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AN ABSTRACT OF THE THESIS OF Carol Susan Evans for the Master of Science
in Geology presented November 22, 1985.

Title: The Geology, Geochemistry and Alteration of Red Butte, Oregon;
a Precious Metal-Bearing paleo hot spring system.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Michael L. Cummings

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Red Butte is located 60 km south of Vale, Oregon, about 20 km west of the Oregon/Idaho border. The butte is within the Owyhee Upland physiographic province of eastern Oregon which lies at the intersection of the Western Snake River Plain, the High Lava Plains, and the Northern Basin and Range provinces.

The butte is composed of Miocene to Pliocene lacustrine and fluvial volcanoclastic sediments. The topography of the butte is controlled by silicification of the sandstones and mudstones which cap it. Silicification and hydrothermal alteration are both structurally and stratigraphically controlled. North-trending normal faults dominate the area, and show progressively less offset in younger units. Strong northwest and minor northeast faults also cut the area.

Anomalous concentrations of Au, As, Sb, and Hg occur in banded quartz, quartz-adularia veins and rarely in calcite-quartz veins cutting basalts. The silicified mudstones at the butte top are generally barren. An hydrothermal explosion crater exposed on the southeast side of the butte lies at the intersection of north and northwest-trending faults. Banded quartz veins, quartz-adularia veins, and quartz-cemented breccias are exposed in the walls of the explosion crater. There is evidence of multiple brecciation events. A few mudstones exposed in the crater wall have an exhalative texture, contain pyrite disseminated along bedding, and contain trace amounts of Au.

The Red Butte system developed as a hot spring venting into a lake, possibly within a caldera. Periodic influxes of air fall tuffs and coarser clastic sediments diluted accumulating fine grained clastic and chemical sediments. As hot, silica saturated fluids rose into cooler lake waters they were cooled and diluted, resulting in silica flocculation near the vents and silicification of the lake sediments as they were deposited. Faults cutting the butte acted as conduits for the hydrothermal fluids. Overpressuring, caused by silica sealing of open fractures, resulted in explosions, generally followed by resealing of the system. Simultaneous faulting, sedimentation, and hot spring activity occurred at different rates throughout the life of the system.

Late in the life of the system, the local water table dropped, and the lake was replaced by a high-energy fluvial system. As the water table dropped below the surface, zones of low pH alteration and bleaching were developed above the hydrothermal vents, implying boiling at depth.

The large explosion crater and bedded explosion breccia on the southeast side of the butte were formed in these last stages of hydrothermal activity.

THE GEOLOGY, GEOCHEMISTRY, AND ALTERATION OF RED BUTTE, OREGON;

A PRECIOUS METAL-BEARING PALEO HOT SPRING SYSTEM

by

Carol Susan Evans

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

MASTER OF SCIENCE

in

GEOLOGY

Portland State University

1986

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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Richard Marty deserves the warmest thanks for his encouragement, support, suggestions, patience, and late night dinners.

This thesis is dedicated to my dog, Tala, who died at Red Butte after 10 years of devoted friendship.

TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
CHAPTER	
I INTRODUCTION.....	1
Goals.....	3
Methods and scope.....	3
Access.....	4
Climate and vegetation.....	5
Epithermal precious metal deposits.....	7
Previous work in the Owyhee area.....	12
Previous geochemical sampling.....	17
DOGAMI report.....	17
Barranger report.....	18
II REGIONAL GEOLOGIC AND TECTONIC SETTING.....	22
Mahogany Mountains caldera.....	29
III GEOLOGY OF RED BUTTE.....	31
Stratigraphy.....	31
Structure.....	40

IV HYDROTHERMAL ALTERATION.....	45
Introduction.....	45
Methods.....	46
Results.....	46
Silicification.....	49
Alteration of basalts.....	55
V VEINS AND BRECCIAS.....	59
Explosion crater and breccia.....	59
Breccias and veins from the crater walls.....	60
VI GEOCHEMISTRY.....	65
Methods.....	65
Results.....	65
Au, As, Sb, Hg.....	67
Rare earth elements.....	69
Oxygen and carbon isotopes.....	75
VII DISCUSSION.....	77
Stratigraphic setting.....	78
Structural history.....	79
Conditions of deposition.....	83
Effects of boiling.....	87
Alteration history.....	90
Controls on metal deposition.....	94
Model.....	95
Comparison with previously described systems.....	97
Conclusions.....	100

Suggestions for further study.....	101
BIBLIOGRAPHY.....	102
APPENDIX A INAA EXPERIMENTAL METHODS.....	109
APPENDIX B BONDAR-CLEGG ANALYSES.....	125
APPENDIX C X RAY DIFFRACTION.....	130

LIST OF TABLES

TABLE		PAGE
I	Characteristics that classify an hydrothermal system as being epithermal.....	8
II	Important epithermal precious metal deposits.....	9
III	Members of the Deer Butte Formation.....	16
IV	Anomalous concentration thresholds from DOGAMI Open File Report 0-83-2.....	18
V	Anomalous concentration thresholds from the Barranger report...	20
VI	Clay minerals in altered rocks at Red Butte.....	47
VII	Main alteration types exposed at Red Butte.....	48
VIII	INAA and Bondar-Clegg results for the same samples.....	66
IX	Summary of results for Au, AS, Sb, and Hg.....	68
X	Samples collected in the crater.....	70
XI	Summary of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ results.....	76
XII	Equations used in construction of stability diagram.....	86
XIII	Energies used to determine elemental concentrations using INAA.....	111
XIV	Elemental concentrations for INAA standards used.....	112
XV	INAA Results.....	113
XVI	Generalized identification criteria for clays.....	133

LIST OF FIGURES

FIGURE	PAGE
1. Physiographic provinces of Oregon.....	2
2. Geologic map of Red Butte.....	map pocket
3. Hydrothermal alteration map of Red Butte.....	map pocket
4. Location map.....	6
5. Correlation of the Deer Butte Formation.....	15
6. Location of area B, Barranger Inc. study.....	19
7. Position of Pacific and North American plates during the Cenozoic.....	24
8. Basin and Range and adjoining provinces.....	25
9. Termination of Basin and Range in the Vale area by the Willow Creek fault.....	27
10a. Measured Section 1.....	32
10b. Measured Section 2.....	33
10c. Measured Section 3.....	34
10c. Measured Section 4.....	35
11. Photomicrographs.....	39
12. Cartoon of butte top stratigraphy.....	41
13. Folding of the lower Deer Butte Formation.....	43
14. Photomicrographs.....	51
15. Photomicrographs.....	54
16. XRD Results for altered basalt, a.....	56
b.....	57
17. Bedded explosion breccia.....	61

18.	Plane table sample location map.....	63
19.	REE Patterns, a,b.....	73
	c,d.....	74
20.	Silica solubility diagram.....	83
21.	Activity Diagram for the System $\log a_{H^+} / K^+$ vs $\log a_{H_4SiO_4}$	85
22.	Cartoon of model of Red Butte.....	96

CHAPTER I

INTRODUCTION

Exposed on the west side of the Owyhee reservoir near the Oregon/Idaho border in eastern Oregon are intercalated sedimentary and igneous rocks of the Deer Butte Formation (Kittleman and others, 1965; Johnson, 1961). These rocks are of late Miocene and early Pliocene age and were deposited in a large north-trending basin which was undergoing concurrent faulting, deformation, sedimentation and igneous activity (Kittleman, 1962; Johnson, 1961; Corcoran, 1962; Malde and Powers, 1962). This area lies within the Owyhee Uplands province of Baldwin (1982) and is bounded by the Great Basin area of the Basin and Range province to the south, the High Lava Plains of Oregon to the west, the Blue Mountains to the north, and the western Snake River Plain to the east (Figure 1) (Thornbury, 1961; Christiansen and McKee, 1978; Baldwin, 1982).

Hydrothermally altered and silicified rocks occur locally at Vale Butte, Deer Butte, Brown Butte, Quartz Mountain, and Red Butte (Gray and others, 1983). Red Butte was selected for study after anomolous concentrations of gold were reported by the Oregon Department of Geology and Mineral Industries in a reconnaissance geochemical sampling program of several proposed Wilderness Study Areas (WSA) in lands administered by the Bureau of Land Management (BLM) (Gray and others, 1983).

Figure 1. Physiographic provinces of Oregon (From Baldwin, 1982)

Goals:

The relations among deformation, sedimentation, volcanism, and hydrothermal activity at Red Butte provide a model for processes that were active in the Owyhee reservoir area during the middle to late Tertiary. The objectives of the study were to: 1) define the age relations among hydrothermal activity and rock alteration at the butte, 2) define the physical controls on alteration, 3) describe the geochemistry and mineralogy of the alteration system, 4) model the hydrothermal system responsible for the alteration at Red Butte, and 5) discuss the precious metal potential of the area.

Methods and Scope:

This work is oriented towards two main tasks. The first task was to locate and map the various hydrothermal alteration zones at Red Butte and define the structural, stratigraphic and lithologic controls on alteration. To address this task, the geology of a six square mile area centered on Red Butte was mapped at a scale of 1:2,400 (Figure 2, in pocket). Mapping was done using a combination of field observations and aerial photographs. Local stratigraphy was first defined by the use of measured sections and later correlated with published stratigraphy where possible (Kittleman, 1962, Kittleman and others, 1965, Johnson, 1961, Maulde and Powers, 1962, Corcoran and others, 1962). The locations and types of hydrothermal alteration at Red Butte were mapped at a scale of 1:8,000 (Figure 3, in pocket). Three large alteration zones exposed at the top of Red Butte were sampled. An alteration zone exposed on the southeast flank of the butte had the most accessible vertical exposures and the most intense alteration.

This zone, therefore, was sampled in greater detail. Mineralogies were analyzed by petrographic techniques and by x-ray diffraction (XRD).

The second task was to define the geochemistry of the various types of alteration. Samples from the major alteration zones and other samples from the top of the butte were analyzed by the following methods: 95 samples were assayed by Bondar-Clegg Corporation for Au, Ag, Hg, As, and Sb; 73 samples were analyzed by instrumental neutron activation analysis (INAA) at Portland State University, including splits from some of the samples assayed by Bondar-Clegg. Eight samples were analyzed for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ at Rice University.

The data obtained in completion of the first and second tasks were used to develop a model for the mineralization and alteration at Red Butte. The model was compared to published models for similar systems and on this basis predictions were made for the presence of similar epithermal systems in the Owyhee Uplands area.

Access:

Red Butte is 100 km (sixty miles) south of Vale, Oregon and 33km (twenty miles) west of the Oregon/Idaho border, in Malheur County, T 25 and 26 S, R 43 and 44 E (Willamette Meridian). The butte lies north of the east-trending bend of the Owyhee River at the southern end of Lake Owyhee (Figure 4). Access is by unimproved Bureau of Land Management (BLM) dirt roads that are passable from June to October. Four wheel drive vehicles are recommended.

Climate and Vegetation:

The area has a dry continental climate with hot summers and moderately cold winters. The average annual rainfall in Vale, Oregon is 23 cm (9.06 inches) (Jones, 1953). The type and amount of vegetation varies with temperature and proximity to water. Sparse sagebrush and cheat grass are the most common plants, but willow grows in sandy areas along the edge of Lake Owyhee.

The study area is characterized by moderate relief produced by differential stream erosion acting on relatively undeformed sedimentary rocks, tuffs and intercalated basalt flows.

Figure 4. Location map

EPITHERMAL PRECIOUS METAL DEPOSITS:

Epithermal precious metal deposits and related hot springs systems have been widely studied (Lindgren, 1933; Sigvaldson and White, 1962; White, 1967; White, and others, 1971; White, 1974, Bethke and Rye, 1973; O'Neil and Silberman, 1974; Burt and Rose, 1979; Meyer and Hemely, 1967; Taylor, 1973, 1979; Buchanan, 1980, 1980; Grindley, 1970; Berger and Tingley, 1980; Berger and Eimon, 1982; Berger, 1983). The following is a summary of the features noted by these workers.

Epithermal gold and silver deposits form in near surface environments, at temperatures ranging from 50-300°C. Lindgren (1933) identified several characteristics of epithermal deposits and hydrothermal systems. These characteristics have been reviewed by recent workers and are listed in Table I.

Epithermal precious metal deposits may occur in any rock type, but the major deposits occur as replacements in sedimentary or volcanic sequences. Shown in Table II is a brief list of important epithermal precious metal deposits.

Areas that have undergone late, multi-stage tectonic fracturing are favored for epithermal deposits. The fractures serve as a plumbing system for the entry and circulation of hydrothermal fluids. The deposits are usually associated with intrusions that may not be exposed, these intrusions are often related to volcanic rocks of rhyolitic to dacitic composition in the region.

TABLE I

CHARACTERISTICS THAT CLASSIFY A HYDROTHERMAL
SYSTEM AS BEING EPITHERMAL

Depth of formation:	Surface to 1,000 m
Temperature of formation:	50-300°C
Form of deposits:	Thin to wide veins, stock- works, disseminations, replacements
Ore textures:	Open space filling, crustification, collo- form banding, comb structure, brecciation
Ore elements:	Au, Ag, (As, Sb), Hg, Te*, Tl*, U*, Pb*, Zn*, Cu*
Alteration:	Silicification, argillization, sericite, adularia, propylitization
Common features:	Fine grained chalcedonic quartz, quartz psuedomorphs after calcite, brecciation

() indicates elements often present in economic concentrations but usually less valuable than associated precious metals.

* Elements generally present in sub- economic concentrations.
From Berger and Eimon, 1980

TABLE II

IMPORTANT EPITHERMAL PRECIOUS METAL DEPOSITS

Veins and replacements in intermediate to felsic volcanic rocks

Au/Ag	Ag/Au
Goldfield, Nevada	Creede, Colorado
Round Mountain, Nevada	Delamar, Idaho
Cripple Creek, Colorado	Tonopah, Nevada
	Virginia City, Nevada
	Guanajuato, Mexico

Veins and replacements in clastic and carbonate sedimentary rocks

Au/Ag	Ag/Au
Carlin, Nevada	Taylor, Nevada
Conola, British Columbia	Hardshell, Arizona

From: Berger and Tingley, 1980, Berger and Eimon, 1982

The size and shape of an epithermal deposit are controlled by the fault and fracture geometry, porosity, permeability, stratigraphy and composition of the host rocks. These factors determine the hydrodynamics of the mineralizing fluid in the system. Repeated use of the same fracture conduits is necessary if economic amounts of precious metals are to be deposited.

Stable isotope studies have shown that the waters circulating in epithermal systems are meteoric (Taylor, 1979). These waters percolate downward, are heated at depth by the intrusion, and form a plume of hot water which rises towards the surface along available fractures. As the hydrothermal plume rises, it leaches metals and other ions from the host rock. Near the surface hydrostatic pressure is reduced and the fluids boil. Boiling, mixing and cooling of hydrothermal solutions are the major agents of precious metal deposition.

The deposition of gangue minerals may produce a self-sealing system. Silica deposition sealed fractures at Round Mountain, Nevada (Berger and Tingley, 1980) and at Guanajuato, Mexico (Buchanan, 1979), while clays produced sealing at Delamar, Idaho (Pansze, 1975). Silicification above the ore zone often forms a barren silica cap which can fracture and re-seal, controlling the boiling and overpressuring of the fluid system below. Repeated episodes of overpressuring, rupture, and violent boiling produce extensive zones of brecciation which are associated with zones of precious metal deposition as at Round Mountain (Berger and Eimon, 1982). Development of a silica cap or some other method of self-sealing may be a critical factor in the concentration of economic amounts of precious metals

Au, Ag, and Hg are characteristically found in the precious metal zone, at or just below the zone of boiling. Hg forms a vapor phase during boiling and also occurs in the zone of silicification above the ore zone.

If a hydrothermal system vents to the surface as in a hot spring, extensive sinter deposits may develop. Active hot spring systems at Broadlands and Wairakei, New Zealand have deposited precious metals at the surface (Grindley, 1970, Weissberg and others, 1979).

Epithermal and hot springs deposits are associated with extensive hydrothermal alteration of the host rock. The alteration mineral assemblage depends on the chemical composition, temperature and pressure of the hydrothermal fluid, the initial chemical composition and mineralogy of the host rock and on the time available for equilibration. Hydrothermal alteration of most alumino-silicate rocks can be classified as propylitic, intermediate argillic, advanced argillic, sericitic and potassic. Most

epithermal systems have zoned alteration and mineralization patterns.

There is a strong vertical control on precious metal deposition.

Several models have been produced by previous workers to describe different epithermal systems. Specific models comparable to the system at Red Butte are discussed.

PREVIOUS WORK IN THE OWYHEE AREA

The stratigraphy of the Owyhee Uplands area is similar to that of southwestern Idaho; early workers extended the geologic units of southwestern Idaho across the border into the study area. Most of the early work in the western Idaho-southeastern Oregon area was done on a regional scale. Sedimentary rocks at Castle Creek, Idaho were assigned to the early to middle Miocene and named the Idaho Formation (Meek, 1870, Cope, 1884). Lacustrine and fluvial deposits in western Idaho were named the Payette Formation (Lindgren, 1898), and assigned a Miocene age based on floral evidence (Knowlton, 1898). Re-interpretation of the Payette flora showed the age of these rocks to be late Eocene (Knowlton, 1902).

In a reconnaissance study of the geology of the area near Deer and Mitchell Buttes, Washburne (1909) extended the Payette and Idaho Formation names into Oregon.

Kirkham (1931) revised the definition of the Payette and Idaho Formations. He called the oldest sedimentary rocks, which are interbedded with what was thought to be Columbia River Basalt (CRB), the Payette Formation and, because of their supposed relation to the CRB, assigned them to the Miocene. He reassigned the name Idaho Formation to the terrestrial sedimentary rocks overlying the units called Columbia River Basalt (now redefined as the Owyhee Basalt) and Owyhee Rhyolite (now the Jump Creek Rhyolite) and assigned them to the Pliocene.

More recent work in the Owyhee area has resulted in subdividing and redefining the Idaho and Payette formations. The Idaho Formation was

elevated to group status (Malde and Powers, 1962; Kittleman, 1962; Kittleman and others, 1965). The Deer Butte Formation was defined and placed in the lower Idaho Group (Kittleman, 1962; Kittleman and others, 1965). The Idaho Group has been restricted to the western Snake River plain and units overlying the Deer Butte Formation in Oregon have been placed in the Idavada Volcanics (Kimmel, 1982, Malde and Powers, 1962). Figure 5 shows the relationship of the Deer Butte Formation to the Idaho Group as discussed by Kittleman (1962), Kittleman and others (1967), and Corcoran, (1962). Formations older than the Idavada Volcanics such as the Deer Butte Formation, Owyhee Basalt, and the Succor Creek Formation were deposited in north-trending basins before the development of the northwest-trending western Snake River Plain downwarp (Malde and Powers, 1962; Kimmel, 1982; Swirydczuk and others, 1982).

The Deer Butte Formation is underlain unconformably by the Owyhee Basalt and is overlain unconformably by the Grassy Mountain Formation (Kittleman, 1962; Johnson, 1961). The type section is at Deer Butte, Oregon. The formation consists of volcanoclastic and clastic fluvial and lacustrine sandstones, silts, shaly tuffaceous mudstones, and minor interbeds of carbonaceous shale. Intercalated within the Deer Butte Formation are high alumina olivine tholeiite basalt flows and related dikes (Kittleman, 1962; Kittleman and others, 1965; Johnson, 1961; Hart and others, 1983). The Deer Butte Formation is subdivided into seven members, given here in ascending stratigraphic order: 1) Red Butte Member, 2) Orlando Spring Member, 3) Furgeson Spring Member 4) Quartz Mountain Basalt Member, 5) Burnt Mountain Member, 6) Sourdough Basin Basalt Member, 7)

Member, 5) Burnt Mountain Member, 6) Sourdough Basin Basalt Member, 7) Mitchell Butte Member. A brief description of the members of the Deer Butte Formation from the work of Kittleman and others, (1965) and Johnson (1961) is given in Table III.

Pliocene		HEMPHILLIAN	IDAHO GROUP.	KITTLEMAN	CORCORAN
		CLARENDONIAN		Grassy Mountain Fm	unconformity
					unconformity
				unconformity	unconformity
		BARSTOVIAN			unconformity
				unconformity	unconformity

Figure 5. Correlation of the Deer Butte Formation

TABLE III

MEMBERS OF THE DEER BUTTE FORMATION

Mitchell Butte Member: Lithic volcanic sandstone, tuffaceous siltstone, silicified arkosic sandstone, pebble conglomerate and oolitic sandstone; unit often cross bedded in coarser units.

Sourdough Basin Basalt Member: olivine basalt, with olivine and pigeonite partly altered to montmorillonite and chlorite; considerable difference in thickness over short distances.

Burnt Mountain Member: yellowish brown, thinly bedded, volcanic sandstone, carbonaceous sandstones and siltstones, generally thin bedded to laminar, crossbedding common in coarser parts.

Quartz Mountain Basalt Member: Series of several olivine basalt flows, olivine and pigeonite often altered to chlorite and montmorillonite, generally a baked zone at the base of lowest flow.

Furgeson Spring Member: similar to Red Butte Member: argillaceous lithic sandstone, minor carbonaceous shale, tuffaceous and volcaniclastic siltstones and claystones, tuffaceous shaley mudstones.

Orlando Spring Member: Laharic breccias, concretionary sandstones and siltstones, an interbed of carbonaceous shale, lower unit; calcite cemented, concretionary sandstones and siltstones, upper unit; brown laharic breccia, local crossbedding.

Red Butte Member: Interbedded lithic sandstone, tuffaceous siltstone, tuffaceous shaley mudstone with minor carbonaceous shale; unit is planar bedded, generally thin bedded to laminated.

From: Johnson, 1961, Kittleman and others, 1965

PREVIOUS GEOCHEMICAL SAMPLING

DOGAMI Report:

In 1982 the Oregon Department of Geology and Mineral Industries (DOGAMI) conducted a reconnaissance geochemical study of 18 wilderness study areas (WSA) in southeastern Oregon on lands supervised by the Bureau of Land Management to determine economic mineral potential (Gray and others, 1983). Red Butte is located in WSA 3-56 and was one of four wilderness study areas included in the Owyhee Reservoir section of the report. The DOGAMI study analyzed silt, soil, and rock chip samples for 17 elements. Anomalous concentration thresholds were determined from frequency tables and histograms of the silt sample population. Anomalous value thresholds are shown in Table IV.

Computer generated overlay maps for Au, W, and Sn show that the Owyhee Reservoir area is mineralized on both the east and west sides of the reservoir. Most of the stream sediment samples from drainages entering the reservoir contained anomalous Au. Rock chip samples from the Owyhee Reservoir area were anomalous in several elements. Soil sample traverses across the top of Red Butte and in the Red Butte area contained several anomalous Au concentrations.

The DOGAMI study reported that Red Butte displayed several classic features of an hot-spring type epithermal Au system. These features were combined with anomalous concentrations for several elements over a large area. DOGAMI suggested that Red Butte should become a major Au exploration target.

TABLE IV
ANOMALOUS CONCENTRATION THRESHOLDS FROM
DOGAMI OPEN FILE REPORT 0-83-2

Au concentrations in ppb, all othes in ppm

Element	Conc.	Element	Conc.	Element	Conc.
Au	5	Co	24	Ni	25
Ag	0.1	Cu	45	Sn	2
As	4.5	Pb	10	W	1
Ba	250	Mn	800	U ₃₀₈	2
Be	1	Hg	0.2	Zn	60
Cd	0.3	Mo	7	Zn/Cd ratio	700

Barranger Report:

In 1984, Barranger Resources Incorporated conducted a reconnaissance study to identify the mineral potential of the Northern Malheur Resource Area, Vale District, Oregon for the BLM (Robinson and others, 1984). Red Butte is adjacent to the southern end of area B of the Barranger study, (Figure 6). Barranger Inc. sampled stream sediment, soil, and rock chips and these samples were assayed for 13 elements. Anomaly threshold concentrations were determined from log transformed statistics for the stream sediment values and are listed in Table V. The approach was similar to the DOGAMI study conducted in 1982.

In the study area, the most prominent cluster of stream sediments containing elevated Au concentrations occurred along Red Butte Canyon in T 25 S, R 43 E. Au concentrations ranged from 15 ppb to 28 ppb. Other anomalous Au concentrations in area B were generally found in the volcanoclastic and sedimentary rocks of the Deer Butte Formation. Soil sampling traverses A and B were located to the west of Red Butte Canyon, in sections 31 and 32, T 25 S, R 43 E. These samples delineated an Ag, Au,

Figure 6. Location of area B, Barranger Inc. study (from Robinson and others, 1984).

TABLE V

ANOMALOUS CONCENTRATION THRESHOLDS
FROM THE BARRANGER REPORT

Anomaly		Anomaly	
Element	Threshold	Element	Threshold
Au (ppb)	10	As	19
Ba	900	Hg (ppb)	4
Cu	70	Mn	1345
Pb	20	Zn	139
		U	2.3

All values in ppm unless otherwise noted
From: Robinson and others, 1984

Ba, Hg, and As anomaly. Ag concentrations up to 6.5 ppm and Au to 340 ppb define the zone of strongest enrichment with As, Ba, and Hg forming a broad geochemical halo on either side. Geochemical relationships along traverse B are similar, but concentrations of Au, Ag, and Ba are lower.

Factor analysis by Barranger Inc. of the stream sediment assays for the entire study area resulted in four geological-geochemical factors: Factor 1 is weighted heavily in Cu, Zn, and Mn, elements generally related to base metal mineralization; Factor 2 is heavily influenced by As, Hg, and Ba, a combination of elements often associated with epithermal precious metal deposits; Factor 3 reflects U enrichment; Factor 4 also suggests base metal mineralization. The Red Butte Canyon area showed the strongest response to factor 2 of the entire study area (Robinson and others, 1984). Other areas in study area B, north of Red Butte also were strongly influenced by factor 2, and were recommended for follow up work.

The report concluded that the entire survey area exhibited several characteristics which make it favorable for precious metals exploration including: an extensional structural regime, high regional heat flow,

presence of active geothermal cells, and permeable host rocks accessible to migrating hydrothermal fluids.

CHAPTER II

REGIONAL GEOLOGIC AND TECTONIC SETTING:

The regional setting of Red Butte reflects the Neogene geologic processes that have been active in the Owyhee Uplands area. The structure of the Owyhee Uplands area has been strongly influenced by the development of the adjoining Basin and Range, Snake River Plain, and the High Lava Plains geologic and tectonic provinces (see figure 1) (Gray and others, 1983). At Red Butte, the north-trending structures of the Basin and Range overlap with the northwest-trending structures of the Brothers fault zone and western Snake River Plain. These overlapping structural trends have created intersecting fault and fracture systems. The structural features are combined with a high regional heat flow for both the Basin and Range and the Snake River Plain (Leeman, 1982; Stewart, 1978; Christiansen and McKee, 1978). The combination of intersecting fault systems and high regional heat flow is a favorable environment for mineralization.

The tectonics of the Basin and Range province are related to the configuration of lithospheric plates off the west coast of North America. The following summary of the relationship between these lithospheric plates and events on the North American continent is from the work of: Atwater (1970), Atwater and Molnar (1973), Coney (1978), Hamilton (1975), Hamilton and Meyers (1966), Stewart (1978), and Smith (1978). During the middle Cenozoic, the Pacific and Farallon plates, separated by the East Pacific

Rise spreading center, were located to the west of the North American continent, and the Farallon plate was being subducted along the western margin of the continent (Figure 7). About 29 m.y. ago, the spreading zone intersected the subduction zone, causing a change in plate geometry and the development of a transform fault system along the western coast of North America (Atwater, 1970; Molnar, 1973). The extension of the Basin and Range and the right-lateral shear of the Brothers Fault Zone, Walker Lane, and western Snake River Plain are believed to be related to this change in plate geometry, and the area of extension generally correlates with the projected location of the subducted Farallon Plate (Atwater, 1970; Stewart, 1978; Smith, 1978). The High Lava Plains-Snake River Plain is the northern boundary to the Basin and Range zone of extension (Stewart, 1978; Lillie and Couch, 1979; Lawrence, 1976).

The Basin and Range province extends from southern Oregon and Idaho southward across Nevada, western Utah, Arizona, and into New Mexico and Mexico (Figure 8). The northern part of the Basin and Range province, from southern Nevada to southeastern Oregon and southern Idaho, is known as the Great Basin.

The Great Basin is a series of north-trending linear mountain ranges separated by intervening valleys. Geophysical characteristics of the Great Basin are a high regional heat flow, a low upper mantle velocity, a thin continental crust, and a regional gravity low (Eaton and others, 1978; Stewart, 1978).

Since Cenozoic time, local and regional extension, expressed as normal faulting, and local strike-slip faulting have dominated the tectonics of

Figure 7. Position of Pacific and North American plates during the Cenozoic. Fine lines indicate faults. Shaded zones indicate important rock outcrops: cross pattern, Mesozoic batholiths; dash pattern, Quaternary rhyolite-basalt flows; generalized anticline symbols, folds in Columbia Plateau basalts; strike-dip symbols, attitudes of upper-mantle layers interpreted as paleosubduction zones (from Smith, R. B., 1978).

Figure 8. Basin and Range and adjoining provinces (from Christiansen and McKee, 1978).

the Great Basin. The present horst and graben physiography is primarily the result of steep normal faulting during the last 10 million years (Stewart, 1983; Christiansen and McKee, 1978; Smith, 1978).

The High Lava plains of Oregon form a northwest-trending zone that marks the northern edge of well developed Basin and Range structure and physiography. The main structural element within these plains is the Brothers Fault Zone, a zone of northwest-trending en echelon faults of small normal to right-lateral displacements. Parallel fault zones, such as the Eugene-Denio lineament, and the Willow Creek fault truncate Basin and Range structures southwest and northeast of the Brothers fault zone respectively. East of the intersection of the Steens Mountains with the Brothers fault zone, Basin and Range type structures continue until they are truncated by the Willow Creek fault near Vale, Oregon (Lillie and Couch, 1979) (Figure 9).

The Snake River Plain is an arcuate depression of low relief that extends from the Owyhee plateau on the Oregon/Idaho border for 500 km across southern Idaho. It cuts across the structural and geologic outcrop trends of the Basin and Range province and the northern Rocky Mountains. The plain is characterized by high regional heat flow and thin continental crust (Leeman, 1982; Malde and Powers, 1962).

The western Snake River Plain is a graben-like structure bounded by northwest-trending en echelon normal faults on the north, and downwarped in the center (Malde, 1959; Leeman, 1982). Northwest-trending structures to the northeast of Vale, Oregon eg., the Willow Creek Fault, may be related to the Western Snake River Plain (Lillie and Couch, 1979).

Figure 9. Termination of Basin and Range in the Vale area by the Willow Creek fault (from Lillie and Couch, 1979).

Beginning in the Middle Miocene, volcanic activity associated with regional uplift and an advancing wave of block faulting transgressed eastward from the Owyhee plateau to form the Snake River plain-Yellowstone plateau province (Armstrong and others, 1975a; Christiansen and Lipman, 1972; Matthews and Anderson, 1973; Suppe and others, 1975).

The Great Basin has been dominated by bimodal rhyolite-basalt volcanism since mid-Cenozoic time and is characterized by the progression of active faulting and volcanism from the center towards both the east and west margins of the province. Southeastern Oregon was a large region of bimodal volcanism starting about 17 m.y. ago (Armstrong, 1978). In the Silver City area of southwestern Idaho, a bimodal volcanic suite was erupted about 15 to 16 m.y. ago and contemporaneous geothermal waters deposited the silver ores of the Delamar and Silver City mining districts (Armstrong, 1978; Pansze, 1975).

The volcanic systems of the eastern Snake River plain and the High Lava plains define symmetrical, oppositely-directed systems (Smith, 1978; Christiansen and McKee, 1978). Starting with early rhyolitic and basaltic volcanism about 17 m.y. ago in the Owyhee Plateau of southwestern Idaho, volcanism migrated northeast along the axis of the eastern Snake River plain, and northwest along the axis of the High Lava plains at about 1 to 3 cm per year. These oppositely propagating systems are now represented by the Newberry volcano at the northwest end and by the Yellowstone Plateau at the northeast end.

The Owyhee Upland is located in the center of this divergent trend of the High Lava Plains and Snake River Plain volcanic fields. Pliocene and

Holocene basalts at Cow Creek Lakes, 17 km south of Red Butte, and at North and South Table Mountain, 3 km east of Red Butte are evidence for continued volcanic activity in the area west of the Owyhee Reservoir.

Mahogany Mountains caldera

Recently, Dr. James Rytuba of the U.S. Geological Survey has mapped the east half of a caldera, the "Mahogany Mountains caldera" across the Owyhee river immediately to the east of Red Butte. The following description is from Rytuba and others (1985). The caldera is described as a Miocene age collapse structure with a maximum diameter of 13 km. It formed as a result of the eruption of the Leslie Gulch Ash-Flow Tuff (the uppermost member of the Succor Creek Formation). The south topographic wall of the caldera coincides with the north scarp of the Mahogany Mountains, and the north topographic wall coincides with a scarp 5 km north of Leslie Gulch. The caldera is filled with a minimum of 460 m of non welded ash-flows, base surge deposits, and well-bedded tuffs of the Leslie Gulch tuff.

Porphyritic rhyolite intrusions and flows were emplaced throughout the caldera but are most abundant along the north margin. Plugs and tuffs of porphyritic rhyolite are locally brecciated and cut by quartz stockwork veining which contains anomalous concentrations of As, Hg, and Zn.

North-trending grabens developed within the caldera after resurgence of the central part. Two north-striking dike systems extend across the caldera and coincide with graben-bounding faults.

The caldera moat and grabens were filled with a minimum of 310 m of

tuff of Spring Creek, which consists of several unwelded ash-flow tuffs. Tuffaceous sediments fill the remainder of the moat. Moat sediments are locally silicified and pyritized and contain anomalous concentrations of Mo, As, Pb, and Zn.

CHAPTER III

GEOLOGY OF RED BUTTE

The Red Butte area (Figure 2) is composed of about 400 m (1,200 ft) of lacustrine and fluvial volcanoclastic and clastic sediments with intercalated olivine basalt flows. These sediments are cut by numerous north-trending normal faults and north-trending olivine basalt dikes. Less prominent fault trends are northwest and northeast. The lower stratigraphic units have steeper dips and greater offset along faults than the uppermost units.

Large areas below the west, south, and southeast sides of Red Butte are covered by landslide debris. The landslides on the west and south are composed of silicified sediments from the butte top, while the landslides along the southeast include a basaltic component as well as material from the butte top.

Stratigraphy:

Four stratigraphic sections were measured; three from exposures in creeks. Section four was measured at the approximate location of Johnson's measured section E (Johnson, 1961) (Figure 10,a,b,c,d). The locations of the measured sections are shown in Figure 2. The sections were measured using pace and compass techniques and an altimeter accurate to plus or minus 7 m (20 ft).

Figure 10a. Measured section 1

Figure 10b. Measured section 2

Figure 10c. Measured section 3

Figure 10d. Measured section 4

Buff colored, tuffaceous siltstones and mudstones with interbedded arkosic sandstone and carbonaceous shale are common in the measured sections and are too common to provide a basis for correlation between sections. Correlations, therefore, are based on more distinctive lithologic units. The brown, calcite cemented, concretionary, basaltic sandstone in measured section 4 is distinctive, and appears to correlate with a similar, but cross bedded, unit in section 1 and the basal sandstone and conglomerate of measured section 2 (Figure 10). This correlation is tentative, since the units have differences in bedding style. They all contain similar lithologies, however, that are different from the overlying and underlying units. The olive drab sandstone overlain by fossiliferous shaley mudstones at the top of measured sections 2 and 3 (Figure 10) are also correlated. This unit directly underlies the basalt below the butte top.

Measured section 4 was used to correlate the sediments at Red Butte with the published stratigraphy. The measured stratigraphy correlates well with measured section E of Johnson (1961) from the same location, therefore, these units are named in ascending order: the Red Butte Member, Orlando Spring Member, Furgeson Spring Member, and Quartz Mountain Basalt Member of the Deer Butte Formation. These names are extended to the other measured sections as shown in Figure 10.

The contact between the Quartz Mountain Basalt and the overlying olive drab sandstone described in measured sections 2 and 3 is either covered and/or faulted in the exposures at Red Butte. This makes the stratigraphic position of the sandstone unit difficult to define. This olive sandstone

overlain by tuffaceous shales does not match Johnson's description for the Burnt Mountain Member, and is not correlated with it in this study. The sequence, including the tuffaceous shale will be informally called unit A in this study.

The olivine basalt flows overlying unit A are lithologically indistinguishable from the Quartz Mountain Basalt, and are similar to descriptions for the Sourdough Basin Basalt (Johnson, 1961; Kittleman, 1962) and high alumina olivine thoeiliite (HAOT) (Hart, 1984). They are coarse, holocrystalline, equigranular basalts with sub-ophitic texture. Correlation of this basalt at Red Butte with the Sourdough Basin Basalt is uncertain, and the sequence of basalt flows below the top of Red Butte will be informally called the upper basalt in this study. The upper basalt is 62 m (200 ft) thick at Red Butte, and consists of at least five flows. At the contact of the upper basalt and the underlying unit A, large, 0.05-1 m, oblate, rounded clasts of unsilicified sediments occur as xenoliths in the lower one m of the upper basalt. These sedimentary xenoliths are not fractured or broken.

The silicified sandstones and siltstones overlying the upper basalt and capping Red Butte are similar to the descriptions given for the Mitchell Butte Member by Johnson (1961), Kittleman (1962), and Kittleman and others (1967). Since the correlation of the two units directly below this is uncertain, this correlation is also uncertain. The silicified sediments capping the butte will be called unit B (lower 2/3 of the silicified butte cap) and unit C (uppermost silicified sandstones) in this study.

The basalt to the northwest of Red Butte (Figure 2) is fine grained, porphyritic, with very sparse olivine phenocrysts and a matrix composed of glass and magnetite. It is much blacker in hand sample and in outcrop than all other basalts exposed at Red Butte. This basalt is lithologically unlike the Deer Butte Basalts (Figure 11a,11b), and will be informally called the black basalt in this study.

Numerous olivine basalt dikes cut the sediments at Red Butte. These dikes are medium to coarse grained, equigranular, with olivine and pyroxene altered to iddingsite, chlorite, and, in some cases, smectite. They are similar lithologically to the Quartz Mountain Basalt and the upper basalt.

The butte top sequence (units B and C) overlying the upper basalt was not included within the measured sections due to steep cliffs, but was studied where accessible. The contact between the upper basalt and the overlying unit B is accessible in only a few places; along the southeast edge of the butte, where there is a notch in the cliff formed at the intersection of two faults, and part of the west edge of the butte, where a fault cuts the cliff. These localities were not on line with any of the measured sections. The butte top sequence consists of silicified tuffaceous mudstones and siltstones interbedded with coarse, cross-bedded sandstones (unit B), capped by silicified, coarse, cross-bedded sandstone and pebble conglomerates (unit C.).

c RB-150b

a RB-44

b RB-169

a: crossed polars, upper basalt

b: crossed polars, black basalt

c: plane polarized light, laminated mudstone

Figure 11. Photomicrographs

The butte top sequence varies from 30 to 60 m in thickness. Unit B is composed of thick (0.3-1 m) planar beds of mudstone and waterlaid crystal tuff, tuffaceous shales with leaf and other plant fossils, and tuffaceous siltstone with minor interbeds of lithic arkose sandstone. A siliceous, planar laminated tuffaceous mudstone is shown in Figure 11c.

The fine grained sediments are overlain by unit C, composed of 5-15 m of coarse, lithic arkose sandstones to pebble conglomerates with high angle cross beds. These coarse clastic rocks contain petrified wood, minor muscovite, rounded grains of chert, rounded basalt clasts, rounded and angular tuff clasts, and angular quartz and feldspar grains. The sediments are composed of generally clean sandstones with little fine grained material, have high original porosities, and are interbedded with silty and muddy tuffaceous sandstones with lower porosities. A cartoon of the butte top stratigraphy is shown in figure 12.

Structure:

Faulting has occurred with numerous orientations at Red Butte, but north-trending normal faults which show progressively less offset in younger units are dominant. Well-developed northwest and minor northeast fault trends also cut the area. Several fault-controlled north-trending basalt dikes are exposed in the area around Red Butte (figure 2). The north-trending faults that cut the butte top dip steeply ($75-90^{\circ}$) and are normal. Offset of the east or west side of these faults is not consistent, but varies from fault to fault. North-trending faults in the area for which sense of displacement could not be directly determined are assumed to

Figure 12. Cartoon of butte top stratigraphy

be normal faults due to the regional tectonic setting and association with known north-trending normal faults.

The northwest-trending faults that cut the butte top also have steeply dipping fault planes ($75-90^{\circ}$). Parallel, near horizontal sets of slickensides are exposed on fault planes trending $N 45^{\circ}W$ in the cliffs on the southeast edge of the butte (center, NW 1/4, section 34). These faults display a distinct strike slip component. Exact measurement of the plunge of the slickensides was not possible.

Where the northwest and north-trending fault sets intersect at the top of the butte, northwest-trending faults are deflected or offset by the north-trending faults in two cases, and one north-trending fault is deflected by a northwest-trending fault. The east-trending normal fault that cuts the northeast end of Red Butte truncates the north-trending fault that it intersects. Fault relationships are shown in Figure 2, the geologic map of Red Butte.

Bedding planes in the lower three stratigraphic units: the Deer Butte Member, Orlando Spring Member, and the Ferguson Spring Member generally have dips of 15° or greater. To the south of Red Butte these units dip up to 45° SSE or SSW and dips change radically across north-trending faults. The amount of offset on some faults is at least the thickness of the Orlando Spring Member, which is exposed on the east side of two faults, and not on the west side of the faults. To the north of Red Butte in the area of Black Butte, the sediments comprising the lower three members of the Deer Butte Formation have been drag folded along faults (Figure 13).

The upper basalt and the units A, B, and C have an outcrop pattern

Figure 13. Folding of the Lower Deer Butte Formation
Photograph looking north from the top of Red Butte

characteristic of near horizontal beds. Dips measured on flat mudstone bedding planes are steepest near faults, these dips may be caused by drag along fault planes. Fault displacement can be easily seen on the edges of the butte where basalt is faulted into contact with sediments. The maximum vertical displacement seen at the butte top is about 10 m. The base of unit B is displaced about 15 m along intersecting faults on the southeast edge of the butte. In this same fault the coarse sandstone of unit C capping the butte shows little to no offset.

CHAPTER IV

HYDROTHERMAL ALTERATION

INTRODUCTION

Analysis of hydrothermally altered rocks exposed at the surface is used as an exploration tool in seeking epithermal and other precious metal deposits. Distribution of alteration mineralogies and associated elements, notably As, Hg, Sb, Au, and Ag in active geothermal systems and in producing mines from epithermal precious metal deposits show marked similarities (Berger, 1980; Buchanan, 1981; Rose and Burt, 1979). Alteration in hydrothermal systems is usually zoned both laterally and vertically, reflecting changes in the composition and the temperature of the hydrothermal fluids with time, differing water/rock ratios, and the extent of host rock-fluid interaction.

Hydrothermal alteration can include dissolution of original minerals, replacement of original minerals by hydrothermal minerals, and precipitation of hydrothermal minerals in both primary and secondary porosity. These processes have operated at Red Butte to produce the observed alteration mineralogies and patterns. The following discussion concerns processes and their relationship to the primary textural mineralogy and textural features of the sediments and basalts.

Methods:

Alteration mineralogies were studied by a combination of petrography and X ray diffraction (XRD). XRD techniques employed and a summary of peaks used in identifying clay minerals are described in appendix B. XRD analyses were done for 39 whole rock powder mounts, 3 mineral separate powder mounts, and 15 clay fraction tile mounts. Table VI lists the clay minerals found in altered rocks, the primary rock types and general stratigraphic and structural locations of the samples.

Results:

The type and intensity of alteration are related to the structure, lithology, primary texture, and stratigraphic position of the host rocks. Alteration of the sediments of unit C, exposed at the top of the butte was more easily observed and documented than alteration in unit B for several reasons. Unit C is exposed over the entire top of Red Butte, and vertical exposures are accessible from the butte top, whereas unit B has limited access, and is exposed only in vertical cliffs. Alteration mineralogies and textural relationships are more easily observed in the coarse sandstones of unit C than in the finer grained sediments of unit B. These factors have caused a built in sampling and descriptive bias towards unit C.

Several types of alteration have been identified at Red Butte including the following alterations of sediments: silicification, adularization, zeolitization, bleaching, and development of iron oxides. Basalts exhibit weak chloritic and argillic alteration. Table VII lists the main alteration types exposed on the top of Red Butte.

TABLE VI

CLAY MINERALS IN ALTERED ROCKS AT RED BUTTE

SAMPLE NO.	ROCK TYPE, LOCATION	CLAYS
RB-46	Basalt: SE edge, near fault	chlorite, mixed layer chlorite-smectite
RB-47	Basalt: S end, near fault	chlorite, mixed layer chlorite-smectite
RB-86	Basalt: SE side, near fault	smectite
RB-87	Basalt: SE side, near fault	smectite
RB-161b	Basalt: E side, fault	smectite
RB-1681	Basalt: E side, basalt/sediment contact	smectite
RBT-16c	Sandstone: SE side	kaolinite*
RBT-16d	Sandstone: SE side	kaolinite*, smectite
RB-165a	Sandstone: SE side, fault	no clay fraction
RB-165b	Sandstone: SE side,	kaolinite*, smectite
RB-152a	Sandstone: SE side, fault	no clay fraction
RB-160c	Sandstone: S side, below silicia cap	smectite

*clay-bearing altered sandstones had a minor clay fraction.

TABLE VII

MAIN ALTERATION TYPES EXPOSED
AT RED BUTTE

Alteration Type	Description
Alteration of Sand and Siltstones;	
Silicification:	quartz overgrowths on clastic grains, syntaxial quartz overgrowths on detrital quartz grains, blending into a chert cement filling some pores
Adularization:	silicification combined with syntaxial adularia overgrowths on detrital orthoclase and sanidine
Bleaching:	silicification combined with replacement of all mafic minerals by chert, slight coarsening of texture in chert clasts, local minor kaolinite
Iron oxide:	silicification combined with replacement of fine-grained rock matrix with red-orange iron oxides, leaching of some lithic clasts, forms brilliant red-orange zones adjacent to bleached areas
Zeolitization:	deposition of heulandite in primary and secondary porosity of strongly silicified and bleached rocks, minor kaolinite and smectite
Alteration of Basalts;	
Weak Chloritic: disseminated carbonates	igneous texture and primary mineralogy (olivine, plagioclase, pyroxene) preserved, relic olivine cores surrounded by masses of chlorite, mixed layer chlorite-smectite, and chalcedonic quartz; greenish in outcrop and hand sample
Argillic: disseminated carbonates	destruction of primary mafic minerals, partial destruction of plagioclase, replacement of plagioclase and primary mafic minerals by masses of smectite, chalcedonic quartz, and minor chlorite; vesicles lined with chalcedonic quartz and smectites; green to reddish brown in outcrop

Silicification is the most common alteration type at Red Butte. The topography of the butte is controlled by a 30-60 m thick layer of silicified sediments of units B and C. Within the silicified sandstones of unit C are large zones containing adularia, zones of bleaching, areas of iron oxide deposition and staining combined with leaching, and minor zones of zeolitization.

Faults that cut the butte top are expressed as linear zones of strong bleaching, silicification, and silica replacement of original textures. These zones grade laterally into zones of bright red orange iron oxide staining or into silicified, unbleached sandstones and mudstones where primary texture and composition are preserved.

Silicification:

Sandstones of units B and C were silicified by deposition of rims of radiating fine grained euhedral to subhedral quartz on lithic clasts and syntaxial quartz overgrowths on detrital quartz grains. The original boundaries of detrital quartz grains are marked by a zone of fine (0.01 mm or smaller) fluid inclusions and opaque impurities. Within unit C, a rim of finely disseminated opaques and reddish iron oxides marks the boundary of lithic clasts which have subsequently been covered by quartz overgrowths. The quartz overgrowths extending from clastic grains merge together forming a chert-textured cement that partially fills primary porosity, with very fine euhedral quartz crystals projecting into the remaining pore spaces.

In sandstones with a fine-grained silty or muddy matrix of units B and C, the development of quartz rims on lithic clasts is apparently restricted by the matrix material, rims are composed of subhedral to anhedral

crystals, and may not be developed at all. The matrix of these rocks is cemented by chert-textured quartz, and the original low porosity of the rocks apparently precluded development of quartz overgrowths. In unit C, rims of impurities and iron oxide have been deposited on lithic clasts prior to deposition of the cherty cement.

In rocks with both fine and coarse grained sedimentary beds, such as RB-150b (from unit B) seen in Figure 14a, development of quartz rims on clasts can be seen in the coarser grained beds, and development of fine grained chert is seen throughout the sample. The opaques in this sample are fine grained (0.01mm) pyrite cubes and pyritahedrons.

Within unit C, textures from areas of silicification associated with leaching and iron oxide rims around clasts indicate at least two episodes of quartz deposition (Figure 14b). The sequence is one of initial deposition of iron oxide rims on clasts; deposition of quartz rims on clasts and syntaxial overgrowths on quartz grains and deposition of chert cement. Some clasts have subsequently been leached away, leaving a hematite boxwork texture. Euhedral quartz crystals have grown from the iron oxide rims into the secondary porosity generated by leaching of the clasts. This alteration sequence is common in the coarse sandstones, and is not spatially restricted.

Silicification of tuffs has produced dense, flinty rocks of massive texture. These rocks are almost entirely composed of very fine grained chert, but small, angular apparently primary quartz grains remain in some samples. Crystals of other minerals have been replaced by chert.

a RB-150b

1mm

b RBT-3

0.1mm

c RBT-9

1mm

a: partially crossed polars

1) quartz overgrowth

2) quartz overgrowth
not developed

b: crossed polars

1) quartz overgrowths

2) iron oxide rims

3) quartz crystals lining

secondary pores

c: crossed polars

1) adularia overgrowth
on feldspar grain2) quartz overgrowth
on quartz grainFigure 14. Photomicrographs

XRD patterns of these silicified tuffs yield only quartz peaks, and no clay size fraction is present. Most of unit B and parts of unit C are composed of flinty silicified tuffs and tuffaceous sediments.

The following alteration types were observed only in unit C:

Adularization; Where present, adularia occurs in sandstones as syntactical overgrowths on angular, detrital grains of sanidine and orthoclase. Boundaries of adjoining secondary quartz and adularia as shown in Figure 14c meet without cross cutting or overgrowing each other. The adularia overgrowths are, therefore, believed to be contemporaneous with the quartz cement described above, and appear to be in equilibrium with them. In siltstones and sandstones with a silty matrix, fine grained adularia that cannot be identified optically occurs in the matrix and has been detected by XRD.

Bleaching; Zones of intense bleaching are combined with silicification along faults. In these areas primary sedimentary textures are indistinct in hand sample. In thin sections the original textures are discernible under plane polarized light, however, boundaries among clasts, quartz overgrowths on clasts, and chert cement are indistinct due to loss of color in the clasts and partial to total replacement of clasts by chert. Fine grained cherty clasts are coarser grained than chert clasts in less strongly silicified rocks. Rims of impurities or iron oxides around lithic clasts are not present. Strongly silicified, bleached rocks from the southeast edge of the the butte in section 35 contain trace amounts of kaolinite. The transition from silicified to strongly silicified, bleached rocks is gradational but a change is discernible in the field based on

color, greater rock density, and observable sedimentary texture. Zones of intense silicification and bleaching are strongly fault controlled, as can be seen in Figure 3.

Iron Oxide Staining; Bright orange-red iron stained, silicified rocks occur mainly along or near the edge of the butte where they surround zones of bleached and strongly silicified rocks (Figure 3). Rocks within these areas weather to deep orange red, and are bright orange on fresh surfaces. The orange iron staining permeates the rocks. Only the larger chert framework clasts maintain their original buff color. Primary sedimentary textures are unaffected except for some local leaching of clasts.

Zeolitization; Heulandite (ideal formula: $\text{Ca Al}_2\text{O}_4 \cdot 7(\text{SiO}_2)$) is the only zeolite detected in the altered rocks that cap Red Butte. On the butte top heulandite is restricted to the area on the southeast cliff (NW 1/4 section 35) adjacent to and above a distinct topographic notch at the intersection of two faults. Heulandite occurs as bright orange stained, pseudo-cubic euhedral crystals coating a fracture in silicified mudstones in sample RBT-16. In sample RB-165a heulandite occurs interstitially to quartz overgrowths and chert cement and partially fills the interiors of some clasts that have been removed by leaching. In sample RB-165a (Figure 15a) chert cemented groups of grains are supported by a groundmass of heulandite. Samples RB-152a and RB-165a are strongly bleached to a pure white, and are from silicified zones adjacent to faults. No feldspars were identified in heulandite-bearing samples. The vertical distribution of heulandite in walls of the notch is about 30 m. Minor heulandite was detected in an unsilicified sample northeast of the butte (RB-160a,b,c).

a RB-165a

0.1mm

c RB-153

1mm

b 138a

1mm

a: crossed polars
 chert cemented sandstone
 with heulandite filling
 pore spaces

b: plane polarized light
 quartz-adularia vein

c: plane polarized light

Figure 15. Photomicrographs

Alteration of Basalts:

Alteration of the upper basalt ranges from partial replacement of mafic minerals by chlorite and minor alteration of plagioclase to chlorite, chalcedonic silica, and disseminated calcite to total replacement of mafic minerals and partial replacement of plagioclase by chlorite, smectite, and chalcedonic silica. The entire upper basalt has undergone weak chloritic alteration producing a greenish color in outcrops and hand samples.

Thin section examination of chloritically altered basalt shows cores of relic olivines surrounded by fine grained masses of chlorite and opaques. Primary igneous opaque minerals are surrounded by brown stained chalcedonic quartz and masses of chlorite. Pyroxenes have fresh boundaries. Plagioclase is generally fresh except for patches adjacent to olivine and or opaque minerals. Disseminated calcite was not visible in thin section, but chloritically altered basalts react to dilute hydrochloric acid.

Figure 16a,b, shows XRD results for RB-46, a propylitically altered, chlorite-bearing basalt and for RB-87, a strongly altered smectite-bearing basalt. In RB-46, the 14.2 Å peak shifts slightly upon glycolation and the 7.2Å peak is broadened with glycolation. In an unmixed chlorite, these peaks would not change with glycolation, therefore, the clay in RB-46 is a mixed-layer chlorite/smectite. The 14.4Å peak for RB-87 shifts to 16.1 Å with glycolation, and collapses upon heating, without a remnant peak at 14 Å. The clay in RB-87 is, therefore, an unmixed smectite.

Figure 16a. XRD Results from altered basalt

Figure 16b. XRD Results from altered basalt

Strongly altered basalts contain smectite, and sometimes minor chlorite. Mafic minerals are completely replaced by chalcedonic quartz intergrown with fine grained smectite. The plagioclase groundmass is mottled with fine grained smectite and chalcedony. Vesicles are lined with 1 to 3 layers of chalcedonic quartz with reddish brown impurities. The most strongly altered basalts are adjacent to faults, and are commonly cut by calcite or calcite-quartz veinlets.

CHAPTER V

VEINS AND BRECCIAS

Veins are defined in this work as chemically deposited fracture fillings in rocks, whereas breccias are defined as rocks consisting of angular clasts which may be supported by finer grained materials (matrix). In many hydrothermal breccias, the matrix is composed of chemically deposited materials. Breccias in which fragments are composed of vein materials are not uncommon.

Breccias and veins at Red Butte are developed along faults and concentrated along the southeastern and western edges of the butte, where they are well exposed in the nearly vertical cliff walls.

Explosion Crater and Breccia:

A distinct topographic notch on the southeast edge of Red Butte is located at the intersection of northeast and north-trending faults (Figure 2). This notch is believed to be the remanent of an explosion crater. Steep cliffs 30 to 60 m high on the west side of the crater expose numerous sub-parallel vertical fault planes striking N 40° W to N 60° W. Veins and breccias are common along these faults and range from 0.5 to 8m wide. The east wall of the crater has been uplifted about 15 m relative to the west side across the intersecting faults.

The walls of the crater offer the best exposures for sampling of the silicified butte top sediments of unit B. Elsewhere, exposures are too

steep or covered with talus. The crater area was sampled along the cliff base at locations are shown in Figure 18. The cliffs are covered with a red-orange soil washed down from the overlying alteration zones, which obscures the relationships between host rocks, veins, and breccias.

Partially filling the the crater are erosional remnants of a bedded breccia of cobble to gravel size clasts supported by a matrix of fine sand to silt size clastic material (Figure 17). This breccia cuts across the silicified sediments of units B and C. Both clasts and matrix of the breccia are composed of a mixture of angular to subangular clasts which include all of the common types of alteration exposed on the butte top except zeolitic. The breccia is sparsely calcite cemented and weathers into broad pillars. One pillar is cut by a 20-30cm wide open textured calcite-quartz vein. Remnants of this bedded breccia are found below overhangs along the west wall of the crater.

This bedded breccia and the associated crater are important vestiges of former violent hydrothermal activity at the butte. A similar breccia is exposed along faults on the west edge of the butte top (SE 1/4, section 27, elevation 1440 ft). It is composed of gravel and cobble size clasts of silicified sandstones, siltstones, and tuffs, is supported by a matrix of fine sand to silt size clasts of the same composition, and is strongly cemented by reddish, iron stained quartz. The breccia forms a small cliff, 30m long by 3-4m high.

Breccias and veins from the crater walls:

The faults that form the west wall of the crater are filled with quartz-cemented breccias, quartz-adularia veins, and breccias composed of

Figure 17. Bedded explosion breccia. Explosion breccia in foreground, silicified cliffs in the background are the west wall of the explosion crater.

silicified sedimentary clasts floating in a fine grained quartz matrix. These veins and breccias are between 6 and 8 m wide. The larger breccias grade from quartz cemented breccias of silicified sedimentary clasts along their edges, to virtually pure quartz veins in their centers.

Minor pyrite is visible in several samples, it is generally very fine grained, and does not usually compose more than 10% of a rock. Rocks of light grey, fine grained quartz with disseminated blebs of pyrite, are occasionally cut by dark grey veinlets (0.5-1mm) of very fine grained pyrite and quartz.

Adularia occurs in veins as coarse (2-3mm), crystals with excellent cleavage visible in hand samples. Some of the relations between adularia and quartz in veins are seen in sample 138 (Figure 15b). Layers of cherty quartz alternate with coarse grained euhedral adularia. The chert and adularia-rich zones are separated by 0.5 mm thick rims of dark impurities and fluid inclusions. Adularia also fills cavities within the chert (blocky crystal outlines in left third of photo). At least five bands of chert separated by three bands of adularia are present in this sample.

Cherty, quartz-cemented breccias containing clasts composed of silicified mudstone and tuff are common. The clasts are generally banded chert, with minor, rounded to angular silt size grains parallel to the bedding.

A breccia composed of brecciated vein material in a matrix of cherty quartz with disseminated iron oxides occurs at the top of the crater. This breccia is shown in Figure 15c. The light colored clasts are greenish in hand sample, and the supporting matrix is red. The opaques seen within the white clasts are reddish cubes, probably relic pyrite.

Figure 18. Plane table sample location map

The contact between the upper basalt and overlying mudstones is exposed along the east wall of the crater. Vertical veins which cross this contact change from calcite veins in the basalt to quartz veins in the silicified mudstones. The transition from calcite to quartz veins occurs over a vertical interval of 0.3 to 1 m at the basalt-mudstone contact. The association of calcite veins with basalt and quartz veins with silicified sediments is common at Red Butte.

Other veins exposed at Red Butte include calcite and calcite-quartz veins cutting the upper basalt and chalcedonic quartz veinlets (.5-5 cm) cutting silicified mudstones and sandstones of the butte top sequence. Wide (0.5-1.5 m) calcite veins cutting the upper basalt are exposed along fault related fractures on the west wall of the butte, in the SE 1/4 of section 27, elevation 4000 to 4200 ft. Veins exposed on the west side of the butte cut the entire upper basalt and the overlying sediments of units B and C. From the basal contact with unit A they cut the upper basalt as calcite veins, then continue upward as quartz veins and quartz cemented breccias in the butte top sequence. On the south end of the butte in the SE 1/4 of section 34, elevation 4160 to 4200 ft is another wide calcite vein cutting the upper basalt. At both of these locations the basalt is cut by numerous small (1-5 cm) calcite veinlets in the wall rock adjacent to the larger veins.

CHAPTER VI

GEOCHEMISTRY

Methods:

Ninety five samples were assayed by the commercial laboratory of Bondar-Clegg Corporation for Au, Ag, As, Sb, and Hg. Seventy three samples were analyzed using INAA techniques at Portland State University, including splits from 19 of the samples analyzed by Bondar-Clegg. For a description of Bondar-Clegg analytical techniques and all Bondar-Clegg results, refer to Appendix A. A description of INAA results and techniques is given in Appendix B.

Locations of all analyzed samples from the butte top are shown on Figure 3, the hydrothermal alteration map of Red Butte .

Results:

Elemental concentrations of Au, As, Sb, and Hg determined by INAA differ from those reported for the same rocks by Bondar-Clegg. These differences may be the result of different analytical techniques, combined with the tendency for Au to be unevenly distributed in a sample, known as the "nugget effect". Duplicate analyses are not numerous enough for meaningful statistical comparison of this variance in the results. The results of Au, As, and Sb analyses obtained by both analysis are shown in table VIII. Concentration trends obtained by neutron activation

TABLE VIII
INAA AND BONDAR-CLEGG ANALYTICAL RESULTS
FOR THE SAME SAMPLES

Sample	Au		As		Sb	
	INAA	BC	INAA	BC	INAA	BC
RB-21	0.110	0.135	65.300	123.000	23.500	20.000
RB-25	0.000	0.015	10.100	25.000	9.300	15.000
RB-47	0.724	0.510	128.500	220.000	4.100	8.000
RB-85	0.000	0.100	8.000	21.000	7.300	0.000
RB-86	0.000	0.005	3.000	10.000	6.900	0.000
RB-87	0.000	0.005	3.000	10.000	6.900	0.000
RB-115a	0.000	0.000	18.500	14.000	0.000	0.000
RB-112	0.333	0.250	2.800	11.000	6.200	12.000
RB-119	1.241	0.940	51.600	100.000	7.300	10.000
RB-120	0.276	0.030	29.300	59.000	6.200	10.000
RB-121	0.570	0.045	20.500	40.000	5.600	10.000
RB-122a	0.362	0.210	2.480	10.000	5.300	0.000
RB-136	0.228	0.190	7.320	24.000	3.560	4.000
RB-137	0.537	0.040	91.600	197.000	41.000	41.000
RB-140	0.000	0.005	3.240	12.000	9.500	10.000
RB-151	0.009	0.010	4.600	9.000	4.600	4.000
RB-153	0.000	0.000	3.600	5.000	4.900	8.000
RBT-3	0.087	0.185	20.500	29.000	18.000	18.000
RB-68	0.000	0.005	8.970	16.000	16.500	13.000
RB-77	0.290	0.290	0.134	24.146	46.750	9.333
Mean	0.238	0.149	24.152	47.957	11.671	9.617
Std. Dv.	0.317	0.223	33.601	61.486	12.001	9.329

All values are expressed in PPM
BC: Bondar-Clegg

are similar to those obtained from Bondar-Clegg, except for As. As concentrations from Bondar-Clegg are generally about twice the concentrations obtained from INAA. Ag was detected in only three of the Bondar-Clegg analyses, and is not detectable by the INAA method used. It will, therefore, not be included in the following discussion. Hg was, furthermore, not detected by the INAA method, and the discussion of Hg concentrations refers to Bondar-Clegg results.

Concentrations for the analyzed elements are reported as anomalous in this study if they equal or exceed the anomalous concentration thresholds given in Table IV from the DOGAMI report.

Au, As, Sb, Hg:

Correlation coefficients comparing Au to As, Sb, and Hg show there is no linear correlation of Au with any of the above elements. Removal of samples which lack detectable Au does not produce any significant linear correlation between Au and the other elements, but samples with high Au concentrations generally are enriched in As and Sb concentrations and occasionally contain anomalous Hg concentrations. Correlation coefficients were also calculated for the various permutations of As, Sb, and Hg. No significant correlation was found between these elements. The correlation coefficients are included in Table IX, which also shows mean, range, and standard deviation for these elements from all analyses.

Au concentrations of 5-35 ppb are common in the silicified sandstones at the top of the butte, but occasionally higher Au concentrations are found in these sandstones. The higher Au concentrations are usually found in areas where the two major fault systems intersect. Low but

TABLE IX
SUMMARY OF RESULTS FOR
Au, As, Sb, and Hg

INAA Results

Element	Mean	Standard Deviation	Correlation Coefficients
Au	0.084	0.19	Au:As 0.21
As	15.28	29.65	Au:Sb 0.15
Sb	8.27	8.64	As:Sb 0.38

Bondar-Clegg Results

Element	Mean	Standard Deviation	Correlation Coefficients
Au	0.042	0.11	Au:As 0.25
As	33.63	35.2	Au:Hg 0.09
Sb	9.38	8.94	Au:Sb 0.14
Hg	0.152	0.184	As:Sb 0.42
			As:Hg 0.24
			Sb:Hg 0.18

All concentrations in ppm

anomalous Au concentrations are also found in the strongly silicified fine grained greenish sediments of the lower butte top sequence. In contrast, silicified reddish to brown mudstones of the butte top are generally barren of detectable Au. The highest gold concentrations are in veins or breccias associated with faults. The highest measured gold concentration (1240 ppb INAA, 945 ppb Bondar-Clegg) was obtained from sample RB-119, a red, strongly silicified breccia block in landslide debris on the west side of the butte. The second highest Au concentration (724 ppb INAA, 510 ppb Bondar-Clegg) was from sample RB-47, a 15 m long composite in the upper basalt, just below the butte top sequence. This sample crossed a 1.3 m wide calcite vein, and numerous calcite veinlets.

Hg concentrations are greatest in veins exposed in the crater wall on

the southeast side of the butte and in the bright red iron oxide zones within unit C at the butte top. The lowest Hg values are from bleached zones and basalts. Table X lists samples from the east and west crater walls with their Au, As, Sb, and Hg content.

Samples 131a,c, 150b, and 128w show that Au, As and Sb are present in the wall rock clasts that occur in the breccias and veins in the walls of the crater. The Au content is greater in the altered sedimentary wall rocks than in basalt wall rocks (eg., 143w and 143w). Au concentrations are at or below the Bondar-Clegg limit of detection (5ppb) in basalt wall rock near the crater.

Rare Earth Elements:

Rare earth elements (REE) detected by INAA have been normalized to chondritic abundance (Nakamura, 1974). Silicified sediments from the butte top and unsilicified sediments from the east slope of the butte have similar LREE enriched patterns with strong negative Eu anomalies. These patterns are shown in Figure 19 a. The REE patterns reflect the felsic volcanic source of the sediments, rhyolites and tuffs which were derived from the Snake River Plain and northern Basin and Range provinces (Leeman, 1982). The basaltic component of the sediments is minor, and does not affect the REE pattern.

REE patterns for silicified sediments at Red Butte are parallel to patterns for unsilicified sediments, but show depletion in all REEs, indicating dilution by addition of silica. Breccias of silicified sediments also have REE patterns parallel to those for unsilicified

TABLE X

SAMPLES COLLECTED IN THE CRATER

<u>West Wall of Crater</u>				
Sample #	Au	As	Sb	Description
152b	7.2	3.90	3.84	white, vuggy, heulandite cemented brecciated sandstone
151b	149.	0.0	2.88	red qtz cemented breccia with white clasts of vein qtz
150b	97.4	1.90	2.79	green-grey silicified, siliceous laminated mudstone, minor euhedral pyrite
150c	221.8	3.30	1.13	white and pink qtz-adu vein
139b	204.9	36.90	37.20	grey qtz vein
139a	180.4	190.30	28.70	breccia: silicified sandstone and mudstone clasts in white qtz matrix
137a	180.4	19.80	17.40	3.4 m wide qtz cemented silicified mudstone breccia, blebs of pyrite in green-grey qtz matrix, colloform qtz in open space
137	53.7 48* 1	91.60 97*	41.00 41*	composite sample of chips across qtz cemented silicified mudstone breccia
136	228 190*	32 24*	3.56 4	composite 1 m sample across qtz-adu vein with sparse mudstone clasts floating in qtz-adu matrix
136b	332.5	7.43	3.46	red qtz cemented breccia: clasts of silicified grey mudstone in matrix of qtz with disseminated blebs of red Fe oxides
135a	104.2	37.10	7.33	breccia: laminated mudstone clasts cut by qtz-adu veins
135d	155	37.60	7.13	grey qtz vein; contains 10% pyrite as blebs and stringers, pyrite veinlets cut across qtz vein

TABLE X (continued)

Sample #	Au	As	Sb	Description
134	na	na	na	breccia: clasts of silicified grey mudstone floating in qtz matrix
131,2,3	298 45*	1.63 7*	14.10 15	composite of samples 131,2,and3 all from breccia of clasts of silicified mudstone floating in white and pink qtz
131m	52	0.53	5.20	qtz matrix of 131,2,3 breccia
128	16.6	5.40	2.27	grey, silicified laminated mudstone, cut by qtz veinlets

East Wall of Crater

142w	0.0	6.92	3.61	basalt adjacent to calcite vein
143v	42.6	0.0	4.02	matrix material from qtz supported breccia cutting silicified mudstone 1 m above basalt/mudstone contact
143w	0.0	1.22	4.50	basalt from basalt/mudstone contact
144	5*	4*	11*	silicified mudstone from above basalt/mudstone contact
145	5*	5*	11*	qtz-calcite vein m above basalt/mudstone contact
147	0.0	2.27	5.60	silicified mudstone

notes: Au concentrations in ppb, others in ppm,
 *denotes Bondar-Clegg assay, all other values from INAA analysis
 qtz = quartz, adu = adularia
 Basalt/mudstone contact refers to the contact between the upper
 basalt and the overlying mudstone of the butte top sequence.

a. REE Patterns in basalts from Red Butte

b. REE Patterns in unsilicified (RB-160 a,b,c)
and silicified sediments (RB-168 k) from Red Butte

Figure 19 a,b. REE Patterns

c. REE Patterns in silicified wall rock (RB-126 W)
and adjacent vein (RB-126 V)

d. REE Patterns in veins from Red Butte (RB-122a, 135v)
and a pyrite-bearing silicified mudstone (RB-150)

Figure 19 c,d. REE Patterns

Oxygen and Carbon Isotopes

Eleven rock samples containing calcite were analyzed for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values (Richard C. Marty, personal communication, 1983). Two water samples from the area were also analyzed for $\delta^{18}\text{O}$ (Table XI) . One sample was from Dry Creek, a surface water source 12 miles north of Red Butte. The other water sample was collected from Twin Springs, an artesian well 15 miles north of Red Butte. The $\delta^{13}\text{C}$ values were very light, but seem to lack meaningful trends. Temperatures calculated are reasonable for the lighter isotope calcite samples if calcite is assumed to have equilibrated with meteoric water. Temperatures are about 100°C too low for the heavy calcite population. The heavier $\delta^{18}\text{O}$ values in the disseminated calcite are clearly anomalous and some mechanism besides equilibration with hot meteoric water is necessary to account for the observed values. The heavy oxygen calcite is associated with the Fe alteration zone and adjacent bleached zone within the siliceous cap on the west side of the butte.

TABLE XI
SUMMARY OF $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ RESULTS

Sample number	^{18}O pdb	^{13}C	Temperature $^{\circ}\text{C}$
RB-85 ¹	-29.86	-8.91	188
RB-141a ¹	-32.8	-6.29	269
RB-64cc ¹	-28.7	-5.72	171
RB-64mk ¹	-24.99	-6.2	120
RB-64wr ¹	-26.17	-5.2	135
RB-74 ¹	-21.9	-6.75	89
RB-76 ¹	-23.2	*	101
RB-46 ²	-33.3	*	284
RB-47 ²	-33.45	-6.07	289
RB-123 ³	-22.5	-7.7	98
RB-30 ⁴	-7.0	1.62	2
RB-28 ⁴	-2.49	*	-14
RB-67 ⁵	-16.2	-2.65	47

Water Samples

Twin Springs	-15.4 $\delta^{18}\text{O}$ smow
Dry Creek	-6.4 $\delta^{18}\text{O}$ smow

notes: 1) calcite disseminated in chloritically altered basalt, near base of upper basalt; 2) calcite veins cutting upper basalt near butte top; 3) sugary calcite-quartz vein cutting bedded breccia at butte top; 4) disseminated calcite from Fe oxidized zone; 5) bleached zone

CHAPTER VII

DISCUSSION

The geology and associated alteration and mineralization at Red Butte are closely tied to the regional setting. The north-trending normal faults are related to north-trending Basin and Range structures. The northwest-trending fault system is related either to the western Snake River Plain, the Willow Creek Fault, or the Brothers Fault Zone, or possibly all three.

The rhyolitic and tuffaceous sediments intercalated with basalts and minor arkosic sandstones of the Deer Formation are typical of lithologies produced by extensional tectonics and related bimodal volcanic suites. The Red Butte area, lying at the center of the diverging trends of rhyolitic volcanism of the High Lava Plains of Eastern Oregon and the Snake River Plain-Yellowstone Plateau, reflects this regional setting in the local lithologies.

The high regional heat flow of the Basin and Range, Snake River Plain, and High Lava Plains and associated volcanic activity were conducive to the formation of calderas such as the McDermitt, White Horse, and Mahogany Mountains calderas (Rytuba, 1979, 1981, 1985). Local hot springs still abound in the Vale-Owyhee area, and Vale is the site of the Vale Known Geothermal Resource Area (Gray, 1983).

Stratigraphic Setting:

Planar and laminated bedding, interbeds of tuffaceous and carbonaceous shale, and minor lenses of arkosic sandstones combined with lacustrine fish fauna were used by Johnson (1961) as indicators of lacustrine deposition. These features are common in rocks of the Red Butte area. Stratigraphic intervals of predominantly lacustrine lithofacies are: the Red Butte, Furgeson Spring, and part of the Orlando Spring members of the Deer Butte Formation, and units A and B. Unit A is generally fine grained and contains abundant planar beds, with minor cross beds and normally graded beds. The fining upward sequence may represent lacustrine turbidite deposits overlain by lake bottom sediments indicative of relatively quiescent conditions, or they may be low energy fluvial sediments overlain by lake bottom sediments. The tabular outcrop pattern, lateral continuity of beds, and general lack of coarse sediments, however, are evidence for lacustrine deposition.

Unit B, above the upper basalt, is composed of fine grained sediments similar to those of unit A, and is overlain by the coarse, cross bedded sandstones and granule to pebble conglomerates of unit C.

The thick (1 m), massive planar beds of very fine grained tuffaceous sediments of unit B are probably the result of rapid influxes of large amounts of direct and reworked air fall tuff into a lake, since these beds are almost completely tuffaceous and do not contain significant amounts of clastic materials. Higher up in unit B, the fine grained, laminated sediments with small scale cut and fill structures were probably the result of a low energy environment with low sediment influx, since the sediments

contain current features but are not highly winnowed. Occasional rapid increases in sediment load are shown by interbeds of coarse clastic material within the laminated mudstones. Units A and B were deposited in a lake while intermittent air falls of tuffaceous material occurred in the immediate vicinity. Periodic influxes of coarser sediments were also deposited. These coarse intervals may represent relatively rare events which abruptly changed the character of the depositional environment, such as storm runoff.

Unit C, the upper one third of the butte, was deposited under high energy fluvial conditions. The sediments are fairly coarse, have high angle cross beds, and generally lack fine grain materials. Angular quartz and potassium feldspar crystals are common in the upper butte top sequence, implying a local source.

Structural History:

The stratigraphic units underlying the Deer Butte Formation dip westward, and are generally not exposed to the west of the Owyhee Reservoir (Kittleman, 1967). North of Red Butte, the course of the Owyhee River is determined by fault lineaments and by the unconformity between the Deer Butte and underlying Succor Creek Formations which marks the eastern margin of the Deer Butte Formation depositional basin (Kittleman and others, 1965). Uplift of the Deer Butte Formation has been greatest in the Red Butte area, where the thickest exposure of the basal Red Butte Member is found (Johnson, 1961).

North-trending faults that cut the lower three members of the Deer Butte Formation are the oldest exposed structures in the Red Butte area.

Exposures of the basal contact of unit A and the underlying lower three members of the Deer Butte Formation are not sufficient to date the onset of movement on the faults that cut both the lower Deer Butte sediments and unit A.

These north-trending faults and associated north-trending basalt dikes may be related to the north-trending graben bounding faults of the Mahogany Mountains caldera (Rytuba and others, 1985). An angular unconformity exists between the lower three members of the Deer Butte Formation and unit A. This unconformity is shown by the differences in dip between the lower three members of the Deer Butte Formation and unit A. It is also indicated by the greater amount of displacement of the lower three members of the Deer Butte Formation along north-trending faults. The unconformity may be local, and related to the possible setting of Red Butte within the Mahogany Mountains caldera.

Intermittent movement along the faults cutting the butte top sequence occurred during deposition. The lower beds of the sequence are vertically displaced up to 30 m along the north-trending faults, whereas coarse sandstones at the top of the butte show little to no vertical displacement along these same faults. Since northwest and north-trending faults exposed at the top of the butte truncate and offset one another, neither set of faults can be definitely said to pre-date the other. Therefore, movement must have occurred on both sets of faults during deposition of the butte top sequence. Movement along the east-trending fault that cuts the northeast end of Red Butte (Figure 2) occurred after deposition and alteration of the butte top sequence, and this fault is the most recently

active structure on the top of the butte.

Deposition of the sediments forming Red Butte and Quartz Mountain within an intra caldera lake would explain several facets of local geology: 1) the dissimilarity of the upper three stratigraphic units at Red Butte and the upper three members of the Deer Butte Formation as described by Johnson (1961) and Kittleman and others (1965,1967), 2) the similarity of lithology, silicification and mineralization between Red Butte and Quartz Mountain, 3) differences between the dip of units below and above the upper basalt. These differences between Red Butte and Quartz Mountain and the surrounding Deer Butte Formation could be explained by the deposition of units A, B, and C of Red Butte and the silicified cap of Quartz Mountain within a local basin of deposition different from that of the upper members of the Deer Butte Formation.

A caldera setting would provide a local heat source for the hydrothermal system at Red Butte, and may help explain mineralization and silicification of sediments here, and provide a mechanism for local anomalous concentration of high Au and other 'epithermal' elements in the unsilicified sediments between Red Butte and Quartz Mountain.

The discovery of a caldera bordering on the Owyhee River enhances the mineral exploration prospects for the region. From south of Red Butte north to Vale, there are several buttes capped by silicified sediments. These may not all have formed in calderas, but they should be examined, sampled and mapped.

CONDITIONS OF DEPOSITION

The solubility of silica in water is strongly temperature dependent, and is not significantly influenced by the presence of other ionic species in solution (Holland and Malinin, 1979). Figure 20 shows the relationship of silica solubility to temperature. From this figure it can be seen that amorphous silica is more soluble than quartz, and rapid cooling of a solution saturated with either quartz or amorphous silica will result in deposition of quartz or amorphous silica (chalcedony or opal).

Cherty, laminated mudstones occur in the McArthur River (HYC) lead-zinc silver deposit (Oehler and Logan, 1977), and in the Waterloo disseminated Ag deposit. The McArthur River cherts have been interpreted as chemical flocculates deposited from a colloidal silica gel (Oehler and Logan, 1977). Bedded lake sediments of massive, fine cryptocrystalline quartz (chert) and lenses of chert parallel to bedding are described from the Waterloo disseminated Ag deposit (Fletcher, 1981) and have been interpreted as lake sediments silicified syngenetically by hot silica-bearing waters debouched into a lake (Fletcher, 1981; Graybeal, 1981).

The presence of quartz and adularia in apparent equilibrium, combined with a general lack of kaolinite in the sandstones of unit C suggest the relative activities of SiO_2 , K, and H in the hydrothermal solutions responsible for general silicification of these sandstones. Plots of $\log (a_{\text{K}^+}/a_{\text{H}^+})$ vs $\log a_{\text{H}_4\text{SiO}_4}$ may be constructed from thermodynamic data

Figure 20. Silica solubility diagram (from Holland and Malinin, 1979).

and have been published by several workers. Figure 21, for example, from Drever (1982), was constructed using data from Helgeson and others (1978). The composition and temperature of the hydrothermal fluids are not known for Red Butte, thus these diagrams can only be used qualitatively. The mineral assemblage and the oxygen isotopic temperatures obtained from calcite can, however, be combined to make a reasonable estimate of the general composition and temperature of the hydrothermal solutions. The slopes of stability diagram lines are, furthermore, dependent on the stoichiometry of the reactions between minerals, and not temperature. Temperature variations change the scale and the relative size of stability fields, but do not change the slope of the lines. The lines for quartz and amorphous silica show the $\log a_{H_4SiO_4}$ for which the solution is saturated with respect to quartz and amorphous silica. The area to the right of the quartz line and to the left of the amorphous silica line represents the composition of fluids saturated with quartz. Fluid compositions which plot in this area would deposit quartz. Fluid compositions which plot to the right of the amorphous silica line are saturated with respect to amorphous silica and would deposit opal. Equations for reactions used to construct this diagram are shown in Table XII.

The euhedral quartz crystals in the sands of units B and C sequence imply deposition from a solution saturated with respect to quartz. The good crystal form of these quartz rims also implies adequate time and space for crystal growth. The $\log a_{H_4SiO_4}$ must lie to the right of the quartz solubility line in Figure 21. The presence of quartz without accompanying opal suggests that the field lies to the left of the amorphous silica

Figure 21. Activity Diagram for the system $\log \frac{a_{H^+}}{a_{K^+}}$ vs $\log a_{H_4SiO_4}$ (from Drever, 1982).

TABLE XII

EQUATIONS USED IN CONSTRUCTION OF STABILITY DIAGRAM

From Drever, 1982

solubility line. The occurrence of adularia suggests that the composition must lie within the potassium feldspar stability field.

The subsequent leaching of clasts and deposition of a second generation of quartz crystals lining the pores was not accompanied by adularia deposition. Thus, fluid composition must have changed, to a composition outside of the potassium feldspar stability field. The small amount of kaolinite in some samples suggests a shift towards the kaolinite stability field.

The fine grained cherts within the mudstones of units B and C may have been originally deposited as amorphous silica (opal). Rapid deposition of

the silica is suggested in the very fine grained texture of the cherts. Opal-ct is rapidly deposited relative to quartz (Drever, 1982) and if it could be deposited it would be (Drever, 1982). Rates of transformation of opal-ct to quartz have been calculated at different temperatures in neutral solutions with no circulation of water (Ernst and Calvert, 1969). At 200°C, complete conversion of opal-ct to quartz takes 47 years; at 100°C, 36,000 years; at 50°C, 4.3 million years; and at 20°C, 180 million years. The processes involved are dissolution and recrystallization (Stein and Kirkpatrick, 1976). The fluid composition during deposition of mudstones and siliceous rocks of unit B was probably to the right of the amorphous silica line. A possible path of the composition of the hydrothermal fluids through unit C through time is shown in Figure 21.

Effects of Boiling:

Rapid changes in the conditions of the hydrothermal fluid are needed to explain a system that deposited alternate bands of quartz and adularia in veins, and deposited quartz and adularia in apparent equilibrium in large areas of coarse sandstones. These changes may be due to boiling of the hydrothermal fluids. Significant amounts of CO₂ and smaller amounts of H₂S are partitioned into the vapor phase during boiling according to the reactions:

The release of these volatiles results in a pH rise in the remaining solution. A pH rise would drive the solution from an area of adularia instability into the field of adularia stability, resulting in the

deposition of adularia. CH_4 and H_2S have a greater rate of partitioning into the vapor phase than do CO_2 and SO_2 respectively (Drummond and Ohmoto, 1979). Oxygen fugacity will rise in the remaining liquid as the ratios of CO_2/CH_4 and $\text{SO}_2/\text{H}_2\text{S}$ increase. Loss of CO_2 and H_2S results in a rise in the activity of S^{--} and HS^- , leading to the formation of strong thio complexes with Au, As, Sb, and Hg (Weissberg, 1969). These complexes are stable at depth, but as they approach the surface, the higher oxygen fugacity causes precipitation of metals.

The above effects of boiling combine to promote metal deposition. Most base metals in solution will precipitate after about 5% of the mass of the solution is lost to the vapor phase (Drummond and Ohmoto, 1979). Au, carried as thio complexes will not precipitate until it nears the surface where the thio complexes are destroyed by oxidation to sulfate. The presence of higher average Au concentrations in the veins than in the silicified sediments is probably due to repeated episodes of boiling.

Repeated episodes of boiling would also cause the alternating mineralogies and textures seen in the quartz adularia veins. Boiling at Red Butte probably occurred by two mechanisms. First, as the plume of hot hydrothermal fluid rose up through fractures in the rock, a point was reached where atmospheric pressure equaled hydrostatic pressure of the rising fluid and non-explosive boiling occurred. Second, explosive boiling occurred when silica deposition sealed the hydrothermal vent. Pressure built up below the seal until it was broken by tectonic fracturing, or by the pressure of the fluid exceeding the confining strength of the silica cap causing a sudden release of pressure which in turn produced violent

boiling. The explosion crater and associated bedded explosion breccia on the southeast side of the butte are evidence for explosive boiling at this location. Similar breccias on the west side are evidence for explosive events in different parts of the system.

ALTERATION HISTORY

Unit A, underlying the upper basalt at Red Butte, is not silicified or altered. The upper basalt has only minor chloritic alteration except near faults and veins. Hydrothermal activity at Red Butte, therefore, commenced after deposition of the upper basalt.

Silicification of the tuffaceous sediments and water laid crystal tuffs that form Red Butte occurred during or shortly after deposition. The large aerial extent of silicification of fine grained sediments, which generally lack compaction structures, and the lack of argillic alteration in the sediments show that hydrothermal alteration and silicification occurred shortly after deposition, and argue for silicification before permeability reduction associated with lithification. It is proposed, therefore, that silicification of the fine grained butte top sequence sediments was syngenetic, and was the result of hot, silica saturated solutions debouching into cooler lake waters, in a manner which is similar to the systems postulated for the HYC and Waterloo deposits (Fletcher, 1981; Graybeal; 1981; Oehler and Logan, 1977). Amorphous silica was rapidly deposited as the hydrothermal solutions experienced a drastic temperature drop upon mixing with the cooler lake waters.

X-ray analyses of Red Butte samples, when combined with petrographic studies show that crystalline quartz is the main type of silica at Red Butte. Chalcedonic quartz is uncommon in sedimentary rocks from the butte. The opal deposited with the sediments has been converted to

cryptocrystalline quartz in the time since deposition.

Unit C, forming the top of the butte, is generally red to red-brown, coarse to fine sandstones containing interbedded mudstones. The sandstones are characterized by Fe oxide rims that were formed around lithic clasts prior to silicification. Reddish mudstones from the butte top are generally barren of Au, and no pyrite is present. Opaque red material with a cubic habit, interpreted as relic pyrite, is present in some chert cemented veins near the butte top. The original pyrite has been destroyed. The lack of pyrite or oxidized pyrite in sediments, combined with relic pyrite in veins near the butte top indicates that the top of the butte was under oxidizing conditions during deposition and silicification of the sediments and alteration of pyrite-bearing vein materials.

Where Heulandite is present, it was deposited in both primary and secondary porosity. Heulandite is stable in and is probably deposited from quartz saturated slightly alkaline solutions (Coombs and others, 1959). A temperature stability range of 150°C to 230°C for heulandite is given by Coombs and others (1959).

Bleached rocks containing heulandite also contain minor kaolinite. The kaolinite field shown in Figure 22 indicates a higher pH than was present in solution during adularia-quartz deposition. Since no adularia was found in the kaolinite-heulandite-bearing rocks, previously deposited adularia was probably dissolved prior to or during deposition of the heulandite and kaolinite, or it was never deposited in these rocks. Although kaolinite and heulandite exist together in bleached rocks from Red Butte, they probably do not represent an equilibrium assemblage. Due to the fine grain

size of the kaolinite, it was not possible to determine textural relationships between heulandite and kaolinite in these samples. On the butte top, bleached zones containing kaolinite and heulandite are associated with faults (Figure 2). This alteration is an overprint of general silicification of the coarse grained sediments of unit C. These bleached zones grade laterally into red, silicified sandstones. Fe oxide stained zones surround the zones of bleaching (Figure 2). This pattern implies the sediments of the butte top were originally oxidized and silicified relatively uniformly, and fault controlled bleaching occurred later. The fault related alteration overprint zones were formed from fluids with a different composition and pH range than the original silicification.

The lower butte (unit B) is greenish grey, lacks Fe oxide rims around lithic clasts, and contains fresh pyrite. These three observations indicate deposition and silicification of the sediments under reducing conditions. Sediments within unit B are strongly silicified along faults, and are silicified over a large area, but silicification is not uniform. These sediments do not contain bleached alteration zones, Fe-oxide zones, or kaolinite.

Pyrite-bearing rocks within unit B, as RB-150 and RB-137, are found adjacent to veins exposed in the crater on the southeast side of the butte. In these Au-bearing rocks, the Au may be related to the pyrite, which in turn may be genetically related to concentrations of primary organic material in the sediments. The pyrite and associated Au may be exhalative features formed as hydrothermal solutions encountered the lake waters. The

pyrite-bearing laminated mudstones and veins have REE patterns different from most of the veins and silicified sediments of the butte. The REE patterns indicate that the samples are among the most strongly altered rocks at the butte, and may have been formed adjacent to a main hydrothermal vent or conduit.

The main controls on alteration at Red Butte are stratigraphic position, lithology, and structural setting. Fine grained sediments from unit B were silicified in a reducing environment, while similar sediments from unit C were deposited under oxidizing conditions. Silicified sandstones at the butte top contain quartz-rim cements not found in fine grained sediments. Sediments adjacent to faults at the butte top have undergone overlapping stages of alteration. Sediments adjacent to conduits in units B and C have REE patterns that indicate a large component of chemically deposited quartz.

The large explosion crater and associated breccia were formed late in the life of the system. The crater cuts all previously deposited and altered rocks, including unit C. The bedded breccia within the crater is believed to be a fallout breccia, composed of material blown out of the crater by explosive activity.

CONTROLS ON METAL DEPOSITION

Stratigraphic position, lithology, and structural setting are controls on metal deposition at Red Butte. These are the same factors that control alteration. The primary porosity and permeability of the unit C sediments at the butte top influence Au deposition. Silicified sandstones contain Au, whereas silicified mudstones from the butte top are barren of Au. In unit B sediments, however, silicified, pyrite-bearing mudstones (RB-150b, and RB-128) contain Au. The proximity to a hydrothermal vent is possibly the main control on Au content in these samples, and in the surrounding rocks.

Large bleached areas, and associated areas of Fe oxide zones in the butte top sediments generally occur along faults. Bleached areas are generally barren of Au, but the Fe oxide stained zones contain Au concentrations range up to 25 and 35 ppb. Structure is a control on metals found in veins and associated breccias. The faults and related fractures that cut the butte top sequence acted as conduits for the hydrothermal fluids that deposited the minerals.

Vertical controls on Au deposition include oxidation/reduction potential of the deposition-alteration environment of units B and C, and the difference in environments of deposition between the lower unit B sediments (lacustrine), and the upper unit C sediments (fluvial).

MODEL

A simplified model for the evolution of Red butte is presented and summarized in Figure 22. The lower four members of the Deer Butte Formation may have been deposited in a large, north-trending basin as observed by Johnson (1961), and Kittleman (1965). Above the Quartz Mountain Basalt Member, unit A, the upper basalt, and units B and C were deposited within the Mahogany Mountains caldera which extended from Quartz Mountain to the east side of the Owyhee River, and included Red Butte. Hydrothermal activity began during deposition of unit B. The major north and northwest-trending fault systems that cut the butte acted as conduits. Sub-aqueous hot springs with temperatures near boiling and of neutral to slightly alkaline composition vented into the lake. Silica was deposited when the hot, silica saturated waters encountered and mixed with cooler lake waters. Near the vents this resulted in the formation of exhalative deposits of massive chert, with minor admixed clastic material. Farther from the vents there was deposition of cherty cement in fine grained material, and devitrification of fine-grained glassy material. Silicification of the sediments was extensive, but not uniform. Trace amounts of Au were deposited in the sediments near the vents. Conditions at the lake bottom were anoxic, and pyrite was deposited.

The processes of sedimentation, hot spring activity, and faulting continued. As silicified sediments built up, the continuing hydrothermal

1. Faults cutting upper basalt and unit 3 act as conduits for hot, silica-saturated hydrothermal fluids. Silica is deposited as these fluids encounter cooler lake waters.

2. Faulting, sedimentation and hydrothermal activity continue.

3. The lake is replaced by a fluvial system depositing coarse, cross-bedded sandstones. Silicification and adularization of sandstones occurs under oxidizing conditions. Boiling in vents concentrates CO_2 and H_2S in vapor phases, zones of acid alteration including bleaching and leaching of the host rock are formed above the vents.

Figure 22. Cartoon of model of Red Butte

activity and faulting formed veins cutting the sediments. Sealing of the conduits by quartz and adularia deposition produced overpressuring of the fluids. Periodic explosive boiling occurred, fracturing the rock, enlarging the conduits, and creating breccias. Boiling also periodically changed the fluid chemistry, and alternating bands of adularia and quartz were deposited in the veins.

The lake was gradually replaced by a fluvial system depositing coarse, cross-bedded sandstones with interbeds of massive to laminated mudstones. Silicification and adularization of these sediments occurred under oxidizing conditions. Au deposition in these sediments was epigenetic, since it was controlled in part by the primary porosity of the sediment. As the sandstones built up, the average water table relative to the depositional surface was lowered until it was below the sediments in places. When boiling occurred in this situation, CO_2 and H_2S became concentrated in the vapor, and zones of acid alteration including bleaching and leaching of the host rock were formed above the vents.

Comparison With Previously Described Systems:

Red Butte has similarities to several deposits described and modeled in previous studies of epithermal precious metal deposits. Waterloo disseminated Ag deposit, (Graybeal, 1981) and the McDermitt Hg mine (Rytuba, 1981; Roper, 1980) have both been attributed to syngenetic mineralization and alteration produced by hot spring vents debouching into lakes. McArthur River Hg-Cu base metal deposit may have formed in a similar setting in marine waters (Oehler and Logan, 1977). These deposits all contain interbeds of mineralized sediments and beds of chert or siliceous

altered sediments, similar in texture and occurrence to the cherts at Red Butte.

Hg minerals at McDermitt occur within argillized tuffaceous sediments deposited in caldera fill lakebeds and within an opaline breccia. The concordant textures and relationships at McDermitt suggest that the flow of the hot springs was intermittent, and that Hg sulfides and silica were deposited at the same time as the tuffaceous sediments (Roper, 1980).

The sandstones of unit A capping Red Butte were silicified, mineralized, and altered under different geochemical conditions than the mudstones of the lower unit B. The upper red quartz-cemented sandstones that give the butte its name have no counterpart in the deposits mentioned above. Mudstones interbedded with the sandstones are generally strongly silicified at Red Butte, implying syngenetic silicification. Textures within the sandstones imply both syngenetic and epigenetic deposition of quartz and development of Fe oxides.

The strongly bleached areas are similar to descriptions of acidic (solfateric) alteration zones in the vapor dominated parts of geothermal systems (White and others, 1971), and to the upper parts of most epithermal models (Berger, 1980; Buchanan, 1981). These acidic alteration systems produce areas of bleaching, with replacement of primary mineralogy by quartz and kaolinite. Kaolinite is a very minor component of the alteration systems at Red Butte, it is found only in trace amounts in the bleached alteration zones. The kaolinite that is present may have formed at the expense of adularia, which is a very minor component of the altered sandstones.

sandstones.

The presence of heulandite in bleached samples containing trace amounts of kaolinite does not match features described in the literature. Zeolitization of tuffaceous sediments in the Jordan Valley area, about 50km south of Red Butte, was described by Hay (1966) but these sediments are not associated with silicification or mineralization.

Buchanan (1981) reviewed several epithermal systems in volcanic settings and proposes an integrated model. This model includes quartz-adularia veins at depths of several hundred meters, quartz as the main gangue mineral, development of large areas of acidic alteration including quartz and kaolinite over the main ore body, and development of breccias and large zones of brecciation by explosive boiling. In this general model, base metals are deposited deep in the system, while precious metals are deposited within and above the zone of boiling. Hg should partition into the vapor phase and be deposited between the zone of boiling and the surface.

Red Butte is somewhat similar to this general epithermal model, and is also similar to the syngenetic models discussed above. Red Butte departs from previously described systems, however, in the style of silicification and the presence of heulandite within what appears to be an "acidic" alteration zone.

CONCLUSIONS

Red Butte was formed within an intracaldera lake. Lacustrine sediments were silicified syngenetically by hydrothermal waters vented into the lake. Concurrent faulting, sedimentation, and hydrothermal activity resulted in deposition of large areas of fine-grained, strongly silicified cherty sediments. Sulfides, Au, As, and Sb were preferentially deposited near the vents. As brittle, cherty sediments built up, they were fractured along north and northwest-trending faults which acted as conduits for the hydrothermal fluids, and veins developed within the conduits. Location of vents was controlled by the intersection of faults. The lake was replaced by a river system, and hot spring activity continued. The hydrothermal system became oxygenated by river water, and sediments were oxidized as they were deposited. Syngenetic silicification of fluvial sandstones occurred by deposition of quartz rim cements. The fine grained matrix of mudstones was silicified into cherty quartz. As the water table dropped, bleached areas of acidic alteration developed above the vents. Epigenetic leaching of sandstones occurred, followed by deposition of a second generation of quartz rim cement.

Red Butte was uplifted relative to the surrounding Deer butte Formation Sediments. This localized uplift may have been caused by doming or resurgence of the caldera floor.

Suggestions for Further Study and Mineral Exploration:

This work constitutes an initial investigation of an area that has received little study and is largely unmapped. Findings of this study suggest that further work in the Vale-Owyhee area could reveal economic precious metal deposits. Quartz Mountain should be studied, and compared to Red Butte; the western boundaries of the Mahogany Mountains caldera (Rytuba and others, 1985) should be defined, the area between Red Butte and Quartz Mountain should be mapped and geochemically sampled; other silicified buttes in the area should be mapped, sampled, and correlated to the regional stratigraphy. The silicified buttes of this area may be remnants of other paleo hot spring systems, and as such are quite likely to be enriched in Au and Ag.

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APPENDIX A

INAA EXPERIMENTAL METHODS AND RESULTS

Chemical analyses for this work were performed using instrumental neutron activation analysis (INAA). INAA is a relatively simple and quick means for determination of multiple trace and major element concentrations from a single sample. INAA involves sealing a weighed sample of material into a polyethylene or fused quartz tube, bombardment of the sample with thermal neutrons to form various radioisotopes and counting the gamma ray decay products of the product radio-nucleides to determine the amount of parent nucleide originally present in the sample.

For this work INAA was performed in the Neutron Activation Lab in the Department of Geology at Portland State University on powdered samples sealed into polyethylene containers. Composite samples were collected as chips in the field, individual rock samples were chipped to .5 cm in a steel "chipmunk". The chipmunk was cleaned with alcohol and dried between samples. About 20 grams of chips were ground to -20 mesh using a hard steel mortar and pestle. The 20 grams of -20 mesh powder was stored in glass vials until all samples were crushed. Splits from samples analyzed by Bondar-Clegg were taken from the powders returned from their lab. Each sample was split using weighing paper until an approximately 1 gram sample was obtained. This sample was placed into a small polyethylene vial which had been previously washed in ethanol and scribed with an identifying

number. The vials were weighed both before and after addition of the sample and the net sample weight was calculated from this data.

The small polyethylene vials containing the powdered rock samples were loaded into larger vials. Two small vials fit in each large vial, one on top of the other. Weighed vials filled with standards BCR-1, O-16, and EMT-7 were included among the samples on both the top and bottom layers. Samples were irradiated for 1.00 hours in a TRIGA Mark II reactor equipped with a lazy susan at a flux of 1.7×10^{12} neutrons/(cm²) located at Reed College, Department of Chemistry, Portland, Oregon. The samples were allowed to decay for 3 days before they were transferred to Portland State University.

The smaller vials containing the individual samples were then removed from the larger vials and each small vial was placed into a fresh, non-radioactive large vial. Gamma-ray decay products were counted for 1000 seconds as soon as possible after transfer to fresh vials to determine as many elements with short half lives as possible. Standards were counted for 3000 seconds. A single GeLi detector hooked to Tracor Northern Hardware and Tracor Northern software were used. The spectra of the samples were stored and later analyzed to yield net counts and error associated with the counting. Table XIII shows the energies used to determine the concentrations of each element. High energies were preferred in determining concentrations, but in many cases high energy peaks were unavailable. The absolute concentration of the elements present in each sample was obtained using a computer program designed to compare net counts in the sample, where elemental concentrations were unknown, with net counts

of the same energy in the standard, where the elemental concentrations were known. Elemental concentrations used for the standards are listed in Table XIV. Error was determined for each sample using statistical means. A copy of the computer program used is not included in this work, but is similar to the program used by Hoffman (1981).

TABLE XIII

ENERGIES USED TO DETERMINE
ELEMENTAL CONCENTRATIONS USING INAA

ELEMENT	FIRST COUNT	SECOND COUNT
Au	411.8	---
As	559 657	---
Ba	216 496.3	216 496.3
Ce	145	---
Co	---	1173.1 1332.4
Cr	---	320
Cs	---	569.2 795.8
Eu	---	121.8 344.7
Fe	1099.2 1292.6	---
Hf	---	133.1 482.2
K	1524	---
La	487 1596	---
Lu	208.7	208.7
Na	1368	---
Rb	---	1076.6
Sb	564 693	1690
Sc	889 1120	889 1120
Sm	103	---
Ta	---	67.7
Tb	---	298.6 879.4
U	228.5 277.9	---
Yb	---	111.4 177

All energies are in Kev.

--- not detected

Samples were counted a second time after 3 to 5 weeks of decay time. The counting interval was expanded to 3000 seconds for samples and 9000 seconds for standards to determine the concentrations of the longer lived

isotopes. Data was obtained and reduced as for the first count. Some elements, such as Fe and Cr were detected in both the first and second counts. This allowed cross checking concentrations of these elements. Concentrations obtained on the first and second count were very close in most cases. The INAA results are given in Table XV.

TABLE XIV
ELEMENTAL CONCENTRATIONS FOR
INAA STANDARDS USED

STANDARD	ELEMENT	CONCENTRATION **
EMT-7	Au	1.85
	As	80
RBT-3*	Sb	18
BCR-1	Ba	650
	FeO	9.3 %
	Sc	32.5
	Sm	5.5
	Ce	53.9
	Lu	0.55
	U	1.74
	Co	36.3
	Cr	19
	Eu	1.95
O-16	Cs	3.5
	Hf	7.8
	Rb	128.
	Ta	2.6
	Tb	1.3
	Th	13.0
	Yb	5.2
	K	3.2 %
	La	37.4
	Na	2.97 %

*Concentration obtained from Bondar-Clegg assay

** All concentrations in ppm except where otherwise noted

TABLE XV
INAA Results

Key to sample types:

SS: Sandstone	Br: Breccia
B: Basalt	MS: Mudstone
T: Tuff	V: Vein

Key to Alteration Types:

S: Silicified	Cl: Chloritic
H: Heulandite	Ar: Argillic
Fe: Iron Oxide	Bl: Bleached

Breccia and Vein matrix material:

Q: Quartz	Ca: Calcite
A: Adularia	C: Sample consists of clasts within a breccia
M: Sample consists of breccia matrix material	

Use of symbols: Rock type/alteration type

Or: Rock type/matrix or cement type

Examples: Br/C Breccia/Clast

V/Q,A Vein consisting of quartz and adularia

MS/S Silicified mudstone

SAMPLE	Al	AS	SB	IA	FE	K	IA
SS/S RB-21A	0.11	65.30	21.50	0.40	1.79	3.58	31.90
SS/S RB-68	0.	0.97	14.50	0.40	0.71	0.49	17.50
V/Q RB-77	0.01	32.50	13.00	0.30	1.50	2.73	7.69
B/C1 RB-85	0.	8.00	0.30	0.40	4.60	2.40	14.70
B/C1 RB-86	0.	3.00	0.20	0.40	2.92	1.71	11.90
B/C1 RB-87	0.	3.80	0.30	0.40	4.30	2.14	15.70
SS/H RB-165A	0.	4.28	0.15	0.30	0.	0.93	28.00
SS/H RB-165B	0.	2.80	0.20	0.40	0.	1.72	33.10
B/T/Q RB-137A	0.10	19.80	0.20	0.40	0.66	2.56	4.06
T/S RB-168A	0.	23.80	0.30	0.60	1.49	2.56	20.70
SS/S RB-168B	0.	2.05	0.12	0.20	0.56	1.27	11.31
MS/S RB-168C	0.	2.77	0.13	0.30	0.84	2.49	14.70
T/S RB-168U	0.	20.90	0.30	0.40	1.37	4.40	33.90
T/S RB-168E	0.	17.70	0.30	0.40	1.41	3.39	27.00
MS/S RB-168F	0.	2.36	0.19	0.40	1.22	3.66	22.30
MS/S RB-168G	0.	2.35	0.16	0.30	1.47	2.88	30.70
MS/S RB-168H	0.	1.50	0.20	0.40	1.07	3.11	26.60
TT/S RB-168I	0.	3.81	0.14	0.20	0.73	4.70	14.00
TT/S RB-168J	0.	6.23	0.13	0.40	1.92	1.80	4.52
TT/S RB-168K	0.	6.05	0.14	0.70	2.75	1.74	7.16
B/C1 RB-168L	0.	11.90	0.30	0.40	2.81	2.36	11.20
B/C1 RB-168M	0.	1.40	0.16	0.30	0.17	3.96	20.50
EMI-7	1.85	80.00	4.20	0.30	4.37	2.58	30.80
RCR-1	0.	0.	0.	0.	9.30	1.07	35.30
Q-16	0.	1.80	1.50	0.30	1.11	3.20	37.40
FC-14	0.	0.	0.59	0.15	0.62	3.40	24.80
FC-14	0.	0.	0.59	0.15	0.62	3.40	24.80
CE	LI	LI	LI	LI	LI	LI	LI
SS/S RB-21A	0.39	4.03	2.30	0.30	72.00	0.26	0.49
RB-68	0.08	2.34	1.55	0.18	29.00	0.23	0.51
RB-77	0.07	2.44	0.85	0.18	18.00	0.17	0.04
RB-85	0.69	16.00	1.90	0.40	27.00	0.26	0.07
RB-86	0.65	11.50	1.50	0.30	0.	0.	0.
RB-87	0.80	14.60	1.60	0.30	45.00	0.36	0.07
RB-165A	0.11	3.85	1.70	0.20	72.00	0.28	0.04
RB-165B	0.66	8.60	4.70	0.30	92.00	0.59	0.07
RB-165C	0.05	1.56	2.00	0.19	16.00	0.17	0.04
RB-168A	0.13	6.82	2.10	0.30	67.00	0.39	1.51
RB-168B	0.09	3.51	1.30	0.19	39.00	0.27	0.04
RB-168C	0.10	3.54	1.50	0.20	32.00	0.22	0.04
RB-168D	0.19	4.23	3.20	0.30	83.00	0.49	0.07
RB-168E	0.34	4.70	2.70	0.30	62.00	0.41	0.07
RB-168F	0.15	5.32	2.90	0.30	71.00	0.42	0.06
RB-168G	0.16	5.06	3.30	0.30	66.00	0.40	0.06
RB-168H	0.42	5.60	3.70	0.40	82.00	0.52	0.07
RB-168I	0.09	7.34	2.80	0.20	47.00	0.31	0.05
RB-168J	0.04	5.42	0.13	0.	14.00	0.12	0.03
RB-168K	0.07	4.58	1.14	0.18	21.00	0.16	0.04
RB-168L	0.55	11.50	1.10	0.30	31.00	0.	0.
RB-168M	0.16	4.57	2.50	0.20	40.00	0.34	0.05
EMI-7	1.84	15.00	1.80	0.30	69.00	0.29	0.06
BCK-1	2.42	32.50	4.10	0.30	54.00	0.55	0.06
Q-16	2.97	3.68	5.20	0.30	90.00	0.76	1.00
FC-14	2.85	3.30	3.50	0.20	61.00	0.50	1.07
FC-14	2.85	3.30	3.50	0.20	61.00	0.50	1.07
LI	LI	LI	LI	LI	LI	LI	LI

SAMPLE	RA	CO	CR	CS	EU	FE	SB
RB-21A	840.00	40.00	240.00	20.00	8.50	0.40	1.40
RB-68	190.00	30.00	250.00	20.00	6.60	0.30	1.30
RB-77	190.00	30.00	240.00	20.00	3.10	1.20	0.70
RB-85	360.00	70.00	240.00	20.00	2.40	1.00	0.60
RB-86	260.00	50.00	260.00	20.00	1.80	0.60	0.40
RB-87	270.00	60.00	175.00	15.00	32.00	1.10	4.40
RB-165	810.00	50.00	9.60	1.70	16.80	0.60	0.50
RB-165R	2270.00	120.00	0.	3.00	20.30	0.70	0.50
RB-137A	150.00	30.00	0.	0.	9.30	0.40	0.90
RB-168A	570.00	60.00	20.00	3.00	90.00	3.00	1.00
RB-168R	240.00	40.00	12.00	2.00	72.00	2.00	0.30
RB-168C	270.00	40.00	0.12	3.00	78.00	3.00	0.50
RB-168H	590.00	70.00	4.10	4.00	29.00	8.00	0.60
RB-168E	480.00	70.00	0.10	3.00	240.00	9.00	0.60
RB-168F	380.00	70.00	4.45	4.00	332.00	11.00	0.50
RB-168H	520.00	60.00	3.17	3.00	159.00	5.00	0.30
RB-168H	1140.00	80.00	3.30	3.00	83.00	3.00	0.40
RB-168J	570.00	50.00	4.26	3.00	69.00	2.00	0.40
RB-168K	410.00	50.00	2.59	2.00	109.00	4.00	1.20
RB-168H	520.00	60.00	16.10	9.00	72.00	2.00	0.40
U-16	530.00	30.00	2.63	3.00	202.00	7.00	0.40
RCR-1	650.00	40.00	0.66	0.	3.50	0.16	0.13

SAMPLE	IA	IR	IE	IH	HH	SR	YB
RB-21A	1.30	0.93	0.06	0.02	6.70	0.	3.00
RB-68	0.48	0.54	0.04	0.13	0.10	0.	0.30
RB-77	0.31	0.32	0.04	0.12	0.10	0.	0.30
RB-85	0.82	0.68	0.08	0.20	2.92	0.04	0.30
RB-86	0.60	0.52	0.06	0.15	2.34	0.02	0.50
RB-87	0.78	0.53	0.07	0.30	5.61	0.	0.40
RB-165	1.10	0.72	0.05	0.19	2.82	0.	0.50
RB-165R	2.58	1.47	0.08	0.30	17.93	0.29	0.30
RB-137A	0.13	0.69	0.04	0.11	1.05	1.00	0.40
RB-168A	1.35	0.89	0.07	0.30	5.61	0.	0.50
RB-168R	0.45	0.48	0.09	0.17	2.00	0.	0.30
RB-168C	0.67	0.55	0.	0.35	0.13	0.	0.30
RB-168H	1.24	0.88	0.09	0.30	2.96	0.	0.60
RB-168E	1.09	0.88	0.	0.30	6.70	0.	0.60
RB-168F	1.24	0.88	0.	0.30	4.90	0.	0.60
RB-168H	1.31	1.13	0.08	0.30	5.70	0.	0.60
RB-168H	1.41	0.97	0.07	0.30	6.10	0.	0.50
RB-168J	0.91	0.65	0.	0.20	6.90	0.12	0.50
RB-168J	0.39	0.04	0.11	0.15	3.93	0.	0.30
RB-168K	0.63	0.38	0.	0.19	2.13	0.	0.
RB-168L	0.59	0.45	0.31	0.03	2.13	0.03	0.40
RB-168H	1.30	0.67	0.	0.30	5.57	0.	0.50
U-16	2.60	1.20	0.04	0.	13.00	0.13	0.30
RCR-1	0.46	1.13	1.00	0.03	5.69	0.02	0.40

RED BUTTE INAA 1ST RUN 2ND COUNT						
SAMPLE	CE	LU			SC	
RB-21A	69.20	1.30	0.31	0.04	4.22	0.03
RB-68	21.20	0.60	0.21	0.02	2.23	0.02
RB-77	14.80	0.60	0.15	0.03	2.38	0.02
RB-85	29.30	1.20	0.32	0.05	15.98	0.07
RB-86	26.40	0.80	0.21	0.04	12.07	0.05
RB-87	32.70	1.00	0.28	0.05	13.95	0.06
RB-165	58.70	1.10	0.26	0.03	3.47	0.03
RB-165B	71.70	1.30	0.59	0.04	8.16	0.04
RB-137A	9.90	0.50	0.21	0.02	1.55	0.02
RB-168A	51.30	1.20	0.33	0.04	6.95	0.04
RB-168B	32.60	0.80	0.17	0.03	3.45	0.03
RB-168C	32.90	0.80	0.16	0.03	3.31	0.03
RB-168D	66.80	1.50	0.45	0.05	4.31	0.03
RB-168E	54.60	1.30	0.35	0.05	4.90	0.03
RB-168F	51.10	1.40	0.35	0.06	5.15	0.04
RB-168G	58.10	1.20	0.49	0.05	5.09	0.04
RB-168H	62.90	1.30	0.47	0.04	5.81	0.04
RB-168I	36.30	0.90	0.35	0.04	7.16	0.04
RB-168J	10.40	0.70	0.	0.	5.46	0.04
RB-168K	11.40	0.70	0.13	0.04	4.49	0.03
RB-168L	17.50	0.80	0.15	0.04	10.95	0.05
RB-168M	47.80	1.10	0.36	0.05	4.50	0.03
Q-16	72.10	1.10	0.64	0.03	3.45	0.02
BCR-1	46.00	0.80	0.55	0.03	32.50	0.05

RED ROUTE-7C 1ST COUNT TOP

SAMPLE	AS	SB	BA	FE	K	LA
Br/C RB1500+C	0.22	1.13	0.12	0.	0.16	4.98
SS/S RB-150	0.10	2.79	0.10	0.	0.37	0.18
Br/Q RB-151	0.01	4.55	0.14	0.	1.47	13.80
Br/Q RB151B	0.15	2.88	0.10	0.	0.45	4.75
Br/H RB-152A	0.01	3.84	0.13	1000.00	0.	0.47
				200.00		0.04
Br/Q RB-153	0.	4.91	0.13	390.00	1.13	2.11
RB-159B	0.	1.68	0.17	900.00	0.94	3.32
SS/H RB160A	0.	1.06	0.18	0.	1.14	1.74
SS/H RB-160B	0.	1.49	0.19	900.00	2.07	2.64
SS/H RB-160C	0.	2.40	0.20	1300.00	2.22	0.
B/Ar RB-161B	0.01	3.34	0.15	0.	2.49	0.20
V/b/c RB-162B	0.	2.13	0.15	0.	2.00	0.60
MS/S RB-164	0.	10.20	0.20	0.	2.66	2.70
B/Cl RB-169	0.	0.	0.	600.00	5.90	0.76
SS/S RB1-3	0.09	18.00	0.30	710.00	1.59	3.99
				190.00		0.16
HCR-1	0.	0.	0.	650.00	9.30	0.18
0-16	0.	0.89	0.17	710.00	1.03	0.10
EM1-7	1.85	2.14	0.14	920.00	4.34	0.12
	0.01	3.00	0.20	200.00	2.29	0.17
					0.12	30.90
					0.30	0.30

RED ROUTE-7C 1ST COUNT TOP

SAMPLE	NA	SC	YR	SM	CE	LU	U
Br/C RB1500+C	0.09	0.	0.84	0.13	0.	0.	0.
SS/S RB-150	0.04	1.50	0.07	0.07	0.82	0.02	0.
Br/Q RB-151	0.09	3.47	0.10	0.18	0.85	0.02	0.
Br/Q RB151B	0.07	0.47	0.05	0.	3.01	0.03	0.
Br/H RB-152A	0.20	2.94	0.09	0.20	0.43	0.01	0.
Br/Q RB-153	0.04	3.95	0.09	0.17	4.06	0.04	0.05
V/b/c RB-159B	0.79	3.45	0.15	0.40	3.24	0.03	0.04
SS/H RB160A	0.26	3.60	0.20	0.40	6.17	0.05	0.08
SS/H RB-160B	0.41	5.23	0.15	0.40	5.74	0.04	0.08
SS/H RB-160C	1.57	7.03	0.07	0.40	8.63	0.07	0.08
B/Ar RB-161B	0.10	2.75	0.16	0.	11.96	0.11	0.07
V/b/c RB-162B	0.36	6.24	0.13	0.	0.	0.	0.
MS/S RB-164	0.06	5.75	0.12	0.20	1.64	0.02	0.
B/Cl RB-169	2.50	23.10	0.30	0.40	4.19	0.04	0.05
SS/S RB1-3	0.16	5.41	0.13	0.30	6.21	0.06	0.08
HCR-1	2.45	32.50	0.20	0.30	5.77	0.05	0.07
0-16	2.97	3.75	0.10	0.40	8.03	0.06	0.07
EM1-7	1.84	14.77	0.14	0.20	85.00	0.05	0.08
					73.00	8.00	0.55

RED ROUTE--7C--2ND CT TOP

SAMPLE	BA	CD	CR	CS	EU	HF	RB							
RP150V+C	260.00	50.00	2.87	0.13	5.60	1.90	12.00	0.50	0.11	0.01	0.	0.	920.00	40.00
RR-150	0.	0.	3.14	0.13	17.00	3.00	6.30	0.30	0.12	0.01	0.75	0.12	950.00	40.00
RR-151	230.00	50.00	3.11	0.09	78.00	12.00	19.60	0.70	0.37	0.01	3.78	0.12	321.00	17.00
RR-151B	0.	0.	1.04	0.08	6.30	1.60	6.00	0.30	0.04	0.01	0.	0.	890.00	40.00
RR-152A	770.00	110.00	0.	0.	11.00	3.00	13.90	0.60	0.53	0.02	5.05	0.19	84.00	12.00
RR-153	360.00	80.00	1.54	0.10	390.00	60.00	13.30	0.50	0.39	0.02	3.31	0.17	360.00	20.00
RR-159B	170.00	30.00	2.28	0.12	15.00	3.00	15.40	0.60	0.98	0.02	5.61	0.17	248.00	13.00
RR-160A	140.00	30.00	2.46	0.14	10.00	2.00	76.00	3.00	0.68	0.03	8.00	0.20	176.00	12.00
RR-160B	710.00	150.00	2.07	0.13	17.00	4.00	48.90	1.80	0.81	0.03	13.00	0.40	490.00	30.00
RR-160C	1150.00	170.00	4.50	0.16	24.00	5.00	24.40	1.00	1.70	0.03	12.00	0.30	390.00	30.00
RR-161B	0.	0.	3.97	0.16	24.00	4.00	8.30	0.40	0.13	0.01	0.	0.	0.	0.
RR-162B	0.	0.	9.10	0.20	90.00	14.00	23.70	0.90	0.41	0.02	1.35	0.17	1190.00	50.00
RR-164	0.	0.	4.74	0.19	28.00	5.00	18.40	0.80	0.55	0.02	3.30	0.20	190.00	20.00
RR-169	700.00	170.00	29.50	0.40	200.00	30.00	0.	0.	1.48	0.05	6.30	0.30	0.	0.
RR-3	680.00	130.00	4.60	0.18	270.00	40.00	11.10	0.50	0.84	0.02	7.80	0.30	850.00	40.00
RCR-1	650.00	130.00	36.30	0.40	19.00	4.00	0.	0.	1.95	0.03	7.50	0.20	120.00	20.00
0-16	160.00	20.00	0.73	0.05	0.	0.	3.50	0.18	0.35	0.01	7.80	0.14	128.00	7.00

RED ROUTE--7C--2ND CT TOP

SAMPLE	SR	TA	TR	TH	YR	CE	LU
RR150V,C	0.38	0.01	0.	1.06	0.19	2.90	0.
RR-150	0.	0.	0.29	2.19	0.19	3.60	0.30
RR-151	0.	0.50	0.61	8.00	0.20	17.20	0.30
RR-151B	0.	0.	0.	1.47	0.15	2.50	0.50
RR-152A	1.00	0.95	0.72	16.50	0.40	31.20	0.30
RR-153	0.	0.60	0.69	9.20	0.30	11.70	0.80
RR-159B	0.	0.92	1.10	11.30	0.20	24.20	0.50
RR-160A	0.16	1.45	1.42	16.80	0.40	32.60	0.60
RR-160B	0.21	1.84	1.88	34.30	0.70	61.00	0.80
RR-160C	0.11	1.42	2.19	29.00	0.60	69.70	1.40
RR-161B	0.	0.	0.	0.	0.	2.60	1.50
RR-162B	0.	0.24	0.	0.	0.	7.90	0.50
RR-164	0.	0.52	0.72	11.00	0.40	22.90	0.50
RR-169	0.	0.83	1.10	5.10	0.50	33.80	0.80
RR1-3	0.	1.20	1.00	19.10	0.50	37.40	1.10
RCR-1	0.	0.85	1.50	14.00	0.40	46.00	1.00
0-16	0.	2.60	1.20	13.00	0.20	32.10	1.20
							0.55
							0.60
							0.06
							0.01

RED BUTTE--7C--2ND CT TOP
SAMPLE SC

RB150V,C	0.75	0.02
RB-150	1.52	0.02
RB-151	3.37	0.02
RB-151B	0.40	0.01
RB-152A	2.90	0.03
RB-153	3.79	0.03
RB-159B	2.80	0.03
RB-160A	3.65	0.03
RB-160B	5.66	0.04
RB-160C	6.70	0.04
RB-161B	2.61	0.03
RB-162B	5.90	0.04
RB-164	5.54	0.05
RB-169	22.75	0.08
RBT-3	5.08	0.04
BCR-1	32.50	0.09
0-16	3.04	0.02

SAMPLE	AU	AS	SR	BA	FE	K	LA
B/Cl RB-13A	0.	0.	0.	0.	7.59	0.	18.10
SS/Fe RB-25	0.	10.10	9.30	0.	0.50	0.	18.70
B/V/CRB-47	0.72	128.50	4.10	0.20	4.25	1.98	14.20
SS/S RB-101	0.19	23.00	27.20	0.40	1.25	1.02	31.70
B/Cl RB-115A	0.	4.10	0.	0.	1.31	0.87	26.50
B/Cl RB-115C	0.	18.50	0.	0.	0.20	0.	16.80
Br/Q RB-112	0.34	2.80	6.16	0.17	1.14	1.90	11.60
Br/Q RB-119	1.24	51.60	7.30	0.	1.37	1.97	11.91
SS/S RB-120	0.03	29.30	6.17	0.18	1.55	1.80	16.80
MS/Fe RB-121	0.06	20.50	5.60	0.20	2.06	0.78	18.50
Br/Q RB-122A	0.36	2.48	5.25	0.13	0.69	0.27	3.66
V/Q RB-123	0.02	1.64	0.	0.	0.	0.02	1.61
Br/Q/CRB126A,H	0.	5.00	0.30	0.17	1.37	1.89	25.40
Br/Q/CRB126B,V	0.02	2.90	3.43	0.14	0.33	2.72	6.98
Br/Q/CRB126C,H	0.	0.	2.78	0.10	0.90	0.	0.35
Br/Q/CRB126D,V	0.02	1.22	3.87	0.13	0.43	0.	0.92
Br/M RB-128,V	0.	0.72	0.66	0.07	0.15	0.	0.74
Br/C RB-128,W	0.02	5.40	2.27	0.12	0.72	1.13	7.18
Br/Q RB-131A,C	0.03	1.63	14.10	0.20	0.81	0.97	5.27
Br/C RB-131A,C	0.03	3.05	5.71	0.20	1.93	1.66	9.37
Br/M RB-131A,M	0.05	0.53	5.20	0.	0.38	0.82	0.91
Br/Q RB-135A	0.14	37.10	7.33	0.	1.31	1.28	2.93
V/Q RB-135B	0.16	36.60	7.13	0.	1.65	1.28	3.04
V/Q RB-136	0.23	7.32	3.56	0.12	1.55	0.63	2.13
Br/Q RB-136B	0.33	7.43	3.46	0.12	1.82	0.70	2.25
Br/Q RB-137	0.05	91.60	41.00	0.40	3.49	0.94	3.19
Br/Q RB-139A	0.18	190.30	28.70	0.30	5.29	1.37	3.80
Br/Q RB-139B	0.20	36.90	37.20	0.40	0.56	1.65	3.46
MS/S RB-140	0.	3.24	9.48	0.17	0.46	0.19	3.03
Br/M RB-142V	0.	0.57	2.85	0.10	0.	0.24	1.54
B/Cl RB-142,W	0.	6.92	3.61	0.19	2.73	1.31	4.47
V/Q RB-143,V	0.04	0.	4.02	0.14	0.	0.69	1.44
V/Q RB-143,W	0.	1.22	4.50	0.20	1.58	1.69	20.70
V/Q RB-145,V	0.	1.04	1.97	0.10	0.35	0.21	2.90
MS/S RB-147,W	0.	2.27	5.60	0.15	1.44	1.49	7.36
BCR-1	0.	0.	0.	0.	9.30	0.58	19.50
0-16	0.	0.	1.30	0.20	1.04	3.20	37.40
ENI-7	1.85	80.00	2.54	0.16	4.55	1.18	25.40

SAMPLE	NA	SC	YB	SH	CE	LU	U				
RB-13A	1.16	0.	2.30	5.56	0.05	39.00	7.00	0.36	0.07	0.	0.
RB-25	0.20	0.	1.51	3.19	0.03	53.00	5.00	0.27	0.04	1.50	0.50
RB-47	0.23	0.	1.50	4.06	0.05	44.00	7.00	0.36	0.06	0.	0.
RB-101	0.20	0.	2.70	6.47	0.05	48.00	6.00	0.42	0.05	0.	0.
RB-115A	0.91	0.	1.80	4.91	0.05	77.00	8.00	0.35	0.06	3.40	1.20
RB-115C	0.86	0.	2.80	6.92	0.05	1910.00	130.00	0.45	0.07	0.	0.
RB-112	0.03	0.	1.80	3.08	0.03	36.00	4.00	0.32	0.04	4.00	0.90
RB-119	0.04	0.	1.80	2.89	0.03	44.00	8.00	0.23	0.06	0.	0.
RB-120	0.09	0.	2.30	3.88	0.03	55.00	8.00	0.44	0.06	3.20	0.80
RB-121	0.14	0.	2.20	4.44	0.03	58.00	10.00	0.34	0.08	3.10	0.80
RB-122A	0.02	0.	0.62	1.18	0.02	22.00	4.00	0.12	0.03	2.40	0.60
RB-123	0.01	0.	0.	0.	0.	0.	0.	0.25	0.03	6.30	1.40
RB126A+H	0.38	0.	2.20	4.90	0.05	77.00	7.00	0.38	0.05	3.40	0.90
RB126B+V	0.12	0.	0.74	1.40	0.02	20.00	3.00	0.09	0.03	1.20	0.40
RB126C+H	0.02	0.	0.	0.11	0.01	0.	0.	0.	0.	0.	0.
RB126B+V	0.03	0.	0.	0.25	0.01	0.	0.	0.	0.	0.	0.
RB-128+V	0.02	0.	0.	0.13	0.01	0.	0.	0.	0.	0.	0.
RB-128+M	0.09	0.	0.56	1.37	0.02	21.00	3.00	0.	0.	1.40	0.40
RB1312+3	0.05	0.	0.64	1.19	0.02	0.	0.	0.	0.	0.	0.
RB131A+C	0.13	0.	1.50	2.40	0.02	35.00	7.00	0.	0.	0.	0.
RB131A+M	0.03	0.	0.	0.20	0.01	0.	0.	0.	0.	0.	0.
RB-135A	0.02	0.	0.87	0.84	0.02	0.	0.	0.17	0.05	5.10	1.20
RB-135B	0.02	0.	1.12	0.93	0.02	0.	0.	0.23	0.05	5.50	1.30
RB-136	0.03	0.	0.	0.40	0.01	0.	0.	0.	0.	1.90	0.50
RB-136B	0.03	0.	0.	0.48	0.01	0.	0.	0.	0.	2.00	0.50
RB-137	0.02	0.	3.20	4.78	0.04	0.	0.	0.46	0.07	0.	0.
RB-139A	0.03	0.	2.80	0.76	0.02	0.	0.	0.72	0.09	17.00	4.00
RB-139B	0.02	0.	2.40	0.76	0.02	0.	0.	0.42	0.06	10.00	2.00
RB-140	0.04	0.	0.45	0.80	0.01	0.	0.	0.	0.	1.50	0.40
RB-142V	0.02	0.	0.	0.33	0.01	0.	0.	0.	0.	0.	0.
RB-142+M	0.14	0.	0.98	1.42	0.02	0.	0.	0.	0.	1.60	0.60
RB-143+V	0.06	0.	0.	0.22	0.01	0.	0.	0.	0.	0.	0.
RB143+M	0.30	0.	2.50	4.55	0.04	67.00	8.00	0.46	0.07	2.90	0.80
RB-145+V	0.02	0.	0.46	0.68	0.01	0.	0.	0.09	0.02	2.20	0.60
RB-147+M	0.04	0.	1.14	1.70	0.02	29.00	4.00	0.16	0.03	0.	0.
BCK-1	1.33	0.	3.40	6.13	0.04	54.00	5.00	0.55	0.06	1.70	0.60
U-16	2.97	0.01	5.20	6.90	0.05	92.00	8.00	0.80	0.07	4.00	1.10
EMI-7	1.06	0.	1.62	0.	0.	71.00	6.00	0.23	0.04	1.80	0.60

SAMPLE	BA	CO	CR	CS	EU	HF	RB						
RB-13A	460.00	39.10	0.50	240.00	20.00	15.50	0.60	1.85	0.04	3.19	0.17	0.	0.
RB-25	530.00	40.00	0.45	0.07	16.80	2.00	1.57	0.12	0.44	4.51	0.12	0.	0.
RB-47	670.00	70.00	0.40	240.00	20.00	2.30	0.30	0.30	0.99	3.10	0.16	237.00	11.00
RB-101	720.00	60.00	2.44	0.14	230.00	20.00	3.97	0.19	1.23	2.46	0.11	156.00	7.00
RB-115A	960.00	80.00	3.63	0.14	197.00	19.00	1.64	0.16	0.93	5.41	0.14	72.00	5.00
RB-115C	360.00	80.00	49.60	0.60	220.00	20.00	1.90	0.40	2.98	3.12	0.20	0.	0.
RB-112	510.00	50.00	3.02	0.14	260.00	20.00	4.70	0.20	0.41	3.18	0.12	295.00	10.00
RB-119	380.00	50.00	5.90	0.20	240.00	20.00	4.60	0.20	0.64	2.82	0.12	352.00	12.00
RB-120	580.00	60.00	4.99	0.17	161.00	15.00	5.00	0.30	0.83	4.83	0.14	399.00	13.00
RB-121	550.00	60.00	9.50	0.30	90.00	9.00	10.80	0.40	0.88	5.20	0.17	183.00	9.00
RB-122A	270.00	30.00	2.59	0.13	530.00	50.00	3.03	0.17	0.19	0.89	0.08	43.00	4.00
RB-123	100.00	17.00	0.19	0.04	5.70	0.80	0.81	0.07	0.	0.15	0.03	0.	0.
RB126A,H	510.00	60.00	3.13	0.13	25.00	3.00	13.20	0.40	0.98	5.73	0.15	292.00	10.00
RB126B,U	240.00	30.00	1.07	0.08	15.10	1.80	4.70	0.20	0.19	1.03	0.07	415.00	13.00
RB126C,H	90.00	30.00	2.24	0.11	13.00	1.60	7.40	0.30	0.	0.	0.	11.00	3.00
RB126B,U	0.	0.	1.85	0.10	15.40	1.80	5.20	0.20	0.06	0.01	0.	19.00	3.00
RB-128U	390.00	40.00	1.24	0.09	20.00	2.00	4.30	0.20	0.21	1.90	0.08	151.00	7.00
R131+2+3	160.00	40.00	1.75	0.12	410.00	40.00	8.90	0.30	0.18	1.23	0.09	157.00	7.00
RB131A,C	310.00	50.00	7.50	0.20	39.00	4.00	17.40	0.60	0.51	2.46	0.13	221.00	10.00
RB131A,H	0.	0.	0.32	0.05	14.80	1.70	6.70	0.20	0.03	0.20	0.05	147.00	6.00
RB-135A	0.	0.	1.11	0.10	15.00	2.00	52.30	1.50	0.17	1.50	0.11	239.00	10.00
RB-135B	0.	0.	1.34	0.10	23.00	3.00	55.00	1.50	0.18	1.51	0.11	258.00	10.00
RB-136	170.00	30.00	1.07	0.08	186.00	17.00	5.60	0.20	0.07	0.24	0.06	89.00	6.00
RB-136H	280.00	40.00	2.23	0.11	4.30	1.30	9.70	0.30	0.08	0.31	0.07	103.00	6.00
RB-137	0.	0.	3.28	0.19	400.00	40.00	11.80	0.40	0.95	0.47	0.13	180.00	10.00
RB-139A	0.	0.	2.66	0.19	16.00	3.00	28.50	0.90	0.40	0.97	0.14	225.00	11.00
RB-139B	250.00	70.00	1.07	0.14	0.	0.	37.50	1.10	0.26	1.17	0.14	274.00	11.00
RB-140	200.00	40.00	1.29	0.09	370.00	30.00	9.56	0.19	0.11	0.67	0.07	28.00	4.00
RB-142,U	0.	0.	1.40	0.09	10.20	1.50	2.83	0.16	0.11	0.29	0.08	29.00	4.00
RB-142W	420.00	80.00	7.20	0.20	43.00	5.00	21.00	0.70	0.42	1.96	0.12	138.00	9.00
RB-143U	140.00	40.00	0.28	0.05	8.00	1.30	7.00	0.30	0.04	0.26	0.05	118.00	6.00
RB-143W	620.00	80.00	3.19	0.14	23.00	3.00	6.60	0.30	0.54	6.52	0.17	189.00	10.00
RB-145U	0.	0.	1.56	0.10	8.40	1.60	11.10	0.40	0.11	0.53	0.07	42.00	5.00
RB-147U	460.00	80.00	4.06	0.16	15.00	3.00	26.40	0.80	0.01	2.27	0.12	208.00	10.00
BCR-1	650.00	70.00	36.30	0.40	19.00	2.00	0.97	0.19	1.95	5.07	0.13	61.00	6.00
EW1-7	580.00	50.00	0.78	0.05	3.30	0.90	3.50	0.13	0.34	7.80	0.12	128.00	5.00
EW1-7	760.00	60.00	9.91	0.15	93.00	9.00	4.00	0.20	1.37	4.58	0.10	134.00	5.00

Sample	SB	SK	TA	TR	IE	TH	YB
RB-13A	0.	0.59	0.97	0.06	0.83	0.07	0.18
RB-25	6.70	0.30	0.93	0.04	0.39	0.08	0.19
RB-47	4.80	0.40	0.70	0.05	0.76	0.07	0.16
RB-101	20.90	0.70	0.28	0.03	1.16	0.05	0.31
RB-115A	0.60	0.12	1.05	0.04	1.04	0.05	0.16
RB-115C	0.	0.	0.83	0.07	1.14	0.09	0.20
RB-112	3.80	0.30	0.58	0.04	0.59	0.04	0.19
RB-119	10.00	0.50	0.65	0.04	0.50	0.05	0.15
RB-120	7.60	0.40	0.95	0.04	0.89	0.05	0.53
RB-121	6.20	0.40	1.04	0.05	0.94	0.06	0.19
RB-122A	3.70	0.30	0.15	0.02	0.27	0.03	0.20
RB-123	0.21	0.05	0.13	0.03	0.	0.	0.10
RB126A+H	1.33	0.18	1.17	0.05	0.99	0.05	0.22
RB126B+O	2.50	0.20	0.20	0.03	0.26	0.03	0.10
RB126C+H	2.07	0.17	0.	0.	0.	0.	0.
RB126B+O	3.20	0.20	0.	0.	0.	0.	0.
RB-128V	0.33	0.07	0.	0.	0.	0.	0.30
RB-128W	1.75	0.17	0.45	0.03	0.35	0.03	0.04
RB131+2+3	10.70	0.50	0.27	0.03	0.21	0.03	0.13
RB131A+C	4.50	0.30	0.59	0.04	0.44	0.05	0.12
RB131A+H	3.30	0.20	0.	0.	0.	0.	0.45
RB-135A	6.70	0.40	0.30	0.03	0.20	0.05	0.15
RB-135B	6.80	0.40	0.33	0.03	0.28	0.05	0.15
RB-136	2.90	0.20	0.	0.	0.	0.	0.60
RB-136B	3.10	0.20	0.08	0.	0.11	0.03	0.49
RB-137	41.00	1.20	0.	0.	2.30	0.08	0.78
RB-139A	39.80	1.10	0.	0.	0.86	0.07	0.19
RB-139B	30.60	0.90	0.	0.	0.61	0.05	0.19
RB-140	6.40	0.30	0.11	0.02	0.13	0.03	1.83
RB-142+O	1.84	0.18	0.08	0.02	0.	0.	0.
RB-142H	2.40	0.20	0.40	0.03	0.29	0.05	0.16
RB-143V	3.00	0.20	0.06	0.02	0.	0.	0.57
RB-143W	3.10	0.30	1.08	0.05	0.88	0.05	0.20
RB-145V	1.32	0.17	0.	0.02	0.12	0.04	0.12
RB-147H	3.90	0.30	1.93	0.15	0.35	0.05	0.17
BCR-1	0.	0.	0.60	0.04	1.15	0.05	0.15
0-16	0.75	0.	2.60	0.04	1.20	0.04	0.15
EM1-7	2.63	0.16	0.59	0.03	0.72	0.04	0.13

SAMPLE	CE		LU		SC	
RB-13A	42.50	1.10	0.41	0.06	27.44	0.09
RB-25	38.30	0.80	0.28	0.03	3.20	0.03
RB-47	34.80	1.00	0.29	0.05	17.09	0.07
RB-101	34.80	0.90	0.40	0.04	3.32	0.03
RB-115A	55.00	1.20	0.25	0.03	3.91	0.03
RB-115C	43.30	1.30	0.52	0.07	34.61	0.08
RB-112	28.30	0.80	0.28	0.04	3.92	0.03
RB-119	30.90	0.80	0.18	0.04	5.00	0.04
RB-120	44.90	1.00	0.38	0.04	5.57	0.03
RB-121	49.30	1.20	0.43	0.05	8.25	0.05
RB-122A	10.40	0.50	0.12	0.02	1.16	0.02
RB-123	2.30	0.20	0.	0.	0.25	0.01
RB126A,H	56.20	1.20	0.33	0.04	4.04	0.03
RB126B,U	13.80	0.50	0.10	0.02	1.07	0.02
RB126C,H	0.74	0.15	0.	0.	0.64	0.01
RB126D,U	1.67	0.20	0.	0.	1.14	0.02
RB-128U	1.50	0.30	0.	0.	0.18	0.01
RB-128W	15.90	0.50	0.09	0.03	2.36	0.02
RB131,2,3	12.90	0.40	0.11	0.03	1.77	0.02
RB131A,C	21.30	0.80	0.19	0.04	6.66	0.04
RB131A,M	1.90	0.20	0.	0.	0.38	0.01
RB-135A	7.00	0.60	0.	0.	2.48	0.02
RB-135B	7.90	0.60	0.	0.	2.73	0.02
RB-135	4.00	0.40	0.	0.	0.54	0.01
RB-136B	3.30	0.40	0.	0.	0.65	0.01
RB-137	11.80	0.70	0.46	0.07	2.84	0.03
RB-139A	12.00	1.00	0.44	0.08	11.54	0.06
RB-139B	9.00	0.60	0.36	0.07	7.71	0.04
RB-140	7.30	0.40	0.	0.	1.17	0.02
RB-142,U	3.10	0.30	0.	0.	1.22	0.02
RB-142W	11.30	0.70	0.	0.	7.73	0.05
RB-143U	2.50	0.30	0.	0.	0.29	0.01
RB-143W	48.80	1.10	0.40	0.09	5.67	0.04
RB-145U	6.20	0.40	0.	0.	0.93	0.02
RB-147W	20.20	0.80	0.	0.	5.58	0.04
BCR-1	46.00	1.10	0.55	0.05	32.50	0.05
Q-16	67.80	1.20	0.67	0.05	3.75	0.02
EMT-7	50.00	1.00	0.29	0.03	15.24	0.03

APPENDIX B

BONDAR-CLEGG ANALYSES

Bondar-Clegg, Inc.
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Telex: 45-681

Geochemical
Lab Report

Report: BCSS-1311 Project: Update: 1 Date: WED AUG 31, 1983

Client: Geologist(s): EVANS, S
No. of Samples: 42

Element(s)	Code = Digestion	/ Finish
AG, HG,	J1 = Aqua regia	/ Atomic absorption
AU,	T1 = Total (fusion or HF)	/ Atomic absorption
AS,	D2 = Nitric-perchloric	/ Colorimetry
SB,	9 = No digestion	/ X-ray fluorescence

—SPECIAL COMMENTS—

All element values are in PPM (parts per million) unless noted immediately above and in column headings.
The following concentration qualifiers are used to indicate restrictions on a specific value for any given element:
= Blank, for a normal population value.

L = Less than the limit of detection.
G = Greater than the limit of detection.
H = Interference (numerical field will show best estimate under circumstances).
K = Less than detection limit, but interference noted.
S = Insufficient sample (numerical field blank.)

N = Undetected (numerical field blank).
R = Analysis done on a reduced sample size relative to the sample population.
Q = Interference noted and reduced sample size (similar to 'R').
T = Less than detection limit on reduced sample size.
Z = Value is forthcoming.

Type sample: R = rock or core, D = soil, S = stream sediment, W = water, V = vegetation.
I = standard, B = lake bottom, F = frost boil, P = pulp, C = concentrate.
Sieve mesh size: 1 or blank = -60, 2 = -20 + 100, 3 = -325, 4 = -20 + 80, 5 = -200, 6 = -60 + 200,
7 = -100, 8 = -35, 9 = -35 + 80, A = pulverized, B = -60, C = -40
D = -20, E = -60 + 270, V = vegetation ash, X = unknown (as received).

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BONDAR-CLEGG

**Geochemical
Lab Report**

Report: BCS3-1311		Project:		Update: 1		Date: MED AUG 31, 1983		Page: 1	
REC#	SAMPLE NUMBER	/T/S	AG/J1 PPM	AU/T1 PPM	AS/D2 PPM	HG/J1 PPM	SB/ 9 PPM		
0001	RB-54 D 1		0.2	0.010	21	0.070	L	2	
0002	RB-69 D 1		0.2	0.010	26	0.070		23	
0003	RB-19 R A		0.2	0.005	97	0.200		22	
0004	RB-22 R A		0.2	L 0.005	6	0.070	L	2	
0005	RB-23 R A		0.2	0.005	58	0.095		8	
0006	RB-31 R A		0.2	L 0.005	24	0.070		11	
0007	RB-32 R A		0.2	0.010	62	0.095		9	
0008	RB-36 R A		0.2	L 0.005	22	0.135		3	
0009	RB-37 R A		0.2	0.005	22	0.140	L	2	
0010	RB-38 R A		0.2	0.015	48	0.420		9	
0011	RB-39 R A		0.2	0.005	28	0.265		14	
0012	RB-40 R A		0.2	0.030	17	0.160		6	
0013	RB-41 R A		0.2	0.060	12	0.145		3	
0014	RB-42 R A		0.2	L 0.005	14	0.090		6	
0015	RB-43 R A		0.2	0.025	23	0.090		4	
0016	RB-45 R A		0.2	L 0.005	7	0.040		3	
0017	RB-46 R A		0.2	0.025	77	0.025	L	2	
0018	RB-53 R A		0.2	0.010	39	0.090		15	
0019	RB-58 R A		0.2	0.005	15	0.070		22	
0020	RB-59 R A		0.2	0.005	7	0.070		26	
0021	RB-60 R A		0.2	0.025	14	0.500		17	
0022	RB-61 R A		0.2	0.055	14	0.115		15	
0023	RB-63 R A		0.2	0.010	8	0.050		13	
0024	RB-66 R A		0.2	0.025	19	0.290		9	
0025	RB-68 R A		0.2	0.005	16	0.070		13	
0026	RB-70 R A		0.2	L 0.005	14	0.180	L	2	
0027	RB-71 R A		0.2	0.025	14	0.115		9	
0028	RB-72 R A		0.2	0.025	8	0.070		12	
0029	RB-73 R A		0.2	0.005	20	0.030		6	
0030	RB-74 R A		0.2	0.005	22	0.105		7	
0031	RB-75 R A		0.2	0.040	17	0.115		6	
0032	RB-76 R A		0.2	0.005	14	0.050	L	2	
0033	RB-77 R A		1.3	0.290	70	0.800		13	
0034	RB-85 R A		0.2	0.010	21	0.080	L	2	
0035	RB-86 R A		0.2	0.005	10	0.090	L	2	
0036	RB-87 R A		0.2	0.005	10	0.035	L	2	
0037	RB-88 R A		0.2	L 0.005	12	0.015	L	2	
0038	RB-89 R A		0.2	0.010	11	0.015		4	
0039	RB-91 R A		0.2	0.005	26	0.015	L	2	
0040	RB-92 R A		0.2	0.040	137	0.035		7	
0041	RB-93 R A		0.2	0.035	123	0.035		4	
0042	RB-94 R A		0.2	0.005	23	0.015		2	

—End of Page 2 of 2—

BONDAR-CLEGG

Geochemical Lab Report

Date: WED AUG 31, 1983 Page: 1

REC#	SAMPLE NUMBER	T/S	AG/J1 PPR	AU/T1 PPR	AS/D2 PPR	HG/J1 PPR	SB/ J PPR
0001	R-B-1A R A		0.2	L 0.005	9	0.050	L 2
0002	R-B-3A R A		0.2	L 0.005	5	0.065	6
0003	R-B-4A R A		0.2	0.005	8	0.065	L 2
0004	R-B-5A R A		0.2	L 0.005	12	0.050	L 2
0005	R-B-6A R A		0.2	0.015	93	0.085	9
0006	R-B-20A R A		0.2	L 0.005	4	0.015	L 2
0007	R-B-21A R A		0.2	0.135	123	0.160	20
0008	R-B-25A R A		0.2	0.015	25	0.035	15
0009	R-B-26A R A		0.2	0.025	4	0.015	14
0010	R-B-27A R A		0.2	0.110	8	0.015	8
0011	R-B-29A R A		0.2	0.010	13	0.015	5
0012	R-B-30A R A		0.5	0.200	22	0.120	13
0013	R-B-33A R A		0.2	0.015	32	0.120	11
0014	R-B-34A R A		0.2	0.025	18	0.195	4
0015	QH-1 R A		0.4	0.125	79	0.065	51

—End of Page 1 of 1—

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Geochemical
Lab Report

Report: BC53-1811		Project:		Update: 1		Date: TUE OCT 25, 1983		Page: 1
REC#	SAMPLE NUMBER	/T/S	AG/J1 PPB	AU/T1 PPB	AS/D2 PPB	HG/J1 PPB	SB/ 9 PPB	
0001	RB-99 D I		0.2	0.015	15	0.100	5	
0002	RB-148 D I		0.2	L 0.005	26	0.100	10	
0003	RB-24 R A		0.8	0.030	60	0.080	26	
0004	RB-47 R A		2.1	0.510	220	0.090	8	
0005	RB-54 R A		0.2	0.005	29	0.070	L 2	
0006	RB-57 R A		0.2	0.035	39	0.130	16	
0007	RB-62 R A		0.2	0.020	14	0.350	13	
0008	RB-64 R A		0.2	0.005	12	0.710	3	
0009	RB-67 R A		0.2	0.010	39	0.140	22	
0010	RB-100 R A		0.2	0.020	34	0.200	L 2	
0011	RB-101 R A		0.4	0.155	77	0.200	29	
0012	RB-102 R A		0.2	0.015	43	0.480	10	
0013	RB-104 R A		0.2	L 0.005	78	0.440	9	
0014	RB-105 R A		0.2	0.020	23	0.200	7	
0015	RB-108 R A		0.2	0.025	75	0.080	12	
0016	RB-109 R A		0.2	0.005	39	0.050	34	
0017	RB-1108 R A		0.2	0.005	22	0.320	18	
0018	RB-112 R A		0.2	0.250	11	0.250	12	
0019	RB-115A R A		0.2	L 0.005	14	0.040	L 2	
0020	RB-119 R A		1.2	0.940	100	0.090	10	
0021	RB-120 R A		0.2	0.030	59	0.730	10	
0022	RB-121 R A		0.2	0.045	40	1.030	10	
0023	RB-122A R A		0.2	0.210	10	0.070	L 2	
0024	RB-131-2-3 COMPOSITE R A		0.2	0.045	7	0.090	15	
0025	RB-135 R A		0.2	0.190	24	0.180	4	
0026	RB-137 R A		1.3	0.040	197	0.670	41	
0027	RB-140 R A		0.2	0.005	12	0.220	10	
0028	RB-144 R A		0.2	0.005	4	0.120	11	
0029	RB-145 R A		0.2	0.005	5	0.070	11	
0030	RB-151 R A		0.2	0.010	9	0.070	4	
0031	RB-153 R A		0.2	L 0.005	5	0.080	3	
0032	RBT-1 R A		0.2	L 0.005	6	0.050	7	
0033	RBT-2 R A		0.2	L 0.005	5	0.100	3	
0034	RBT-3 R A		0.2	0.185	29	0.120	18	
0035	RBT-4 R A		0.2	0.005	26	0.230	L 2	
0036	RBT-5 R A		0.2	0.015	19	0.030	13	
0037	RBT-7 R A		0.2	0.055	78	0.030	15	
0038	RBT-9 R A		0.2	0.010	103	0.020	20	
0039	RBT-10 R A		0.2	0.015	29	0.060	6	
0040	RBT-16B R A		0.2	L 0.005	97	0.120	3	
0041	RBT-16D R A		0.2	L 0.005	41	0.170	L 2	
0042	1 UNKNOWN LIGHT RED R A		0.2	0.005	19	0.040	13	

—End of Page 2 of 2—

—End of Page 2 of 2—

APPENDIX C

X RAY DIFFRACTION TECHNIQUES

X-ray diffraction was used to determine the presence and types of clay minerals, and other minerals too fine grained to be identified optically. Sample preparation for clay mounts followed the procedure outlined below:

Calcium Carbonate Removal: The sample was placed in a 500 ml pyrex beaker and the beaker was filled with 0.1 N HCl. The sample was left in acid until effervescence ceased. Leachates were decanted, and the sample was washed with 0.1 N HCl. The sample was then rinsed twice with distilled water.

Clay Preparation, dispersion, and fractionation: 1) Samples were each placed in a 500 ml stainless steel beaker, using a 2% Na_2CO_3 solution for flushing. Four grams anhydrous Na_2CO_3 were added and the volume brought up to 200 ml with distilled water. Samples were boiled for 5 minutes while being agitated with a high speed rotary stirrer and then were transferred to centrifuge tubes, rinsed with 2% Na_2CO_3 solution, and centrifuged at high speed (2000 rpm) for 3 minutes. The supernatant liquid was decanted.

2) 200 ml dilute Na_2CO_3 was added to the residue, stirred with a rotary stirrer, and the sample was again centrifuged at 750 rpm for 5 minutes. This step brings down the silt fraction, leaving the -2 micron clay size fraction in suspension. The suspension was poured into a flask and saved.

3) Step 2 was repeated 3 times, saving the suspension each time, and the

final silt residue was discarded.

Saturation with Ca^{2+} : 1) The sample suspension from steps 2 and 3 was placed in a centrifuge tube; about 100 ml of 1 N CaCl_2 was added to fill the tube; and samples were stirred with a rotary stirrer for 5 minutes. Samples were centrifuged at high speed for 5 minutes, and the clear supernatant discarded.

2) Step 1 was repeated three times.

3) 100 ml distilled water was added, stirred with a rotary stirrer, centrifuged at 2000 rpm for 5 minutes, and the supernatant discarded.

4) Step 3 was repeated twice.

5) 100 ml methanol was added stirred with a rotary stirrer, centrifuged at high speed for 5 minutes, and the supernatant discarded.

6) Step 5 was repeated twice. Some samples continued to flocculate after up to 10 repetitions of steps 5 and 3. When these samples were re-suspended by saturation with Na_2CO_3 and centrifuged, they left no clay size fraction in suspension.

Mounting: The clay suspensions produced by the above techniques were mounted on porous tiles by drawing the clay suspension through the tiles using a vacuum pump.

Special Treatments: The following treatments were used on clay samples in order to elicit changes in the basal d-spacing that are diagnostic of specific clays:

1) Solvent saturation; clay tiles were saturated with ethylene glycol or DMSO by setting them overnight in a covered petri dish with several drops of the solvent in the bottom of the dish;

2) Heat treatment: after the first XRD scan, tiles were heated at 100°C ,

and 300°C for 1 hour. They were x-rayed between heating at different temperatures.

Identification: Table XVI summarizes the criteria that were used to identify the clays.

TABLE XVI
Generalized Identification Criteria
For Clays

Mineral	Basal Spacing, ; Treatments			
	Ca	Ca+Solv.	100°C	300°C
Kaolinite	7.0-7.2	7.0-7.2	7.0-7.2	7.0-7.2
Halloysite	7.2-7.3	7.2-7.3	7.2	7.2
Halloysite hydrated	10	10	7.2	7.2
Smectite	14-15	17-18	11-13	10-11
Illite or Mica	10	10	10	10
Vermiculite	14-14.5	14-14.5	10	10
Cholorite	14	14	14	14

Notes: Smectite peaks are generally broad with weak higher order reflectors.

Powder Mount preparation: Random powder mounts were made of 35 samples and these samples were X-rayed from 3° to 60° 2 θ . Powder mounts were prepared by grinding about 10 grams of the rock or mineral sample to -100 mesh with a steel mortar and pestle. The powdered sample was then placed in a plastic vial with about an equal volume of instant coffee, and stirred with a plastic stirring ball in an automatic stirrer for at least 3 minutes. The instant coffee is a

filling material which does not produce x-rays and packs well. The mixture of coffee and rock was then packed into an aluminum or plastic holder and x-rayed.