td>
<td>464526</td>
<td></td>
<td>+</td>
<td>yes+</td>
<td>buff</td>
<td>61° Nar-16</td>
<td>12.3A Brd-10</td>
<td></td>
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<tr>
<td>8-6</td>
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<td></td>
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<td>yes+</td>
<td>buff</td>
<td>61.1° Nar-23</td>
<td>15.0A Brd-19</td>
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</tr>
<tr>
<td>8-7</td>
<td>464528</td>
<td></td>
<td>+</td>
<td>yes+</td>
<td>buff</td>
<td>61.2° Nar-17</td>
<td>15.2A Nar-20</td>
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<tr>
<td>8-8</td>
<td>464529</td>
<td></td>
<td>+</td>
<td>yes+</td>
<td>tan</td>
<td>62.2° Nar-18</td>
<td>15.2A Sharp-44</td>
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</tr>
<tr>
<td>8-9</td>
<td>464530</td>
<td>McDermit</td>
<td>+</td>
<td>yes+</td>
<td>buff</td>
<td>62° Nar-17</td>
<td>15.2A Sharp-60</td>
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</tr>
<tr>
<td>8-10</td>
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<td>Caldera</td>
<td>+</td>
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<td>tan</td>
<td>62° Brd-15</td>
<td>14.2A Brd-26</td>
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</tr>
<tr>
<td>8-11</td>
<td>464532</td>
<td>Hectorite</td>
<td>-</td>
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<td>62° Brd-5</td>
<td>15.2A Nar-15</td>
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<td></td>
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</tr>
<tr>
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<td>14.5A Nar-27</td>
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</tr>
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<td>8-17</td>
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<td></td>
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<td>buff</td>
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<td>15.0A Brd-13</td>
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<td>8-20</td>
<td>464541</td>
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<td>61.8° Brd-9</td>
<td>15.2A Brd-10</td>
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</tr>
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</table>

*Ethylene Glycol Shift Convention:*
- **Yes+** = shift with peak enhancement
- **Yes** = shift only
- **Yes-** = shift with peak diminishment
- **No** = no shift
<table>
<thead>
<tr>
<th>Lab No.</th>
<th>Field No.</th>
<th>Location</th>
<th>Smectite</th>
<th>Feldspar</th>
<th>Quartz</th>
<th>Zeolite</th>
<th>Calcite</th>
<th>Cristobalite</th>
<th>Other</th>
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<tbody>
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<td>trace</td>
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<td>trace</td>
<td>trace</td>
<td>minor</td>
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<td>trace</td>
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<td>McDermitt</td>
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## McDERMITT CALDERA AREA - HECTORITE

### X-Ray Identification - Colloidal Fraction

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## Acid Soluble Arsenic and Acid Soluble Lead in Smectite Crude Ores from P. E. Galli Explorations

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