Appendix N:

Field Investigation Report- Hydrology Analysis (2009)

FIELD INVESTIGATION REPORT

HYDROLOGY ANALYSIS

3M REDDING HARD-ROCK AGGREGATE QUARRY
SHASTA COUNTY, CALIFORNIA

Prepared for

Resource Design Technology, Inc.

June 30, 2009

BROWN AND CALDWELL

10540 White Rock Road, Suite 180

Rancho Cordova, California 95670

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1. INTRODUCTION

This report presents the result of field activities conducted for the Hydrology Assessment at the proposed 3M Hard Rock Aggregate Quarry located in Shasta County, California (Figures 1 and 2). The objective of this study is to provide the hydrology data and analyses appropriate for the application package and subsequent review under the California Environmental Quality Act (CEQA). The proposed project is a greenfield quarry site in an area that has not been previously mined. The scope of work conducted for this project is as described in the May 5, 2009 proposal from Brown and Caldwell to Resource Design Technology and included completion of the following four tasks:

Task 1 – Review and compilation of readily available existing data

Task 2 – Drilling and well installation

Task 3 – Surface Water and Groundwater Sampling

Task 4 – Preparation of this report.

A detailed discussion of the methods and procedures used to complete each of these tasks is presented in Section 2.0. The results and summary of this testing are presented in Sections 3.0.

2. METHODS AND PROCEDURES

This section presents the methods and procedures used to complete the field activities for the hydrology assessment.

2.1 Review of Existing Data

The initial task for this project included obtaining and reviewing available records related to the overall geology and hydrogeology in the vicinity of the site. To develop this knowledge base for the project, the following information was obtained:

- Core logs for the site produced by 3M in 1980.
- The 1906 United States Geological Survey (USGS) geologic map for the Redding Quadrangle.
- Master Thesis by Fudge (2008) entitled *Evidence for Regional Extensional Faulting at Grey Rocks Ridge, Eastern Klamath Mountains, California*.
- USGS Open-File Report 91-595 discussing gold-bearing quartz veins in the Klamath Mountains.
- Paper by Potter et al (1990) entitled Early Paleozoic stratigraphic, paleoeographic, and biogeographic relations of the eastern Klamath belt, northern California.
- The 2008 aerial photo and topographic map produced by Pace Engineering for Resource Design Technology.

The findings of this review were used to focus the drilling and well installation described in Section 2.2. Copies of the 1980 core logs, 1906 USGS geologic map, Fudge (2008) Master Thesis, and USGS Open-File Report 91-595 are presented in Appendix A. The aerial photo and topographic map produced by Pace Engineering is shown on Figure 2.

As discussed in the May 5, 2009 proposal, the original scope anticipated looking at 4 aerial photographs in stereo sets. However, no readily available photos were found for the site.

2.2 Drilling of Boreholes and Installation of Monitoring Well

The locations of the new boreholes, designated B-1 through B-3, and new monitoring well, designated MW-1, are shown on Figure 2. The drilling of these boreholes was conducted by WDC Exploration of Zamora California using air-rotary methods. WDC Exploration is a C-57 California State licensed driller.

Following utility clearance, the drilling of the boreholes was conducted on April 28, 2009 through May 1, 2009. Initially, a 10-inch drilling bit was used for installation of a 20-foot conductor casing as required by the Shasta County Environmental Health Department (SCEHD) as part of the drilling permit. A 6-inch diameter steel conductor casing was then grouted into place with an approximate above ground stickup of 1 foot. After installation of this conductor casing, the pilot boring was drilled to total depth using a 6.625-inch diameter downhole button hammer bit. During drilling, rock samples were collected at 5-foot intervals or change in material type for lithologic logging. Samples were described by a California Professional Geologist using common rock nomenclature and recorded on a geologic boring log. Copies of the geologic boring logs for the four new boreholes are presented in Appendix B.

After drilling to total depth in each boring, a two-inch diameter PVC casing was installed to total depth. Well construction diagrams for each of these wells are presented in Appendix B and are summarized on Table 1.

2.3 Water Quality Sampling

Both surface water and groundwater samples were collected and analyzed to establish a baseline for CEQA analysis. The methods and procedures used for collection of these samples are discussed below.

2.3.1 Surface Water Sampling

Three surface water samples, designated SW-1 through SW-3, were collected on March 30, 2009 from drainages located to the east and west of the proposed quarry location at the approximate locations shown on Figure 2. Samples were collected as follows:

- Clean disposable tubing attached to a low flow pump was placed directly into the stream flow at each location.
- Approximately 3 tubing volumes were then pumped through the system.
- After purging, the sample containers supplied by the analytical laboratory were then directly filled from the discharge end of the tubing.

Samples collected for metals analysis were field filtered with a 0.45 micrometer inline filter prior to placement in the appropriate container. Prior to collection, field parameters including temperature, pH, oxidation-reduction potential (Eh), and specific conductance (also referred to as electrical conductivity, or EC) were measured in the field. The meter was calibrated prior to field use following the manufacturer's guidelines.

Each sample was submitted under chain-of-custody for analysis at a California State certified analytical laboratory, California Laboratory Services (CLS). CLS is located in Rancho Cordova, California. Samples collected were analyzed for the following parameters:

- Metals using EPA Methods 6010 B, 6020, and 7470;
- Alkalinity (total and as carbonate/bicarbonate) by Standard Test Method 2320B;

- General Water Chemistry: total dissolved solids (TDS) by Method 160.1, Specific Conductance by Method 150.1, pH by Method 160.1, and Anions (7) by EPA Methods; and
- Hardness by EPA Method 130.2

For water quality assurance/quality control (QA/QC) purposes, a duplicate sample was collected from SW-1 and submitted for the same analysis listed above. Copies of the field records of water sample forms, chain-of-custody forms, and the analytical laboratory reports are presented in Appendix C.

2.3.2 Groundwater Sampling

The first round of groundwater sampling was conducted on May 27, 2009. Based on information collected during drilling of the boreholes that indicated the recovery of water was slow into each boring with the exception of B-1, prior to collecting water samples, water level measurements were collected on May 26, 2009 to assess the potential for wells going dry during purging. Based on this information, well MW-1 was purged dry on May 26, 2009 using a submersible pump and allowed to recover overnight. The groundwater sample was then collected on May 27, 2009 with no additional purging. The water levels recorded for wells B-2 and B-3 indicated only a 1 to 2-foot water column in each well (see Table 1). As such, these groundwater samples were collected without purging of the well. Water samples collected from MW-1, B-2, and B-3 were collected using a clean disposable bailer. After collection, the water was placed into containers supplied by the analytical laboratory.

Prior to sampling well B-1, the well was purged a minimum of 3 well casing equivalents using a submersible pump. During purging, field parameters (pH, conductivity, Eh, and temperature) were monitored for stabilization. The sample for this well was collected from a clean disposable bailer, as was done with other borings, following a 15-minute recovery period and removal of the groundwater pump used in purging. Samples collected for metals analysis were field filtered with a 0.45 micrometer inline filter prior to placement in the appropriate container. Samples were submitted to CLS for the same parameters listed above for surface water samples.

For water quality assurance/quality control (QA/QC) purposes, a duplicate sample was collected from B-1 and submitted for the same analysis listed above. Copies of the field records of water sample forms, chain-of-custody forms, and the analytical laboratory reports are presented in Appendix C.

3. RESULTS

This section summarizes the results of the field investigation completed at the proposed 3M quarry. The analytical laboratory reports for this analysis are presented in Appendix C and summarized on Table 2a and 2b. A summary of the field measurements is provided on Table 2c.

3.1 Hydrogeology/Geology

As described by Potter et al (1990), the site lies within an area referred to as the eastern Klamath terrane of the eastern Klamath belt. Units within the eastern Klamath terrane include in ascending order the Copley Greenstone, Balaklala Rhyolite, and Kennett Formations. The 1906 USGS geologic map showing these formations in the vicinity of the site is included in Appendix A. The Copley Greenstone consists mainly of altered basaltic-andesitic flows, tuffs, and breccias and is estimated to be about 1,800 meters thick. It is overlain by the Balaklala Rhyolite along a contact that is locally gradational. This unit is mostly altered silicic flows, dikes, sills, tuffs, and breccias and is as much as 1,100 meters thick. The Kennett Formation depositionally overlies the Balaklala Rhyolite and consists of a lower part made up of volcaniclastic sandstone to mudstone and siliceous mudstone and siltstone and upper part made up of lenses of limestone inferred to have been deposited by sediment gravity flows. As discussed in the USGS Open-File Report 91-595 (Appendix A), precious metal deposits have been observed throughout this area. Figure 4 from this report shows the distribution of identified lode gold deposits.

In 1980, 3M conducted an extensive coring program at the proposed quarry site. A map showing the location of these core holes is included in Appendix A. Thirteen of these core logs were provided by 3M and are also included in Appendix A. As seen in these core logs, greenstone divided as "greenstone", "greenstone breccia, "conglomerate", and "weathered/broken" is the main rock type indentified and is most likely the Copley Greenstone Unit. The 1906 USGS map also indicates a unit in this area referred to as the Bass Mountain Diabase that would also consist of greenstone type material. A rhyolite unit was identified in one of the core logs provided (R-23-80) from an elevation of approximately 1,146 feet above mean sea level to 1,050 feet above mean sea level. It is not known if this unit is part of the Balaklala Rhyolite. The geologic boring logs produced for this investigation are consistent with the 1980 core logs with the exception that no rhyolite unit was identified. Pyrite mineralization was identified in the 1980 coreholes and boreholes completed for this investigation.

As discussed on Section 2.3.2, groundwater was encountered in each of the four boreholes drilled for this investigation. In two of the boreholes, B-2 and B-3, water was not observed in the boreholes up to 4 days after drilling. During the groundwater sampling event conducted

approximately 26 days after drilling, 1 to 2 feet of water was recorded in each of these wells. For well MW-1, water was not recorded immediately after drilling but was recorded the day after. Based on information collected during sampling of MW-1, it was estimated that the recharge rate was significantly less than 1 gallon per minute.

Borehole B-1 was observed during drilling and groundwater sampling to produce minor amounts of groundwater. The groundwater production rate was estimated at 1 to 2 gpm during drilling and was observed at less than 1 gpm during groundwater sampling purging operations. The groundwater purging operated at a flow rate of approximately 2 to 3 gpm and dewatered the well within 45 minutes.

3.2 Surface Water Sampling

The three surface water samples had similar water quality signatures and were all dominated by calcium-bicarbonate, as illustrated on Figures 3 and 5. Surface water samples SW-2 and SW-3 were collected on the east side of the ridge where the proposed quarry is located and had similar total dissolved solid values. SW-1 was located on the western side of the ridge and demonstrates total dissolved solid measurement of nearly twice that of SW-2 and SW-3. Metals detected in all three water samples included calcium, magnesium, and sodium (Table 2a). A single detection of barium at 22 ug/L was detected in SW-3. Other general minerals and anions detected in these samples include bicarbonate, chloride, and sulfate (Table 2b). The field parameters (Table 2c) were all consistent with natural surface water conditions with temperatures ranging from 12 to 14 °C, pH ranging from 6.99 to 7.65, and conductivity ranging from 145 to 200 uS/cm. Oxidation reduction potential measurements indicate a moderately oxidizing environment.

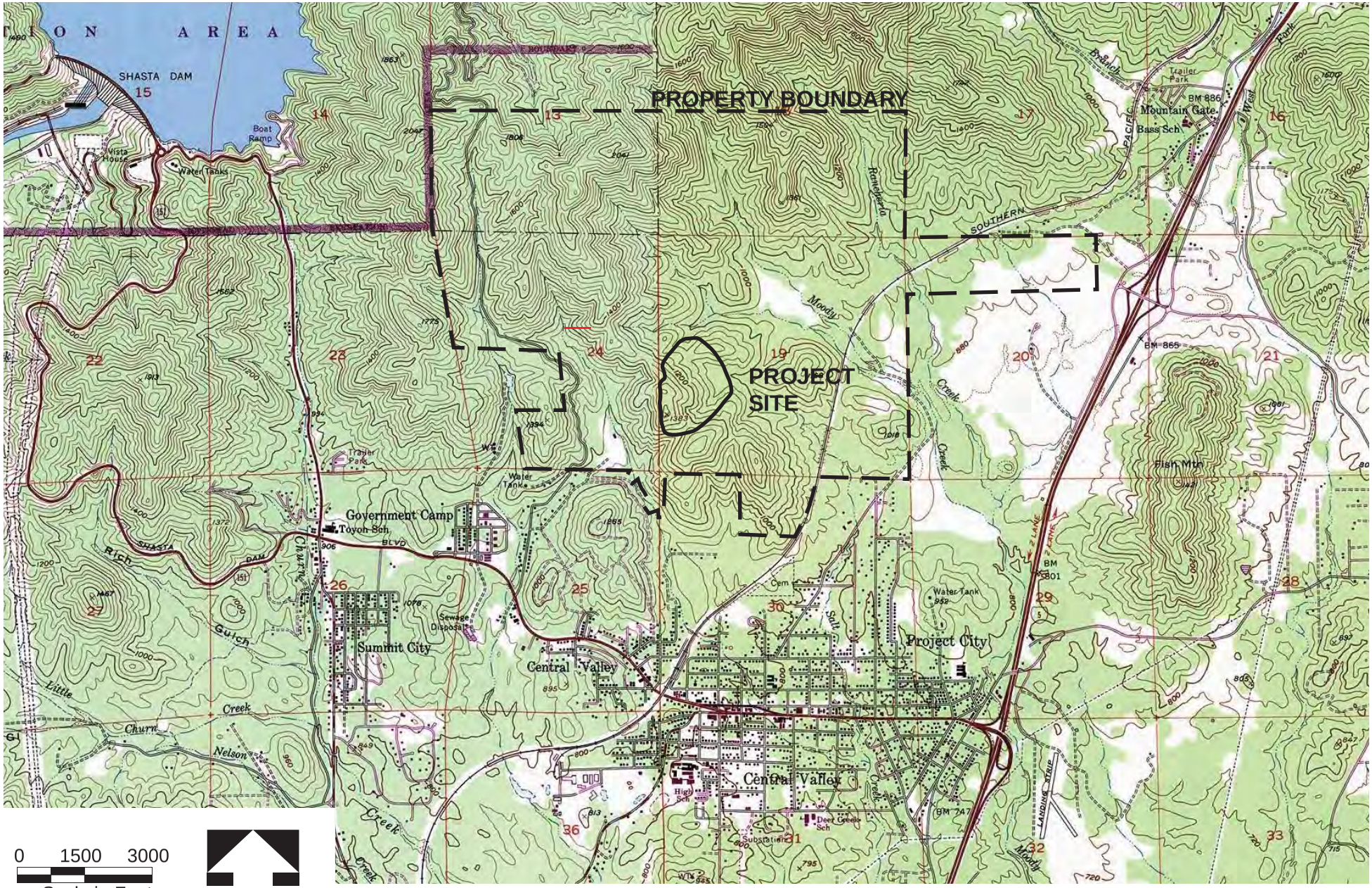
3.3 Groundwater Sampling

As indicated in Section 2.3.2, samples collected from borings B-2 and B-3 are highly suspect with respect to the nature of the water observed in the borehole. The lack of a significant water column and inability to recharge rapidly may suggest that this water is not necessarily representative of typical groundwater in the vicinity of the boreholes and should be used with caution. These water samples were analyzed to document the water quality of the water that was present for comparison purposes. Three of the four borings, B-1, B-2, and MW-1 demonstrate a calcium-bicarbonate water type, as illustrated on Figures 4 and 5. Water in borehole B-3 demonstrated a sodium-bicarbonate water type and may not be representative of typical groundwater.

Metals (Table 2a) detected in all four water samples included calcium, magnesium, manganese, and sodium. The sample from B-2 also had low detections, slightly above the detection limits, of barium and iron. The sample from B-3 also had low detections, slightly above the detection limits of antimony, arsenic, molybdenum, potassium, and vanadium. Other general minerals and anions detected in these samples (Table 2b) include bicarbonate, chloride, and sulfate. The sample from B-3 also contained low detections, slightly above the detection limit of ammonium and fluoride. The field parameters (Table 2c) for the groundwater samples had temperatures ranging from 17 to 23 °C, pH ranging from 7.74 to 8.29, and conductivity ranging from 210 to 650 uS/cm. Oxidation

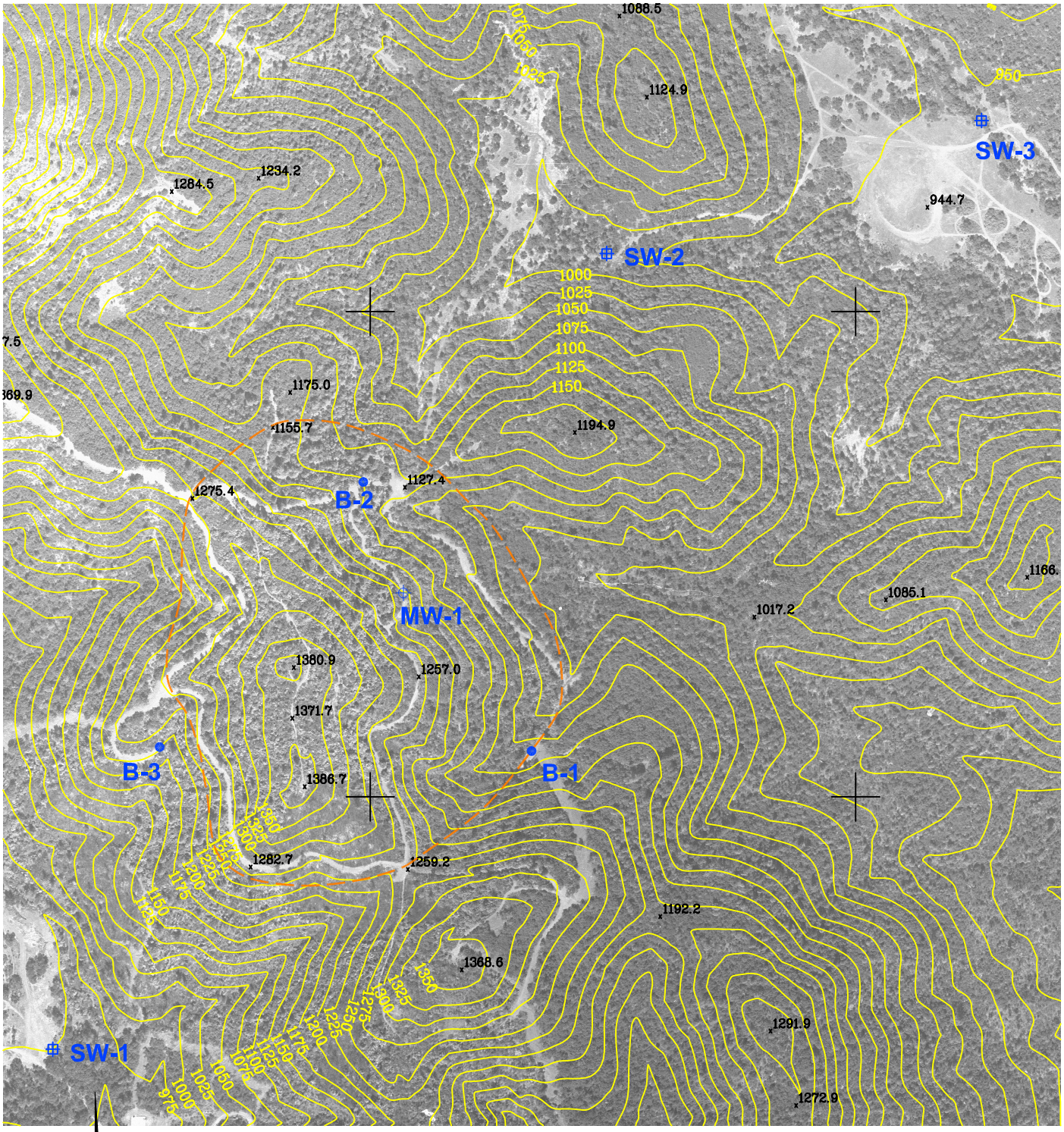
reduction potential measurements indicate both slightly oxidizing and slightly reducing environments.

FIGURES



Source: National Geographic TOPO!

BROWN AND CALDWELL	DATE 6-30-09 PROJECT 137108-003	3M Quarry, Shasta, California Site Location Map	FIGURE 1



Surface Water Sampling Location

Monitoring well Location

Boring Location

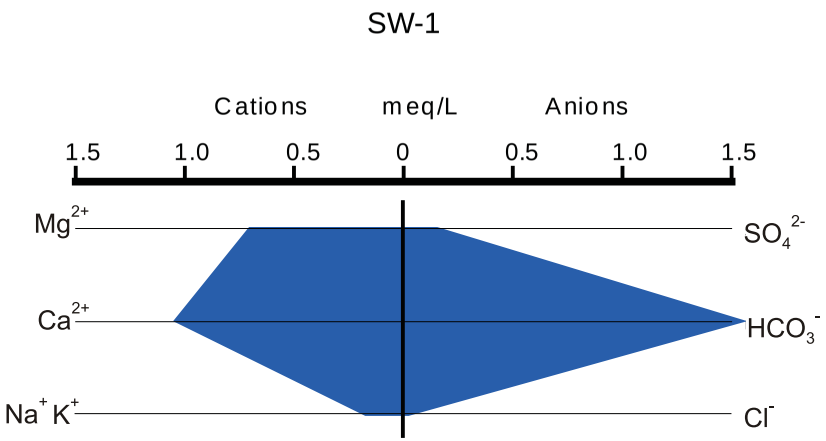
Proposed Quarry Boundary

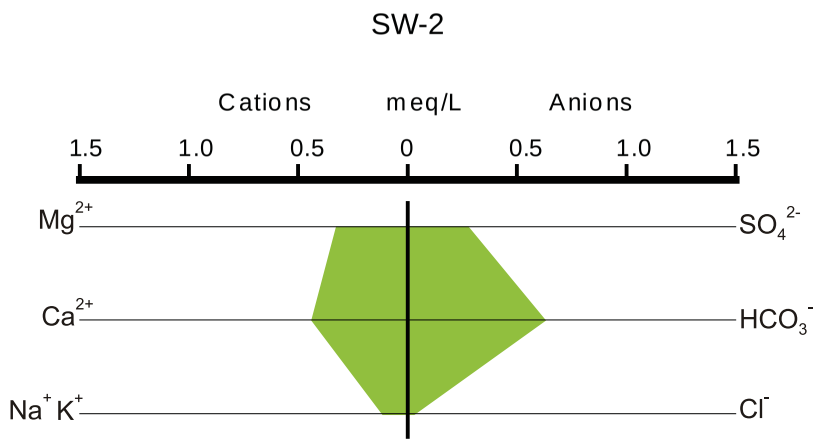
0 300 600

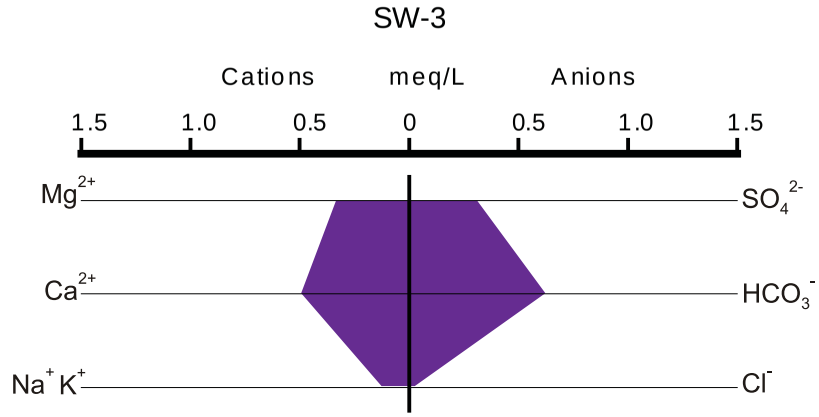
SCALE IN FEET

BROWN AND CALDWELL	DATE 6-30-09 PROJECT 137108-003	3M Quarry, Shasta, California Sampling Locations	FIGURE 2

Path: P:\37000\137108 - 3M Redding Hard Rock Qua Filename: Fig2-SamplLocs Plot date: Jun 30, 2009-09:25:35am CAD User: jrogers Xref Filename:







Legend

Ca^{2+}	Calcium
Mg^{2+}	Magnesium
Na^{+}	Sodium
K^{+}	Potassium
Cl^{-}	Chloride
SO_4^{2-}	Sulfate
HCO_3^{-}	Bicarbonate
NO_3^{-}	Nitrate
meq/L	milliequivalents per liter

BROWN AND CALDWELL

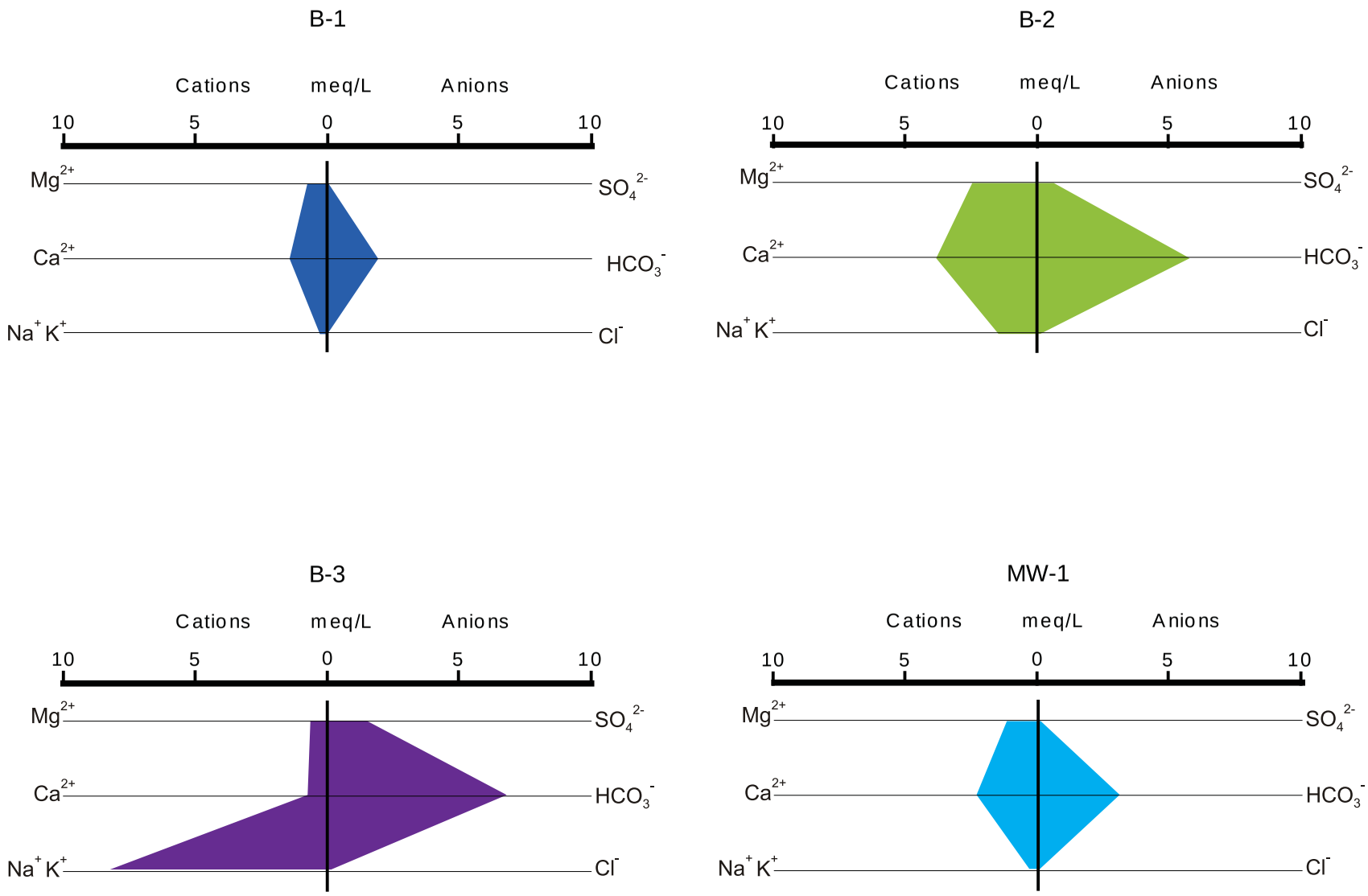
DATE 6-30-09

PROJECT 137108-003

3M Quarry, Shasta, California

Stiff Diagrams for Surface Water Samples - March 30, 2009

FIGURE 3



Legend

Ca^{2+}	Calcium
Mg^{2+}	Magnesium
Na^{+}	Sodium
K^{+}	Potassium
Cl^{-}	Chloride
SO_4^{2-}	Sulfate
HCO_3^{-}	Bicarbonate
NO_3^{-}	Nitrate
meq/L	milliequivalents per liter

BROWN AND CALDWELL

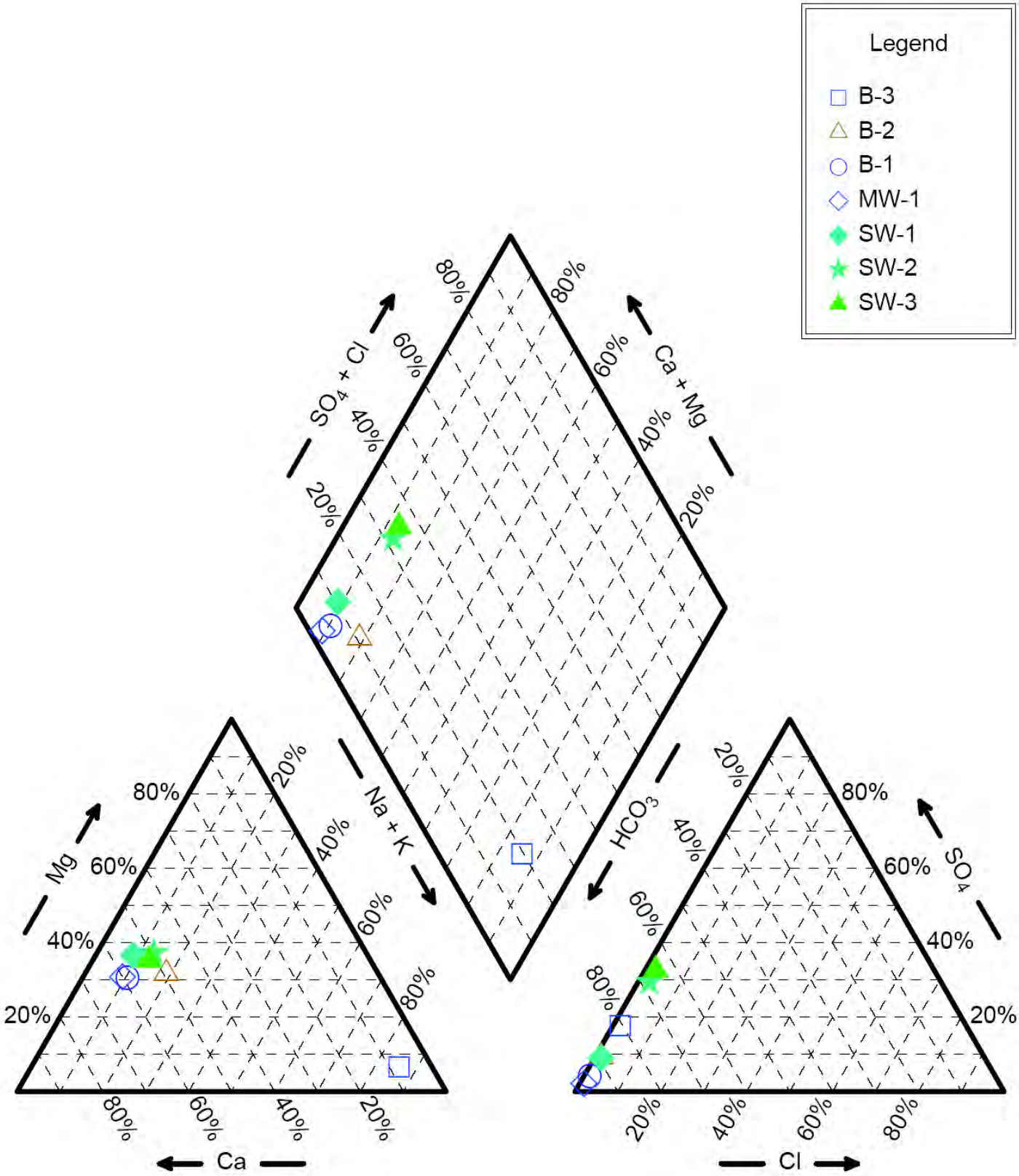
DATE 6-30-09

PROJECT 137108-003

3M Quarry, Shasta, California

Stiff Diagrams for Groundwater Samples - May 27, 2009

FIGURE 4



BROWN AND CALDWELL	DATE 6-30-09 PROJECT 137108-003	3M Quarry, Shasta, California Piper Diagram for Water Samples from Proposed Moody Creek Quarry Vicinity	FIGURE 5

P:\37000\137108 - 3M Redding Hard Rock Quarry\Assessment Report\Figures

TABLES

Table 1. Summary of Well Construction Details
Proposed Moody Creek Quarry, Shasta County, California

Location Name	*Sample Date*	*Total Depth (ft)*	*Conductor Interval (ft. msl)*	*Open Interval (ft. msl)*	*Screen Length (ft)*	*Depth To Water (ft)*	*Height of water in Well (ft)*	*Estimated Surface Elevation (ft. msl)*	*Estimated Water Surface Elevation (ft. msl)*	*Notes*
B-1	5/27/2009	49.80	1115 - 1095	1095 - 1065	20	17.95	31.85	1115	1097.05	~1 gpm reacharge rate
B-2	5/27/2009	49.95	1150 - 1130	1130 - 1100	20	48.03	1.92	1150	1101.97	Water likely condensate
B-3	5/27/2009	49.90	1200 - 1180	1180 - 1150	20	48.82	1.08	1200	1151.18	Water likely condensate
MW-1	5/26/2009	99.70	1200 - 1180	1180 - 1100	20	22.86	76.84	1200	1177.14	<1 gpm recharge rate

Note:
ft = Feet
ft. msl = Feet above mean sea level
gpm = gallons per minute

Table 2a. Summary of Analytical Results - Metals
Proposed Moody Creek Quarry, Shasta County, California

Water Type	*Location Name*	*Sample Date*	*Aluminum (µg/L)*	*Antimony (µg/L)*	*Arsenic (µg/L)*	*Barium (µg/L)*	*Beryllium (µg/L)*	*Cadmium (µg/L)*	*Calcium (µg/L)*	*Chromium (µg/L)*	*Cobalt (µg/L)*	*Copper (µg/L)*	*Iron (µg/L)*	*Lead (µg/L)*	*Magnesium (µg/L)*	*Manganese (µg/L)*	*Mercury (µg/L)*	*Molybdenum (µg/L)*	*Nickel (µg/L)*	*Potassium (µg/L)*	*Selenium (µg/L)*	*Silver (µg/L)*	*Sodium (µg/L)*	*Thallium (µg/L)*	*Vanadium (µg/L)*	*Zinc (µg/L)*
Surface Water	SW-1	3/30/2009	<50	<6.0	<5.0	<20	<5.0	<10	**21000**	<10	<20	<10	<100	<5.0	**8300**	<20	<0.20	<20	<20	<1000	<5.0	<10	**3900**	<1.0	<20	<20
	SW-1 Dup	3/30/2009	<50	<6.0	<5.0	<20	<5.0	<10	**21000**	<10	<20	<10	<100	<5.0	**8500**	<20	<0.20	<20	<20	<1000	<5.0	<10	**3900**	<1.0	<20	<20
	SW-2	3/30/2009	<50	<6.0	<5.0	<20	<5.0	<10	**9000**	<10	<20	<10	<100	<5.0	**4100**	<20	<0.20	<20	<20	<1000	<5.0	<10	**2800**	<1.0	<20	<20
	SW-3	3/30/2009	<50	<6.0	<5.0	**22**	<5.0	<10	**9900**	<10	<20	<10	<100	<5.0	**4100**	<20	<0.20	<20	<20	<1000	<5.0	<10	**2900**	<1.0	<20	<20
Ground-Water	B-1	5/27/2009	<50	<5.0	<5.0	<20	<5.0	<10	**28000**	<10	<20	<10	<100	<5.0	**8800**	**31**	<0.20	<20	<20	<1000	<5.0	<10	**5700**	<1.0	<5.0	<20
	B-1 (Dup-1)	5/27/2009	<50	<5.0	<5.0	<20	<5.0	<10	**30000**	<10	<20	<10	<100	<5.0	**9100**	**26**	<0.20	<20	<20	<1000	<5.0	<10	**5800**	<1.0	<5.0	<20
	B-2	5/27/2009	<50	<5.0	<5.0	**38**	<5.0	<10	**77000**	<10	<20	<10	**150**	<5.0	**30000**	**150**	<0.20	<20	<20	<1000	<5.0	<10	**34000**	<1.0	<5.0	<20
	B-3	5/27/2009	<50	**8.1**	**6.2**	<20	<5.0	<10	**15000**	<10	<20	<10	<100	<5.0	**7700**	**25**	<0.20	**35**	<20	**1900**	<5.0	<10	**190000**	<1.0	**7.0**	<20
	MW-1	5/27/2009	<50	<5.0	<5.0	<20	<5.0	<10	**48000**	<10	<20	<10	<100	<5.0	**15000**	**81**	<0.20	<20	<20	<1000	<5.0	<10	**8500**	<1.0	<5.0	<20

Note:
µg/L = micrograms per liter

Table 2b: Summary of Analytical Results - Non-Metals
Proposed Moody Creek Quarry, Shasta County, California

Water Type	*Location Name*	*Sample Date*	*Alkalinity, Bicarbonate as CACO3 (mg/L)*	*Alkalinity, Carbonate as CACO3 (mg/L)*	*Alkalinity, Hydroxide as CACO3 (mg/L)*	*Alkalinity, Total as CACO3 (mg/L)*	*Ammonia as Nitrogen, Total (mg/L)*	*Bromide (mg/L)*	*Chloride (mg/L)*	*Electrical Conductivity (µmhos/cm)*	*Flouride (mg/L)*	*Hardness as CACO3 (mg/L)*	*Nitrate as N (mg/L)*	*Nitrite as N (mg/L)*	*Sulfate (mg/L)*	*Total Dissolved Solids (mg/L)*
Surface Water	SW-1	3/30/2009	**96**	<5.0	<5.0	**96**	<0.10	<0.10	**1.0**	**200**	<0.10	**88**	<0.50	<0.10	**7.6**	**130**
	SW-1 Dup	3/30/2009	**97**	<5.0	<5.0	**97**	<0.10	<0.10	**1.0**	**200**	<0.10	**87**	<0.50	<0.10	**7.6**	**130**
	SW-2	3/30/2009	**38**	<5.0	<5.0	**38**	<0.10	<0.10	**0.82**	**100**	<0.10	**40**	<0.50	<0.10	**13**	**65**
	SW-3	3/30/2009	**38**	<5.0	<5.0	**38**	<0.10	<0.10	**0.83**	**110**	<0.10	**42**	<0.50	<0.10	**15**	**75**
Ground-Water	B-1	5/27/2009	**120**	<5.0	<5.0	**120**	<0.10	<0.10	**1.1**	**230**	<0.10	**100**	<0.50	<0.10	**4.1**	**140**
	B-1 (Dup-1)	5/27/2009	**110**	<5.0	<5.0	**110**	<0.10	<0.10	**1.1**	**230**	<0.10	**100**	<0.50	<0.10	**4.1**	**140**
	B-2	5/27/2009	**350**	<5.0	<5.0	**350**	<0.10	<0.10	**3.4**	**710**	<0.10	**310**	<0.50	<0.10	**29**	**440**
	B-3	5/27/2009	**420**	<5.0	<5.0	**420**	**0.14**	<0.10	**5.4**	**910**	**0.18**	**43**	<0.50	<0.10	**73**	**700**
	MW-1	5/27/2009	**190**	<5.0	<5.0	**190**	<0.10	<0.10	**1.2**	**370**	<0.10	**180**	<0.50	<0.10	**3.3**	**210**

Note:
mg/L = milligrams per liter
µmhos/cm = micromhos per centimeter

Table 2c. Summary of Field Water Quality Measurements
Proposed Moody Creek Quarry, Shasta County, California

Water Type	*Location Name*	*Sample Date*	*Temperature (°C)*	*Conductivity (uS/cm)*	*pH (pH units)*	*Oxidation Reduction Potential (mV)*
Surface Water	SW-1	3/30/2009	14.24	149	7.65	69
	SW-2	3/30/2009	14.62	200	7	95
	SW-3	3/30/2009	12.9	145	6.99	100
Ground-Water	B-1	5/27/2009	17.8	210	8.14	-42
	B-2	5/27/2009	18.7	650	7.74	4
	B-3	5/27/2009	22.5	573.8	8.29	-30
	MW-1	5/27/2009	18.6	351	6.19	40

Notes:
°C = Degrees Celcius
uS/cm = Microseimens per centimeter
mV = millivolts

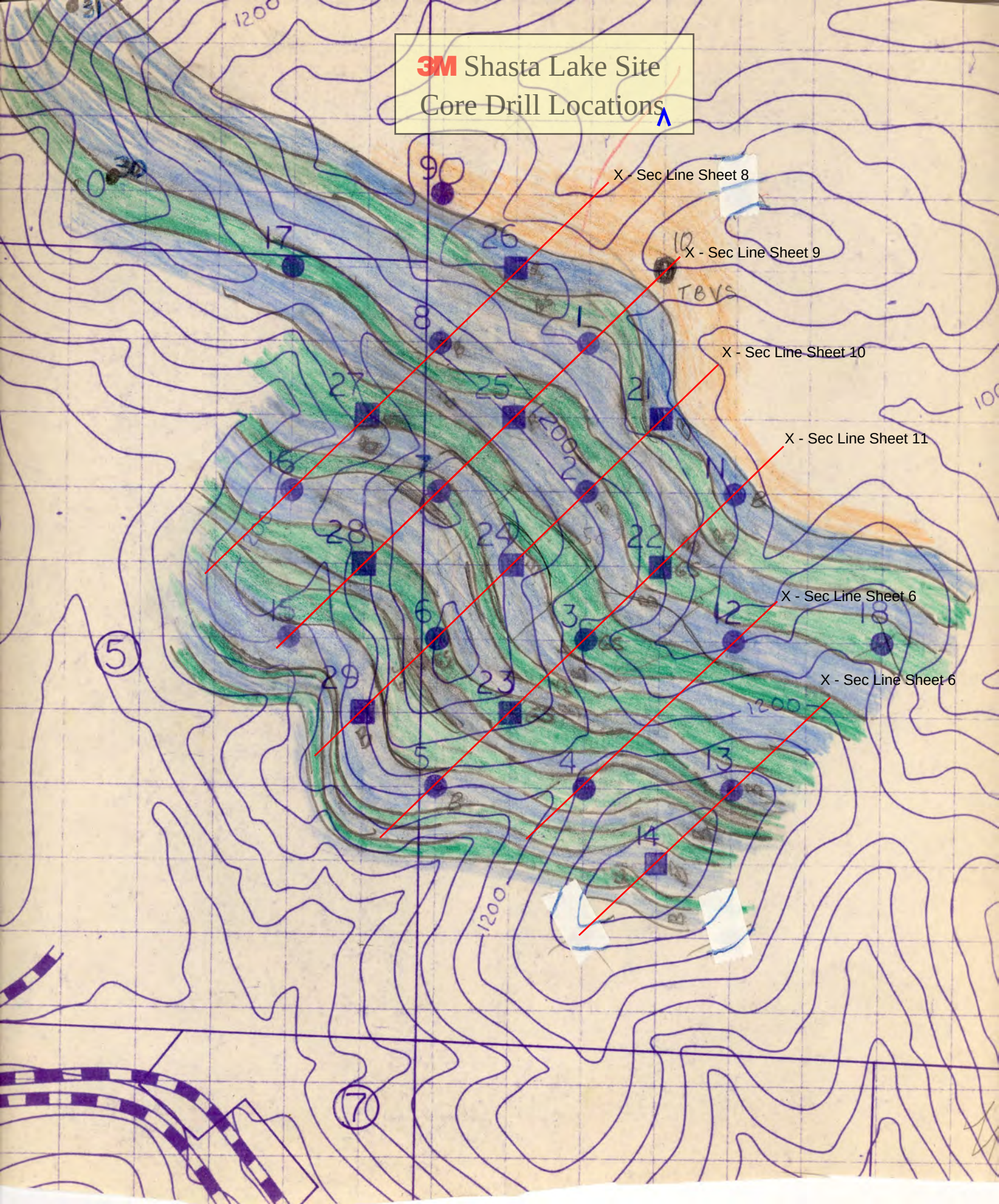
Appendix A

Previous Reports and Investigations

- Core logs for the site produced by 3M in 1980.
- The 1906 United States Geological Survey (USGS) geologic map for the Redding Quadrangle.
- Master Thesis by Fudge (2008) entitled *Evidence for Regional Extensional Faulting at Grey Rocks Ridge, Eastern Klamath Mountains, California*.
- USGS Open-File Report 91-595 discussing gold-bearing quartz veins in the Klamath Mountains.

- Core logs for the site produced by 3M in 1980.

3M Shasta Lake Site
Core Drill Locations



3M Geology

DESCRIPTION

1114.6'

0

1100 #5 Lift

0' - 40' - Overburden - Weathered residual soil, clay and rock rubble

20

34' - 36' - Wea GS Boulder

40' - First Core

40

GS Breccia - Spheroidal, Irregular Qtz and Hornblend Fillled Vesicles in GS Breccia. Strong Qtz Veining

60

1050 #6 Lift

Smaller Rounded Clasts Minor to Mod Pyrite

Ovuloids of Qtz ~2-10mm in Coarse Volc Breccia

80

Strong Pyr. in Gray Clasts ~85Ft.

Massive, Brecciated GS with minor spotty Pyrite

100

Very Broken Core of Brecciated GS at 110Ft.

1000 #7 Lift

120

Broken Core GS breccia

140

GS breccia - minor qtz veining in competent core fm 138'-158'

4" qtz vein in broken GS breccia core @ 158'

160

950

165' BOH

City	Shasta Lake
State	CA
Hole No.	R-1-80
Loc. N	498750
Loc. E	1896750
Collar El	1114.6
Core Size	BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	2/12/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Weathered

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION

1237.7'

0

0' - 45' - Overburden - Weathered residual soil, clay and rock rubble

20

1200 #3 Lift

40

45' - First Core - 45' - 47' Very Fractured

GS Breccia -
51' - 52' - Spheroidal, Irregular Qtz Inclusions in GS
57' - 59' - Irregular Qtz Inclusions in GS Breccia

60

80

1150 #4 Lift

88' - 97' - GS Breccia, moderate alteration, dense, very fine xtln, minor qtz veining

100

GS Breccia, moderate alteration, dense, very fine xtln, minor qtz veining

120

130' - 6" vein of white qtz in GS Breccia
132'-135' - Broken Core of Brecciated GS
135'-138' - Change to gry-grn, dense GS, minor pyrite

1100 #5 Lift

140

Pyrite noted at 158'

160

2" qtz vein in broken GS breccia core @ 161'
Broken and Fractured Core at intervals 175'-183' and 194'-199'

180

1050 #6 Lift

200

City	Shasta Lake
State	CA
Hole No.	R-2-80
Loc. N	498250
Loc. E	1896750
Collar El	1237.7
Core Size	BX
Logged By	CEN
Date	2/80
Drilled By	Boyles
Drill Date	2/20/80

Vertical Scale
1 in. = 20 ft.

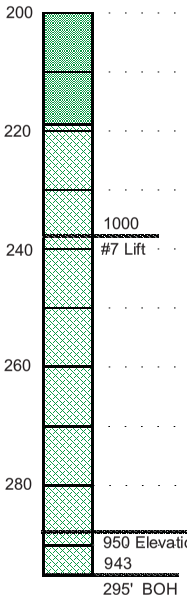
Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

DESCRIPTION



219' - Change to GS Breccia, moderate alteration, dense, very fine xtln, minor qtz veining, minor pyrite.

GS Breccia, moderate alteration, dense, very fine xtln, minor qtz veining, minor

3M Geology

City	Shasta Lake
State	CA
Hole No.	R-2-80
Loc. N	498250
Loc. E	1896750
Collar El	1237.7
Core Size	BX
Logged By	CEN
Date	2/80
Drilled By	Boyles
Drill Date	2/20/80

Vertical Scale
1 in. = 20 ft.

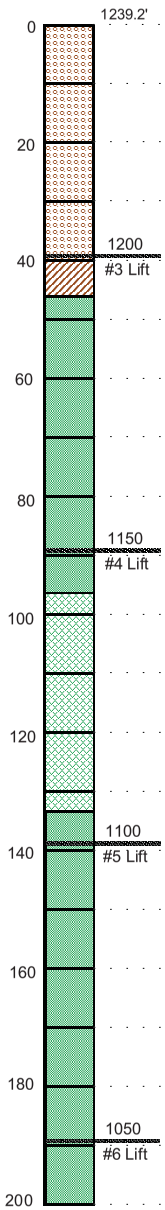
Rock Type-Discription Legend:

- Risiduum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Gm-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

DESCRIPTION



0' - 40' - Overburden - Weathered, residual soil, clay and rock rubble

40' - 46' - First Core - 40' - 46' Fractured Wea Core

Dense, very fine xtln, gry-grn GS. Moderate Pyrite grading to minor level at 85'. Minor to moderate qtz veining.

96' - GS Breccia, moderate alteration, dense, very fine xtln, minor qtz veining, minor pyrite

133' - Change to Gry-grn Greenstone with occasional narrow veins <1/2" of white qtz.

GS, gry-grn, dense, minor pyrite, minor qtz veining.

Occasional variable sized breccia 0.5-2" inclusions in GS.

Broken and Fractured Core at intervals 174'-184' and 189'-202'

3M Geology

City	Shasta Lake
State	CA
Hole No.	R-3-80
Loc. N	497750
Loc. E	1896750
Collar El	1239.2
Core Size	BX
Logged By	CEN
Date	2/80
Drilled By	Boyles
Drill Date	2/24/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

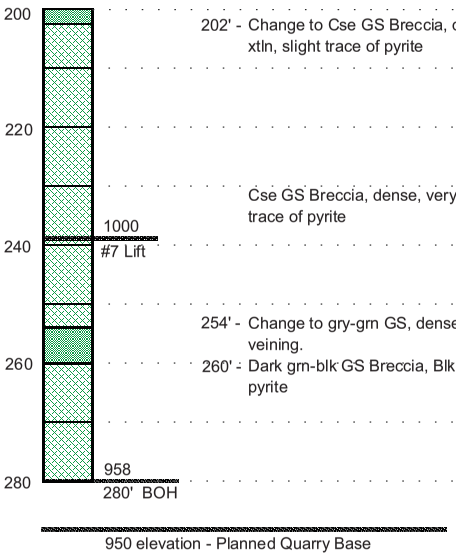
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



202' - Change to Cse GS Breccia, dense, very fine xtln, slight trace of pyrite

Cse GS Breccia, dense, very fine xtln, slight trace of pyrite

254' - Change to gry-grn GS, dense, minor pyrite, qtz veining.

260' - Dark grn-blk GS Breccia, Blk qtz veining, minor pyrite

City	Shasta Lake
State	CA
Hole No.	R-3-80
Loc. N	497750
Loc. E	1896750
Collar El	1239.2
Core Size	BX
Logged By	CEN
Date	2/80
Drilled By	Boyles
Drill Date	2/24/80

Vertical Scale
1 in. = 20 ft.

Rock Type-
Discription Legend:

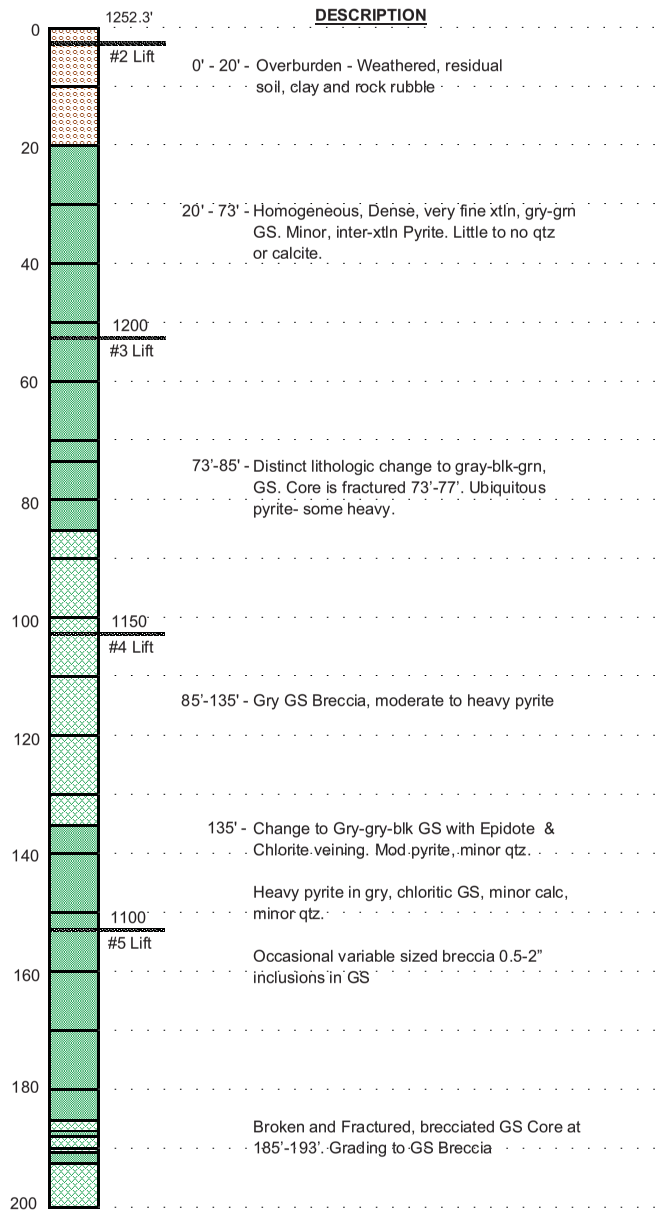
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



0' - 20' - Overburden - Weathered, residual soil, clay and rock rubble

20' - 73' - Homogeneous, Dense, very fine xtln, gry-grn GS. Minor, inter-xtln Pyrite. Little to no qtz or calcite.

73'-85' - Distinct lithologic change to gray-blk-grn, GS. Core is fractured 73'-77'. Ubiquitous pyrite- some heavy.

85'-135' - Gry GS Breccia, moderate to heavy pyrite

135' - Change to Gry-gry-blk GS with Epidote & Chlorite veining. Mod pyrite, minor qtz.

Heavy pyrite in gry, chloritic GS, minor calc, minor qtz.

Occasional variable sized breccia 0.5-2" inclusions in GS

Broken and Fractured, brecciated GS Core at 185'-193'. Grading to GS Breccia

City	Shasta Lake
State	CA
Hole No.	R-4-80
Loc. N	497250
Loc. E	1896750
Collar El	1252.3
Core Size	NX-BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	3/5/80

Vertical Scale
1 in. = 20 ft.

Rock Type-
Discription Legend:

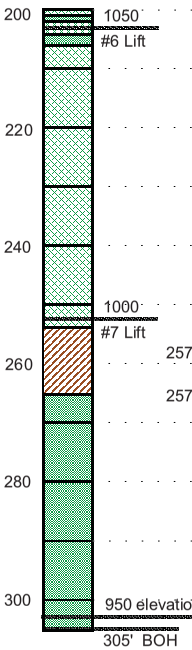
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



Cse GS Breccia, dense, very fine xtln, slight trace of pyrite

Gry-grn GS Breccia, heavy pyrite.

Gry-grn GS Breccia, mod to heavy pyrite

Gry, Pyritic, Calcitic, GS Breccia,

257'-265' - Broken, very fractured core at contact

257'-265' - Distinct Lithologic Change to Grn, Homogeneous, fine xtln, GS with minor pyrite and calcite. No Breccia.

950 elevation - Planned Quarry Base

City	Shasta Lake
State	CA
Hole No.	R-4-80
Loc. N	497250
Loc. E	1896750
Collar El	1252.3
Core Size	NX-BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	3/5/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

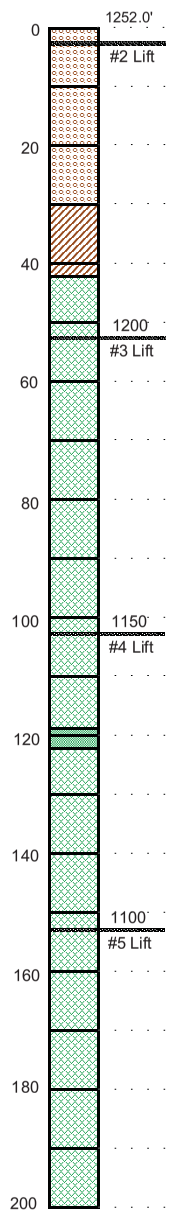
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



0' - 30' - Overburden - Weathered, residual soil, clay and rock rubble

30' - 42' - Brkn, Wea, GS Breccia, soft.

42'-119' - Gry GS Breccia, moderate to heavy pyrite

119'-122' - Gry-grn, very fine xtln, dense GS with slight pyrite.

Broken and Fractured, brecciated GS Core from 198'-244' with trace of visible pyrite

City	Shasta Lake
State	CA
Hole No.	R-5-80
Loc. N	497250
Loc. E	1896250
Collar El	1252.0
Core Size	NX-BX
Logged By	BWK-CEN
Date	2/80
Drilled By	Boyles
Drill Date	2/14/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

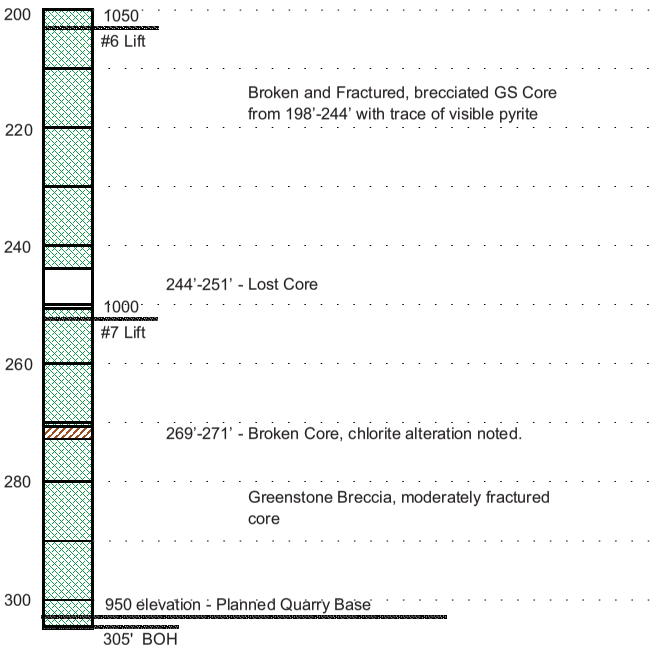
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



City	Shasta Lake
State	CA
Hole No.	R-5-80
Loc. N	497250
Loc. E	1896250
Collar El	1252.0
Core Size	BX
Logged By	BWK-CEN
Date	2/80
Drilled By	Boyles
Drill Date	2/14/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

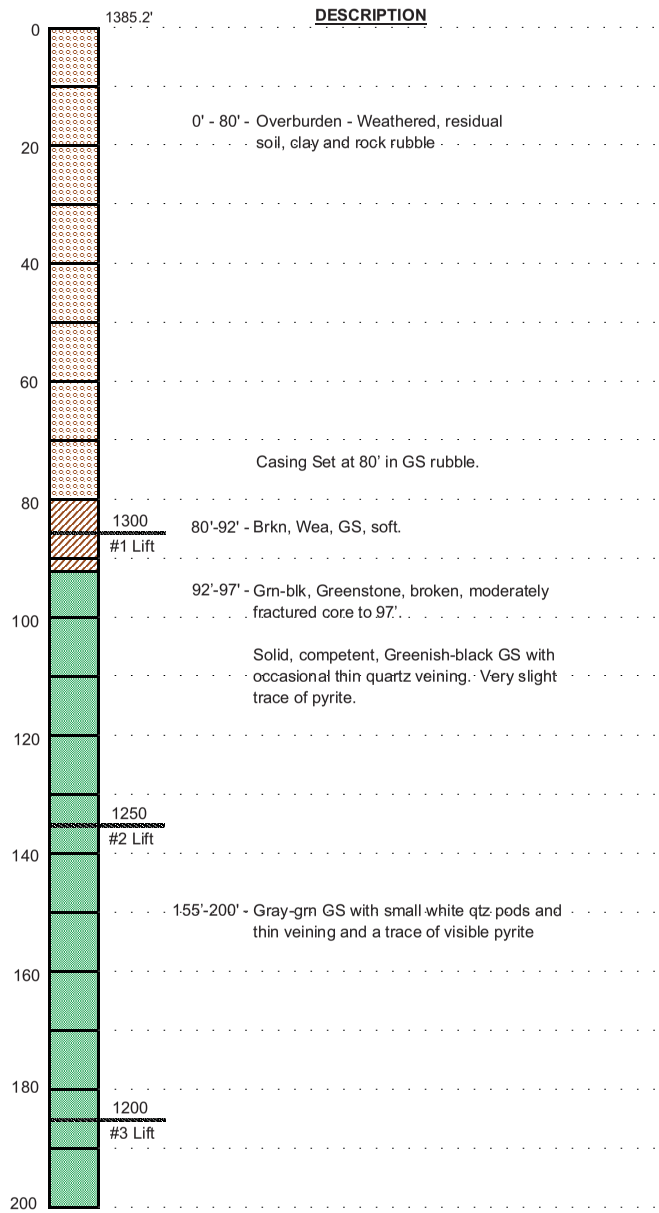
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



City	Shasta Lake
State	CA
Hole No.	R-6-80
Loc. N	497673
Loc. E	1896338
Collar El	1385.2
Core Size	BX
Logged By	CEN
Date	2/80
Drilled By	Boyles
Drill Date	1/25/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

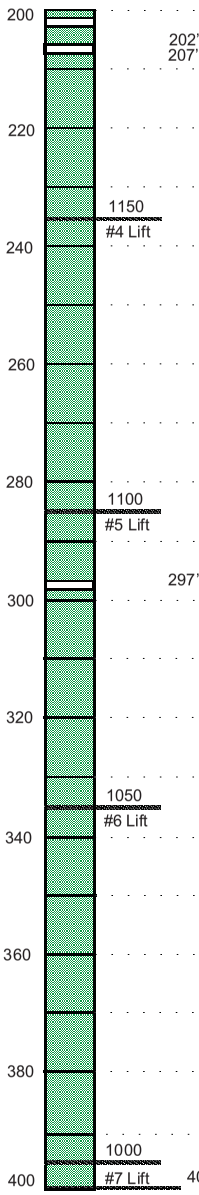
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



202'-203' - 12" thick white qtz veining
207'-208' -

Dense, gry-grn GS Core with secondary qtz as pods and void fillings. Slight trace of visible pyrite on fractures.

297'-298' - 12" thick whte qtz in homogenous, gry-grn GS

400' BOH

City	Shasta Lake
State	CA
Hole No.	R-6-80
Loc. N	497673
Loc. E	1896338
Collar El	1385.2
Core Size	BX
Logged By	CEN
Date	2/80
Drilled By	Boyles
Drill Date	1/25/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

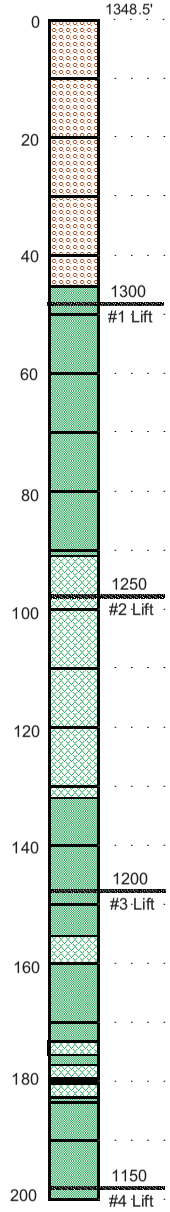
- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



0' - 45' - Overburden - Weathered, residual soil, clay and rock rubble.

45' - 91' - Gry-grn GS with minor qtz veining, slight visible pyrite

91'-132' - Gry-grn GS Breccia.

2" vein of qtz in gry-grn GS Breccia at 125'

Gry-grn GS with occasional thin (<1") qtz veins and vesicle fillings

155'-160' - Gray-grn GS Breccia

173'-183' - Interlayered,GS and GS Breccia

Gry-grn GS

Change at 200' to GS Breccia

City	Shasta Lake
State	CA
Hole No.	R-7-80
Loc. N	498250
Loc. E	1896250
Collar El	1348.5
Core Size	NX-BX
Logged By	CEN-BWK
Date	2/80
Drilled By	Boyles
Drill Date	1/28/80-2/6/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION

200
220
240
260
280
300
320
340
360
380
400

Dense, gry-grn GS Breccia, minor foliation present (foliation plane at 60d to core). Secondary qtz as pods and void fillings. Visible pyrite on fractures.

1100
#5 Lift

Vesicular, qtz filled GS and GS Breccia with 1" max dia. breccia clasts. Qtz at 2-6%.

1050
#6 Lift

316'-318' - Very Broken GS Breccia, soft - leached.

Thin, Andesitic Tuff Unit at ~ 330'

GS Breccia/conglomerate with very minor calcopyrite, pyrite. Most sulfides associated with gray, rhyolitic clasts and on fractures.

1000
#7 Lift

354' - Very Broken, wea core

382'-396' - Very Broken GS Breccia, soft - leached. Little to no complete core.

950 Planned Base of Quarry

City	Shasta Lake
State	CA
Hole No.	R-7-80
Loc. N	498250
Loc. E	1896250
Collar El	1348.5
Core Size	NX-BX
Logged By	CEN-BWK
Date	2/80
Drilled By	Boyles
Drill Date	1/28/80-2/6/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION

400
420
440

407'-415' - Soft, Brkn, Leached GS Breccia

Hard, GS Breccia, some fractured core.

Soft, Brkn, Leached zone at BOH

450' BOH

City	Shasta Lake
State	CA
Hole No.	R-7-80
Loc. N	498250
Loc. E	1896250
Collar El	1348.5
Core Size	NX-BX
Logged By	CEN-BWK
Date	2/80
Drilled By	Boyles
Drill Date	1/28/80-2/6/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
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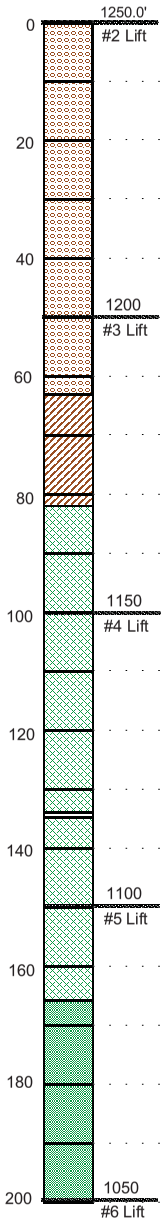
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology



DESCRIPTION

0' - 63' - Overburden - Weathered, residual soil, clay and rock rubble

63'-82' - Very broken, weathered core - Fractures are all oxidized; vesicles are weathered out with some qtz remaining.

Soft gray moderately leached GS Breccia to 90'.

Minor oxidation on fractures in generally hard, competent GS Breccia. Periodic zones of visible pyrite

6" vein of white qtz @ 135'.

166' - Chg to hard massive homogeneous, dk grn, andesitic tuff (GS). Moderate to heavy inter-granular pyrite.

City	Shasta Lake
State	CA
Hole No.	R-8-80
Loc. N	498750
Loc. E	1896250
Collar El	1250.0
Core Size	BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	2/9/80

Vertical Scale
1 in. = 20 ft.

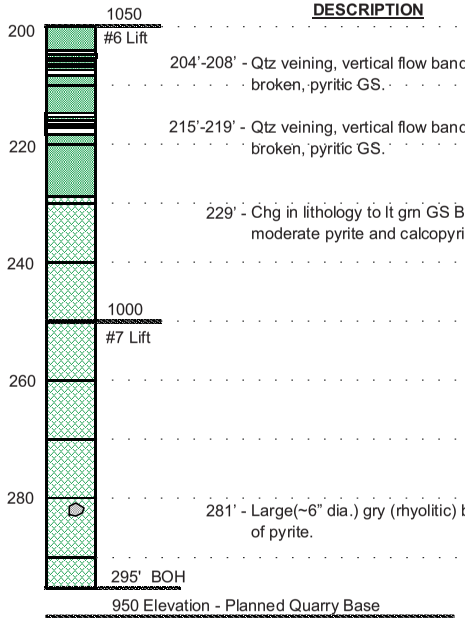
Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology



DESCRIPTION

204'-208' - Qtz veining, vertical flow banding, very broken, pyritic GS.

215'-219' - Qtz veining, vertical flow banding, very broken, pyritic GS.

229' - Chg in lithology to lt grn GS Breccia. Minor to moderate pyrite and calcopyrite.

281' - Large(~6" dia.) gry (rhyolitic) breccia block full of pyrite.

City	Shasta Lake
State	CA
Hole No.	R-8-80
Loc. N	498750
Loc. E	1896250
Collar El	1250.0
Core Size	BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	2/9/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION

1098.4'

0' - 30' - Overburden - Weathered residual soil, clay and rock rubble

30' - First Core - set casing

30' - 38' - Heavy Weathering with clay, brkn- incomplete core 50% rec

1050 #6 Lift

38' - 64' - Moderate weathering on fractures in GS Breccia

63' - 64' - Very brkn, weathered seam at base of wea. zone

2" qtz vein @ 82'
Competent, hard GS Breccia, minor qtz as thin veins and pods. No visible pyrite.

1000 #7 Lift

Competent, hard GS Breccia, minor qtz and calcite as thin veins and pods (~2-5%). No visible pyrite.

950 - Planned Base of Quarry

155' BOH

City	Shasta Lake
State	CA
Hole No.	R-21-80
Loc. N	498500
Loc. E	1897000
Collar El	1098.4
Core Size	NX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	4/12/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Weathered

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION

1190.9'

0' - 20' - Overburden - Weathered, residual soil, clay and rock rubble

20' - 39' - Highly Weathered GS - Fully Oxidized Core Cross Section

1150 #4 Lift

Mod pyrite noted at 43'

53' - Base of Weathering
Homogeneous, fine xtln, sugar textured, grn, GS. Some brecciation noted.

NX Core to 70' then chg to BX

1100 #5 Lift

99'-101' - Brkn, Wea., GS

106'-120' - Change to Gry-grn GS Breccia

120' - Lithologic change to Dk grn, massive, porphyritic GS.

Dk grn, massive, porphyritic GS. Minor thin epidote, calcite & qtz veining.

1050 #6 Lift

177.5' - 2" qtz vein in very homogeneous dk grn GS.

Gradually increasing amounts of silica and calcite

1000 #7 Lift

City	Shasta Lake
State	CA
Hole No.	R-22-80
Loc. N	498000
Loc. E	1897000
Collar El	1190.9
Core Size	NX-BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	4/1/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

DESCRIPTION

3M Geology

200

211'-222' - Abundant qtz-calc veining

220

Massive, homogeneous dk grn por GS

240' BOH

240

950 elevation - Planned Quarry Base

City	Shasta Lake
State	CA
Hole No.	R-22-80
Loc. N	498000
Loc. E	1897000
Collar El	1190.9
Core Size	NX-BX
Logged By	BWK
Date	2/80
Drilled By	Boyles
Drill Date	4/1/80

Vertical Scale
1 in. = 20 ft.

Rock Type-
Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Conglomerate
- Wea/Brkn

Log Abbreviation
Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

DESCRIPTION

1318.6'

0

1300
#1 Lift

0' - 35' - Overburden - Weathered, residual soil, clay and rock rubble

20

Casing Set at 35' in GS rubble.

40

35' - 55' - Soft, decomposed GS, highly wea and oxidized.

60

NX to 71' Remainder BX core.

1250
#2 Lift

Gry-grn GS. Occasional minor brecciation.

80

81'-177' - Gry-grn GS Breccia, no visible sulfides

100

Occasional minor sulfides in breccia clasts and very minor qtz veining

1200
#3 Lift

120

140

160

1150
#4 Lift

180

177'-268' - Dk gry, very fine xtln, Rhyolite welded tuff, Ignimbritic flow banding evident.

200

3M Geology

City	Shasta Lake
State	CA
Hole No.	R-23-80
Loc. N	497500
Loc. E	1896500
Collar El	1318.6
Core Size	NX-BX
Logged By	MCG-CEN
Date	2/80
Drilled By	Boyles
Drill Date	3/27/80

Vertical Scale
1 in. = 20 ft.

Rock Type-
Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Rhyolite
- Wea/Brkn

Log Abbreviation
Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
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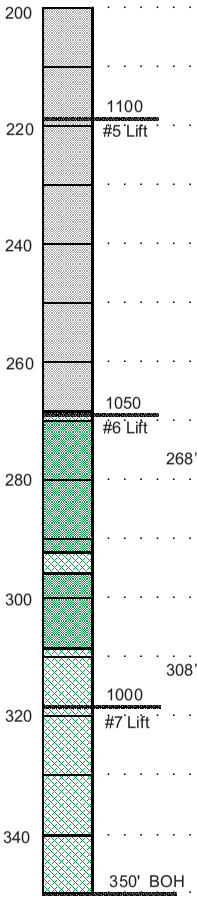
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



Dk gry, very fine xtln, Rhyolite welded tuff, Ignimbritic flow banding evident. Secondary alteration of epidote and chlorite along banding.

268'-308' - Alternating layers of GS Breccia and Gry-grn GS. Minor sulfides and qtz.

308'-350' - Gry-grn GS Breccia with slight visible pyrite in hard, competent core.

950 Elevation - Planned Base of Quarry

City	Shasta Lake
State	CA
Hole No.	R-23-80
Loc. N	497500
Loc. E	1896500
Collar El	1318.6
Core Size	NX-BX
Logged By	MCG-CEN
Date	2/80
Drilled By	Boyles
Drill Date	3/27/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Rhyolite
- Wea/Brkn

Log Abbreviation Legend:

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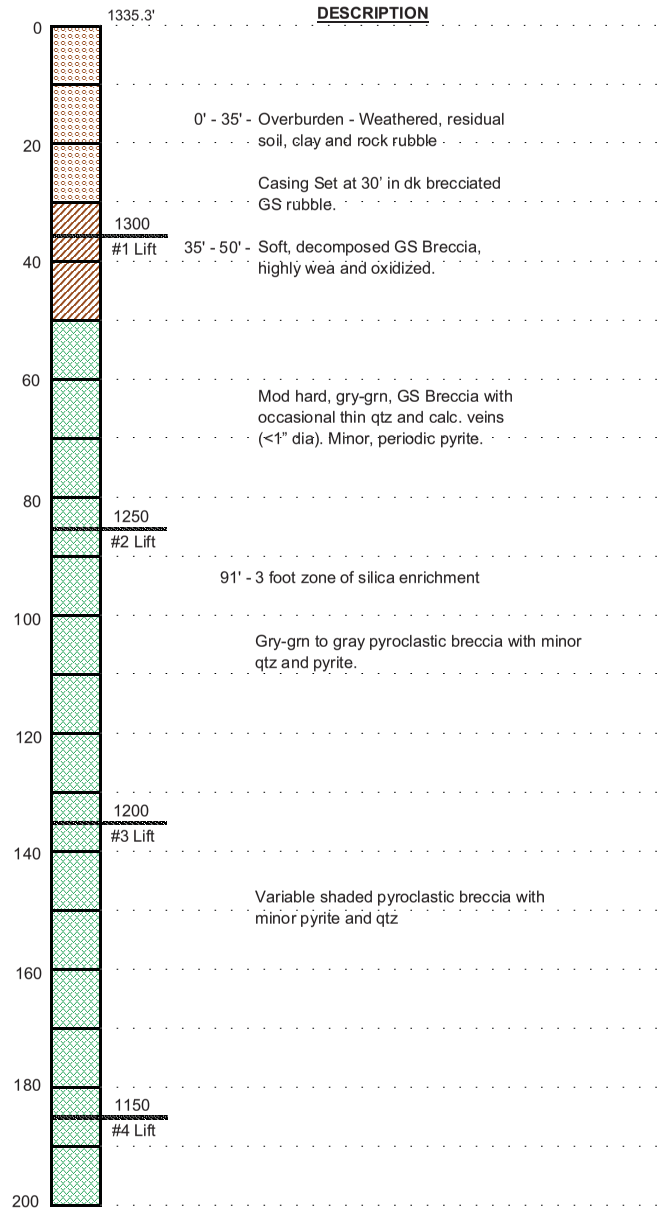
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Gm-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



0' - 35' - Overburden - Weathered, residual soil, clay and rock rubble

Casing Set at 30' in dk brecciated GS rubble.

35' - 50' - Soft, decomposed GS Breccia, highly wea and oxidized.

Mod hard, gry-grn, GS Breccia with occasional thin qtz and calc. veins (<1" dia). Minor, periodic pyrite.

91' - 3 foot zone of silica enrichment

Gry-grn to gray pyroclastic breccia with minor qtz and pyrite.

Variable shaded pyroclastic breccia with minor pyrite and qtz

City	Shasta Lake
State	CA
Hole No.	R-24-80
Loc. N	498000
Loc. E	1896500
Collar El	1335.3
Core Size	NX
Logged By	MCG
Date	2/80
Drilled By	Boyles
Drill Date	3/22/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

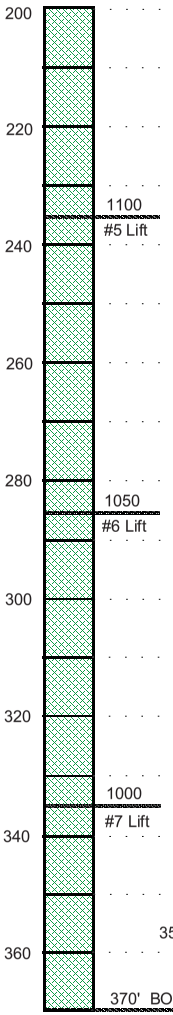
- Residuum/Soil
- Greenstone
- GS Breccia
- Rhyolite
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



Lt gry to gry grn, pyroclastic breccia. Qtz and calcite fracture fillings and patches. Variable xtln texture with variable color.

Med gry-grn, GS Breccia. Minor sulfides and qtz.

350' - 370' - Gry-grn GS Breccia with slight visible pyrite in mottled, broken core.

950 Elevation - Planned Base of Quarry

City	Shasta Lake
State	CA
Hole No.	R-24-80
Loc. N	498000
Loc. E	1896500
Collar El	1335.3
Core Size	NX
Logged By	MCG
Date	2/80
Drilled By	Boyles
Drill Date	3/22/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

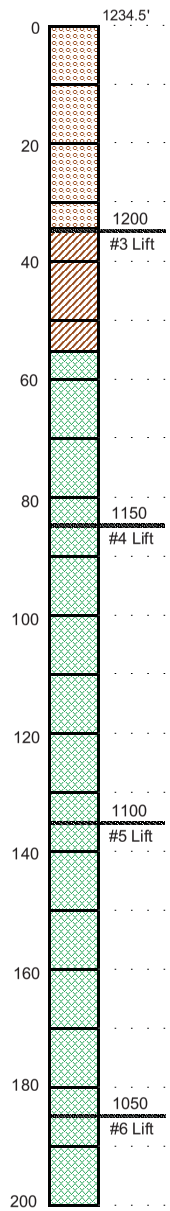
- Residuum/Soil
- Greenstone
- GS Breccia
- Rhyolite
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



0' - 34' - Overburden - Weathered, residual soil, clay and rock rubble

34' - 55' - Soft, decomposed GS Breccia, highly wea and oxidized. Patchy secondary qtz.

Casing set @ 20 ft. , NX to 70 ft. Remainder BX core

Mod hard, gry-grn, GS Breccia with occasional thin qtz and calc. veins (<1" dia). Minor, periodic pyrite.

82' - 8" thick vein of white qtz in generally fine xtln, lt gry, broken GS Breccia.

Pale Gry-grn to gray pyroclastic breccia with minor qtz.

Pale Gry-grn to gray pyroclastic breccia with minor qtz.

City	Shasta Lake
State	CA
Hole No.	R-25-80
Loc. N	498500
Loc. E	1896500
Collar El	1234.5
Core Size	NX-BX
Logged By	MCG
Date	2/80
Drilled By	Boyles
Drill Date	3/22/80

Vertical Scale
1 in. = 20 ft.

Rock Type-Discription Legend:

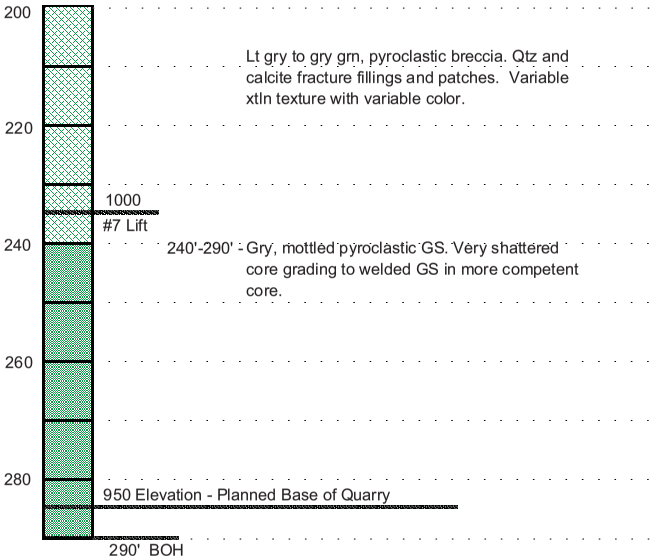
- Residuum/Soil
- Greenstone
- GS Breccia
- Rhyolite
- Wea/Brkn

Log Abbreviation Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

3M Geology

DESCRIPTION



Lt gry to gry grn, pyroclastic breccia. Qtz and calcite fracture fillings and patches. Variable xtln texture with variable color.

240'-290' - Gry, mottled pyroclastic GS. Very shattered core grading to welded GS in more competent core.

City	Shasta Lake
State	CA
Hole No.	R-25-80
Loc. N	498500
Loc. E	1896500
Collar El	1234.5
Core Size	NX
Logged By	MCG
Date	2/80
Drilled By	Boyles
Drill Date	3/22/80

Vertical Scale
1 in. = 20 ft.

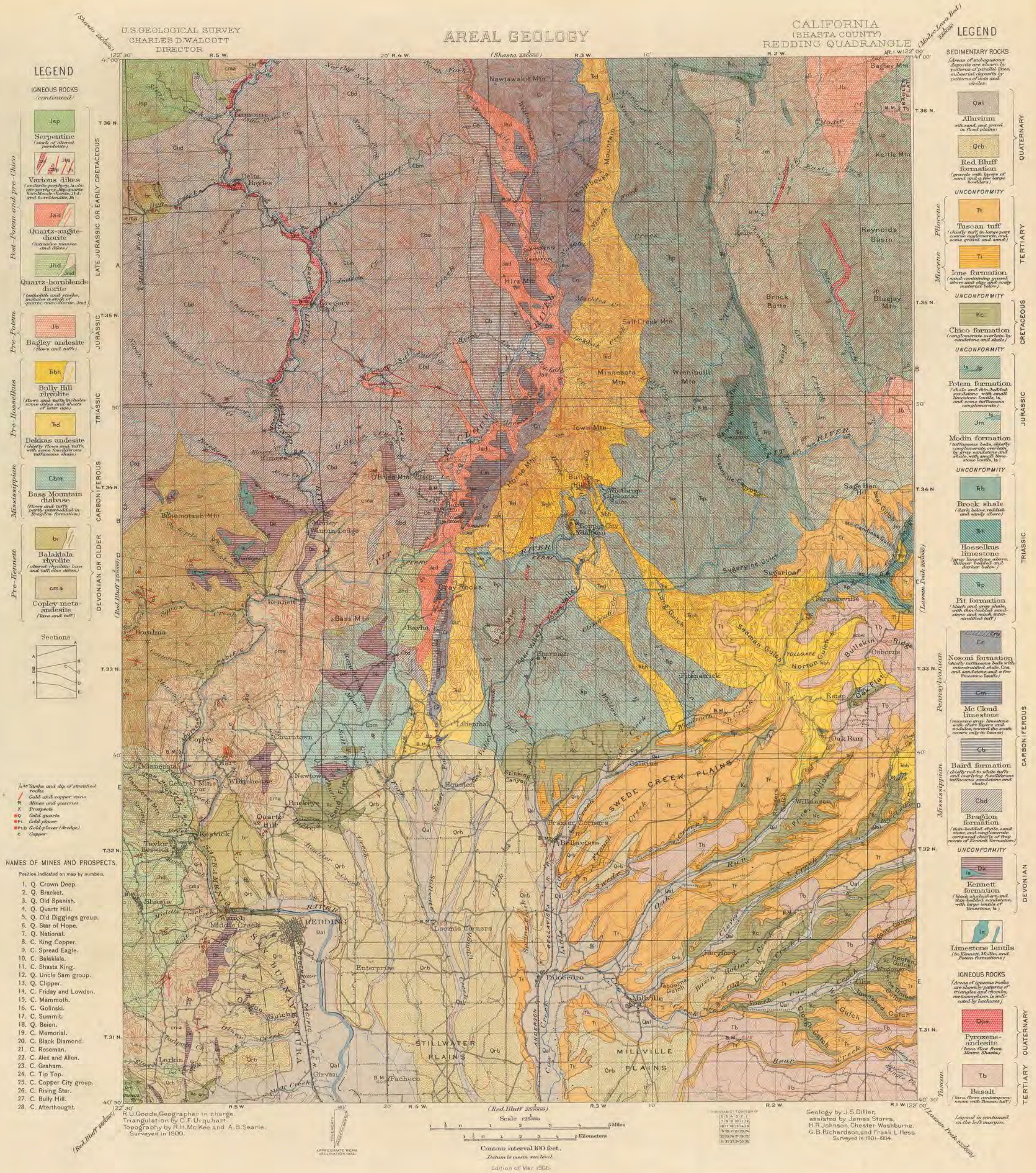
Rock Type-
Discription Legend:

- Residuum/Soil
- Greenstone
- GS Breccia
- Rhyolite
- Wea/Brkn

Log Abbreviation
Legend:

Alt-	Altered
Brkn-	Broken
Brn-	Brown
Cse-	Coarse
Dk-	Dark
Fn-	Fine
Gry-	Gray
Lt-	Light
Med-	Medium
Grn-	Green
Cgl-	Conglomerate
Por-	Porphyritic
Wea-	Weathered
GS-	Greenstone
Xtln-	Crystalline
Qtz	Quartz

- The 1906 United States Geological Survey (USGS) geologic map for the Redding Quadrangle.


U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR
AREAL GEOLOGY
CALIFORNIA
(SHASTA COUNTY)
REDDING QUADRANGLE
LEGEND
IGNEOUS ROCKS
(continued)
Serpentine
Various dikes
Quartz-augite-diorite
Quartz-hornblende diorite
Bagley andesite
Bully Hill rhyolite
Dekkas andesite
Bass Mountain diabase
Balaklala rhyolite
Copley meta-andesite
Sections
LEGEND
SEDIMENTARY ROCKS
Alluvium
Red Bluff formation
UNCONFORMITY
Tuscan tuff
Ione formation
UNCONFORMITY
Chico formation
UNCONFORMITY
Potem formation
Modin formation
UNCONFORMITY
Brock shale
Hosselkus limestone
Pit formation
Nosoni formation
Mc Cloud limestone
Baird formation
Bragdon formation
UNCONFORMITY
Kennett formation
Limestone lentils
IGNEOUS ROCKS
Pyroxene-andesite
Basalt
QUATERNARY
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
CARBONIFEROUS
DEVONIAN
Pliocene
Miocene
Pennsylvanian
Mississippian
LATE JURASSIC OR EARLY CRETACEOUS
JURASSIC
TRIASSIC
CARBONIFEROUS
DEVONIAN OR OLDER
Post-Potem and pre-Chico
Pre-Potem
Pre-Hosselkus
Mississippian
Pre-Kennett
Legend is continued on the left margin.
Strike and dip of stratified rocks
Gold and copper veins
Mines and quarries
Prospects
Gold quartz
Gold placer
Gold placer (dredge)
Copper
NAMES OF MINES AND PROSPECTS.
Position indicated on map by numbers.
1. Q. Crown Deep.
2. Q. Bracket.
3. Q. Old Spanish.
4. Q. Quartz Hill.
5. Q. Old Diggings group.
6. Q. Star of Hope.
7. Q. National.
8. C. King Copper.
9. C. Spread Eagle.
10. C. Balaklala.
11. C. Shasta King.
12. Q. Uncle Sam group.
13. Q. Clipper.
14. C. Friday and Lowden.
15. C. Mammoth.
16. C. Golinski.
17. C. Summit.
18. Q. Beien.
19. C. Memorial.
20. C. Black Diamond.
21. C. Roseman.
22. C. Alex and Allen.
23. C. Graham.
24. C. Tip Top.
25. C. Copper City group.
26. C. Rising Star.
27. C. Bully Hill.
28. C. Afterthought.
SWEDE CREEK PLAINS
STILLWATER PLAINS
MILLVILLE PLAINS
REDDING
SACRAMENTO RIVER
PIT RIVER
R. U. Goode, Geographer in charge.
Triangulation by C. F. Urquhart.
Topography by R. H. McKee and A. B. Searle.
Surveyed in 1900.
Scale 1/125000
Contour interval 100 feet.
Datum is mean sea level.
Edition of Mar. 1906.
Geology by J. S. Diller,
assisted by James Storrs,
H. R. Johnson, Chester Washburne,
G. B. Richardson, and Frank L. Hess.
Surveyed in 1901-1904.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

STRUCTURE SECTIONS

CALIFORNIA
(SHASTA COUNTY)
REDDING QUADRANGLE

LEGEND

IGNEOUS ROCKS
(continued)

SHEET SYMBOL — SECTION SYMBOL

Post-Potem and pre-Chico — LATE JURASSIC OR EARLY CRETACEOUS

- Jsp — **Serpentine** *(stock of altered peridotite)*
- Ja, Jhd, Jdp, Jh — **Various dikes** *(andesite-porphyry, Ja; dacite-porphyry, Jdp; quartz-hornblende-diorite, Jhd; and hornblendite, Jh)*
- Jad — **Quartz-augite-diorite** *(intrusive masses and dikes)*
- Jhd, Jmd — **Quartz-hornblende-diorite** *(batholith and stocks; includes a stock of quartz-mica-diorite, Jmd)*

Pre-Potem — JURASSIC

- Jb — **Bagley andesite** *(flows and tuffs)*

Pre-Hosselkus — TRIASSIC

- Ŧbh — **Bully Hill rhyolite** *(flows and tuffs; includes some dikes and sheets of later age)*
- Ŧd — **Dekkas andesite** *(chiefly flows and tuffs, with some fossiliferous tuffaceous shale)*

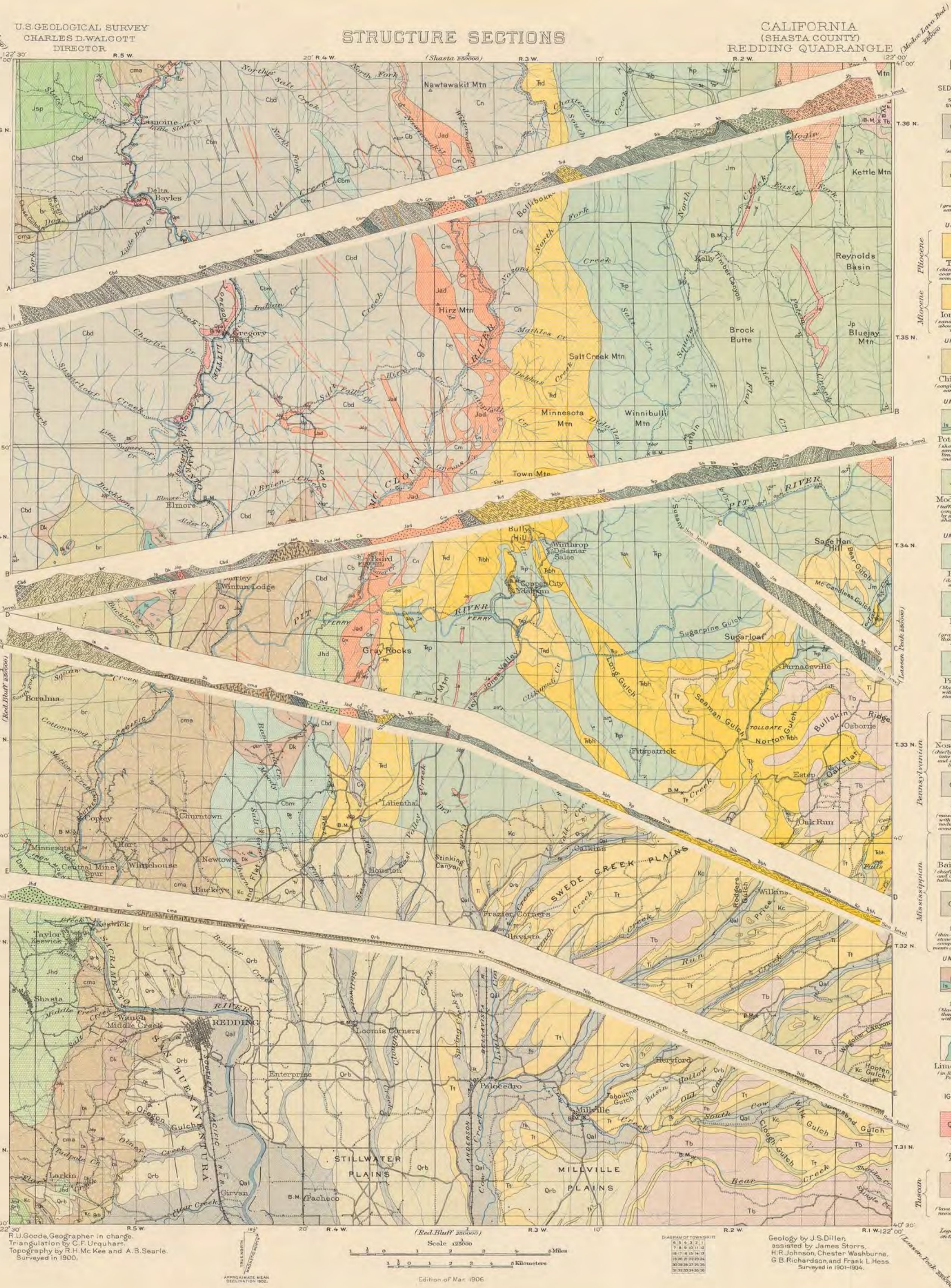
Mississippian — CARBONIFEROUS

- Cbm — **Bass Mountain diabase** *(flows and tuffs partly interbedded in Bragdon formation)*

Pre-Kennett — DEVONIAN OR OLDER

- br — **Balaklala rhyolite** *(altered rhyolitic lava and tuff; also dikes)*
- cma — **Copley meta-andesite** *(lava and tuff)*

↗35° Strike and dip of stratified rocks



LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

QUATERNARY

- Qal — **Alluvium** *(silt, sand, and gravel in flood plains)*
- Qrb — **Red Bluff formation** *(gravels with layers of sand and a few large bowlders)*

UNCONFORMITY

TERTIARY

- *Pliocene* — Tt, Ttib — **Tuscan tuff** *(chiefly tuff, in large part coarse agglomerate, and some gravel and sand)*
- *Miocene* — Ti (Combined with Tuscan tuff on sections) — **Ione formation** *(sand containing gravel above and clay and coaly material below)*

UNCONFORMITY

CRETACEOUS

- Kc — **Chico formation** *(conglomerate overlain by sandstone and shale)*

UNCONFORMITY

JURASSIC

- ls, Jp — **Potem formation** *(shale and thin-bedded sandstone with small limestone lentils, ls, and some tuffaceous conglomerate)*
- ls, Jm — **Modin formation** *(tuffaceous beds, chiefly conglomerate, overlain by gray sandstone and shale, with small limestone lentils, ls)*

UNCONFORMITY

TRIASSIC

- Ŧb — **Brock shale** *(dark below, reddish and sandy above)*
- Ŧh — **Hosselkus limestone** *(gray limestone above, thinner bedded and darker below)*
- Ŧp — **Pit formation** *(black and gray shale, with thin-bedded sandstone and much interstratified tuff)*

CARBONIFEROUS

- *Pennsylvanian* — Cn, Cns — **Nosoni formation** *(chiefly tuffaceous beds with interstratified shale, Cns, and sandstone, and a few limestone lentils)*
- *Pennsylvanian* — Cm — **Mc Cloud limestone** *(massive gray limestone with chert layers and nodules; toward the south occurs only in lenses)*
- *Mississippian* — Cb — **Baird formation** *(chiefly red to white tuffs and overlying fossiliferous tuffaceous sandstone and shale)*
- *Mississippian* — Cbd — **Bragdon formation** *(thin-bedded shale, sandstone, and conglomerate composed chiefly of fragments of Kennett formation)*

UNCONFORMITY

DEVONIAN

- Dk, ls — **Kennett formation** *(black shale, chert, and thin-bedded sandstone, with large lentils of limestone, ls)*

- ls — **Limestone lentils** *(in Kennett, Modin, and Potem formations)*

IGNEOUS ROCKS

QUATERNARY

- Qpa — **Pyroxene-andesite** *(lava flow from Mount Shasta)*

TERTIARY

- *Tuscan* — Tb (Combined with Tuscan tuff on sections) — **Basalt** *(lava flows contemporaneous with Tuscan tuff)*

Legend is continued on the left margin.

R.U. Goode, Geographer in charge.
Triangulation by C.F. Urquhart.
Topography by R.H. Mc Kee and A.B. Searle.
Surveyed in 1900.

APPROXIMATE MEAN DECLINATION 1902.

Scale 1/125000

Edition of Mar. 1906

Geology by J.S. Diller,
assisted by James Storrs,
H.R. Johnson, Chester Washburne,
G.B. Richardson, and Frank L. Hess.
Surveyed in 1901–1904.

- Master Thesis by Fudge (2008) entitled *Evidence for Regional Extensional Faulting at Grey Rocks Ridge, Eastern Klamath Mountains, California*.

EVIDENCE FOR REGIONAL EXTENSIONAL FAULTING AT GREY ROCKS RIDGE, EASTERN KLAMATH MOUNTAINS, CALIFORNIA

By

Emily C. Fudge

A Thesis

Presented to

The Faculty of Humboldt State University.

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Environmental Systems:

Geology

October, 2008

EVIDENCE FOR REGIONAL EXTENSIONAL FAULTING AT

GREY ROCKS RIDGE,

EASTERN KLAMATH MOUNTAINS,

CALIFORNIA

By

Emily C. Fudge

Approved by the Masters Thesis Committee:

Dr. Susan Cashman, Major Professor Date

Dr. Brandon Schwab, Committee Member Date

Dr. Harvey Kelsey, Committee Member Date

Dr. Chris Dugaw, Graduate Coordinator Date

Chris Hopper, Interim Dean, Research, Graduate Studies, and International Programs

ABSTRACT

Geologic mapping of the Grey Rocks Ridge area identified three klippes of Devonian Copley Greenstone separated from the underlying Trinity terrane by an undulating extensional fault and preserved by oblique down-dropping on NW-NE striking faults. The Grey Rocks klippe and the Horse Heaven Meadows klippe dip shallowly (5 to10 degrees) to the N-NE and have convex boundaries. The basal fault is associated with regional extensional faulting that extends across the Eastern Klamath Mountains.

Geochemical analysis links the greenstone pillows of the Grey Rocks and Panther Rock klippes to the Copley Greenstone of the Redding terrane. The Horse Heaven Meadows klippe is comprised mainly of fractured slate with minor amounts of volcanic breccias and tuffs, forming a localized lens within the Copley Greenstone. A similar metasedimentary and metavolcanic lens is located in the southern section of the Grey Rocks klippe.

The three klippes form the hanging wall of a regional extensional fault that juxtaposes the three klippes over the underlying Trinity terrane. The undeformed greenstone pillows of Grey Rocks and Panther Rock klippes and the fractured metavolcanic and metasedimentary units of the Horse Heaven Meadows klippe clearly contrast with the mylonite and fault breccia at the contact and with the serpentinized mafic/ultramafic complex (Trinity terrane) of the footwall. Geochemical values of fault zone mylonite indicate elevated values of Al_2O_3 and depleted values of MgO when

compared to ultramafic compositional values, supporting a mixing of upper and lower plate components.

Fault outcrop characteristics include mylonite, foliated fault breccia zones, and parallel foliation observed in proximal greenstone and ultramafic rocks. Quartz veins run both parallel and perpendicular to foliation, suggesting that injection of hydrothermal fluids accompanied faulting and accommodated extensional deformation of more coherent rock. In thin section, fault proximal rocks in the upper and lower plate exhibit shear microstructures including foliation, s-c fabrics, planar mineral alignment, sigma clasts, pull-apart clasts, and perpendicular to foliation quartz veining.

Felsic dikes intrude the fault breccia at the base of the Horse Heaven Meadows klippe and intrude parallel to the fault zone at the base of the Grey Rocks klippe. Emplacement of the parallel dike is interpreted to be syntectonic with the extensional faulting event based on shear and extensional microstructures such as anastomosing foliation and perpendicular to foliation quartz veining.

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INTRODUCTION

At Grey Rocks ridge, located in the Klamath and Trinity Mountains of northern California, three small bodies of greenstone and fine-grained metasedimentary rocks overlie the Trinity ultramafic complex. The ―Grey Rocks outlier" (Irwin, 1966) occupies a key position in the tectonic evolution of the Klamath Mountains provenance. Conflicting interpretations on the structural relations and stratigraphic affiliation of the Grey Rocks outliers include: formation as part of a classic ophiolitic sequence (Brouxel and Lapierre, 1988), formation in an island arc (Irwin, 1981; Albers and Bain, 1985; Doe et. al, 1985), formation in a suprasubduction zone (Wallin and Metcalf, 1998), remnant of a thrust plate (Irwin, 1966; Brouxel et al., 1989), and tectonic emplacement by extensional faulting (Schweickert and Irwin, 1989; Masson, 2002; Cashman and Elder, 2002).

The project concentrates on mapping three klippes in the Grey Rocks area (Plate 1), identifying the nature of the contact between the Trinity ultramafic complex and the structurally overlying metasedimentary and metavolcanic units, and geochemically and descriptively correlating the geologic units with known formations using x-ray fluorescence analysis.

The three klippes are termed the Panther Rock klippe, the Horse Heaven Meadows klippe, and the Grey Rocks klippe. To maintain continuity the term greenstone will relate to both hydrothermally altered basalts and basalts altered in the greenschist facies. The term mylonite refers to fine-grained fault rocks that form as a result of ductile

deformation at temperatures between 250 ^{o}C – 350 ^{o}C and depths of 10 to 15 km. Mylonitic texture includes a planar foliation and recrystallization of minerals (Twiss and Moores, 1992).

Geologic Setting

Regional Geology

The Klamath Mountains Province is comprised of a series of arcuate, accreted terranes resulting from Paleozoic to Mesozoic subduction along the western plate boundary of the North American plate (Irwin, 1960; 1963; 1966; 1972; 1994). Terranes young to the west and are separated by major north-south-striking, east-dipping thrust faults (Irwin, 1966; 1972; 1994). Mesozoic plutons and dikes intrude the terranes (Irwin, 1966; 1994). N-S Tertiary extensional faulting cuts across all terranes of the Eastern Klamath Mountains (Schweickert and Irwin, 1989; Cashman and Elder, 2002).

Eastern Klamath Belt

The study site is located within the Eastern Klamath Belt, which is the oldest and eastern-most accreted terrane (Fig. 1). The Eastern Klamath Belt is subdivided into the Trinity, Yreka, and Redding terranes based on distinctive stratigraphic successions, magmatic histories, and age relations of rock units (Irwin, 1966; 1972; 1994). Mesozoic post-amalgamation plutons, including the Shasta Bally batholith, Castle Crags pluton, and Craggy Peak pluton area, have intruded all three terranes within the Eastern Klamath Belt (Irwin, 1994).

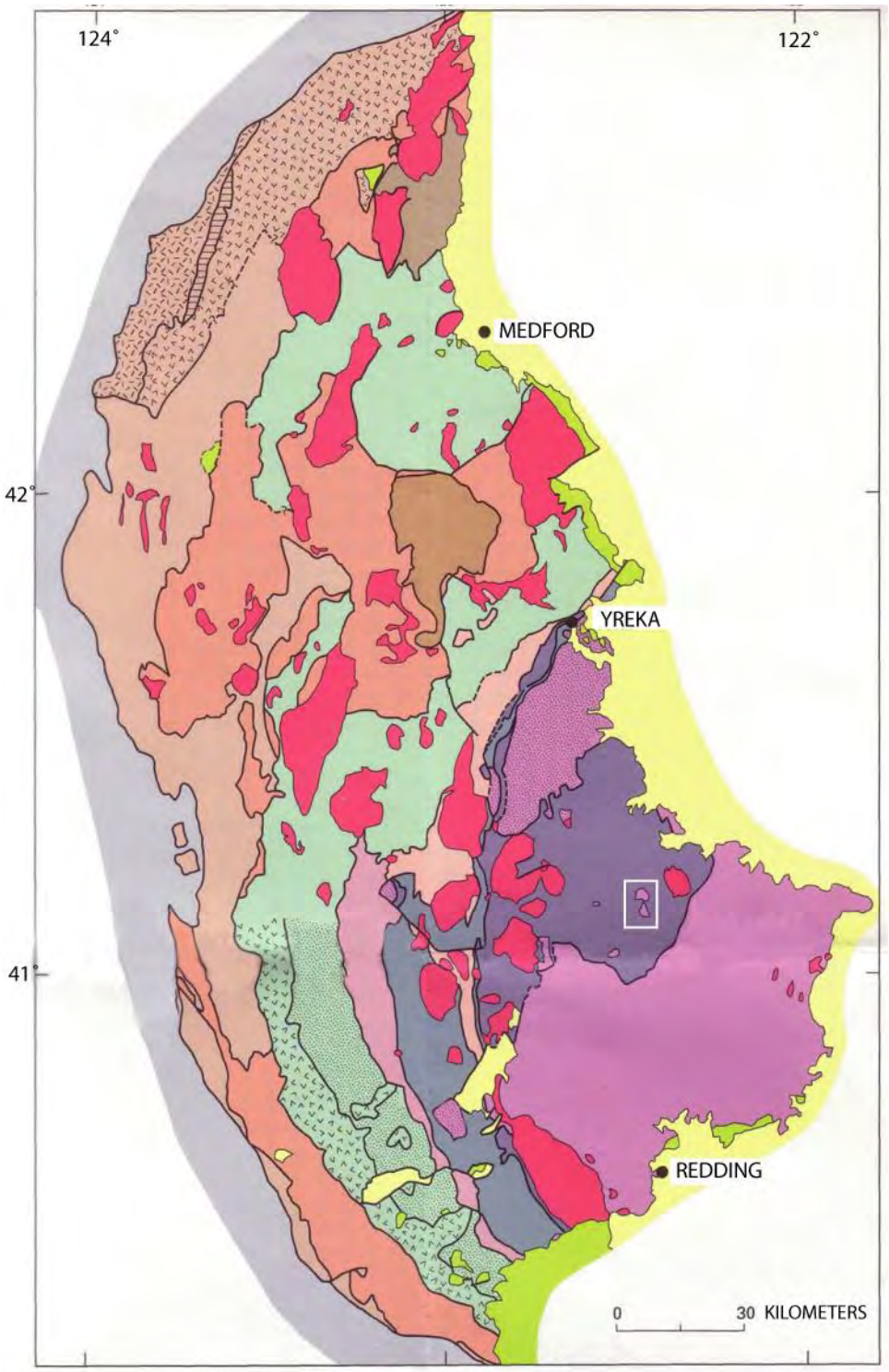


Figure 1A: Geologic Map of the Klamath and Trinity Mountains, Northern California, compiled by Irwin (1994). Bounding box shows the location of the Grey Rocks study area.

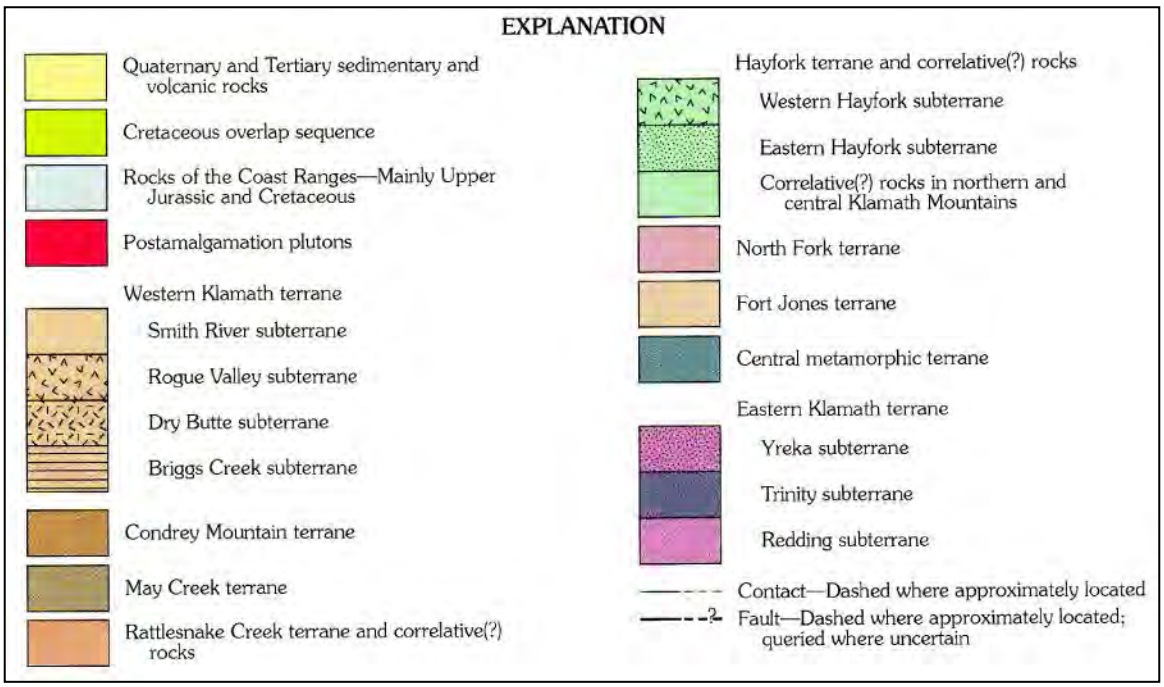


Figure 1B: Legend for the geologic map in Figure 1A (Irwin, 1994).

Trinity Terrane. The Trinity terrane, at the center of the Eastern Klamath Belt, is the oldest of the three terranes dating from Vendian to Siluro-Devonian (Jacobsen et al., 1984; Lindsley-Griffin et al., 2006), and is stratigraphically the lowest terrane in the Eastern Klamath Belt (Irwin and Lipman, 1962). The Trinity terrane is estimated to be between 6.5 and 8 km thick based on models combining seismic, gravity, and aeromagnetic data (Zucca et al., 1986).

The polygenetic Trinity terrane consists of tectonically foliated, ultramafic packages and two crustal sequences, one Vendian and one Siluro-Devonian with minor associated Siluro-Devonian volcanic rocks (Lindsley-Griffin, 1977; 1991; Quick, 1981; Irwin, 1994; Metcalf et. al., 2000; Lindsley-Griffin et al., 2006). One tectonically foliated ultramafic package contains the Vendian gabbroic to felsic plutonic suite and represents an ophiolitic crustal sequence (Lindsley-Griffin et al., 2006). Ordovician felsic dikes and plutons intrude the tectonically foliated, ultramafic packages and the Vendian sequence (Mattinson and Hopson, 1972; Lindsley-Griffin et al., 2006). The Siluro-Devonian gabbroic to felsic plutonic suites intrude units throughout the Trinity terrane and part of the Yreka terrane. The Siluro-Devonian suites are cogenetic with the Yreka terrane Siluro-Devonian volcanic flows and the Siluro-Devonian Redding volcanics (Wallin et al., 1991; Wallin and Metcalf, 1998; Metcalf, et al. 2000; Lindsley-Griffin et al., 2006).

Yreka Terrane. The Yreka terrane is structurally and stratigraphically complex, and consists of thin, fault-bounded slices of Vendian to Devonian shale, sandstone, phylite, schist, greenstone, and mélange units (Lindsley-Griffin, 1977; Potter et al., 1977; Lindsley-Griffin et al., 1991; Irwin, 1994; Lindsley-Griffin et al., 2006). Volcanic flows

within the Yreka terrane are the extrusive component of the Siluro-Devonian intrusive suite found within the Trinity terrane (Wallin and Metcalf, 1998). The Trinity-Yreka contact is faulted in all locations (Lindsley-Griffin, 1977; 1991; Potter et al., 1977; Schweickert and Irwin, 1989; Miller and Harwood, 1990; Lindsley Griffin et al., 1991; Cashman and Elder, 2002; Lindsley-Griffin et al., 2006).

Redding Terrane. The Redding terrane consists of Devonian to Jurassic volcanic and marine sedimentary units (Kinkel et al., 1956; Miller, 1989; Miller and Harwood, 1990; Irwin, 1994). The Devonian Copley Greenstone comprises the oldest stratigraphic layer of the Redding terrane and consists of pillow lavas, tuffs, volcanic flows and breccias, and some shales (Kinkel et al., 1956; Lapierre et al., 1985; Brouxel et al., 1988). Massive flows dominate the lower half of the unit, whereas the upper half is characterized by pillow lavas and interbedded pyroclastic deposits (Kinkel et al., 1956). Near Redding the upper Copley Greenstone is dominated by pillow lavas with minor amounts of ~~"t~~uffaceous slaty sediments and sandstones with granitic debris" (Lapierre et al., 1985).

The Copley Greenstone is estimated to be at least 1800 meters thick (Diller, 1905; Lapierre et al., 1985; Brouxel et al., 1988). The contact between the Devonian Copley Greenstone and the Ordovician Trinity terrane is faulted at all locations (Wagner and Saucedo, 1987; Schweickert and Irwin, 1989; Irwin, 1994; Cashman and Elder, 2002). Overlying and interfingering with the Copley Greenstone are the Devonian Balaklala Rhyolite, dated by a Devonian fish fossil plate (Boucot et al. 1974), the mid-Devonian Kennett Formation, and the Mississippian Bragdon Formation (Kinkel et al., 1956).

The Mississippian Bragdon Formation consists mainly of argillite with minor amounts of conglomerate, silt, and sandstone, and rare fossiliferous units in the upper section (Kinkel et al., 1956; Miller 1989; Miller and Harwood, 1990). Chert pebble conglomerate is a distinctive unit within the formation and used for identification (Albers and Robertson, 1961). The majority of the conglomerate beds are located in the lower section of the Bragdon Formation, within 165 to 500 meters from the base. The conglomerates form lenticular beds that range up to several hundred meters thick and contain large portions of chert and limestone clasts (Kinkel et al., 1956; Albers and Robertson, 1961). The upper portion of the Bragdon Formation (structurally upper-most 2800 m) is dominated by sand-rich turbidites (Watkins, 1986; Miller and Cui, 1989). Sedimentary lithics dominate clast compositions throughout the formation, with some beds containing minor amounts of epiclastic volcanic lithics mixed in heterogeneously with the sedimentary clasts, and fewer beds with reworked pyroclastic debris (Miller and Cui, 1989). Internal deformation skews thickness measurements, but stratigraphic thickness estimates range from 900 m (Diller, 1905) to >2000 m (Watkins, 1986). Structural thickness estimates range up to 4400 meters thick (Watkins, 1986). In some locations, the Bragdon Formation conformably overlies the Balaklala Rhyolite and Kennett Formations, but elsewhere, the Bragdon Formation unconformably overlies the Kennett Formation (Kinkel et al., 1956) or Devonian Copley Greenstone (Kinkel et al., 1956; Albers and Robertson, 1961), or is faulted against the Balaklala Rhyolite or Copley Greenstone (Kinkel et al., 1956). The upper contact conformably grades into the

overlying Baird Formation, which contains Mississippian fish fossils (Watkins 1986; Miller and Cui, 1989).

Contact Relations. Faults bound the Trinity terrane both with the overlying Yreka terrane in the north (Potter et al., 1977; Miller and Harwood, 1990; Cashman and Elder, 2002; Lindsley-Griffin et al., 2006) and with the overlying Redding terrane in the south (Wagner and Saucedo, 1987; Schweickert and Irwin, 1989; Irwin 1994; Cashman and Elder, 2002). The structurally complex Yreka terrane contains multiple fault slices that displace Yreka fault blocks with the underlying Trinity terrane (Potter et al., 1977; Lindsley-Griffin, 1977). Outliers observed in the Callahan and Cecilville/Richter mine areas contain upper plate Yreka units with low-angle basal faults (Cashman and Elder, 2002).

The faults in the south, including the La Grange, Carrville, and Deer Creek faults, separate the Redding terrane from the underlying Trinity terrane and have been identified as low-angle, extensional faults (Schweickert and Irwin, 1989; Goldstein, 1997; Cashman and Elder, 2002). The Deer Creek and Carrville faults separate Devonian Copley Greenstone from the underlying Trinity terrane (Goldstein, 1997; Cashman and Elder, 2002); a similar relationship of greenstone overlying Trinity terrane mafic and ultramafic rocks is observed at Grey Rocks. Earlier interpretations have identified faults that bound the Trinity terrane with the Redding and Yreka terranes and underlie various outliers as thrust faults, including the basal contacts of the klippes at Grey Rocks (Irwin, 1966; Potter et al., 1977; Harwood and Miller, 1990; Charvet et al., 1990; Lindsley-Griffin,

1991). The significance of these faults as extensional faults is that they record an extensional event within a classically compressive zone.

The ambiguous nature of the contact between the Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes and the underlying Trinity ultramafic complex has resulted in multiple conflicting interpretations. Depositional and tectonic hypotheses for the origin of Grey Rocks greenstone and metasedimentary bodies include: 1) part of a single, complete ophiolite sequence formed along a slow spreading ridge (Lindsley-Griffin, 1977; Brouxel and Lapierre, 1988; Boudier et al., 1989), 2) part of a single, complete ophiolite displaced by Paleozoic thrust faulting (Charvet et al., 1990), 3) part of a polygenetic ophiolite (Wallin et al., 1988; Lindsley-Griffin, 1991; Lindsley-Griffin et al., 2006), 4) the extrusive component of the Siluro-Devonian intrusive suite depositionally overlying a polygenetic Trinity terrane (Wallin and Metcalf, 1998; Metcalf et al., 2000), and 5) an upper plate remnant of Yreka and/or Redding terrane resulting from Tertiary detachment faulting (Schweickert and Irwin, 1989; Masson, 2002; Cashman and Elder, 2002).

Greenstone units at Grey Rocks and Panther Rock klippes were mapped as ―Trinity basalts" and interpreted as part of a complete ophiolitic suite by Brouxel and Lapierre (1988). Boudier et al. (1989) suggest the Trinity ophiolite formed at a slow spreading ridge citing spatial relations between ultramafic rocks, cumulate gabbros, dikes, and pillow basalts as evidence. In this interpretation, the basal contacts of the Grey Rocks greenstone and metasedimentary units were identified as depositional and the

structurally high location of the greenstone and metasedimentary units as evidence for their position in a classic ophiolitic sequence.

The basal contacts of greenstone, metavolcanic, and metasedimentary rocks at Grey Rocks, Panther Rock, and Horse Heaven Meadows have been described as partially depositional and partially tectonic (Charvet et al., 1990). According to this interpretation, Grey Rocks and Panther Rock klippe greenstones represent part of an ophiolite that has experienced Paleozoic thrust faulting. The basal contacts of the Grey Rocks and Panther Rock klippes are described as thrust faults. The faulting event occurred after the greenstone pillows formed, but predated deposition of sedimentary rocks at Horse Heaven Meadows klippe. The Horse Heaven Meadows klippe is interpreted by Charvet et al. (1990) as an in-place section of Mississippian Bragdon shale with a depositional basal contact.

In contrast, geochronological analysis of metagabbro, gabbro, and tonalite in the Trinity terrane shows that the Trinity terrane consists of two ophiolitic sequences, one Vendian and one Siluro-Devonian in age, and formed over a period of 180 m.y. (Wallin et al., 1988; Lindsley-Griffin, 1991; Wallin et al., 1991; Wallin et al., 1995; Metcalf et al., 2000). These data, combined with mapping and description of the Yreka and Trinity terranes (Quick, 1981; Lindsley-Griffin, 1991; Lindsley-Griffin et al., 2006) indicate a complex polygenetic history for the Trinity terrane, which is the basis for the most recent interpretations of the Eastern Klamath Belt. Wallin and Metcalf (1998) indicate that the basal contact of greenstones at Grey Rocks could be faulted but interpret this contact as depositional.

First to suggest that the contact between the Trinity terrane and the Redding terrane is a low-angle detachment fault were Schweickert and Irwin (1989). They extended their observation of a low-angle normal fault at the La Grange mine, southwest of the Trinity terrane, to speculate that the imbricate faulting observed in the Yreka terrane may represent the break-away region of a south moving Redding terrane block that forms the upper plate of a regional-scale detachment fault. Masson (2002) identified a possible fault beneath the Grey Rocks klippe. According to Masson's (2002) interpretation, metasedimentary rocks at the Horse Heaven Meadows klippe depositionally overlie Trinity terrane peridotite and a deeper fault cuts through the peridotite, juxtaposing Trinity terrane against Trinity terrane. Cashman and Elder (2002) support a low-angle normal fault interpretation through identification of several klippes with low-angle basal faults separating Yreka and Redding terrane units with the underlying Trinity terrane.

The purpose of this study is to identify the nature of the basal contacts of the Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes, and to utilize detailed mapping, petrography, and XRF analysis to associate each of the three klippes with a known rock assemblage (Plate 1).

PETROGRAPHY

The following rock descriptions, listed from oldest to youngest, describe the units observed at Grey Rocks, Horse Heaven Meadows, Panther Rock, and surrounding area (Plate 1). Unit names follow those of Irwin (1994) and Lindsley-Griffin et al. (2006). For locations mentioned in text, refer to Figure 2.

Trinity Terrane

Rock units of the Trinity terrane observed within the study area include 1) the Ordovician Trinity ultramafic sheet (Oum), termed the "Trinity peridotite" (Quick, 1981), and 2) various Ordovician to Siluro-Devonian gabbroic and dioritic suites (O/SDgb) (Irwin, 1994). Undated hornblende porphyry dikes (SDd) are also described here; these may be related to the Siluro-Devonian volcanic suite described by Lindsley-Griffin (1991) and Lindsley-Griffin et al. (2006). These units are mapped together here as Trinity ultramafic complex, (Ouc), with the exception of mappable dikes (SDd) near contacts with the Horse Heaven Meadows, Grey Rocks, and Panther Rock klippes. Lindsley-Griffin (1991) and Wallin et al. (1988) have used the Trinity ultramafic complex (Ouc) description to refer to the combination of the Trinity ultramafic sheet (Oum) and various intrusive suites (O/SDgb).

Mapping the extent of the O/SDgb intrusions is complex and beyond the scope of this project. For a detailed description of the various intrusions, refer to Lindsley-Griffin (1977; 1991), Lindsley-Griffin and Griffin (1983), Quick (1981), Cannat and Lecuyer (1991), Boudier et al. (1989), Metcalf et al. (2000), and Lindsley-Griffin et al. (2006).

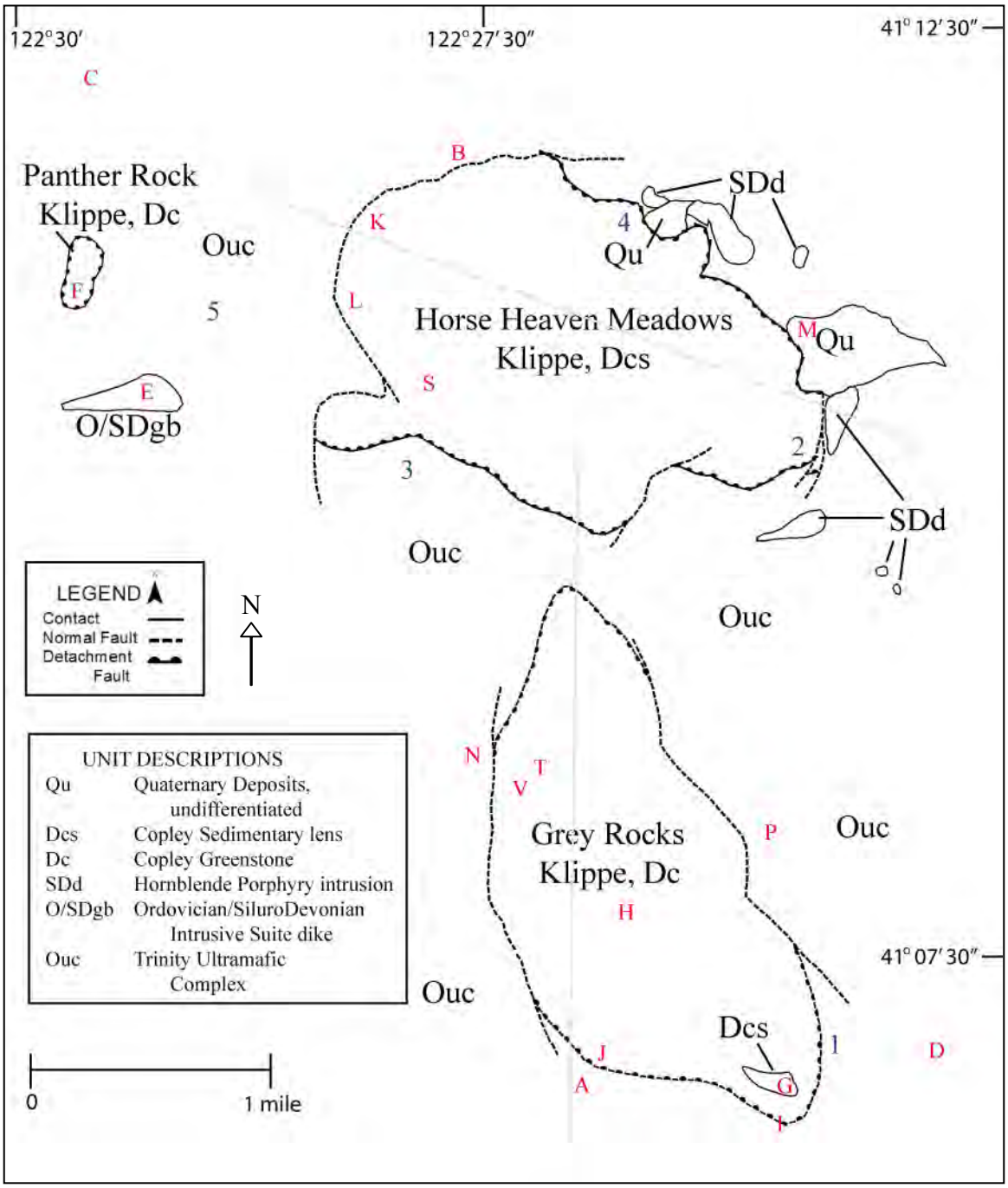


Figure 2: Location Map. Letters refer to sites noted within text. Numbers refer to samples listed in Table 1.

The three Trinity units comprising the Trinity ultramafic complex in the study area are described and listed in order of known ages, oldest to youngest.

Ultramafic Rocks (Oum)

The Trinity ultramafic unit, comprised mainly of serpentinite, is the oldest, most abundant unit in the mapped area and corresponds with the Trinity ultramafic sheet (Oum). The majority of the Trinity ultramafic sheet is Ordovician in age (Jacobsen et al., 1984), although minor sections of the northwest Trinity terrane near the Yreka terrane are dated as Vendian (Wallin et al., 1988; Wallin, 1990; Lindsley-Griffin, 1991; Wallin et al., 1995; Lindsley-Griffin et al., 2006). The majority of geologic mapping of the Trinity ultramafic sheet details the northern boundary adjacent to the overlying Yreka terrane. There, the ultramafic unit includes Ordovician feldspathic harzburgite, lherzolite, and dunite and Vendian plagiogranite and metagabbro (Lindsley-Griffin, 1977; 1991; Quick, 1981; Brouxel and Lapierre, 1988; Wallin et al., 1988; Boudier et al., 1989; Wallin et al. 1995; Lindsley-Griffin et al., 2006). Further east, in the Mt. Eddy area, the Ordovician units collectively termed the ―Trinity peridotite" are 20 to 50% serpentinized with serpentinization increasing near intrusions (Quick, 1981). However, serpentinization in the western and northwestern parts of the Trinity ultramafic unit (Lindsley-Griffin, 1991), and within the Grey Rocks area (this project), is more extensive ranging up to complete serpentinization.

Location A (Fig. 2) near the southern contact of the Grey Rocks klippe, exhibits the complexity and altered nature of the Trinity ultramafic sheet. Undeformed dark to blackish green serpentinitized peridotite is layered within pale green serpentinite,

possibly representing a layered peridotite. Fractures parallel the layering in the serpentinite, striking N75W and dipping 50NE (Fig. 3).

The dark to blackish green serpentinized peridotite has undergone complete psuedomorphic alteration to serpentine and opaque magnetite forming serpentinite (Fig. 4). The opaque magnetite, which is faintly aligned in hand sample, preserves the original grain boundaries and idiomorphic granular texture. The dark to blackish green serpentinized peridotite can be observed in the north at Location B (Fig. 2).

A range of mafic to intermediate discontinuous dikes and plutons of the Ordovician to Siluro-Devonian intrusive suites O/SDgb have intruded the Trinity ultramafic sheet (Oum) and caused alteration zones near intrusion contacts. Along the steep banks of Castle Creek, serpentine country rock displays local metamorphism, shearing, and development of schistose at intrusive contacts (Fig. 5). In other locations, for example Helen Lake at Location C (Fig. 2), the intrusion-serpentinite contacts are broadly gradational. The integrated, gradational, and discontinuous nature of the contact zones are reasons for ambiguity and variation on different published maps.

Mafic Intrusive Rocks (O/SDgb and unofficial SDd)

The Ordovician and Siluro-Devonian intrusive suites include plutons and dikes of tonalite, plagiogranite, diabase, diorite, aplite, basalt, gabbro, and pyroxenite that have been described and mapped in detail throughout the Trinity terrane (Lindsley-Griffin, 1977; 1991; Quick, 1981; Brouxel and Lapierre, 1988; Wallin et al., 1988; Boudier et al., 1989; Metcalf, et al., 2000). A detailed description of the Trinity ultramafic complex (Ouc), specifically the intrusive suites, is presented in Quick (1981) and Lindsley-Griffin

Figure 3: Photograph of pervasive parallel fractures, striking N75W and dipping 50NE, in the massive light green serpentinite of the Trinity ultramafic sheet (Oum), SW of Grey Rocks klippe, Location A (Fig. 2). The fractures parallel 15 cm thick sections of dark to blackish green serpentinite (Oum), interpreted as a layered peridotite. View is to the NW.

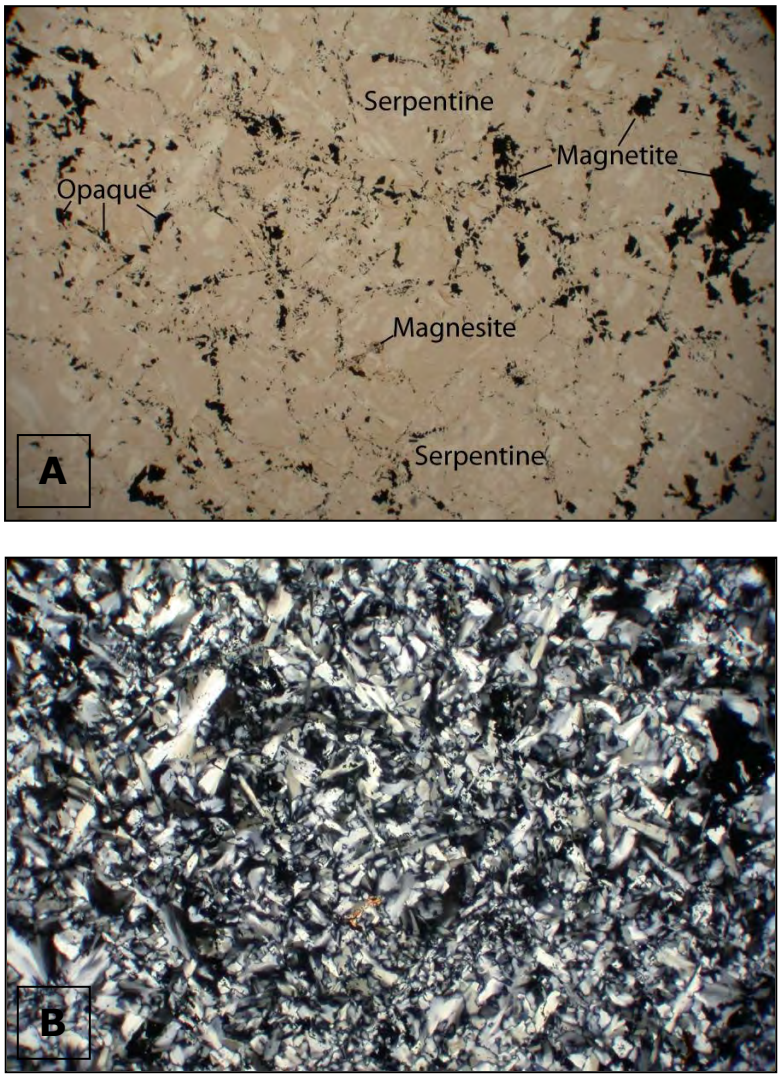


Figure 4: Photomicrographs of dark to blackish green serpentinite unit of the Trinity ultramafic sheet (Oum). Sample UM-2, Location A (Fig. 2), width of image is 1.75 mm, A) in plane polarized light and B) in cross polarized light. Serpentinite is comprised mainly of serpentine, opaque magnetite, and minor magnesite. Psuedomorphic alteration of pyroxene and olivine preserve the original idiomorphic granular texture, large equant grains outlined by smaller opaque minerals.

Figure 5: Photograph of dike-serpentinite contact. Intrusion of an aphanitic basalt dike (O/SDgb) causes contact metamorphism and localized foliation zones within the massive serpentinite of the Trinity ultramafic sheet (Oum). Foliated zone is approximately 8 cm thick. Photo location is from Castle Creek near Location 4 (Fig. 2), view is to the NE. Local zones of schistosity within the serpentinite are commonly observed adjacent to dikes and plutons.

(1991). The Trinity ultramafic unit is described as polygenetic with several dikes ranging in composition from plagiogranite to gabbric and ages spanning from Ordovician to Siluro-Devonian (Wallin et al., 1988; Wallin et al., 1991; Wallin et al., 1995; Wallin and Metcalf, 1998). Tonalitic plutons and dikes are dated as Ordovician, ranging from 455 to 485 Ma (Mattinson and Hopson, 1972). The Siluro-Devonian gabbroic and dioritic suite, dated by Jacobsen et al. (1984), includes a characteristic pegmatitic gabbro along with intrusions of pyroxenite, gabbro, diorite, and aplite (Quick, 1981; Lindsley-Griffin, 1991). Cannat and Lecuyer (1991) mapped basalt dikes and plutons south of Grey Rocks klippe at Tamarack Lake and northeast of Horse Heaven Meadows klippe at Castle Lake.

Within the Grey Rocks study area, small plutons of fine-grained diabase, diorite, and gabbro intrude the Trinity ultramafic sheet (i.e., Locations D and E, Fig. 2). Composition, grain-size, and texture are variable from pluton to pluton and given the multitude and variety of intrusions, a detailed description is beyond the scope of this project. Observable at several locations, the diabase, diorite and gabbro grade into each other and are intruded by the pegmatitic hornblende gabbro (i.e., Location D, Fig. 2). All felsic to gabbroic dikes and plutons within the study area are small and discontinuous with the exception of the pegmatitic hornblende gabbro (O/SDgb) that covers large areas to the north of Horse Heaven Meadows klippe and east of Grey Rocks klippe.

Pegmatitic Hornblende Gabbro (O/SDgb). The pegmatitic hornblende gabbro, comprising the area near Helen Lake (Location C, Fig. 2) and Boulder Peak, the eastern side of Grey Rocks Basin and Mears Ridge area (Location D, Fig. 2), and the Seven Lakes Basin area, corresponds to the younger plutonic component of O/SDgb in Irwin

(1994) and Silurian gabbroic suite of Lindsley-Griffin (1991). The pegmatitic gabbro is comprised primarily of aggregates of coarse-grained (0.5 to 5 cm) pyroxene, hornblende, plagioclase, and quartz. Unlike the smaller dikes and sills, this unit forms large plutons. Near Helen Lake (Location C, Fig. 2), the irregular and complex O/SDgb pluton boundary with the Trinity ultramafic sheet (Oum) can be observed, displaying a zone of O/SDgb intrusions interfingering with hydrothermally altered Trinity ultramafic sheet. Other units associated with the pegmatitic hornblende gabbro include intrusions of pyroxenite, gabbro, diorite of various compositions, and aplite (Lindsley-Griffin, 1991).

Porphyritic Hornblende Andesite. (SDd). Small discontinuous hypabyssal plutons of porphyritic hornblende andesite intrude Trinity terrane ultramafic rocks on the southeastern side of the Horse Heaven Meadows klippe, near Locations 4 and 2 (Fig. 2). These plutons are irregularly shaped, appear undeformed, and are up to 1700 m in diameter. In the field, the andesite is lavender grey with black hornblende phenocrysts up to 3 mm in length. In thin-section, the andesite contains euhedral hornblende crystals about 3mm in length (locally altered to fine-grained amphiboles, chlorite, and calcite), euhedral 1mm plagioclase phenocrysts altered to saussurite and fine-grained clay; and minor pyrite phenocrysts. The fine-grained groundmass consists of microcrystalline quartz, plagioclase, chlorite, and small laths of clinozoisite.

Devonian Copley Greenstone (Dc and Dcs)

The Devonian Copley Greenstone is the basal unit of the Redding terrane (Kinkel et al., 1956; Miller and Harwood, 1990; Irwin, 1994). Massive greenstone and pillow

greenstone of Panther Rock and Grey Rocks klippes have been mapped as Copley Greenstone based on petrographic characteristics (Wagner and Saucedo, 1987; Irwin, 1994) and as ―Trinity ophiolitic basalts" based on petrographic and geochemical characteristics (Brouxel and Lapierre, 1988; Brouxel et al., 1988).

Panther Rock Klippe: Greenstone Pillows (Dc)

Greenstone caps Panther Rock klippe (Location F, Fig. 2) and exhibits classic pillow structures, aphanitic texture, and irregular quartz veins. Only the very top of Panther Rock contains in-place pillow structures with float comprised solely of greenstone blocks blanketing the slopes. The basal contact between the pillows and the underlying Trinity ultramafic complex is obscured; however, based on map relations, the minimum unit thickness is estimated at 27 meters.

The greenstone of Panther Rock klippe is aphanitic, comprised of radial, fibrous actinolite, chlorite, plagioclase, fine-grained microcrystalline and larger quartz, euhedral clinozoisite, square 0.5 mm relict pyroxenes that are being replaced by chlorite, and fine-grained clays (Fig. 6). The intergranular texture is overprinted by alteration minerals.

Grey Rocks Klippe

Greenstone Pillows (Dc). Greenstone pillows form the majority of Grey Rocks klippe. A minor metavolcanic/metasedimentary lens (Dcs) is interstratified with pillow greenstone in the southern section of the klippe (Location H, Fig. 2; and Fig. 7). In outcrop, classic aphanitic, green to reddish brown pillow structures are apparent (Fig. 8). The greenstone unit is coherent and lacks a pervasive tectonic fabric, only exhibiting a faint foliation near the basal contacts with the Trinity ultramafic complex, (Location I

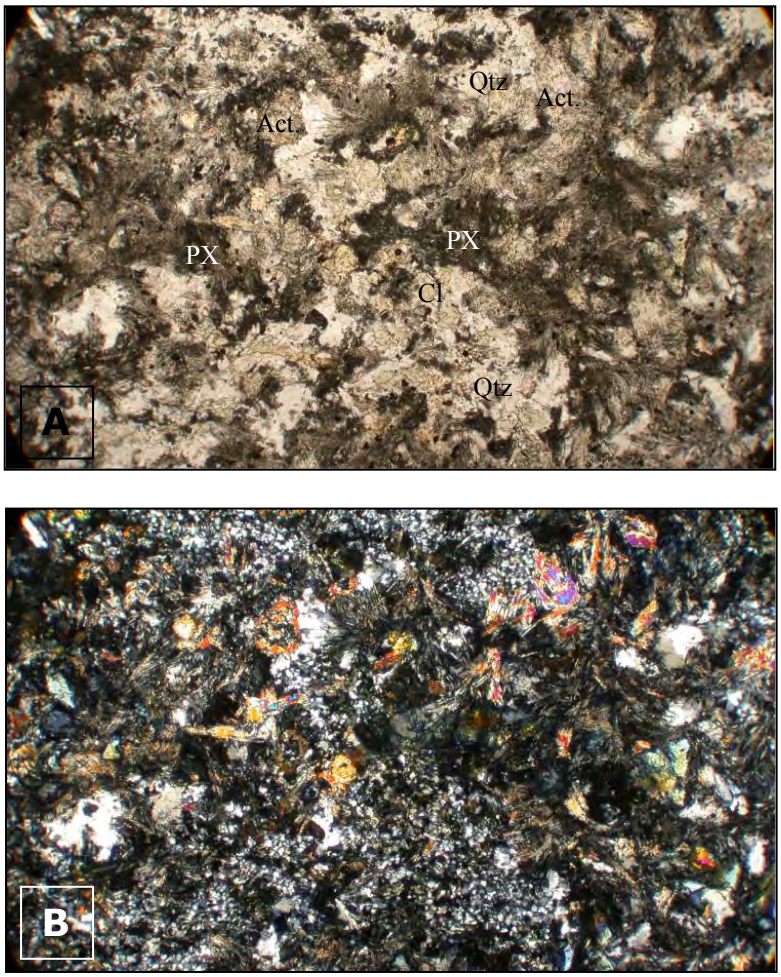


Figure 6: Photomicrographs of Panther Rock greenstone pillows, Dc. Sample PR-1, Location F (Fig. 2), width of image is 3.2 mm, A) in plane polarized light and B) in cross polarized light. Mineralogy includes radial, fiberous actinolite (Act.), chlorite (Cl), quartz (Qtz.), euhedral clinozoisite, square 0.5mm relict pyroxene (PX) replaced by chlorite, and fine-grained clay.

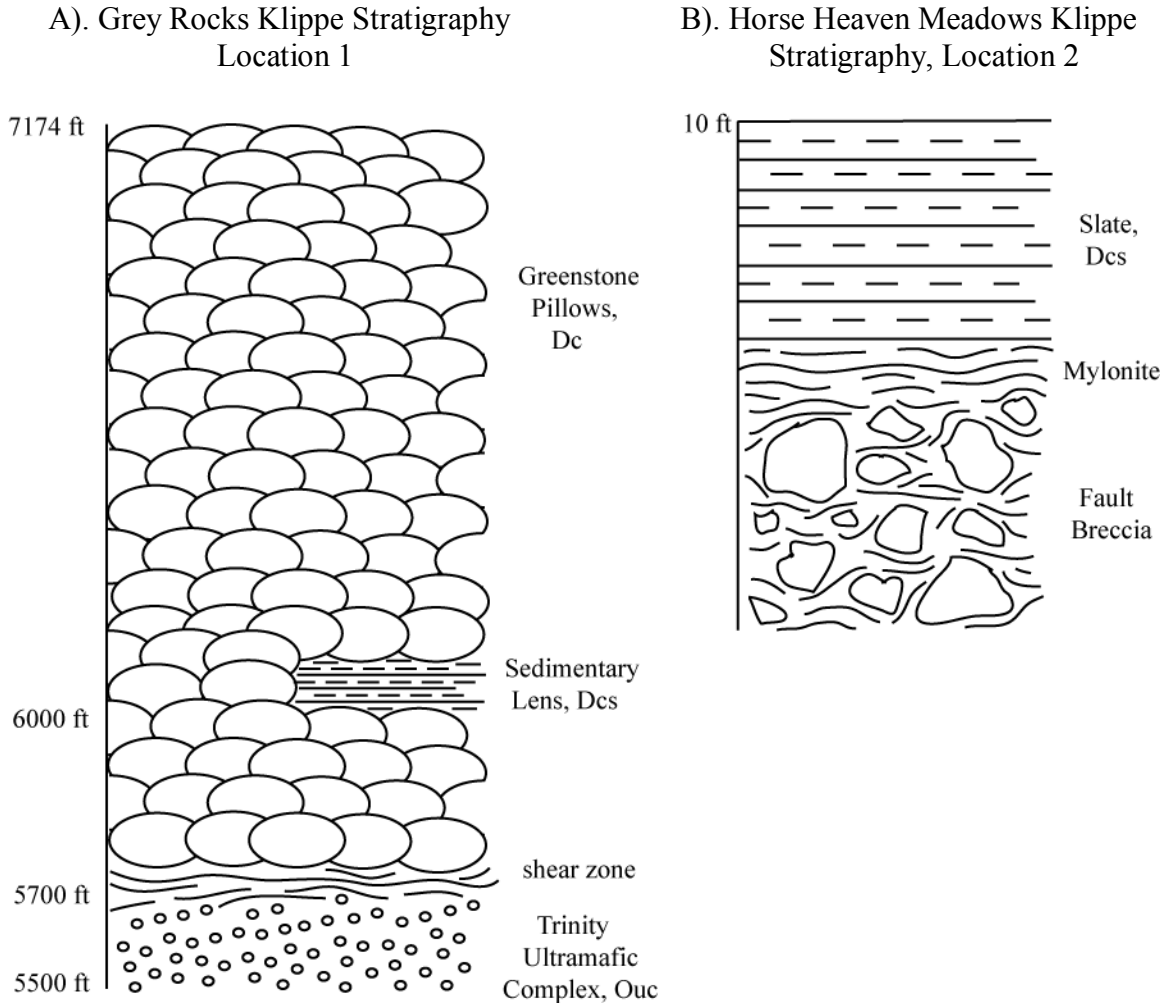


Figure 7: Stratigraphic columns of Grey Rocks klippe (Location 1, Fig. 2), and Horse Heaven Meadows klippe (Location 2, Fig. 2).

along Mears Ridge and in the saddle at Location J, Fig. 2). The basal contact of the greenstone is a fault and will be further discussed in the Structure section. The minimum thickness of the Grey Rocks klippe greenstone is 340 meters.

The greenstone pillows of Grey Rock klippe have a fine-grained intergranular texture and are comprised mainly of chlorite, plagioclase, microcrystalline quartz, clinozoisite, opaque minerals, relict clinopyroxene altering to actinolite and chlorite, and fine-grained clays (Fig. 9). Plagioclase display sparrow-tail edges and are altering to epidote group minerals and clays. The intergranular texture is consistent with pillow basalts and the sparrow-tail plagioclase laths are indicative of rapid cooling. Based on the mineral assemblage: albite-actinolite-chlorite-epidote observed in the Panther Rock and Grey Rocks greenstones, these rocks have been metamorphosed to greenschist facies.

Meta-Volcanic/Sedimentary unit (Dcs). The Grey Rocks klippe metasedimentary/metavolcanic lens, Dcs, consists of both fine-grained slate and volcaniclastic tuffaceous beds that are discontinuous, conformable, and syndepositional with the greenstone unit (Location G, Fig. 2). An exact thickness was not determined because of the lenticular nature of the unit, but the maximum thickness of the metasedimentary/metavolcanic lens is less than 60 meters thick. The fissile slate is dark reddish brown to dark brown and fine-grained. The dark brown tuffaceous medium pebble breccia is a massive, unsorted, angular, polymictic, clast-supported volcanic medium pebble breccia with a fine-grained quartz, chlorite, and clay matrix (Fig. 10). Clast sizes range up to 0.75 cm. Clast compositions include a) microcrystalline quartz, b) aligned fine-grained plagioclase, epidote, and chlorite, and c) single grain clasts of quartz

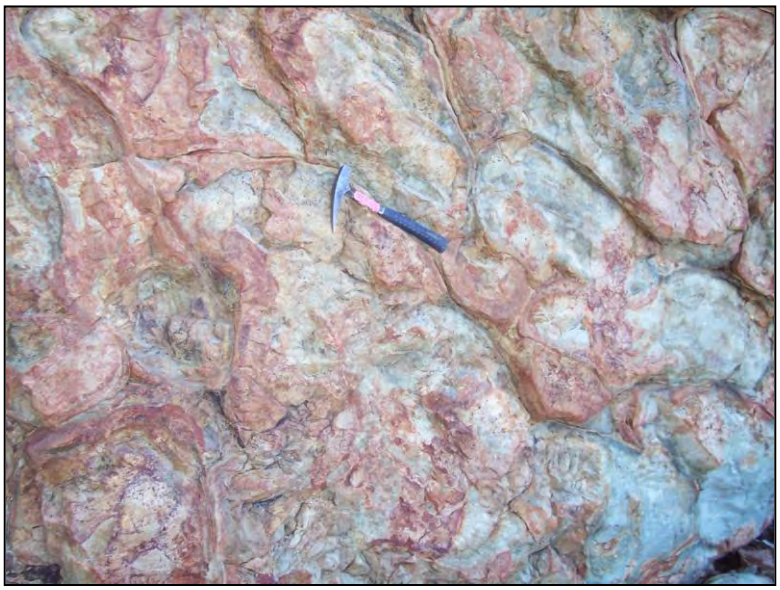


Figure 8: Photograph of greenstone from the Grey Rocks klippe, Dc (Location H, Fig. 2). Photograph depicts the classic pillow structure typical of greenstone in the study area. View is to the NW. Hammer for scale.

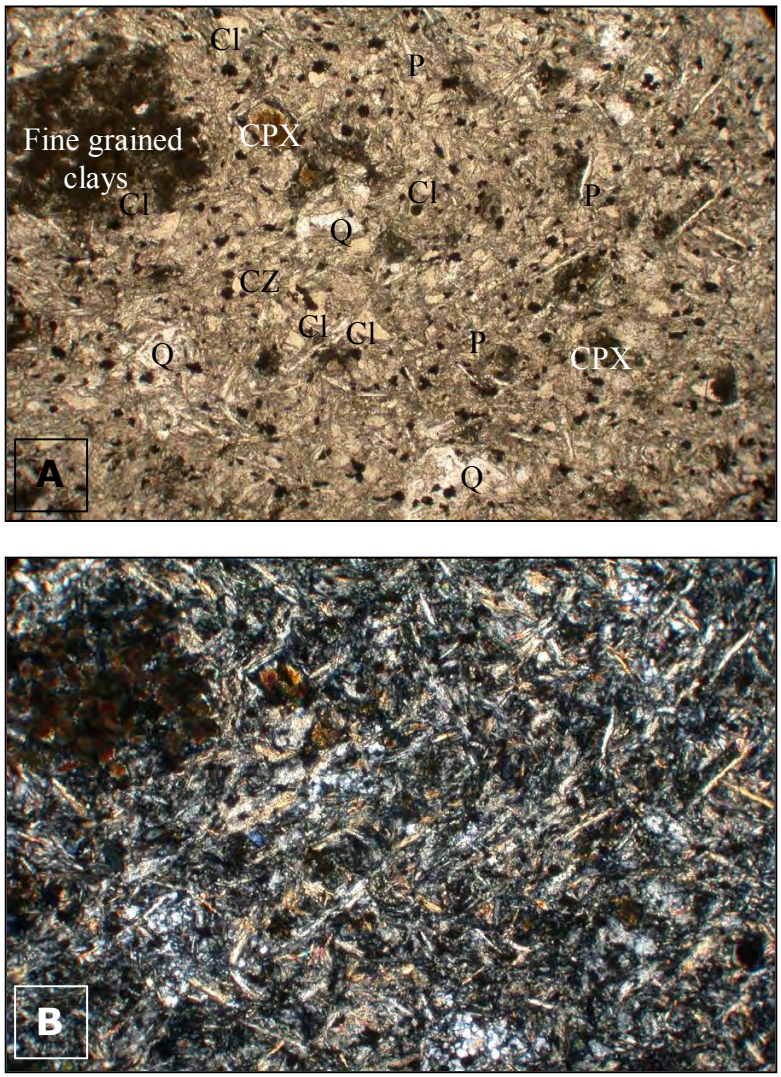


Figure 9: Photomicrographs of greenstone from Grey Rocks klippe, Dc. Sample GR-6, Location H (Fig. 2), width of image is 3.2 mm, A) in plane polarized light and B) in cross polarized light. Mineralogy includes microcrystalline quartz (Q), relict plagioclase crystals degrading to saussurite (P), large unidentified minerals degrading to fine-grain clay, and relict clinopyroxenes (CPX) rimmed with chlorite. Secondary alteration minerals include clinozoisite (CZ), saussurite, chlorite (Cl), and fine-grained clay. Plagioclase crystals display swallow-tail textures typical of pillow basalts.

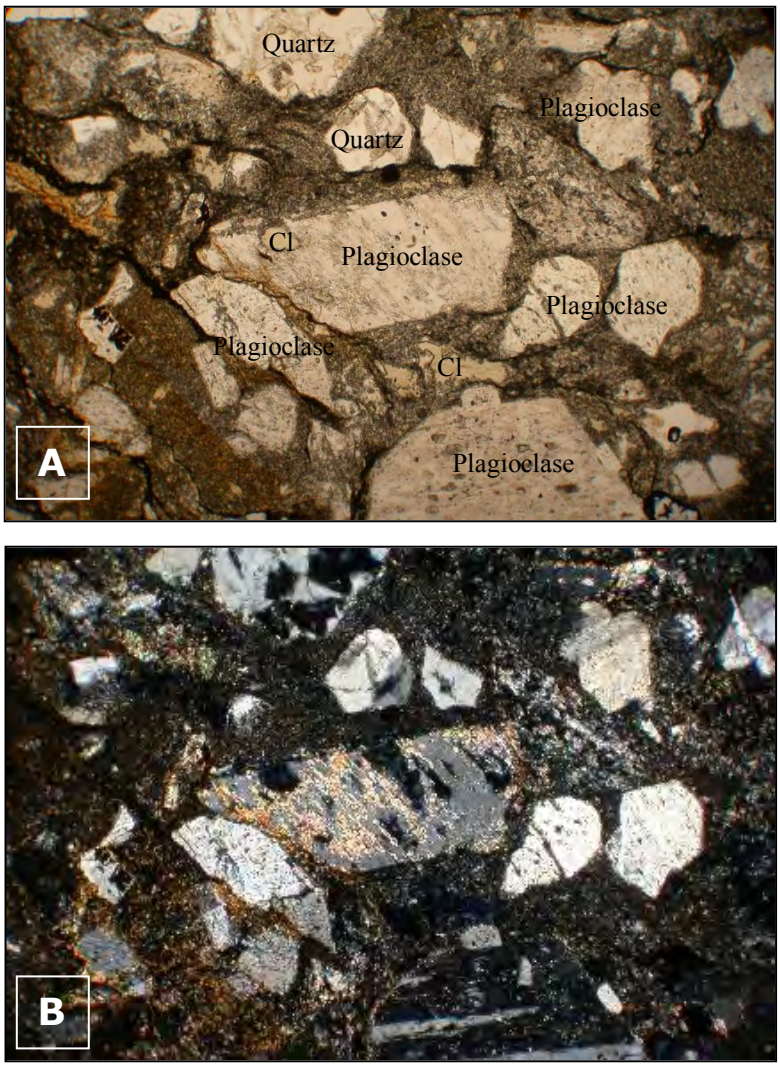


Figure 10: Photomicrographs of tuffaceous breccia, from the Grey Rocks klippe metasedimentary unit, Dcs. Sample SV-6, Location G (Fig. 2), width of image is 3.2 mm, A) in plane polarized light and B) in cross polarized light. Poorly-sorted, angular, polymictic, clast-supported tuffaceous medium pebble breccia with a fine-grained quartz, chlorite, and clay matrix. Pebble to sand sized clasts include: clasts of microcrystalline quartz; diorite clasts comprised of aligned fine-grain plagioclase, epidote, and chlorite (not photographed); and single grain clasts of quartz, plagioclase, and chlorite (Cl). Large sections of the matrix appear to have been recrystallized into chlorite, possibly replacing volcanic glass.

plagioclase, and chlorite (originally clasts of volcanic glass). Large sections of the matrix appear to have been recrystallized into chlorite, possibly replacing original volcanic glass.

Horse Heaven Meadows Klippe: Slate, Tuff, and Volcanic Breccia (Dcs)

Horse Heaven Meadows klippe consists of tilted, highly fractured, fine-grained dark reddish brown to dark brown slate with minor amounts of interbedded tuffs and volcanic breccias. The metasedimentary unit is juxtaposed with the Trinity ultramafic complex by faults at all contacts. An accurate thickness is hard to determine because the klippe is tilted, has irregular bedding, and is highly fractured. At the western edge (Location K, Fig. 2), a coherent section approximately 20 meters thick is exposed; however, the sedimentary unit appears to be at least 60 meters thick based on dip measurements, exposure width, and topography.

Tuffs and volcanic breccias display maximum clast sizes ranging from sand to cobbles. An example of a coarse tuff is exposed at Location K (Fig. 2) and in Figure 11. This glass-rich, matrix-supported unit exhibits poorly sorted, angular to sub-rounded clasts of volcanic glass, single grains of subhedral and microcrystalline quartz, and subhedral relict grains now comprised of actinolite. The fine-grained matrix is composed of chlorite, micas, volcanic glass, and fine-grained clays.

The pyroclastic breccia (Location L, Fig. 2) is a discontinuous, unsorted, angular, polymictic, matrix-supported metavolcanic unit with clasts ranging up to cobble size and a chlorite, microcrystalline quartz, epidote, and fine-grained clay matrix (Fig. 12). Clasts are volcanic, containing a) epidote and quartz, b) microcrystalline quartz, c)

Figure 11: Tilted shale and sandy tuff beds from the NW margin of the Horse Heaven Meadows klippe, Location K (Fig. 2). View is to the SE with rock hammer for scale.

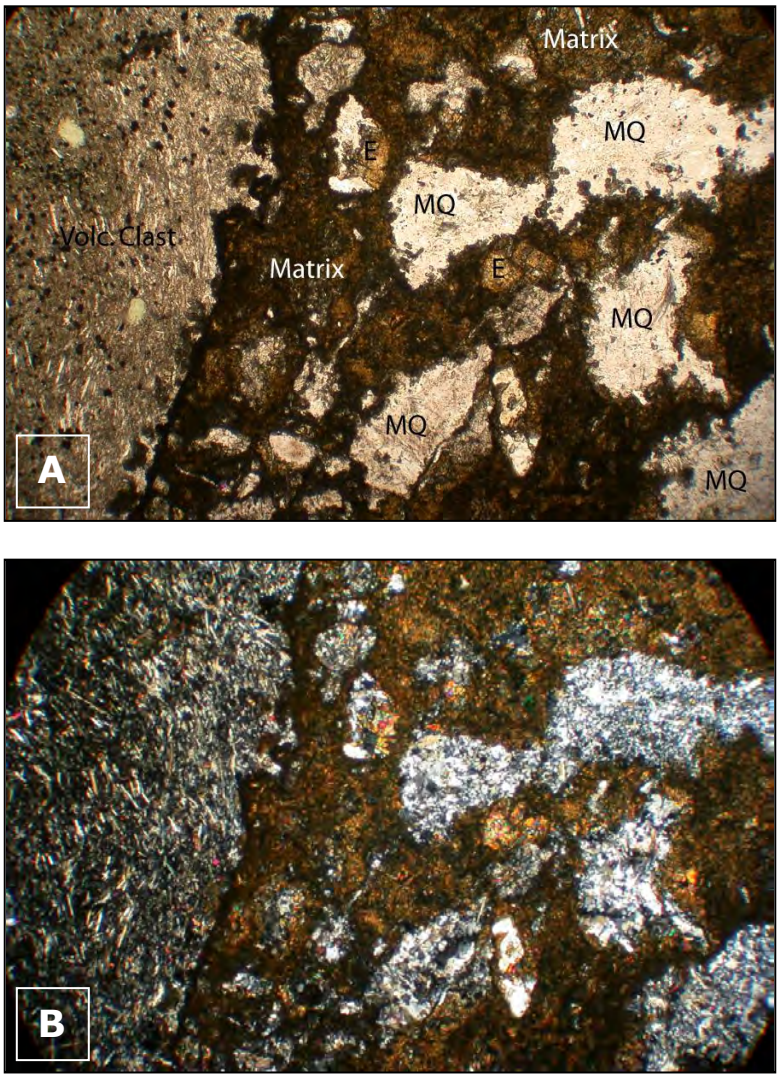


Figure 12: Photomicrographs of pyroclastic breccia of the Horse Heaven Meadows klippe, Dcs. Sample SV-2, Location L (Fig. 2), width of image is 3.2 mm, A) in plane polarized light and B) in cross polarized light. Unsorted, angular, polymictic, matrix supported pyroclastic breccia with a chlorite, microcrystalline quartz (MQ), epidote (E), and fine-grained clay matrix. Clasts consist of 1) epidote and quartz; 2) microcrystalline quartz; 3) microcrystalline quartz with chlorite, plagioclase laths, and opaque minerals; and 4) fiberous actinolite, microcrystalline quartz, chlorite, epidote, and saussurite.

microcrystalline quartz with chlorite, plagioclase laths, and opaque minerals, and d) fibrous actinolite, microcrystalline quartz, chlorite, epidote, and saussurite (relict plagioclase). At the outcrop scale, clast boundaries are faint but become more distinguishable in thin-section. The blending of clast boundaries is likely due to the aphanitic and epidote overgrowths that have overprinted the unit and original grain boundaries.

Felsic Dikes

Two felsic dikes cross-cut the foliation in fault breccia at the base of the Horse Heaven Meadows klippe (Location 2, Fig. 2), and a third intrudes parallel to foliation in fault rocks in the shear zone at the base of the Grey Rocks klippe (Location 1, Fig. 2). The dikes are fine-grained, felsic, and only observed in the lower plate and fault zone rocks. The dikes have not been dated.

The two felsic dikes that intrude fault breccia (Location 2, Fig. 2) are 4 meters apart, 1.3 meters thick, strike parallel at N32E, dip 76N, and are similar in composition and texture. The allotriomorphic granular grano-dioritic dike consists mainly of <0.5 mm quartz, 1 to 1.25 mm mantled, poikilitic plagioclase with epidote group inclusions, and minor orthoclase feldspar (Fig. 13). Other minerals include chlorite, saussurite, and reddish brown opaque minerals.

The aphanitic rhyolite dike, classified based on the Jensen cation plot (Jensen, 1976), consists mainly of microcrystalline to <0.4 mm quartz, <0.5mm poikilitic plagioclase with epidote group inclusions, and minor anorthoclase feldspar (Fig.14).

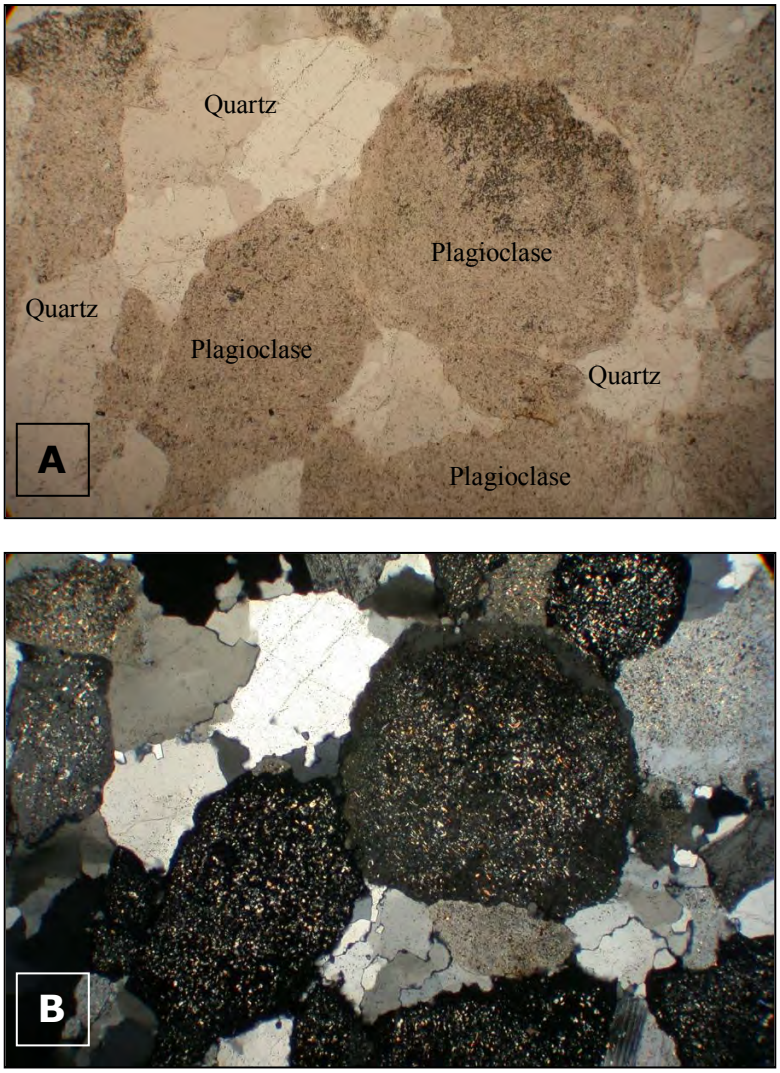


Figure 13: Photomicrographs of allotriomorphic granular grano-diorite dike. Sample D-2, Location 2 (Fig. 2), width of image is 3.2 mm, A) in plane polarized light and B) in cross polarized light. Dike is comprised mainly of coarse (1.25 to 1mm), mantled, poikilitic plagioclase, orthoclase, and quartz. Plagioclase contains epidote group inclusions and has altered to saussurite and chlorite.

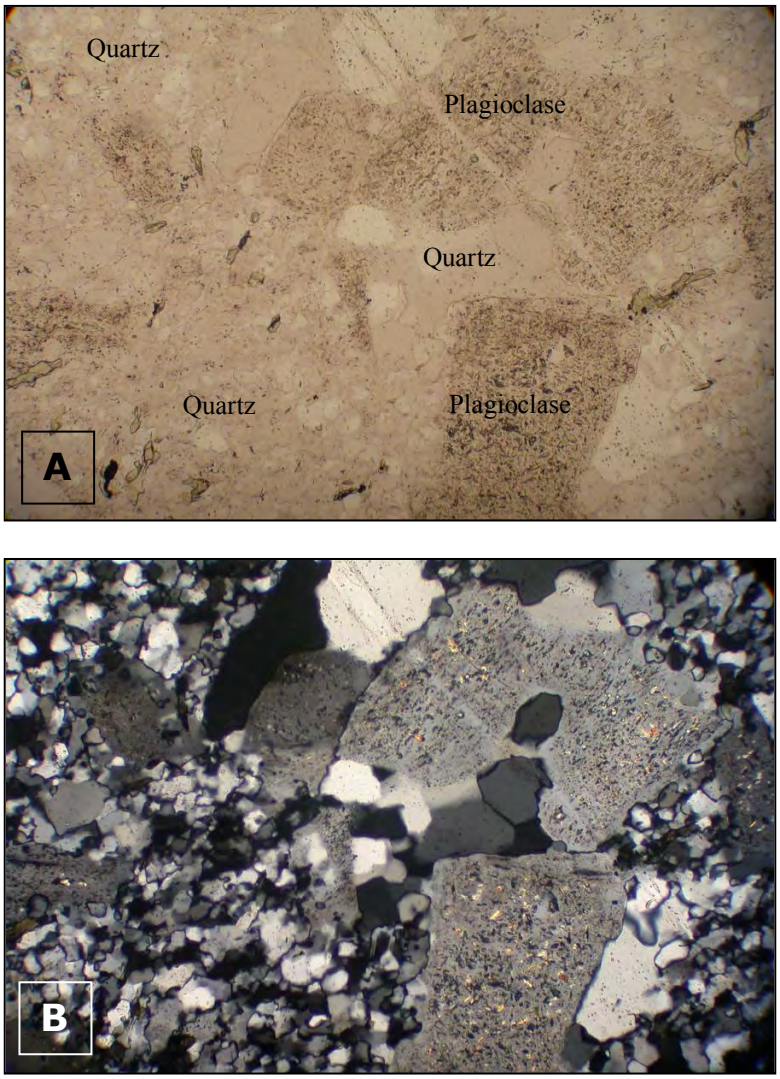


Figure 14: Photomicrographs of aphanitic rhyolite dike. Sample D-1, Location 2 (Fig. 2), width of image 1.37 mm, A) in plane polarized light and B) in cross polarized light. Dike is comprised of fine-grain (0.5 mm) plagioclase, anorthoclase feldspar, and coarse grain to microcrystalline quartz, with some secondary alteration to chlorite and saussurite. Plagioclase crystals display mantled edges and poikilitic texture with epidote group inclusions.

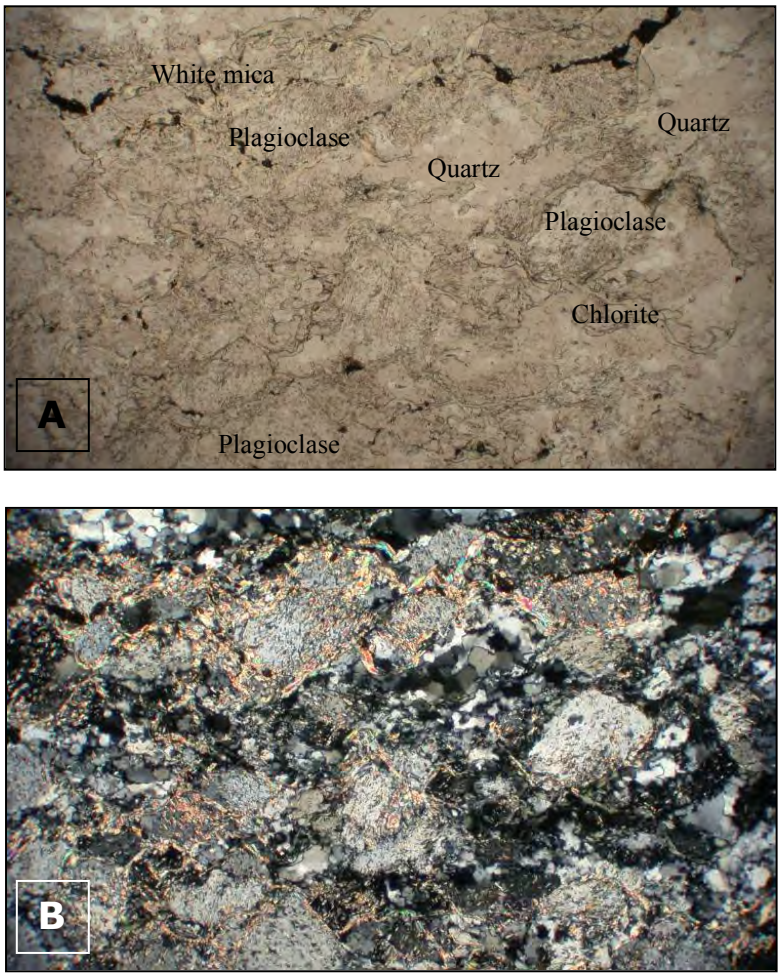


Figure 15: Photomicrograph of aphanitic rhyolite dike intruding parallel to the basal fault of Grey Rocks klippe. Sample SHZD-8, Location 1 (Fig. 2), width of image 3.2 mm, A) in plane polarized light and B) in cross polarized light. Dike consists mainly of strongly aligned, poikilitic plagioclase containing fine-grain epidote group inclusions, minor amounts of orthoclase feldspar, and quartz, in a groundmass of chlorite, fine-grained white mica, saussurite, and fine-grained clay. Dike displays anastomosing, moderately rough foliation (~horizontal in this photomicrograph) defined by thin bands of white mica and quartz that flow around the plagioclase crystals creating augens.

Some feldspar crystals exhibit mantling, myrmekite texture, and grid like twinning typical of anorthoclase feldspar in hypabyssal intrusive rocks. Secondary minerals include chlorite, saussurite, and reddish brown opaque minerals. The rhyolite dike displays chilled margins.

The third aphanitic rhyolite dike, classified based on the Jensen cation plot (Jensen, 1976), is about 1 meter thick and intrudes parallel to the fault zone in the Grey Rocks klippe basal shear zone (Location 1, Fig. 2). Microscopic shear fabric, observed in thin-section, shows that the sheared rhyolite consists mainly of strongly aligned, poikilitic plagioclase containing fine-grained epidote group inclusions and quartz, with lesser amounts of orthoclase feldspar, chlorite, fine-grained white micas, saussurite, and fine-grained clays. An anastomozing and moderately rough foliation, defined by thin bands of white mica and quartz, flows around the plagioclase crystals creating augens (Fig. 15). Quartz veins cross-cut the dike approximately perpendicular to foliation.

Quaternary Deposits

Quaternary deposits in the Grey Rocks, Panther rock, and Horse Heaven Meadows area include glacial moraines and till, alluvial deposits, and a variety of landslides including debris slides and slumps. Because the glacial history is beyond the scope of this project, only the large landslide deposits near bedrock contacts were mapped (Plate 1 and Fig. 2).

The surficial deposits in the area are apparent in airphotos, where massive landslides (i.e. Location M), glacial moraines (i.e. Location N), glacial erratics (i.e. near

Location 3), and poorly sorted glacial till (everywhere) cover the landscape. Grey Rocks ridge has been carved out, creating cirques, and glacial erratics have collected on the slopes below.

Large Quaternary landslide and slump deposits (Qu) occur along the eastern edge of the Horse Heaven Meadows klippe (near Locations 4 and M, Fig. 2) where they obscure the fault contact (Fig. 16). The landslides and scarps start within the slate and the toes extend to and locally fill Castle Creek valley. The coherent slump block at Location M (Fig. 2) is about 20 meters high and consists of slate. This coherent block is surrounded by a debris flow deposit consisting of an incoherent mixture of metasedimentary blocks, Trinity mafic and ultramafic blocks, and indiscernible soil.

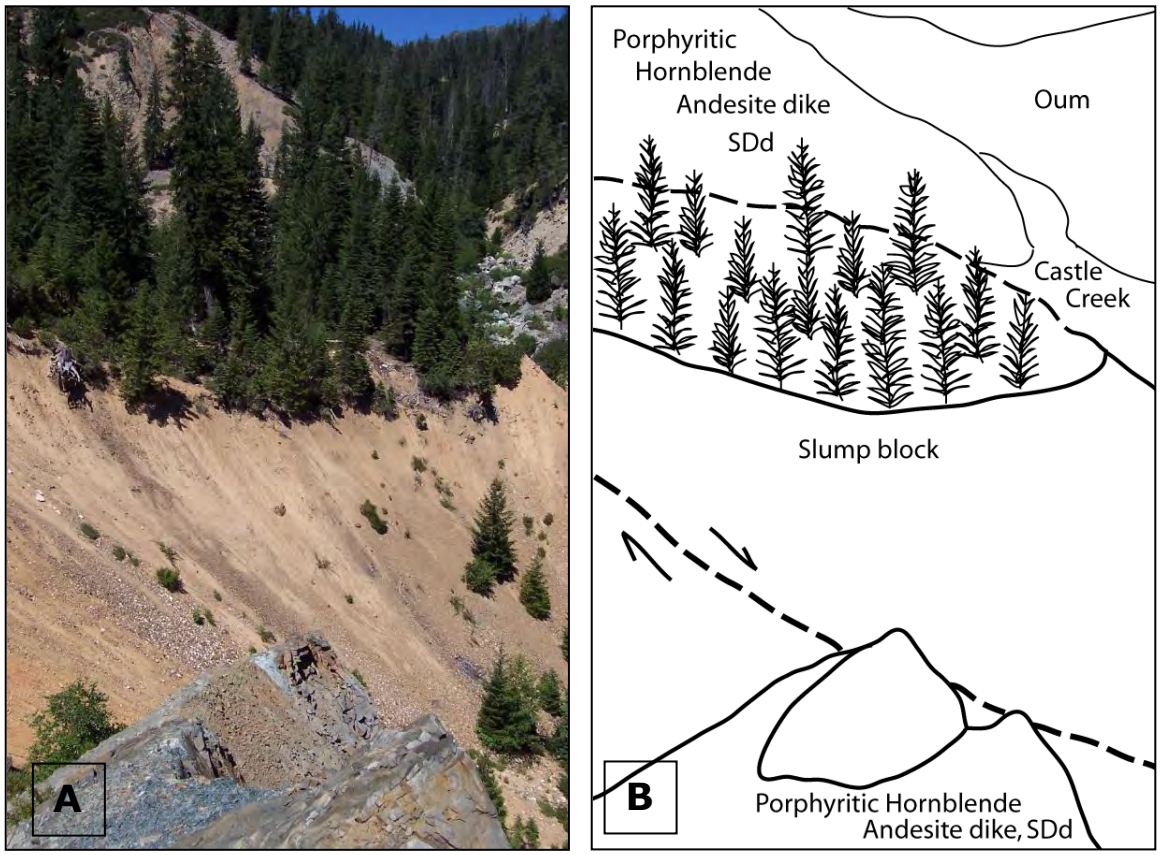


Figure 16: Photograph looking north upstream of Castle Creek at northeast margin of Horse Heaven Meadows klippe (Location 4, Fig. 2). A) Photograph and B) sketch depict a slump block of upper plate shale that has slid into Castle Creek.

GEOCHEMISTRY

Geochemical studies have proved useful for determining the origin and metamorphic history of rocks within the Eastern Klamath Belt (e.g. Lapierre et al., 1985; Brouxel et al., 1987; Brouxel and Lapierre, 1988; Brouxel et al., 1988; Metcalf, et al., 2000). The geochemical analyses conducted in this project were designed to test proposed stratigraphic correlations between 1) the greenstones of the Grey Rocks and Panther Rock klippes and the Copley Greenstone, and 2) felsic dikes in the Grey Rocks project area and felsic dikes found at the other fault contacts in the Klamath Mountains Provenance (e.g. Cashman and Elder, 2002). Geochemical analyses also were used to look for evidence of the incorporation of upper and lower plate components in fault zone samples.

GREENSTONE ANALYSES

Rocks from a similar source will display similar geochemical signatures (Rollinson, 1993). To determine whether the greenstones of Panther Rock and Grey Rocks klippes were derived from the same source as the Copley Greenstone, samples from the three greenstones were crushed, powdered, and analyzed using x-ray fluorescence spectrometry (Table 1, Fig. 2).

Pillow basalts typically undergo hydrothermal alteration during formation, as heated water circulates through the fresh basalt (Humphris and Thompson, 1978a). In the process of hydrothermal alteration, both major and trace element compositions are commonly altered. Bulk elements Al_2O_3, TiO_2, and P_2O_5 are typically more stable than

other major elements. However, the relative abundances of some more mobile elements, such as CaO and MgO, can be used to determine the extent of hydrothermal alteration (Humphris and Thompson, 1978a).

Humphris and Thompson (1978a) found a pattern of 1:1 CaO replacement by MgO in hydrothermally altered basalts. Circulating water deposits MgO and removes CaO. Graphing CaO against MgO content from fresh and altered basalts results in a negative trend that signifies an increase in hydrothermal alteration. Samples displaying extensive hydrothermal alteration no longer reflect original composition. To determine whether Panther Rock klippe, Grey Rocks klippe, and Copley Greenstone have been too altered for comparison, their CaO and MgO content have been plotted with both fresh and altered samples from Humphris and Thompson (1978a) (Fig. 17).

The replacement trend of MgO for CaO is defined by basalt samples from Humphris and Thompson (1978a) and outlined by the dashed line (Fig. 17). Greenstone samples from Grey Rocks klippe, Panther Rock klippe, and the Copley Greenstone exhibit generally varying extents of hydrothermal alteration, plotting both within and outside the defined trend. Sample GR-6 is the only greenstone sample that plots near fresh basalts, indicating the least amount of hydrothermal alteration. This particular greenstone sample is from a site located the farthest from the basal fault zone (Location H, Fig 2). The other greenstone samples are located closer to fault zones (Fig. 2) and have experienced increased hydrothermal alteration.

Samples plotting with values outside the dashed line in Figure 17 have been left out of further comparisons of bulk and trace compositional values. Other studies that

Table 1. Geochemical values of samples from Grey Rocks project. *Data from petrology lab at CSU Fresno. (page 1 of 6)

SAMPLE NUMBER	LOC	NAME	MAP UNIT	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O
Upper Plate														
SV-1	L	Copley	Dcs	57.11	0.695	14.60	8.38	0.10	6.33	8.61	4.11	0.02	0.043	7.68
SV-2	L	Copley	Dcs	55.74	0.719	16.59	7.49	0.09	4.88	8.87	5.52	0.07	0.033	8.12
SV-3	K	Copley	Dcs											
SV-4	S	Copley	Dcs	78.64	0.165	11.15	2.38	0.05	1.11	3.43	0.53	2.50	0.033	8.31
SV-5	S	Copley	Dcs	76.33	0.273	12.36	3.19	0.07	1.79	2.19	2.04	1.72	0.044	8.32
SV-6	G	Copley	Dcs	57.09	0.872	20.44	11.31	0.10	6.07	0.07	2.16	1.80	0.092	12.57
GR-1	T	Copley	Dc	61.66	0.497	12.10	6.61	0.10	9.57	8.01	0.55	0.84	0.065	7.25
GR-2	T	Copley	Dc	58.30	0.591	14.64	5.95	0.09	11.46	4.36	4.45	0.04	0.112	10.22
GR-3	T	Copley	Dc	56.08	0.805	14.92	7.92	0.12	8.49	8.76	2.66	0.17	0.065	7.93
GR-4	V	Copley	Dc	49.31	0.877	17.73	8.76	0.13	12.79	6.61	2.63	1.08	0.078	9.82
GR-5	V	Copley	Dc	57.97	0.579	12.74	6.34	0.11	6.72	15.17	0.01	0.33	0.032	6.69
GR-6	H	Copley	Dc	55.17	0.678	14.07	7.74	0.13	8.45	10.56	3.07	0.03	0.087	8.42
PR-1	F	Copley	Dc	65.75	0.476	11.14	5.51	0.09	7.48	6.75	2.73	0.04	0.021	3.14
PR-2	F	Copley	Dc	44.70	0.582	13.50	9.51	0.24	17.45	13.23	0.68	0.07	0.044	8.76
PR-3	F	Copley	Dc	50.33	0.460	13.56	7.06	0.23	14.69	10.95	2.09	0.60	0.034	12.9
PR-4	F	Copley	Dc	45.56	0.649	13.33	9.30	0.24	18.22	11.65	0.79	0.23	0.022	8.96
PR-5	F	Copley	Dc	62.74	0.571	14.02	5.87	0.08	9.12	3.51	3.93	0.09	0.077	8.9
PR-6	F	Copley	Dc	53.31	0.633	13.96	8.19	0.13	13.76	7.99	1.08	0.92	0.033	8.22
PR-7	F	Copley	Dc	57.77	0.567	12.32	6.51	0.11	11.58	7.87	1.44	1.82	0.021	6.44
COP-1		Copley	Dc	58.45	0.486	15.32	9.38	0.28	9.93	3.76	2.06	0.31	0.033	9.36
COP-3		Copley	Dc	54.21	0.844	15.10	9.21	0.16	9.32	7.72	3.00	0.36	0.078	9.83
COP-4		Copley	Dc	58.25	0.776	14.02	8.77	0.13	7.92	6.91	3.04	0.10	0.078	9.69
COP-5		Copley	Dc	52.85	0.555	17.48	11.20	0.33	12.45	2.89	1.88	0.33	0.034	11.46
COP-6		Copley	Dc	50.54	0.474	12.92	6.93	0.13	10.67	15.27	2.96	0.06	0.049	17.66
COP-7		Copley	Dc	54.36	0.540	13.07	7.98	0.11	12.41	8.02	3.44	0.03	0.033	9.05
COP-8		Copley	Dc	50.62	0.471	12.92	6.93	0.13	10.59	15.26	2.96	0.07	0.048	17.15
COP-9		Copley	Dc	52.29	0.809	16.42	7.62	0.14	9.58	6.85	4.60	1.62	0.069	13.34
COP-10		Copley	Dc	53.46	0.794	15.89	8.24	0.16	10.10	5.60	5.37	0.28	0.093	14.27
COP-11		Copley	Dc	55.11	0.666	14.88	7.39	0.15	9.78	6.21	5.56	0.18	0.079	11.26

Table 1 continued. (page 2 of 6)

SAMPLE NUMBER	LOC	NAME	MAP UNIT	Ba	Ce	Cl	Co	Cr	Cs	Cu	F	Ga	Hf	La	Nd	Ni	Pb
Upper Plate																	
SV-1	L	Copley	Dcs														
SV-2	L	Copley	Dcs	16.3	0	33.3	32.2	143.9	2	321.4	100.7	17.7	3.9	22.9	19	33.3	0.1
SV-3	K	Copley	Dcs														
SV-4	S	Copley	Dcs	4064.1	362.2	15.1	0	154.3	4.4	18.1	0	8.6	7.1	31.9	22.9	29.6	10.6
SV-5	S	Copley	Dcs	932.8	73.3	20.5	4.7	105.5	4.1	26.6	0	10.9	7.5	43.3	26	27.7	4
SV-6	G	Copley	Dcs	577.5	64.3	33.3	63.5	76.8	2.3	29.7	752.5	18.2	4.4	45.6	53.8	37.6	8.9
GR-1	T	Copley	Dc	37.2	0	26.1	31.5	321	2.3	130.2	139.6	11.4	4.2	10.6	8.8	91.1	0
GR-2	T	Copley	Dc	45.5	1.3	24.1	36.5	270.2	3.2	20.7	136.1	5.2	5.4	33.9	26.4	115.5	0
GR-3	T	Copley	Dc	18	0	20.8	39.5	214.8	1.9	22.7	157	15.6	3.8	15.1	14.5	33.7	0.05
GR-4	V	Copley	Dc	64.1	7.8	25.1	50.9	312.8	1.9	9.7	136.5	16.6	3.6	21.8	25.1	95.3	0
GR-5	V	Copley	Dc	0	0	19.3	16.4	376.6	1.6	98.5	86.1	15.6	3	0	0	73.1	0
GR-6	H	Copley	Dc	0	0	30.2	35.5	347.3	1.7	24.9	233.3	15.2	3.2	7.9	5.1	73.7	0
PR-1	F	Copley	Dc	1.4	0	19.9	28.8	567.1	2.9	11.8	155.4	10.6	4.6	11	9	140.5	2.3
PR-2	F	Copley	Dc	0	0	21.4	54.3	536.8	0.9	0	251.1	12.9	1.9	0.3	7.9	151.2	0
PR-3	F	Copley	Dc	34.6	0	29.6	37.1	429.4	2.4	27	0	5.3	4.1	8.2	12.7	112.8	0
PR-4	F	Copley	Dc	0	0	25.3	55	557.8	1.2	41.9	249.7	10.1	2.4	11.3	10.2	149.7	1.9
PR-5	F	Copley	Dc	35.8	0	29.3	33.3	347.2	3.4	41	0	4.8	5.4	29.3	28	124.3	0
PR-6	F	Copley	Dc	39	0	33.6	45.2	336.5	2	38	82	9.2	3.8	15.4	12.2	107.8	0.6
PR-7	F	Copley	Dc	78.5	0	36	31.2	289.5	2.5	43.8	8	8.1	4.2	7.4	7.7	89.3	0
COP-1		Copley	Dc	59.3	5.9	21.2	56.8	158.7	2.1	281.4	499.9	14.6	4.1	26.2	36.1	40.7	0.8
COP-3		Copley	Dc	60.9	7.3	31.4	49.1	215.2	1.7	41.9	323	16.2	3.6	19.4	22.5	36.6	2.6
COP-4		Copley	Dc	50.4	0.6	22.5	45.8	254.4	2	58.3	193.4	16.9	4	21.8	22.2	42.3	7.1
COP-5		Copley	Dc	68.3	9.1	22.4	69.7	151.5	1.7	432.4	603.9	17.6	3.8	39.1	42.9	40.7	0.4
COP-6		Copley	Dc	15.2	0	50.3	29.7	367.8	2.6	27.4	282.4	5.1	4.4	11.8	0	120.2	0.3
COP-7		Copley	Dc	10.7	0	32.4	46.3	769.4	2.2	62	413.4	11	3.9	19.5	22.2	155.7	0
COP-8		Copley	Dc	8.7	0	52.3	29.8	373	2.6	26	301.5	5.6	4.2	12.3	0	122.1	0
COP-9		Copley	Dc	362.0	28.3	28.4	36.9	155.7	2.4	76.5	64.1	13.5	4.2	17.3	21.5	59.5	3.8
COP-10		Copley	Dc	77.4	7.5	28.9	45.9	73.3	2.4	109.5	44.9	14.5	4.0	26.5	23.9	35.2	0.0
COP-11		Copley	Dc	45.1	2.0	31.7	41.0	52.6	2.6	91.4	173.6	13.2	4.3	20.7	22.0	43.0	0.7

Table 1 continued. (page 3 of 6)

SAMPLE NUMBER	Rb	S	Sc	Sr	Ta	Th	U	V	Zn	Zr
Upper plate										
SV-1										
SV-2	3.5	24.5	27.2	172.9	0.8	8.2	1.4	295.9	41.9	66.9
SV-3										
SV-4	54.3	28.8	9.3	49.5	1.5	30.1	4.8	0	24.1	139.2
SV-5	49.2	106.9	7.4	122.6	1.6	30.5	5.1	15.1	29.5	163.9
SV-6	54.9	41.3	7.4	80.4	0.9	10.7	1.6	214.8	177.7	100.2
GR-1	15.7	55.9	22.3	56.6	0.9	11.9	1.9	302	46.5	32.4
GR-2	12.4	22.2	14.6	106.5	1.3	18.9	3.4	107.1	50.4	48.5
GR-3	5	23.5	25	311.5	0.7	7.9	1.4	226.8	48	78.2
GR-4	13.7	24.1	19.8	116.5	0.7	6.7	1.1	242.8	67.5	56.6
GR-5	4.2	21.6	40	41.9	0.6	5.1	0.8	220.6	29.8	28.6
GR-6	2	23.5	28.9	65.3	0.7	5.9	0.9	265.3	49.5	32.8
PR-1	10	25.5	22.6	39.7	1.1	16.8	2.7	215.2	37.3	26.2
PR-2	0	20.8	36.5	161	0.4	0	0	198.7	66.9	30.5
PR-3	14.5	21.9	28.4	45.3	0.9	11.2	2	174.5	60.9	23.2
PR-4	0.2	18.6	33.1	96.5	0.4	0.3	0	182.1	70.5	26.5
PR-5	13.9	25.4	12.7	51.6	1.3	19.7	3.5	122.1	53.4	40.3
PR-6	16.4	23.8	22.7	180.2	0.8	7.6	1.3	163.6	54.9	49.4
PR-7	33.9	21.1	22.7	125.7	1	12.1	2.1	160.1	49.7	42.9
COP-1	9.5	28.3	14.5	121.4	0.9	8.5	1.5	206.7	247.3	51.8
COP-3	5	32.9	22.9	236.6	0.7	5.7	1	246.8	66.9	72.3
COP-4	3.5	26.7	20.8	256.2	0.8	7.8	1.3	245.7	62.5	71.9
COP-5	6.6	29.8	13	89.6	0.8	5.2	0.8	214.5	321.5	49.9
COP-6	8.2	78.1	35.6	57.8	0.9	13.4	2.3	168.8	48.7	31.8
COP-7	4.5	27.5	23.4	70.9	0.9	9.6	1.6	188.1	49	35.5
COP-8	7.6	80.3	35.8	58.2	0.9	13	2.3	164.1	49	32.1
COP-9	20.5	65.3	20.8	141.7	0.9	10.9	1.9	236.2	52.1	58.7
COP-10	7.6	57.3	18.8	57.3	0.9	11.4	1.9	272.0	64.2	46.1
COP-11	8.1	41.0	19.6	132.6	1.0	13.1	2.2	218.6	54.9	49.1

Table 1 continued. (page 4 of 6) **Data obtained from Petrology lab at CSU Fresno*

SAMPLE NUMBER	LOC	NAME	MAP UNIT	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O	TOTAL
Fault Rocks															
COP-12*		Copley	Dc	62.08	0.921	17.96	8.61	0.26	6.41	0.08	1.76	1.84	0.083		100.80
COP-13*		Copley	Dc	50.88	0.410	12.09	29.14	0.06	7.13	0.02	0.22	0.03	0.013		103.30
C0P-14*		Copley	Dc	60.94	0.403	14.85	6.98	0.06	2.48	13.76	0.39	0.12	0.022		100.06
SHZ-1*	4	Copley	Dcs	58.14	0.090	3.14	6.75	0.14	27.35	4.10	0.25	0.03	0.013		100.26
SHZ-2	2	Copley	Dcs												
SHZ-3*	2		Fault	54.75	0.050	4.68	10.01	0.19	23.85	6.05	0.36	0.04	0.024		100.27
SHZ-4*	4		Fault	55.83	0.120	2.57	5.01	0.12	24.28	11.29	0.68	0.08	0.026		100.33
SHZ-5*	3		Fault	61.35	0.050	1.36	4.50	0.04	27.63	4.79	0.25	0.02	0.014		100.73
SHZ-6*	1		Fault	66.28	0.734	13.02	7.08	0.09	7.52	3.57	1.59	0.04	0.070		100.24
SHZ-7*	1		Fault	53.11	0.070	6.24	9.76	0.12	20.92	9.44	0.29	0.03	0.016		100.63
SHZD-8*	1	Undated	Dike	80.41	0.201	11.04	2.24	0.04	0.84	0.34	4.58	0.27	0.040		99.67
Lower Plate				SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O	TOTAL
D-4		Trinity	Ogd	50.01	0.575	13.78	8.81	0.16	16.83	6.64	3.14	0.02	0.045	11.14	
D-1	2	Undated	O?d	76.91	0.087	12.39	1.53	0.01	1.39	0.37	7.14	0.14	0.033	7.87	
D-2	2	Undated	O?d												
D-3	4	Trinity	SDgb												
SHZ-9	2		Fault	59.08	0.561	14.01	5.78	0.13	13.36	2.54	4.42	0.03	0.079	10.72	
SHZ-10	2		Fault												
UM-1		Trinity	Oum	44.70	0.131	9.41	7.68	0.15	30.81	6.95	0.15	0.00	0.022	8.09	
UM-2*	A	Trinity	Oum	46.57	0.030	1.04	9.52	0.07	42.47	0.19	0.03	0.07	0.018		99.85
UM-3	B	Trinity	Oum	45.63	0.034	1.47	7.40	0.13	45.24	0.09	0.00	0.00	0.000	12.04	
UM-4	B	Trinity	Oum	45.09	0.045	1.70	7.46	0.13	45.49	0.08	0.00	0.00	0.000	10.49	

Table 1 continued. (page 5 of 6)

NEW NAME	LOC	NAME	MAP UNIT	Ba	Ce	Cl	Co	Cr	Cs	Cu	F	Ga	Hf	La	Nd	Ni	Pb
Fault Rocks																	
COP-12		Copley	Dc	318.8			300.2	17.9				27.0	4.4	57.8	27.9	19.3	
COP-13		Copley	Dc	79.2			647.4	18.1				20.4	15.4	94.8	28.8	19.2	
C0P-14		Copley	Dc				229.7	17.9				20.9	4.4	63.6	27.8	19.5	
SHZ-1	4	Copley	Dcs				326.0	19.7				22.9	5.4	72.4	28.2	37.1	
SHZ-2	2	Copley	Dcs														
SHZ-3	2		Fault				523.4	21.2				22.2	3.1	80.2	28.4	41.1	
SHZ-4	4		Fault				272.6	18.4				22.6	4.2	64.3	28.1	35.3	
SHZ-5	3		Fault				243.2	18.8				28.6	4.4	77.3	28.2	32.5	
SHZ-6	1		Fault				286.7	17.9				22.4	2.9	63.3	28.0	21.4	
SHZ-7	1		Fault				360.7	19.9				20.9	2.9	76.9	28.4	32.6	
SHZD-8	1	Undated	Dike	40.3			141.0	17.9				25.2	9.5	54.5	28.1	19.6	
Lower Plate				**Ba**	**Ce**	**Cl**	**Co**	**Cr**	**Cs**	**Cu**	**F**	**Ga**	**Hf**	**La**	**Nd**	**Ni**	**Pb**
D-4		Trinity	Ogd														
D-1	2	Undated	O?d	165.5	17.9	63	0.8	145.1	4.8	58.7	0	11	8.3	60.5	38.7	59.9	36.2
D-2	2	Undated	O?d														
D-3	4		SDgb														
SHZ-9	2		Fault	81.2	13.2	48.6	44.4	258.1	3.7	453.8	7.8	8.5	6.4	31.3	35.4	244.7	3.9
SHZ-10	2		Fault														
UM-1		Trinity	Oum	0	0	35	64.9	1716.5	2.7	0	0	6.7	4.6	15.5	50.9	1387.2	0.4
UM-2	A	Trinity	Oum				486.4	19.6				23.7	4.4	76.0	28.1	53.5	
UM-3	B	Trinity	Oum	61.2	21.8	17.6	94.8	2021.4	4.1	0	0	0.7	6.7	59.8	73.4	2163.8	0
UM-4	B	Trinity	Oum	62.2	22.5	26.1	90.8	2695.8	4.2	1.9	0	3.1	6.7	64.5	82.9	2213.1	3

Table 1 continued. (page 6 of 6)

SAMPLE NUMBER	Rb	S	Sc	Sr	Ta	Th	U	V	Zn	Zr	Y	Nb	Sm	Eu	Tb	Yb
Fault Rocks																
COP-12	95.4		43.3	108.3	3.8			234.1	219.9	105.5	38.9	23.1	7.8	2.4	1.1	3.0
COP-13	42.8		51.1	97.0	3.2			157.9	148.5	66.1	32.4	41.1	5.1	1.9	1.1	3.0
C0P-14	42.2		35.3	96.3	3.8			113.7	87.0	58.1	31.2	68.1	7.6	1.9	1.1	3.0
SHZ-1	40.5		28.9	96.0	3.8			34.4	87.8	57.4	31.2	65.3	6.7	2.1	1.1	3.1
SHZ-2																
SHZ-3	41.8		35.0	95.8	3.9			48.4	86.2	57.8	31.0	67.0	6.1	2.1	1.1	3.1
SHZ-4	40.2		30.3	95.8	3.8			24.3	87.8	58.1	31.2	67.0	7.0	2.0	1.1	3.1
SHZ-5	25.9		24.6	100.3	3.8			27.2	132.6	61.4	32.6	6.2	7.3	1.9	1.1	3.1
SHZ-6	39.9		37.6	97.5	3.8			144.5	88.3	60.1	31.2	67.5	8.4	2.0	1.1	3.0
SHZ-7	42.5		31.6	95.9	3.8			40.2	87.8	57.3	31.0	68.1	5.0	2.0	1.1	3.1
SHZD-8	40.5		21.9	97.5	3.8			23.8	91.8	67.9	31.8	66.4	9.1	1.8	1.1	3.0
Lower Plt.	**Rb**	**S**	**Sc**	**Sr**	**Ta**	**Th**	**U**	**V**	**Zn**	**Zr**	**Y**	**Nb**	**Sm**	**Eu**	**Tb**	
D-4																
D-1	26.2	29.5	3.7	63.8	2	37.8	6.6	8.3	12.7	88.8						
D-2																
D-3																
SHZ-9	14.7	29.1	11.1	51.5	1.5	23	4	145.6	49.7	79.5						
SHZ-10																
UM-1	6.8	21.4	20.1	6.3	1.2	12.8	2.2	90.4	65.2	26.2						
UM-2	42.2		30.9	96.1	3.9			22.0	92.4	57.4	31.2	65.3	6.6	1.9	1.1	3.2
UM-3	16.4	110.2	4	16.4	1.9	24.5	4.4	34	38.5	14.6						
UM-4	16.4	92	4.1	16.5	2	25.5	4.6	35.8	59.6	14.6						

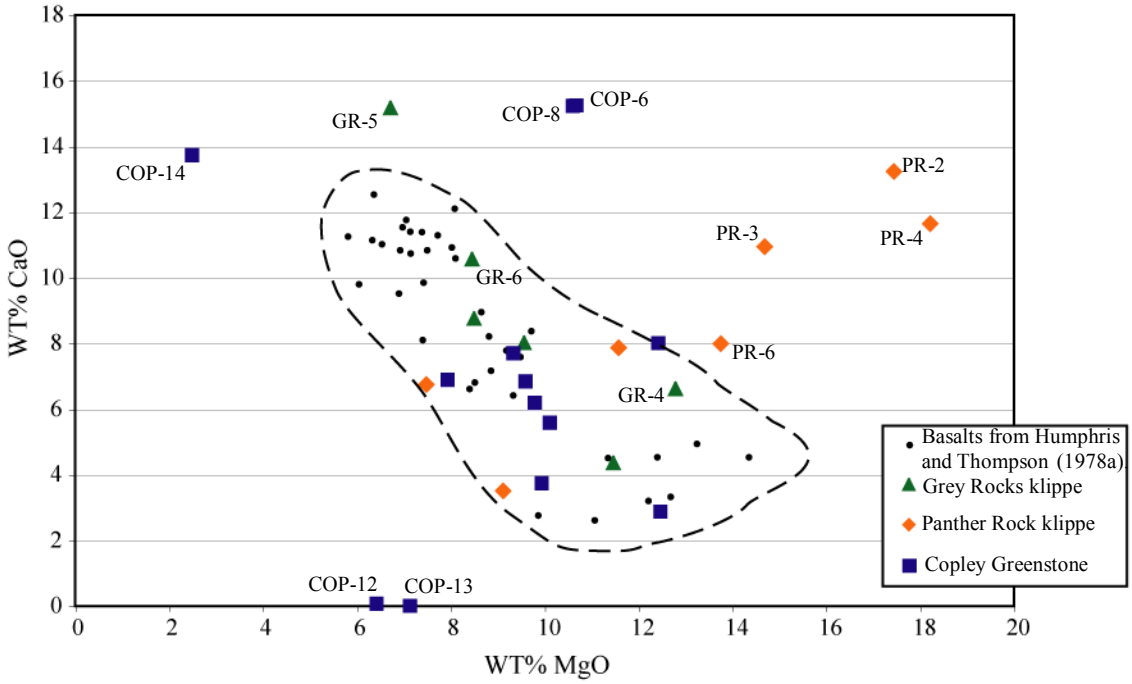


Figure 17: Plot of CaO vs. MgO in Greenstones from Grey Rocks and Panther Rock klippes, and the Copley Greenstone. Values are compared to those from fresh and altered basalts (Humphris and Thompson, 1978a). Dashed outline represents hydrothermally altered basalts.

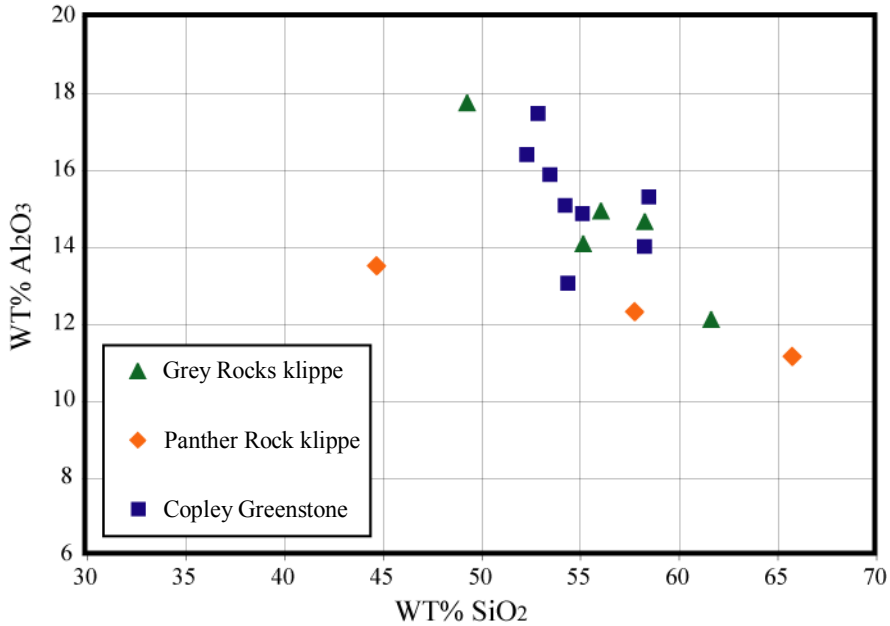


Figure 18: Plot of Al_2O_3 vs. SiO_2 for greenstone samples from Grey Rocks, Panther Rock, and Copley Greenstone.

have used data from Humphris and Thompson (1978a) have interpreted data that lie outside the trend as either being from another magma source or as experiencing increased alteration (Barrow and Metcalf, 2006). The samples from this study are unlikely to be from different sources, as samples from similar locations lie both within and outside the field of fresh and hydrothermally altered basalts (Fig. 17) (i.e., GR-4 and GR-5). The samples that plot outside the dashed area are interpreted to have experienced increased levels of alteration and are not reliable for comparison.

Bulk Rock Composition Comparison

Humphris and Thompson (1978a) found that bulk SiO_2 can be depleted or enhanced as SiO_2 is leached from the altered rock and then precipitated in veins within pillow rims. SiO_2 comprises the major portion of the bulk composition, so variation in SiO_2 affects the rest of the bulk composition values. Harker diagrams have been used to eliminate scatter due to variations in SiO_2. The diagrams typically exhibit negative trends between bulk elements and percent SiO_2.

Plotting values from this project on Harker diagrams displayed only weak trends and inconclusive results, with the best correlation between Al_2O_3 and SiO_2 (Fig. 18). Because of the lack of clearly defined trends, correlation of the trace elements between the greenstones was used for further classification and identification.

Trace Element Composition Comparison

Some trace elements are more mobile than others and can be enhanced or removed during alteration. Minor and trace elements that are more stable under greenschist facies alteration include Cr, Zr, and REEs (Humphris and Thompson, 1978b).

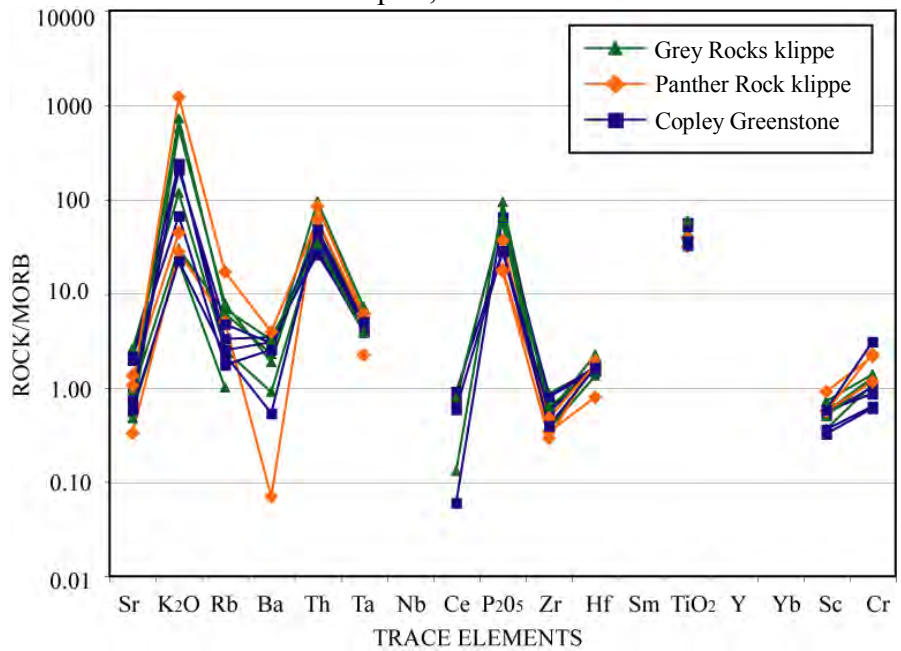
To compare the trace elements of all three greenstones, spider diagrams have been plotted using MORB normalization values of Pearce (1983) (Fig. 19a), and chondrite normalization values of Thompson (1982) (Fig. 19b).

From the trace element patterns exhibited in these two diagrams, the greenstones of the Panther Rock and Grey Rocks klippes are geochemically related to the Copley Greenstone of the Redding terrane. This interpretation supports other interpretations of a cogenetic link between ―Trinity basalts" (Brouxel 1988) and the Copley Greenstone (Wallin and Metcalf, 1998). Wallin and Metcalf (1998) interpret the Siluro-Devonian intrusive suite within the Trinity terrane as cogenetic with the Copley Greenstone. They compared data of ―Trinity terrane" gabbros, dikes, pillow basalts and Copley Greenstone samples compiled from Lapierre et al. (1985), Brouxel et al. (1988), Brouxel and Lapierre (1988), Brouxel et al. (1989), Brouxel et al. (1991), Cannat and Lecuyer (1991), Petersen et al. (1991), and Gruau et al. (1995). Wallin and Metcalf (1998) interpret the geochemical similarity, spatial relations, and age relations between these units as indicative of a cogenetic system. Data from this project further supports this cogenetic interpretation.

Felsic Dikes Analyses

Numerous dikes are observed intruding mafic and ultramafic rocks of the Trinity terrane. Although none of the dikes are observed intruding the upper plate klippes, three felsic dikes are observed intruding fault rocks. Two felsic dikes intrude fault zone rocks at the base of the Horse Heaven Meadows klippe (D-1, D-2) and a third tectonized felsic

A. Comparison of greenstones from Grey Rocks and Panther Rock klippes and Copley Greenstone samples, normalized to MORB.



B) Comparison of greenstones from Grey Rocks and Panther Rock klippes and Copley Greenstone samples, normalized to chondrite values.

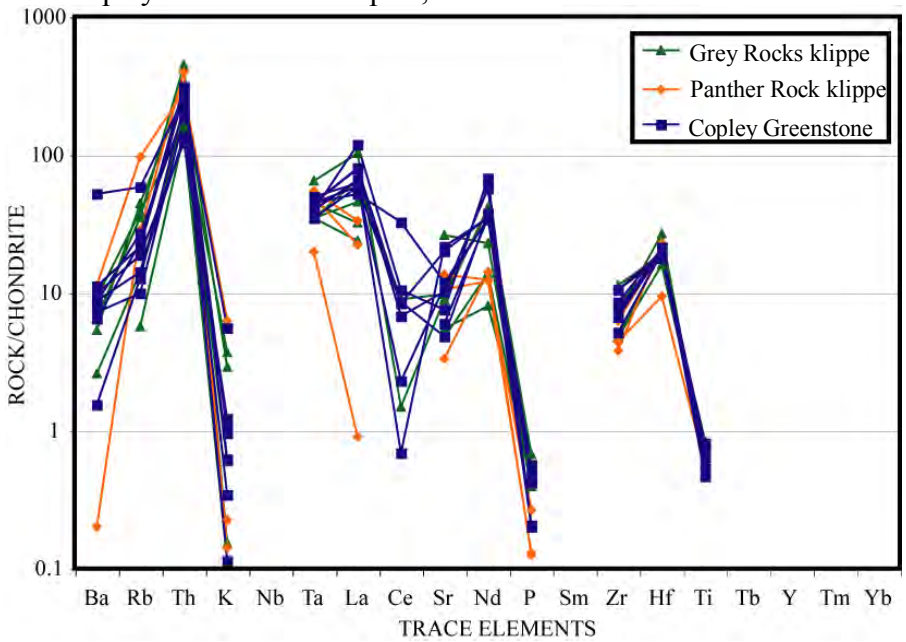


Figure 19: REE patterns of greenstones from Grey Rocks and Panther Rock klippes and Copley Greenstone samples using A) MORB (Pearce, 1983) and B) chondrite (Thompson, 1982) values.

dike (SHZD-8) intrudes parallel to the fault zone at the base of the Grey Rocks klippe (Locations 2 and 1, Fig. 2). The mineralogy and bulk composition of the felsic dikes support an affinity between the two dikes sets from this project (Table 2); however, the structural relations of the two dike sets indicates a timing difference of emplacement that also constrains timing for part of the basal faulting event. Sample D-1 and sample SHZD-8 are both rhyolite dikes categorized by the Jensen cation plot (Jensen, 1976). Similarly, the bulk compositional values reflect comparable elemental percentages (Table 2). The structural relations of the dikes dates the fault parallel dike at Location 1 as syntectonic with the basal fauting indicated by the shear microstructures (Fig. 15) and the other two dikes at Location 2 as post-basal faulting by cross-cutting the fault breccia (Fig. 2). The difference in emplacement timing between the dike sets could constrain the timing of faulting if dated.

Fault parallel, felsic dikes (muscovite-bearing dacite, muscovite-bearing rhyolite, and plagioclase porphyry) were mapped intruding detachment faults between the Copley Greenstone and Trinity terrane mafic and ultramafic rocks at Deer Creek (Mt. Shasta area) and along the Carrville fault (Trinity Lake area) (Table 2 and Fig. 20) (Goldstein, 1997; Cashman and Elder, 2002). Geochemical analyses were conducted to test correlation between felsic dikes at Locations 1 and 2 (Fig. 2) and those observed at Mt. Shasta area and Trinity Lake by Cashman and Elder (2002). Felsic dikes from Cashman and Elder (2002) and the two rhyolite dikes (D-1, SHZD-8) were plotted on a TAS diagram (Fig. 20); however, the plot yielded inconclusive results as to whether the dikes are from a similar source.

Table 2. Chemical Analyses of Felsic dikes that intrude faults that form the upper contact of the Trinity terrane. Values are weight percent. Samples have been normalized to 100 percent.

SAMPLE #	LOCATION	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P205
SHZD-8	Grey Rocks klippe, LOC 1	80.41	0.201	11.04	2.24	0.04	0.84	0.34	4.58	0.27	0.040
D-1	Horse Heaven Meadows klippe, LOC 2	76.91	0.087	12.39	1.53	0.01	1.39	0.37	7.14	0.14	0.033
96-HG-8AM*	MT. SHASTA	69.09	0.235	16.26	3.45	0.06	1.28	1.22	4.85	3.52	0.032
96-HG-8B*	MT. SHASTA	71.06	0.224	15.13	2.92	0.05	1.57	0.45	5.52	3.05	0.021
94-28*	TRINITY LAKE	66.38	0.563	15.84	4.15	0.09	3.53	1.13	3.82	4.33	0.174
94-29A*	TRINITY LAKE	72.09	0.137	16.00	1.91	0.05	0.55	0.67	5.19	3.34	0.063
93-31M*	TRINITY LAKE	66.04	0.500	16.06	4.39	0.10	3.86	0.63	4.76	3.46	0.198
94-95*	TRINITY LAKE	71.09	0.148	17.07	1.95	0.06	0.49	0.42	5.58	3.15	0.042
94-20M*	TRINITY LAKE	68.30	0.399	17.18	3.37	0.05	1.61	1.03	4.57	3.34	0.147
94-35M*	TRINITY LAKE	69.10	0.449	15.52	3.48	0.07	1.76	1.12	3.64	4.59	0.265
94-29B*	TRINITY LAKE	70.53	0.150	14.83	3.40	0.07	0.72	0.70	6.25	3.26	0.090
94-35BM*	TRINITY LAKE	67.68	0.485	16.05	4.38	0.11	3.01	0.13	5.17	2.81	0.169

*From Cashman and Elder, 2002.

Table 3. Chemical Analyses of Shear Zone rocks from Grey Rocks and Horse Heaven Meadows klippes shear zones with Upper Plate rocks from Grey Rocks klippe and Lower Plate rocks from the Trinity terrane.

Location/Descr.	Sample #	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
Gray Rocks klippe Loc. H - greenstone	GR-6	55.17	0.68	14.07	7.74	0.13	8.45	10.56	3.07	0.03	0.09
Grey Rocks klippe Loc. 1 - sheared greenstone	SHZ-6	66.28	0.73	13.02	7.08	0.09	7.52	3.57	1.59	0.04	0.07
Grey Rocks klippe Loc. 1 - mylonite	SHZ-7	53.11	0.07	6.24	9.76	0.12	20.92	9.44	0.29	0.03	.016
Trinity ultramafic sheet Loc. A - serpentinite	UM-2	46.57	0.03	1.04	9.52	0.07	42.47	0.19	0.03	0.07	0.018
Horse Heaven Meadows klippe Loc. 4 - mylonite	SHZ 1	55.83	0.12	2.57	5.01	0.12	24.28	11.29	0.68	0.08	0.026
Horse Heaven Meadows klippe Loc. 2 - mylonite	SHZ-3	54.75	0.05	4.68	10.01	0.19	23.85	6.05	0.36	0.04	0.024

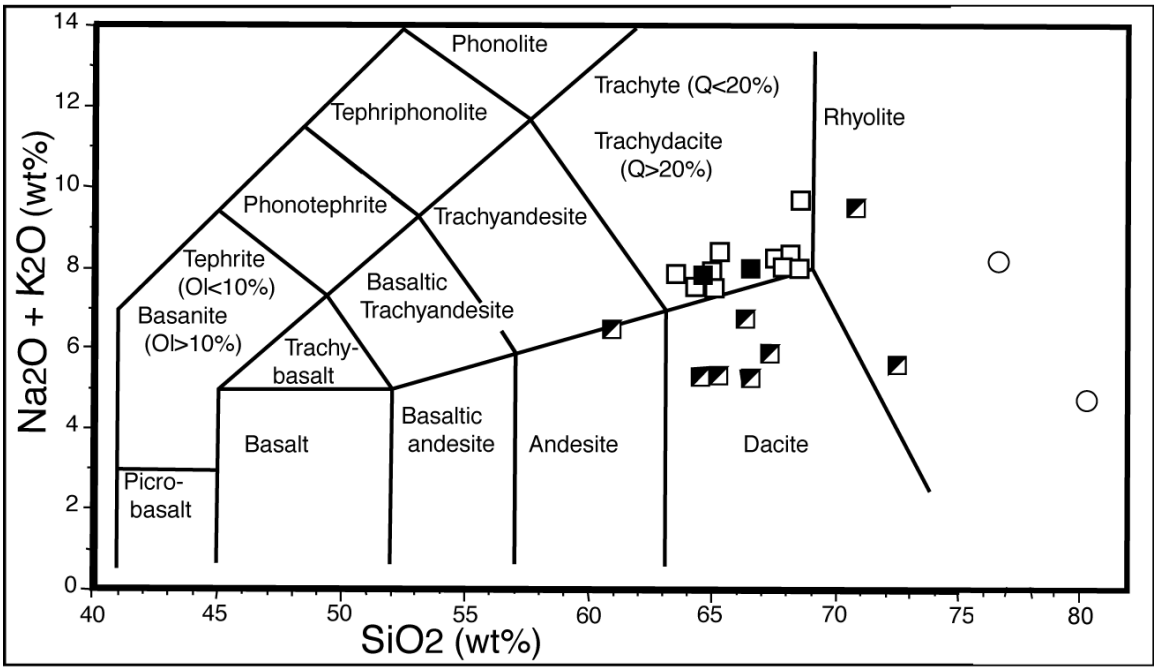


Figure 20: Total alkalis vs. silica plot (TAS) from LeBas et al. (1986). Circles - dikes from Location 1 and 2 (this project). Black squares – Deer Creek; Half-white squares – Cecilville; White squares – Trinity Lake (Cashman and Elder, 2002).

Fault Rocks Analyses

Grey Rocks Klippe Basal Shear Zone

The shear zone exposed at the southeast contact of the Grey Rocks klippe (Location 1, Fig. 2) is a nine-meter thick zone of coherent and sheared layers that incorporate both upper and lower plate units. Rock types observed in the shear zone are mylonite (SHZ-7), greenstone (SHZ-6), and rhyolite (SHZD-8). Bulk compositions of shear zone samples were measured to determine the origin of fine-grained material in the shear zone and to assess the relative importance of components from the upper and lower plates of the fault.

Comparing bulk compositions of upper plate and lower plate samples with those of shear zone samples indicates a mixing of upper and lower plate rock components in the shear zone. The greenstone sample GR-6 from the upper plate and Trinity ultramafic sheet sample UM-2 from the lower plate are used as limits, representing upper and lower plate values of rock units proximal to the exposed shear zone near Grey Rocks basin, (Table 3 and Location 1, Fig. 2). The shear zone mylonite, sample SHZ-7, has bulk composition values that fall between the upper and lower plate values (Table 3 and Fig. 21A). A comparison of shear zone sample SHZ-7 with lower plate sample UM-2, indicates increased amounts of Al_20_3 and depleted amounts of MgO in the shear zone. This shift in bulk composition is interpreted as evidence for incorporation of Al_20_3-rich upper plate material in the shear zone during faulting.

More coherent sections of the shear zone are comprised of greenstone, represented by sample SHZ-6, and resemble upper plate greenstone (GR-6) samples rather than lower plate (UM-2) and mylonite (SHZ-7) samples of the shear zone. Sample SHZ-6 exhibits lower MgO, higher SiO_2, and higher Al_2O_3 values than the lower plate sample UM-2 and the mylonite SHZ-7 (Table 3).

In comparison with the upper plate greenstone (GR-6), coherent greenstone sections in the shear zone (SHZ-6) have higher SiO_2 and lower CaO content. The coherent greenstone sections (SHZ-6) exhibit extensive quartz veining that accounts for the elevated SiO_2 content. The quartz veining is also interpreted as accommodating some of the extension within the shear zone. Other greenstone samples close to the fault zone have exhibited low CaO content due to increased hydrothermal alteration. The lower CaO content in sample SHZ-6 is interpreted as resulting from increased hydrothermal alteration along the fault zone. An affinity of the coherent sections with upper plate greenstone is expected as the lower plate is comprised of units that more readily deform and would more likely exhibit extreme shearing.

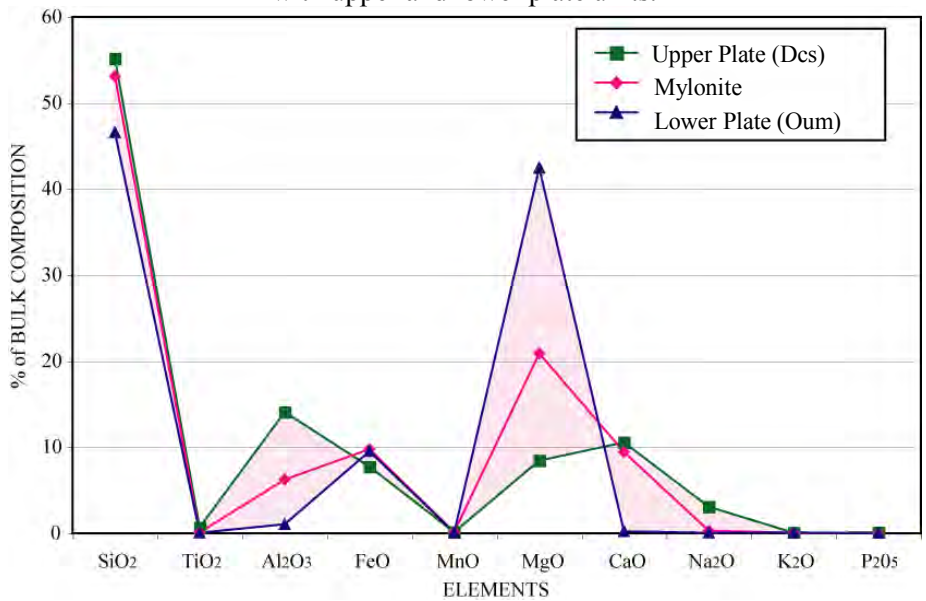
Horse Heaven Meadows Klippe Shear Zone:

Shear zone exposures of the mylonitic basal contact of the Horse Heaven Meadows klippe are located at Locations 2 and 4 (Fig. 2). The shear zone exposed at the southeast contact of the Horse Heaven Meadows klippe (Location 2, Fig. 2) is the clearest exposure, displaying a direct contact between slate of the upper plate and mylonite of the fault zone. Here, the shear zone is at least 3 meters thick and is comprised of mylonite (SHZ-3), fault breccia (SHZ-9), and felsic dikes (D-1 and D-2). Bulk compositions of

mylonite samples from basal shear zones of Horse Heaven Meadows (SHZ-3, SHZ-4) and Grey Rocks (SHZ-7) klippes are compared to determine whether the mylonite samples are uniform.

Based on the geochemical affinity of the bulk compositions of the three mylonite samples, the mylonitic layer observed at the base of Horse Heaven Meadows klippe consists of the same mylonite as occurs at the base of the Grey Rocks klippes (Fig. 21B and Table 3). All samples are enriched in Al_2O_3 and SiO_2 and are depleted in MgO compared to ultramafic samples observed in the lower plate (UM-3, UM-2).

A. Bulk composition comparison of mylonite Grey Rocks basal shear zone with upper and lower plate units.



B) Comparison of mylonite samples from Horse Heaven Meadows and Grey Rocks klippe basal fault zones.

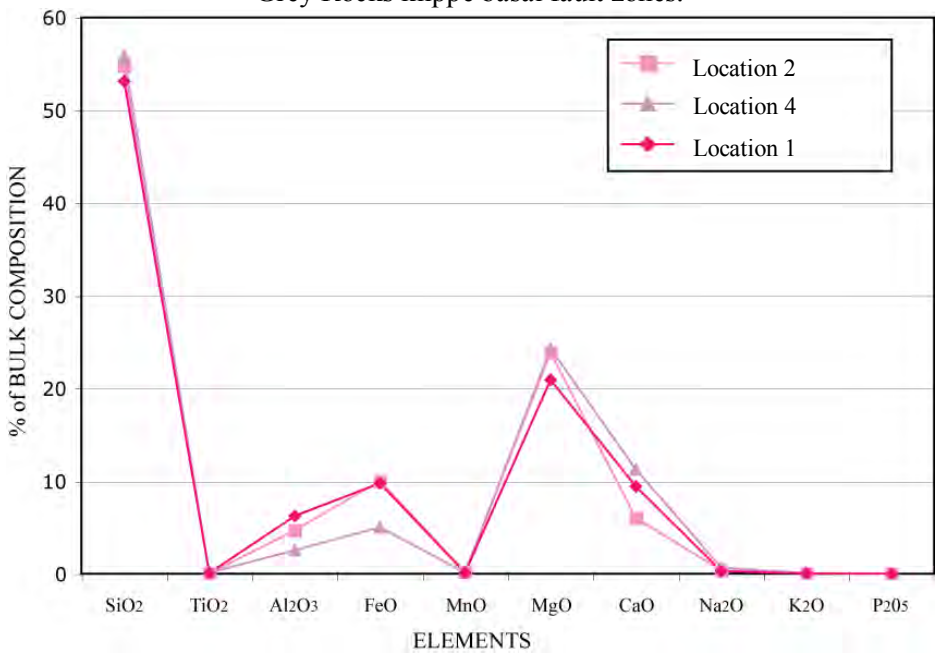


Figure 21. Comparison of A) Grey Rocks shear zone mylonite with samples from the upper (Dc: GR-6) and lower (Oum: UM-2) plate limits. Colored area defines values between upper and lower plate values. Shear zone incorporates both upper and lower plate components resulting in a bulk analysis that lies within the two compositional limits. B) Comparison of mylonite samples from Location 1 (Fig. 2) at the base of Grey Rocks klippe and Locations 2 and 4 (Fig. 2) from the base of Horse Heaven Meadows klippe. Mylonite samples are similar in composition indicating a uniformity of mixing within the shear zone.

STRUCTURE

The basal contact between the Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes with the underlying Trinity ultramafic complex is a 9 to ~85 meter thick fault zone, comprised of coarse-grained breccia, foliated breccia, and mylonite. The fault displaces younger Copley Greenstone and metasedimentary units of the Redding terrane over older Trinity ultramafic complex of the Trinity terrane. Foliation in the upper plate is solely observed adjacent to the basal contact (i.e. Location J, I, 1, 2). Locations 1 through 5 are the best exposures of the basal fault zone between the three klippes and the lower plate. Location 1 is located at the base of the Grey Rocks klippe, Locations 2, 3, and 4 are located at the base of the Horse Heaven Meadows klippe, and Location 5 is located near the base of the Panther Rock klippe.

Grey Rocks Klippe Basal Shear Zone

A 9 meter thick shear zone is exposed at the base of Grey Rocks klippe on the southeast side of Grey Rocks ridge in Grey Rocks basin (Location 1, Fig. 2) Here, the fault plane strikes N10W and dips 34SW, and consists of both coherent and foliated zones (Fig. 22). At Location I (Fig. 2), foliation in the greenstone and ultramafic rocks strikes N30W and dips 72NE. Rocks in the fault zone include mylonite, fractured sections of greenstone with quartz intrusions, and a felsic dike.

Coherent greenstone units (SHZ-6) in the fault zone range from 25 cm to 1 meter in thickness and are separated by 5 cm to 15 cm thick layers of micaceous mylonitic shear rocks (SHZ-7). Coherent greenstone units are greenish dark-grey, fine-grained,

Figure 22: Photographs of Grey Rocks klippe basal shear zone at the fault contact between the greenstone of the Grey Rocks klippe (Dc) and the Trinity ultramafic complex (Ouc). SE margin of Grey Rocks klippe, Location 1 (Fig. 2). Fault zone consists of both sheared and coherent sections of rock within the nine meter thick shear zone. A) Thicker, 28 cm to 1 meter thick, coherent sections of greenstone are separated by thinner layers, 5 to 18 cm, of sheared micaceous mylonite. B) 70 cm thick section of sheared mylonite with Sharpie pen for scale.

fractured, and intruded by multiple sets of offset quartz and calcite veins. The greenstone is comprised of very fine-grained chlorite, quartz, clinozoisite, amphibole, plagioclase degraded to saussurite, and clays. Faint mineral alignment, defined by elongate grains of chlorite and amphiboles, is visible in thin-section (Fig. 23). Foliation in the greenstone unit is solely observed adjacent to the basal fault zone (Location 1, I, and J, Fig. 2).

Incoherent sections are mylonitic, exhibit shear microstructures, and commonly range in thickness from 5 to 15 cm with one section being 1 meter thick (Fig. 24A-D). The 1 meter thick incoherent zone exhibits a strong foliation striking N10W and dipping 43SW. Mylonite is comprised mainly of talc, white micas, serpentine, chlorite, actinolite, and clays. In thin-section, mylonitic foliation is defined by mineral banding, mineral alignment defining a faint s-c fabric, and porphyroclasts of relic hornblendes forming sigma clasts. (A sense of shear was not determined because samples orientation was unclear.)

The sheared rhyolite dike (SHZD-8) has anastomosing and moderately rough foliation. Thin bands of white mica, chlorite, epidote, and quartz flow around the plagioclase crystals creating augins and defining the foliation. Shearing of the dike indicates that dike emplacement may have been syntectonic. Veins cross-cut the foliation perpendicularly and may indicate deformation within an extensional faulting regime.

HORSE HEAVEN MEADOWS KLIPPE BASAL FAULT ZONE

A 3 to ~85-meter thick shear zone is exposed at the base of Horse Heaven Meadows klippe at Locations 2, 3, and 4 (Fig. 2). The klippe forms a convex bowl, with

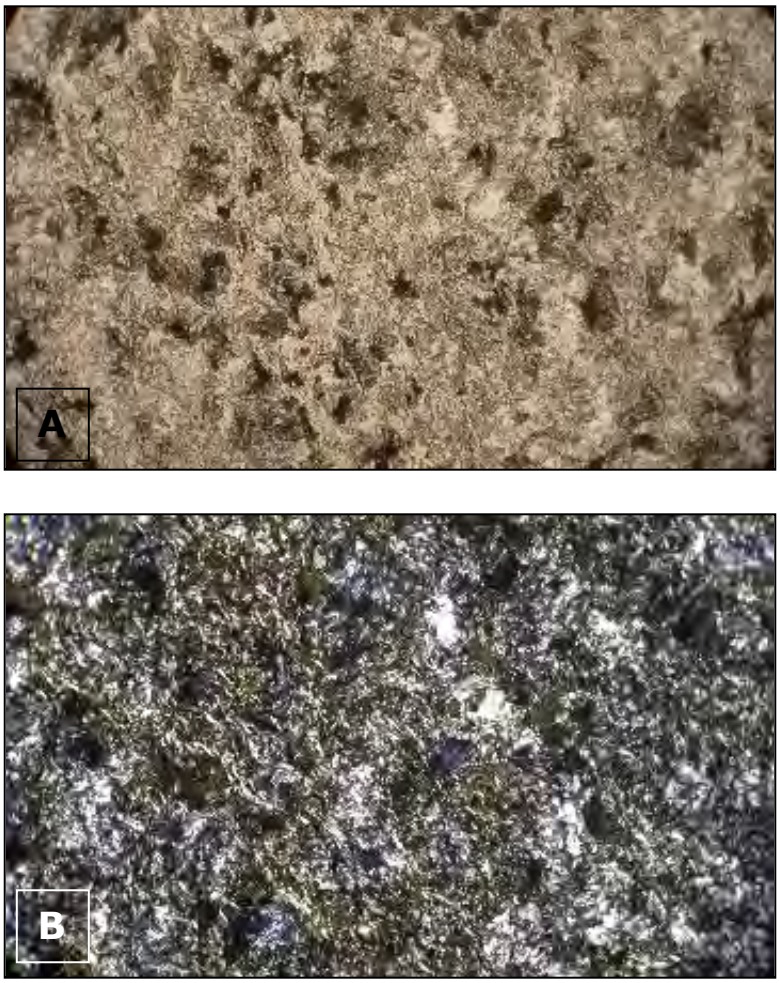
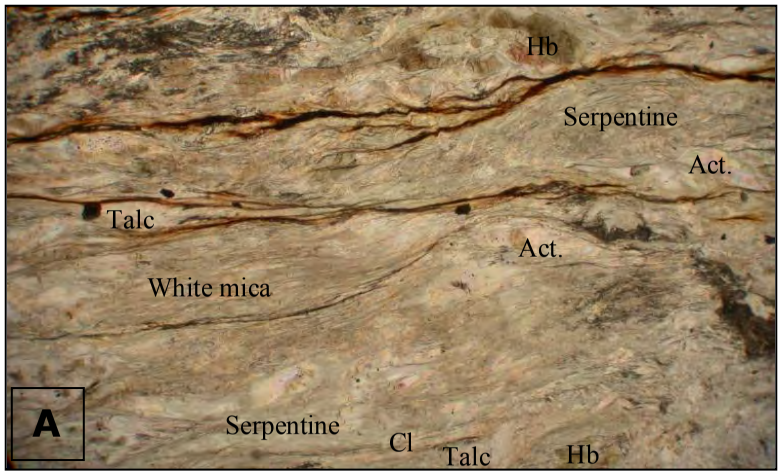
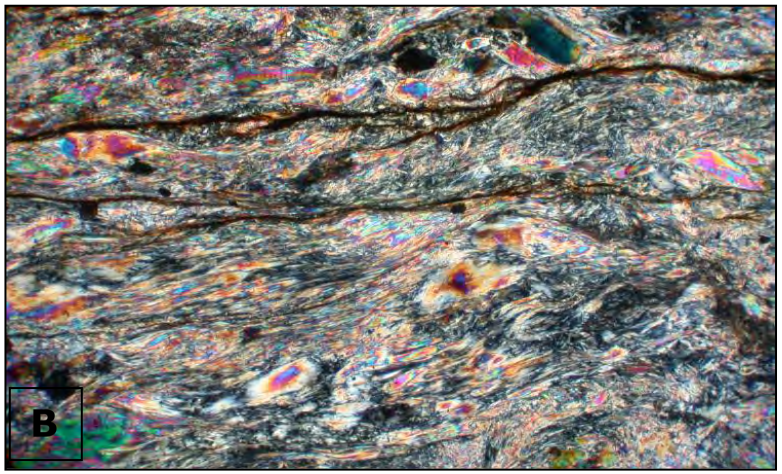


Figure 23: Photomicrograph of coherent greenstone from the Grey Rocks klippe basal shear zone. Sample SHZ-6, Location 1 (Fig. 2), width of image 1.37 mm, A) in plane polarized light and B) in cross polarized light. Sample consists of very fine-grained chlorite, quartz, clinozoisite, amphiboles, and clay. Faint mineral alignment (from upper left corner to lower right corner of image) is defined by aligned chlorite and amphibole crystals.





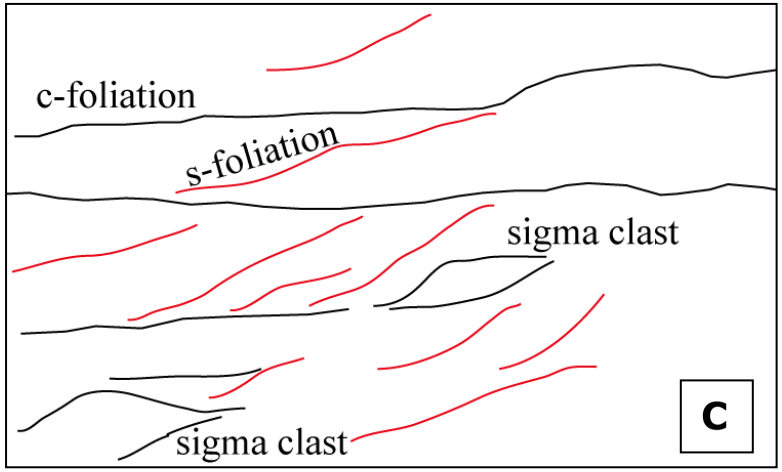
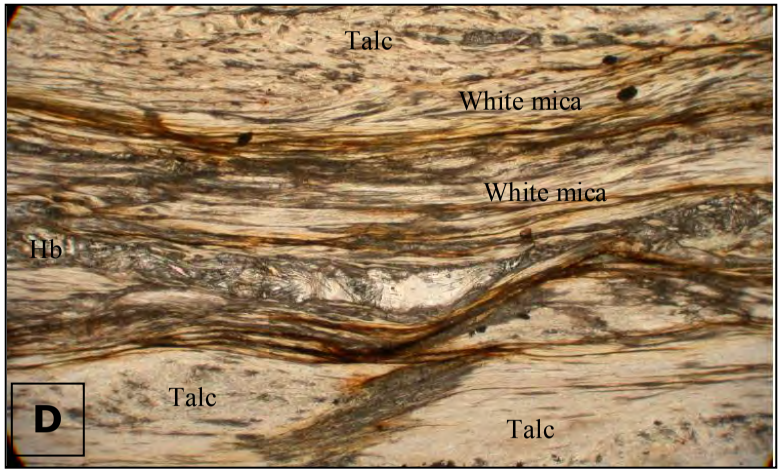
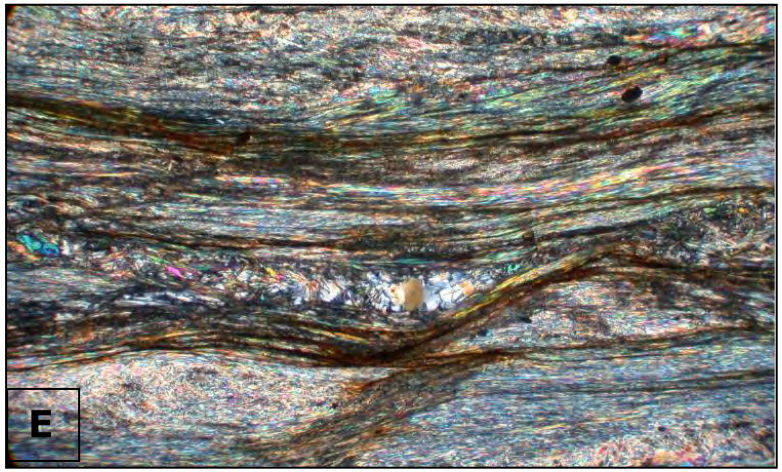
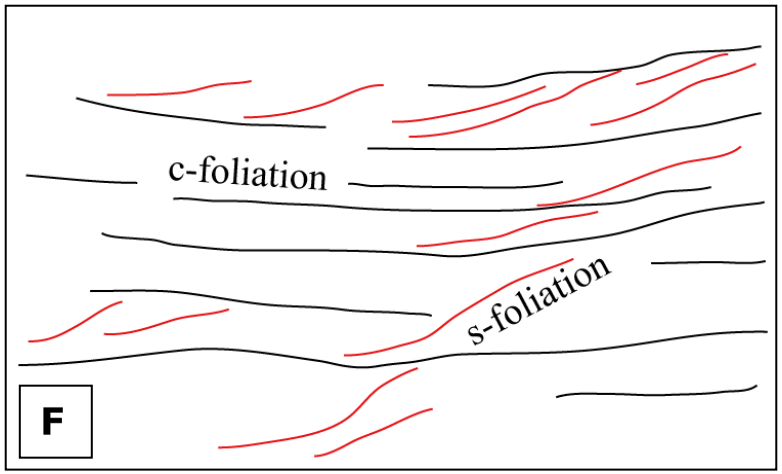


Figure 24: Photomicrograph of mylonite from Grey Rocks klippe basal shear zone (continued on next page), Location 1 (Fig. 2). Sample SHZ-7, width of image 3.2mm, A and D) in plane polarized light, B and E) in cross polarized light, C and F) sketches of A and D. Rock consists of talc, white mica, serpentine, chlorite, hornblende, actinolite. Hornblende altered to actinolite and talc along some s-foliation surfaces. Texture includes mineral banding, s-c fabric, and porphyroclasts of hornblendes forming sigma clasts. A and D are sketches that display s-c foliations and sigma clasts.


Talc
White mica
White mica
Hb
Talc
Talc
D


E


c-foliation
s-foliation
F

the basal fault dipping shallowly to the N-NE. The basal fault zone rocks consist of sheared slate, mylonite, coarse-grained breccia, foliated breccia, and felsic dikes. Foliation in upper plate rocks and increased quartz veins in en echelon patterns are observed solely adjacent to the basal fault.

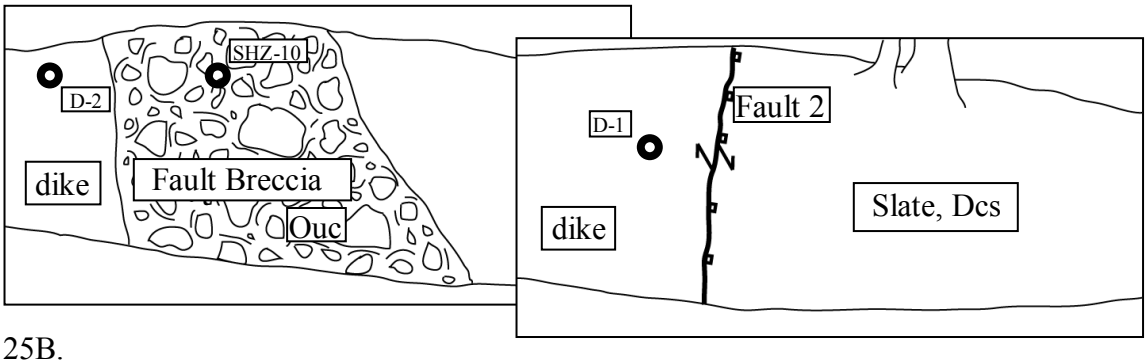
Location 2) Mile Marker 8.75

Mile Marker 8.75 is a key locality because it is the only place exhibiting direct contact between the Horse Heaven Meadows klippe and the Trinity ultramafic complex (Fig. 25A-B). This location has been described and was previously interpreted as a conformable depositional contact (Boudier et al., 1989; Charvet et al., 1990) (Fig. 25C). Based on identification of shear microstructures in both upper and lower plate rocks, the contact is reinterpreted as a fault contact.

The sequence includes upper plate slate of the Horse Heaven Meadows klippe, fault mylonite, fault breccia, two dikes, and lower plate serpentinized peridotite (Fig. 7B and Fig. 25). The slate directly overlies the fault zone mylonite. The basal fault between the upper plate slate and the ultramafic rocks is defined by mylonitic foliation that strikes N41E and dips 35NW. Fault breccia is juxtaposed with the slate/mylonite block on either side by two younger oblique normal faults. Two felsic dikes approximately 1 to 1.3 meters thick intrude the fault breccia on the western side of the outcrop, striking parallel to the younger faults.

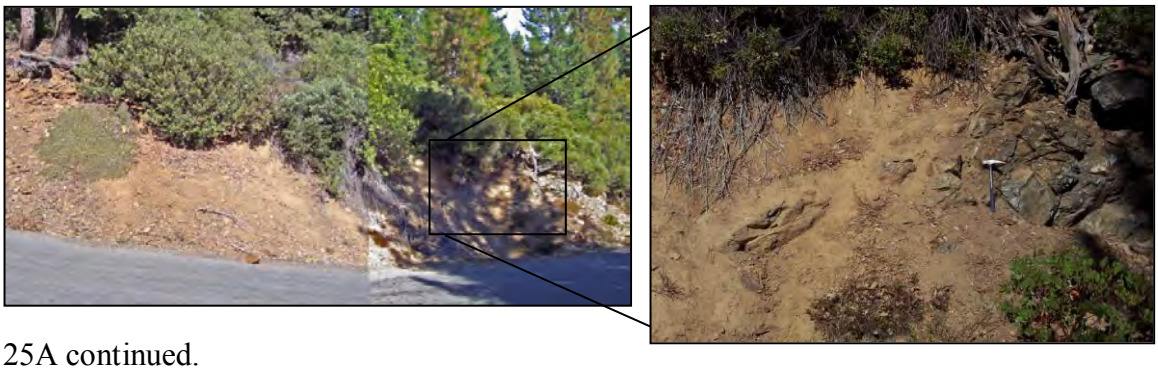
Near the basal fault, the blocky, dark reddish grey, fine-grained slate has two pervasive cleavage planes striking N80E and dipping 25N and striking N26W and dipping 21SW. Bedding was not determined.

25A.

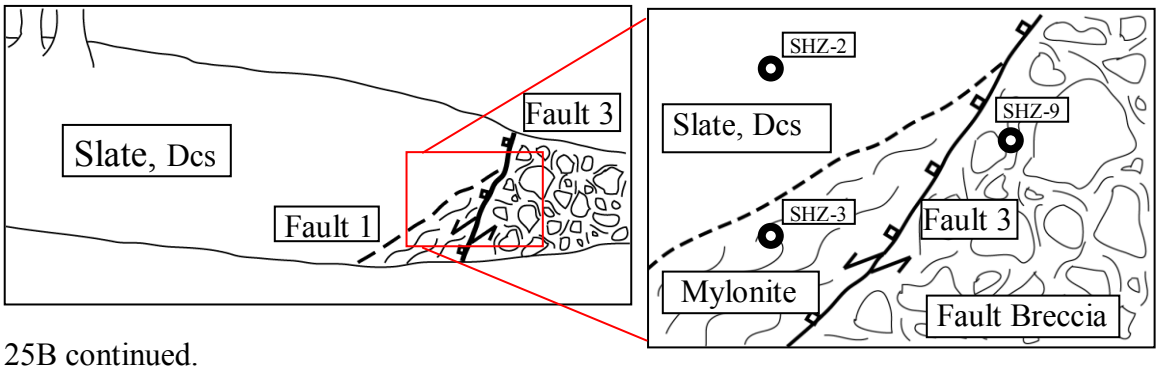


25B.

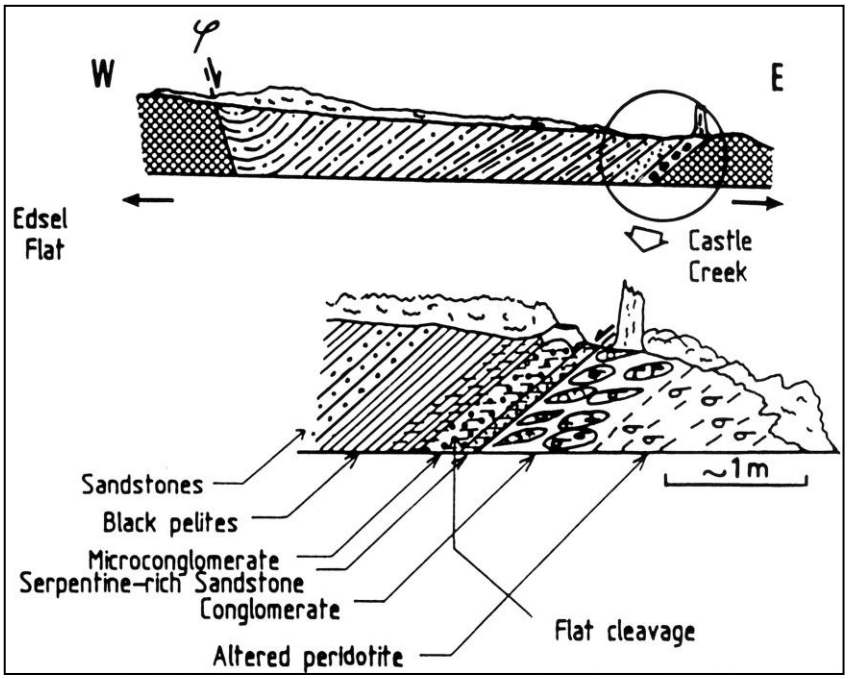
Figure 25: Interpretations of the basal fault contact between upper plate metasedimentary rocks and lower plate ultramafic rocks of the Trinity terrane at the SE margin of the Horse Heaven Meadows (Location 2, Fig. 2).
A) Photo mosaic of Location 2, continued on next page. View is to the NW. Outcrop is approximately 17 meters wide. Eastern edge continues on next page. Inset is a photo of foliated mylonite at the direct contact between the slate (Dcs) and Trinity ultramafic complex (Ouc). Hammer for scale.
B). Interpretive sketch of 25A photo mosaic showing sample locations.
C) Previously published interpretation of Location 2 as a sedimentary sequence conformably overlying altered peridotite (Charvet and others, 1990).



25A continued.



25B continued.



25C.

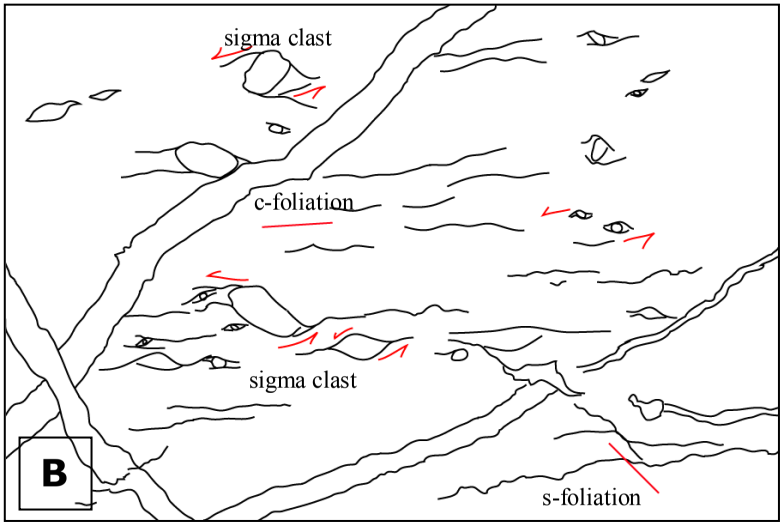
Microstructures within the upper plate slate, visible in thin-section, include sigma clasts, s-(flattening) foliation, c-(shear) foliation, and thin quartz veins oriented either parallel to foliation, or, more commonly, cutting obliquely across foliation (Fig. 26). Both the rough s and c-foliations are defined by shape-preferred orientation of fine-grained crystals of actinolite, chlorite, and epidote. The sigma clasts are replaced by fine-grained chlorite-actinolite-epidote group minerals, and have actinolite and chlorite ~~"~~tails".

Several episodes of quartz veining have occurred, evident from the web of veins that cut through each other. Quartz veins account for 15 percent of the slate thin section. The offset displayed in several veins represents a change from a ductile deformation regime to a brittle deformation regime.

Directly beneath the upper plate slate is a thin (15 to 25 cm) mylonite zone. The light-green sheared mylonite displays a strong foliation, striking N41E and dipping 35NW. The foliation parallels the contact of mylonite with the slate. Both the mylonite zone (Fault 3) and the upper plate slate are cut by the younger fault (Fault 2, Fig. 25B).

In thin-section, the mylonitic texture is defined by very strong compositional layering into bands, very strong shape-preferred orientation of minerals, and sigma clasts (altered to tremolite and opaque minerals) (Fig. 27). The mylonite consists of fine-grained white mica, serpentine, chlorite, tremolite, and opaque minerals.

The fault breccia, comprising the thicker part of the shear zone, is visible on opposite sides of the younger, oblique-normal faults (Fig. 25A,B). The dark blackish green fault breccia with mafic and felsic clasts is at least 4 meters thick. The fault breccia is comprised of clasts ranging up to boulder size in a serpentine, quartz, chlorite, and



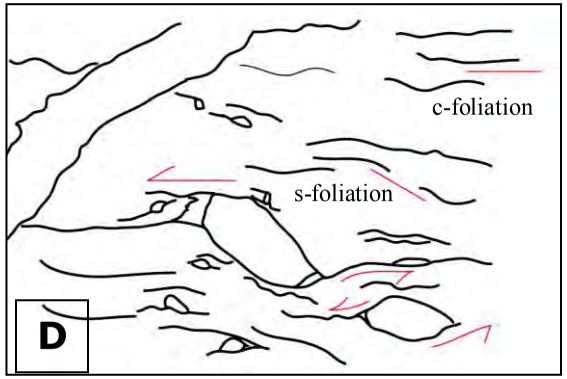


Figure 26. Photomicrograph and sketches of s-c fabric in sheared slate from the shear zone at the base of Horse Heaven Meadows klippe. Sample SHZ-2 is from the SE margin of the klippe, Location 2.
A) Photomicrograph in plane polarized light with field of view 3.2 mm; depicting several cloudy microcrystalline sigma clasts and deformed quartz veins.
B) Sketch of A depicting microstructures and inferred sense of motion. s-fabric, flattening foliation, dips shallowly to the right, and c fabric (shearing) is horizontal.
C) Photomicrograph in plane polarized light with field of view 1.37 mm; depicting a close-up view of a sigma clast. Displays crystal growth in the tails of the clast and alignment of fine-grain minerals.
D) Sketch of C depicting microstructures and sense of motion inferred from features.

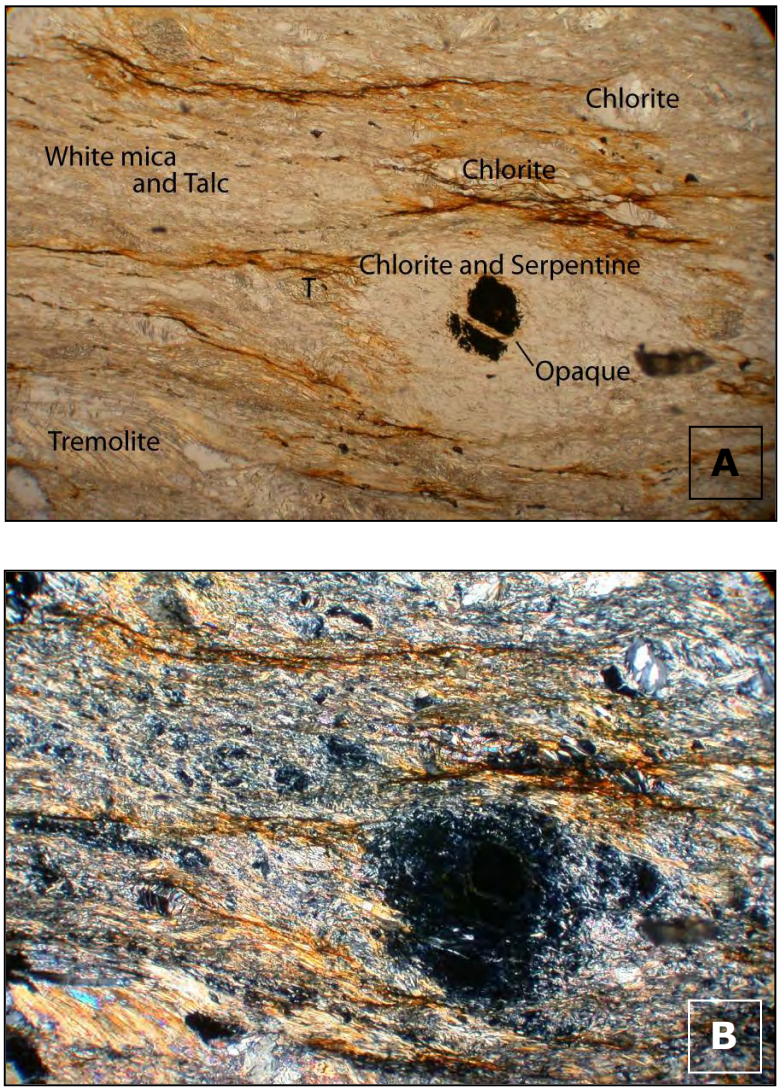


Figure 27: Photomicrographs of mylonite from the fault contact at the SE margin of the Horse Heaven Meadows klippe. Sample SHZ-3, Location 2 (Fig. 2), width of image is 3.2mm, A) in plane polarized light and B) in cross polarized light. Mylonitic unit consists mainly of fine-grained white mica, serpentine, chlorite, tremolite (T), and opaque minerals. Texture includes mineral alignment, sigma clasts, and undulatory extinction in crystals.

Figure 28: Photograph of an angular 20 cm plagiogranite boulder within the fault breccia zone at the base of the Horse Heaven Meadow klippe (Location 2, Fig.2). Sample SHZ-9.

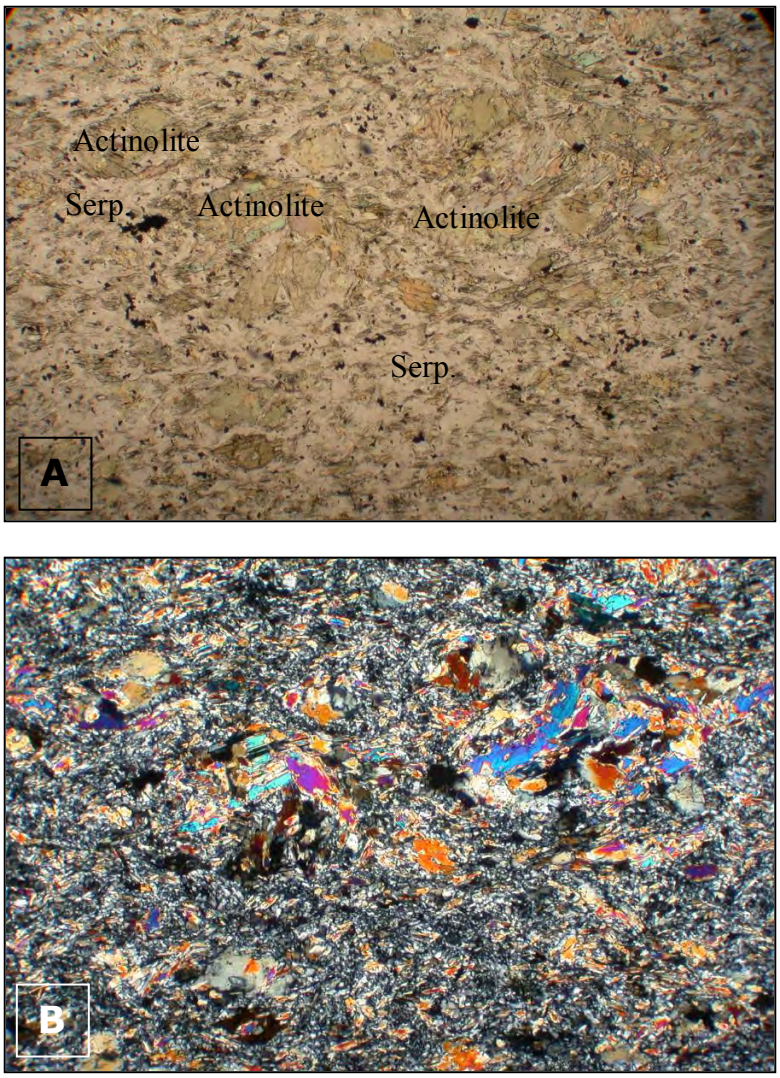


Figure 29: Photomicrographs of a clast within the fault breccia from the basal fault contact between the Horse Heaven Meadows klippe and the Trinity ultramafic complex, Ouc. Sample SHZ-10, Location 2 (Fig. 2), width of image is 3.2 mm, A) in plane polarized light and B) in cross polarized light. Mineralogy includes actinolite, serpentine and fine-grained clays. Anastomosing cleavage planes are defined by the serpentine and clays that flow around the actinolite crystals.

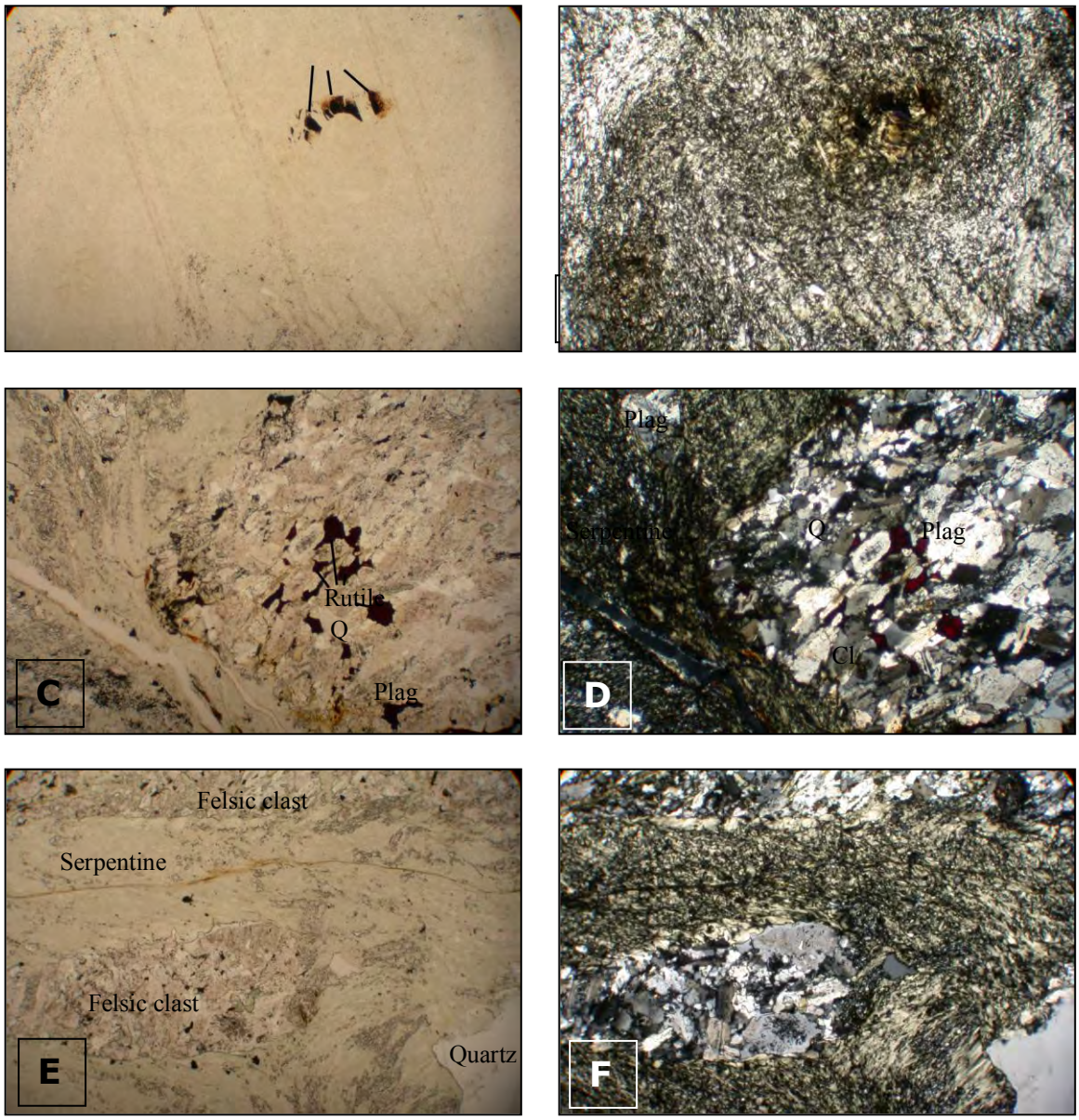


Figure 30: Photomicrographs of fault breccia from the fault zone at the base of the Horse Heaven Meadows klippe. Sample SHZ-9, Location 2 (Fig. 2), width of images are 3.2 mm. Photomicrographs A) in plane polarized light and B) cross polarized light display serpentine matrix with fractured pyrite. Photomicrographs C) in plane polarized light and D) in cross polarized light, display typical angular plagiogranite clasts within the serpentine matrix (Plag-plagioclase, Cl-chlorite, Q-quartz). Photomicrographs E) in plane polarized light and F) in cross polarized light display the serpentine matrix flowing around the plagiogranite clasts.

smectite matrix (Fig. 28). Blocks in the breccia are plagiogranite, amphibolite, and serpentine, (Fig. 29 and Fig. 30). In thin section, the serpentine breccia matrix consists of serpentine around small angular plutonic clasts, creating planar crystal alignment between clasts (Fig. 30). Several clasts exhibit pulled apart clasts with quartz fibers in spaces between fragments (Fig. 30A,B) indicating an extensional deformation regime.

Although the source of the plagiogranite clasts within the fault breccia cannot be uniquely identified, the rock types in the breccia unit occur in the Trinity terrane. Several different generations of plagiogranite are described within the Trinity ultramafic complex (Quick, 1981; Lindsley-Griffin, 1991).

Location 3) Tamarack Creek Junction

Location 3 (Fig. 2), near Tamarack Creek junction with forest road 25, was previously mapped as Devonian Copley Greenstone (Dc) (Irwin, 1994). Many of the greenstone ―outcrops" near this area are not actually bedrock but boulder-sized glacial erratics, ranging up to 3-meters in diameter. Based on the composition of rocks along the contact, the contact is reinterpreted here as part of the fault zone breccia that comprises the basal fault of the Horse Heaven Meadows klippe.

In outcrop the foliated fault breccia contains clasts ranging up to 15 cm in diameter and deformed quartz veins within a foliated, fine-grained matrix. The fault zone matrix consists mainly of white mica, talc, and serpentine with some tremolite and chlorite. Clast compositions resemble those at Location 2 (Fig. 2) and consist primarily of plagiogranite, amphibolite, and diorite. Quartz veins are folded and boudinage. A strong foliation is prominant, striking N74W and dipping 68SW (Fig. 31).

Figure 31: Photograph of fault breccia, sample SHZ-5, in outcrop at Location 3 (Fig. 2), at the base of the Horse Heaven Meadows klippe.

In thin-section, the texture includes faint mineral alignment (defined by the serpentine, white mica, and talc), ghost augins, and cracks in the tremolite. The foliation is defined by faint mineral banding and alignment of talc and white mica.

Location 4) Loop Road Contact

The fault contact at Location 4 (Fig. 2) has mylonite and shear zone structures similar to the fault exposures at Locations 2 and 3 (Fig. 2). In outcrop, the mylonite is pale green and fine-grained. The mylonite consists of white mica, talc, fibrous tremolite, opaque minerals surrounded by fine-grained serpentine, and chlorite. In thin-section, a strong foliation is defined by mineral alignment of elongate minerals and by compositional banding of tremolite-rich layers, white mica, and talc. The opaque minerals appear to be replacing pre-existing minerals; they occur in augins with diffuse boundaries.

Panther Rock Klippe

The base of the Panther Rock klippe greenstone is completely obscured by glacial till; however, down-slope of the greenstone approximately 85 meters, a fault breccia zone is exposed. This section of fault breccia represents the basal fault of Panther Rock klippe. The thin remnant of greenstone that comprises the klippe is more extensively altered than the greenstone of the Grey Rocks klippe. The high degree of alteration may be a result of closer proximity to the basal fault.

Location 5: Lower Panther Rock klippe Fault Breccia

A small outcrop of fault breccia can be observed between Panther Rock klippe and Tamarack Creek (Location 5, Fig. 2). The outcrop of fault breccia separates the Panther Rock klippe greenstone from the underlying ultramafic sheet. Similar to the other fault breccias, the fault breccia at Location 5 contains angular plagiogranite, diorite, and amphibolite blocks ranging up to 20 cm in diameter within a serpentine matrix.

High Angle Faults

Younger, high angle normal faults bound the east and west margins of the Grey Rocks and Horse Heaven Meadows klippes, down-dropping the klippes and preserving them. The bounding normal faults tend to strike N-NW along the east and west sides of the Grey Rocks klippe and N, NE, or E along the margins of the Horse Heaven Meadows klippe.

Location P) Grey Rocks Klippe

The younger faults bounding the Grey Rocks klippe are best observed at Location P (Fig. 2) on the eastern side of the klippe. Here, the pegmatitic hornblende gabbro of the Trinity terrane comprises a ridge directly adjacent to the klippe. Although the saddle between the Grey Rocks greenstone and the gabbro ridge is covered, foliated serpentine between upper plate greenstone and the gabbro ridge strikes N9E and dips 61NW. This foliation orientation is similar to the strike and dip of the high-angle bounding fault, as inferred from the map pattern of the faults.

Location 2) Mile Marker 8.75

The best example of high angle normal faults bounding the Horse Heaven Meadows klippe is exposed at Location 2 (Fig. 2) in a road-cut exposure at the southeast margin of the Horse Heaven Meadows klippe (Fig. 25). In the road-cut, two high-angle faults juxtapose fault breccia on either side of a down-dropped segment of the basal shear zone and overlying slate of the Horse Heaven Meadows klippe. The fault surface of the eastern-most fault (Fault 2, Fig. 25A,B) is exposed, striking N42E and dipping 60NW. The fault surface of the western-most fault (Fault 1, Fig. 25A,B) is inferred to be parallel-subparallel to a dike, which strikes N32E and dips 76NW. The amount of displacement on either fault is speculative because of the lack of continuous stratigraphy across either fault; however, based on the location of the rest of the Horse Heaven Meadows klippe and the basal fault, the sliver has been down-dropped at least 15 meters.

The younger faulting may be responsible for tilting the basal shear zone contact and for the highly fractured nature of the metasedimentary rocks in the Horse Heaven Meadows klippe. Other normal faults may be present within the klippe but are hard to distinguish because the metasedimentary rocks have little compositional variation and are also fractured. The irregular basal contact of the Horse Heaven Meadows klippe suggests the presence of many small internal faults within the klippe. Several active landslides and slumps on the eastern border of the klippe occur along the steeply dipping normal faults that bound the klippe (Plate 1).

DISCUSSION

Relationship of Grey Rocks and Panther Rock Klippe Greenstones to the Trinity and Redding Terranes.

Petrologic and geochemical analysis of the greenstones from Grey Rocks and Panther Rock klippes links them with the Copley Greenstone of the Redding terrane (Fig. 19). Based on trace element comparisons of the three units normalized to either MORB or chondrites, samples from the three units are indistinguishable; therefore, the greenstones of Grey Rocks and Panther Rock klippes are interpreted as Devonian Copley Greenstone.

This interpretation conflicts with the previously published interpretations of Brouxel et al. (1988). Although greenstone and slate of the ―Grey Rocks outlier" were originally assigned to the Redding terrane (Copley Greenstone) by Irwin (1966) and Wagner and Saucedo (1987), Brouxel and Lapierre (1988) reinterpreted the greenstones of Grey Rocks and Panther Rock klippes as ―Trinity pillow basalts." The Trinity terrane pillow basalt unit of Brouxel and Lapierre (1988) also included greenstone at Sanford Pass (near the Carrville Fault area) and at Deer Creek near Mt. Shasta. This interpretation of the greenstones as ―Trinity pillow basalts" deposited within the Trinity terrane was based on their geochemical affinity with and proximity to gabbroic plutons and dikes in the Trinity terrane, and the considerable distance between these greenstone units and the Copley Greenstone (Brouxel and Lapierre, 1988; Fig. 25C).

Subsequent mapping of the Sanford Pass/Carrville Fault area by Cashman and Elder (2002) identified greenstone as Copley Greenstone and the basal contact of the greenstone as a fault. Similarly, remapping of the Deer Creek outlier by Goldstein (1997) also identified the Deer Creek outlier as part of the Copley greenstone and the basal contact as a fault.

Relationship of Metasedimentary Rocks in Horse Heaven Meadows and Grey Rocks Klippes to the Redding Terrane.

Metasedimentary rocks in the Horse Heaven Meadows and Grey Rocks klippe have been previously interpreted as a section of Mississippian Bragdon Formation (Charvet et al., 1990). In contrast, based on stratigraphic description comparisons with the Bragdon Formation and the Copley Greenstone, metasedimentary rocks in the Horse Heaven Meadows and Grey Rocks klippes are interpreted here as lenses within the greenstone and are assigned to the Copley Greenstone as Dcs.

The Bragdon Formation is comprised mainly of argillite; however, the formation is characterized by thick lenticular conglomerate beds dominated by rounded clasts of chert, limestone, shale, and sandstone, and, most notably, by lenses of chert pebble conglomerate, (Diller, 1905; Kinkel et al., 1956; Albers and Robertson, 1961). Although clasts in the Bragdon Formation are typically non-volcanic (Diller, 1905), some layers exhibit rounded volcanic clasts that are mixed with rounded sedimentary clasts (Miller and Cui, 1989). In contrast to Bragdon Formation conglomerates, the volcanic breccias and coarse tuffs within the Horse Heaven Meadows and Grey Rocks klippes are comprised solely of angular metavolcanic and single-grain clasts.

The Copley Greenstone has been separated into lithologically distinctive lower and upper sections (Lapierre et al., 1985). The upper section consists primarily of pillow lavas but also contains minor pyroclastic and tuffaceous sedimentary beds (Kinkel et al., 1956; Lapierre et al., 1985). Near Redding, Lapierre et al. (1985) describe ~~"tu~~ffaceous slaty sediments" interbedded with the Copley Greenstone. The southern section of Grey Rocks klippe exhibits a similar relationship of interbedded greenstone and tuffaceous metasedimentary beds.

The lack of conglomerate beds and rounded clasts, lack of limestone, chert, shale, and sandstone clasts in the breccia units and the dominance of volcanic clasts and ash/volcanic glass matrix compositionally distinguishes the metasedimentary and metavolcanic units of the Horse Heaven Meadows and Grey Rocks klippes from the Bragdon Formation and compositionally links the klippes units to the Copley Greenstone. Based on these compositional and spatial relations, the metasedimentary and metavolcanic units of Horse Heaven Meadows and Grey Rocks klippes are interpreted as localized sedimentary deposits within the Copley Greenstone.

Basal Shear Zone Contact of Grey Rocks, Horse Heaven Meadows, and Panther Rock Klippes.

The basal contact between the Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes and the underlying Trinity ultramafic complex is a fault contact (Fig. 32A,B). The conclusion that the basal contacts of the klippes are faults is consistent with prior work that has suggested regional tectonic extensional events (Schweickert and Irwin, 1989; Masson, 2002; Cashman and Elder, 2002). The interpretation of basal fault

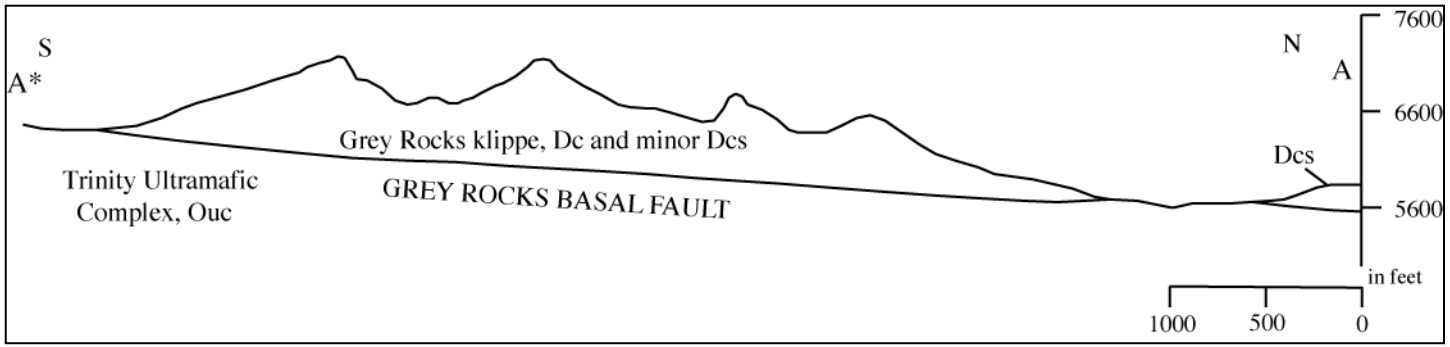


Figure 32A: Cross-section of Grey Rocks klippe depicting shallow tilt of basal fault to the north.

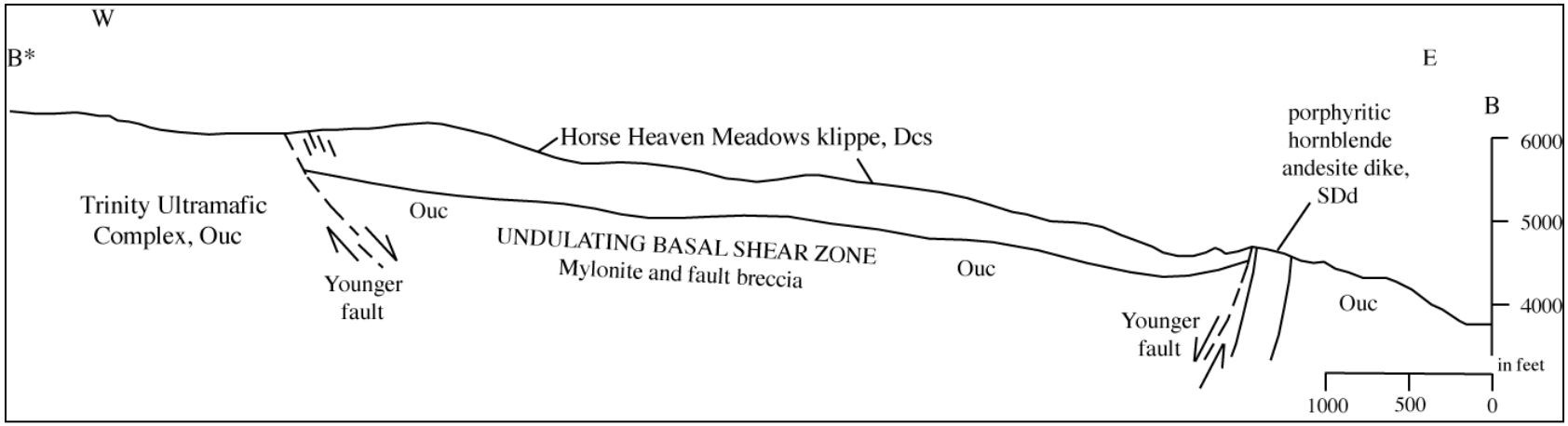


Figure 32B: Cross-section of the Horse Heaven Meadows klippe (Dcs) depicting the undulating basal fault and the high angle faults on the east and west margins of the klippe. (Refer to Figure 2 for locations of transects A-A* and B-B*).

contacts for these greenstone bodies conflicts with the depositional contact interpretation of Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes suggested by Brouxel and Lapierre (1988), Boudier et al. (1989), Charvet et al. (1990), and Wallin and Metcalf (1998).

The basal fault is a low-angle undulatory normal fault that dips shallowly to the N-NE, places younger Redding terrane units over older Trinity terrane units, and has fault zone microstructures that record extensional deformation, (Figure 32B). The shallow, generalized N-NE dip of the Grey Rocks and Horse Heaven Meadows klippes (Figure 32) was determined based on structural relations between the klippes and the underlying Trinity terrane. Fault zone microstructures such as pulled-apart clasts, boudinage quartz veins, and perpendicular to foliation and fault plane quartz veins identify the fault as extensional.

The minimum stratigraphic separation on the fault is 1400 meters based on the correlation of Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes with the upper section of the Copley Greenstone and omission of the massive flows that typify the lower half of the Copley Greenstone. The greenstone pillows and minor metasedimentary and metavolcanic lenses observed at Grey Rocks, Panther Rock, and Horse Heaven Meadows klippe have been correlated with the upper 400 meters of the Copley Greenstone as described by Lapierre et al. (1985) and Kinkel et al. (1956). This correlation and the structural thickness observed in the field identifies an omission of stratigraphy, namely, 1400 meters of massive basalt flows comprising the lower Copley Greenstone.

The basal fault contains mineral assemblages and microstructures that indicate a passage from a deep to shallow pressure and temperature regime during deformation.

Deformation on the fault occurred under greenschist facies conditions evident by greenschist mineral assemblages in deformational microstructures. The mineral assemblages in the Grey Rocks klippe shear zone are albite-epidote-actinolite-chlorite in the greenstone, white mica-epidote-chlorite-albite-quartz in the fault parallel rhyolite dike, and talc-tremolite-antigorite-chlorite in the mylonite, of which all are indicative of metamorphism under greenschist facies conditions (Raymond, 1992). Greenschist facies conditions generally occur at a depth of 10 to 15 km and in temperatures of 300-450°C (Twiss and Moores, 1992). Greenschist facies minerals, chlorite and actinolite, are observed defining foliation in the greenstone of the Grey Rocks klippe shear zone (Location 1, Fig. 2). Chlorite, white mica, and epidote define the foliation that flows around plagioclase crystals in the fault-parallel rhyolite dike. In the mylonite, serpentine, chlorite, and talc minerals are within sigma ~~–ta~~ils" and talc, serpentine, white mica, and chlorite define foliation. These metamorphic minerals within the deformational features identify the presence of greenschist metamorphic conditions at the time of formation, and in turn, identify the approximate depth of faulting as ~10 to 15 km.

Although not as indicative of specific pressure/temperature regimes as the mineral assemblages in Grey Rocks klippe shear zone, the basal fault of the Horse Heaven Meadows klippe similarly has some greenschist minerals within the microstructures of fault zone rocks. The mylonite at Location 2 (Fig. 2) has foliation defined by white mica

and serpentine; the slate has actinolite, epidote, and chlorite defining s-c foliations and actinolite and chlorite in sigma ~~-ta~~ils".

The passage from a deeper pressure-temperature regime (of greenschist facies) to relatively shallower conditions is marked by a change in deformation behavior. At temperatures and pressures less than 250 ^{o}C and 10 km, the fault zone no longer deformed ductilely through recrystallization of minerals and formation of s-c fabric. Brittle deformational features, such as fault breccia, fractures, and fault perpendicular vein intrusions of quartz and calcite formed within the fault zone.

Although the Grey Rocks, Panther Rock, and Horse Heaven Meadows basal fault zone structures record both brittle and ductile deformation, it is unclear whether the majority of slip on the fault occurred in the brittle or the ductile regime. The regional model for the sequence of events that may have lead to the present-day structural relations of the klippes is depicted in Figure 34. Neither this model nor the present day exposure can completely define the full extent of the pressure-temperature-depth regime history of the faulting. It remains unclear as to whether the majority of the slip occurred prior to uplift and exhumation of the footwall thereby mainly faulting within a ductile regime, or whether the majority of slip accompanied exhumation of the footwall thereby mainly faulting within a brittle regime.

Regional Implications

Schweickert and Irwin (1989) were first to propose a regional extensional faulting event that involved the La Grange Fault, Carrville Fault, and the entire contact between

the Redding and Trinity terrane (Fig. 33 and Fig. 34). The detachment fault interpretation is based on consistencies in the N-NE trend of faults in the Yreka area, spatial relations of younger on older units, the structural omission of units along the La Grange Fault, and orientations of grabens of younger deposits (Schweickert and Irwin, 1989). A–Trinity arch" trends NE and sets the ultramafic center topographically higher than younger units to the north (Yreka terrane) and south (Redding terrane) (Schweickert and Irwin, 1989; Figure 34). Based on the tilt of dated gravels at the La Grange mine (McDonald, 1910; Irwin, 1963), the faulting would be confined to the Oligocene but may have begun in the early Tertiary.

Mapping and petrographic analyses of rocks from Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes support interpretations of a regional extensional faulting event that extended across the eastern Klamath Mountains region (Schweickert and Irwin, 1989; Masson, 2002; Cashman and Elder, 2002). The klippes are located at a midpoint between the breakaway faults of the Yreka/Trinity terrane boundary and the faults of the Redding/Trinity terrane boundary. The importance of the extensional basal fault identified at Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes is that it provides a link between faulting in the north and faulting in the south. These three klippes represent a portion of the upper plate that contain Redding terrane units and record extensional faulting that once extended across the eastern Klamath Mountains region.

Both Redding and Yreka terrane units occur in the upper plate of the extensional fault. In addition to Grey Rocks, Panther Rock, and Horse Heaven Meadows klippes, other Redding and Yreka terrane allochthons with extensional basal faults near Callahan,

Deer Creek, Oregon Mountain, Cecilville, and Richter mine have been interpreted as relating to the same extensional faulting event (Cashman and Elder, 2002). Cashman and Elder (2002) identified allochthons with extensional basal faults with upper plate components of both Redding terrane units (near the Callahan fault and at Deer Creek) and Yreka terrane units (Oregon Mountain, Cecilville, and the Richter mine in southern Scott Valley). Grey Rocks, Panther Rock, and Horse Heaven Meadows klippe have Redding terrane Copley Greenstone and metasedimentary units comprising the upper plate.

Felsic dikes are an additional structural feature similar among all of the allochthons (Cashman and Elder, 2002). The felsic dikes intrude parallel to the basal fault or cross-cut the fault breccia. The felsic dike that intrudes parallel to the shear zone of Grey Rocks klippe is significant in that it contains shear fabric. The shear fabric identifies emplacement as syntectonic. This dike could be used in a future project to identify the exact timing of the faulting event and to test correlation to a Tertiary age as suggested by MacDonald (1910) and Schweickert and Irwin (1989).

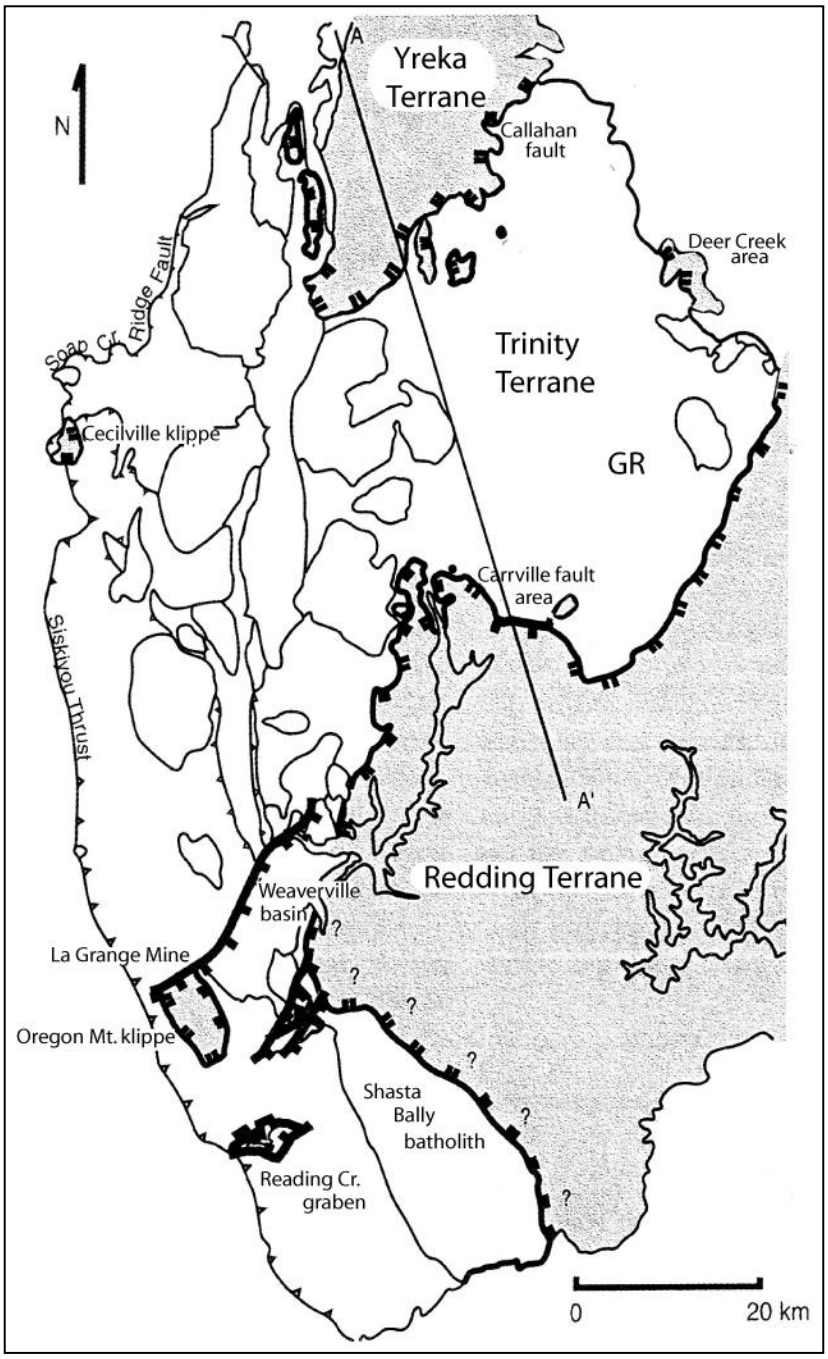


Figure 33: Simplified structural map modified from Schweickert and Irwin (1989) and Cashman and Elder (2002), showing major structural elements supporting a regional detachment fault system. GR represents Grey Rocks area. Cross-section in Figure 34 is along line A-A'.

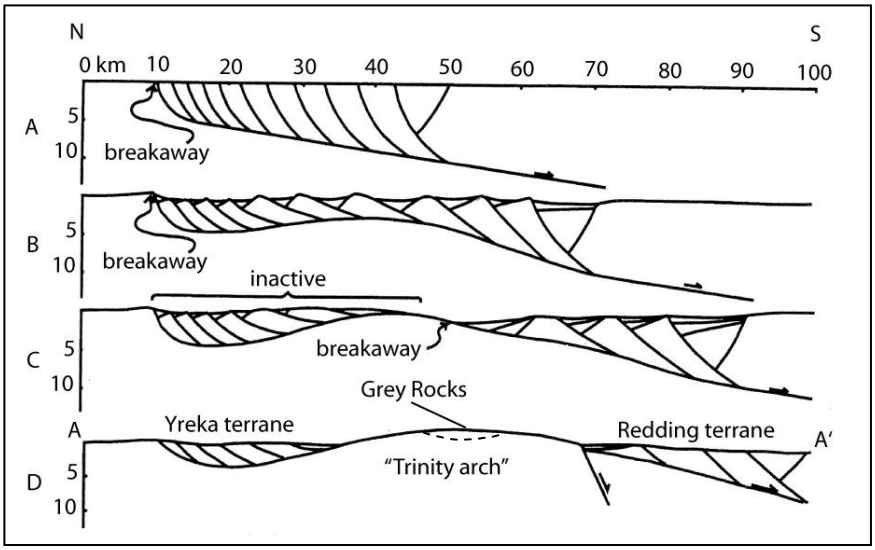


Figure 34: Schematic diagram of cross-sections depicting development of a simplified detachment fault in the EKB, modified from Cashman and Elder (2002). Grey Rocks area is located on the Trinity arch.

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CONCLUSIONS

The greenstones of the Grey Rocks and Panther Rock klippes are geochemically linked with the Devonian Copley Greenstone of the Redding Terrane, despite the spatial disparity between the outliers and the Redding terrane. The metasedimentary and metavolcanic units of the Horse Heaven Meadows klippe and metasedimentary units of the Grey Rocks klippe comprise localized sedimentary lenses (Dcs) within the Copley Greenstone Formation (Dc). Younger NW-NE trending faults have down-dropped the klippes and preserved them.

The basal fault contacts of the Panther Rock, Grey Rocks, and Horse Heaven Meadows klippes are part of a regional extensional fault system. The basal fault zone strikes N-NW and dips 5-10 degrees to the E-NE. The fault forms a 9 to 85 meter thick zone of deformation, comprised of both mylonite and fault breccia. Although the fault zone structures record both brittle and ductile deformation, the pressure-temperature-depth regime history of faulting remains. Both the present-day structural relations and the regional model are inconclusive as to whether the majority of slip on the fault occurred in the brittle or the ductile regime.

All intrusions within the study area solely intrude footwall rocks of the Trinity ultramafic complex or the fault zone, and are not observed intruding the overlying klippes. A syntectonic rhyolite dike intrudes parallel to the fault zone at Grey Rocks klippe shear zone and two younger felsic dikes cut through the fault breccia at the Horse

Heaven Meadows klippe. Radiometric age dating of these dikes might provide a minimum age for the faulting event.

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APPENDIX A:
TABLE OF SAMPLE LOCATIONS, GPS LOCATIONS, MINERALOGY, ROCK TYPE, AND INTERPRETATION.

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 1 of 7.

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
Upper plate											
SV-1	L	Copley Greenstone metasedimentary and metavocanic	Dcs	pyroclastic breccia	discontinuous, unsorted, angular, polymictic, matrix supported metavolcanic unit. Chlorite, microcrystalline quartz, epidote, and fine-grained clay matix. Clasts range up to cobble size; are volcanic, comprised of 1) epidote and quartz; 2)microcrystalline quartz; 3) microcrystalline quartz with chlorite, plagioclase laths and opaques; and 4) fiberous actinolite, microcrystalline quartz, chlorite, epidote, and saussurite (relict plagioclase). In outcrop, clast boundaries are faint but become more distinguishable in thi section. Blending ofclast boundaries due to actinolite and epido overgrowths that have overprinted the unit and original grain boundaries.	Upper plate	none				
SV-2	L	Copley Greenstone metasedimentary and metavocanic	Dcs	pyroclastic breccia		Upper plate					
SV-3	K	Copley Greenstone metasedimentary and metavocanic	Dcs	Coarse tuff	glass-rich matrix-supported unit with fine-grained, poorly sorted angular to subrounded clasts. Fine-grained matrix composed of chlorite, micas, volcanic glass, and fine-grained clays. Clasts consist ofvolcanic glass; single grains ofsubhedral and microcrystalline quartz; and subhedral relict grains now compris ofactinolite.	Upper plate	UTM	10 T	5 45	449 576	21 80
SV-4	S	Copley Greenstone metasedimentary and metavocanic	Dcs			Upper plate	none				
SV-5	S	Copley Greenstone metasedimentary and metavocanic	Dcs			Upper plate	none				
SV-6	G	Copley Greenstone metasedimentary and metavocanic	Dcs	Tuffaceous mediumpebble breccia	massive, unsorted, angular, polymictic, clast-supported volcanic unit with a fine-grained clay, quartz, and chlorite matrix. Large sections ofmatrix have recrystallized into chlorite, replacing original volcanic glass. Clasts range in size up to 0.75 cm; have volcanic textures; have compositions of1) microcrystalline quart 2) aligned fine-grained plagioclase, epidote, and chlorite; and 3) single grain clasts ofquartz, plagioclase, and chlorite.	Upper plate	UTM	10 T	5 45	475 516	29 92

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 2 of 7.

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
GR-1	T	Copley Greenstone	Dc	Greenstone pillows	chlorite; plagioclase with sparrow-tail edges altering to epidote group minerals and cloudy clays; microcrystalline quartz; opaque minerals; clinozoisite; relict clinopyroxene altering to actinolite and chlorite; fine-grained clays. Intergranular texture.	Upper plate	UTM	10 T	5 45	449 538	38 4
GR-2	T	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	449 538	38 4
GR-3	T	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	449 538	38 4
GR-4	V	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	457 537	56 59
GR-5	V	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	457 537	56 59
GR-6	H	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	45 518	463 88
PR-1	F	Copley Greenstone	Dc	Greenstone float	radial, fibrous actinolite; chlorite;plagioclase, fine-grained microcrystalline and larger quartz; euhedral clinozoisite; square 0.5mm relict pyroxenes altering to chlorite; fine-grained clays. Aphanitic texture with overprint of alteration minerals.	Upper plate	UTM	10 T	5 45	429 572	7 89
PR-2	F	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	428 571	32 58
PR-3	F	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	428 571	32 58
PR-4	F	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	428 571	32 58
PR-5	F	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	427 570	84 91
PR-6	F	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	427 570	84 91
PR-7	F	Copley Greenstone	Dc	Greenstone pillows		Upper plate	UTM	10 T	5 45	427 570	84 91

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 3 of 7.

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
COP-1		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 45	389 971	60 62
COP-3		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 44	369 981	83 73
COP-4		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 44	369 981	83 73
COP-5		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 45	389 971	60 62
COP-6		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 44	368 982	29 96
COP-7		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 44	368 983	12 27
COP-8		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 44	368 982	29 96
COP-9		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 45	495 402	63 71
COP-10		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 45	495 402	63 71
COP-11		Copley Greenstone	Dc	Greenstone flow		Upper plate	UTM	10 T	5 45	495 402	63 71

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 4 of 7.

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
Fault Rocks											
COP-12		Copley Greenstone	Dc	Greenstone		Upper plate	none				
COP-13		Copley Greenstone	Dc	Greenstone		Upper plate	none				
C0P-14		Copley Greenstone	Dc	Greenstone		Upper plate	none				
D-1	2		Dike	rhyolite	dike consisting mainly of microcrystalline to <0.4 mm quartz, anorthoclase feldspar, and <0.5 mm poikilitic plagioclase with epidote group inclusions. Some plagioclase crystals exhibit mantling, myrmekite texture, and grid like twinning. Secondary minerals include chlorite, saussurite, and reddish brown opaques Aphanitic texture. Displays chilled margins.	Post-tectoni with shear zone	UTM	10 T	5 45	479 556	66 89
D-2	2		Dike	allotriomorphic granular grano-diorite	dike consisting mainly of <0.5 mm quartz, 1 to 1.25 mm mantled poikilitic plagioclase with epidote group inclusions, and minor orthoclase feldspar; minor amounts of chlorite, saussurite, and reddish brown opaques.	Post-tectoni with shear zone	UTM	10 T	5 45	479 556	66 89
SHZ-1	4	Copley Greenstone metasedimentary and metavocanic	Dcs	Slate	Slate	Upper plate	UTM	10 T	5 45	466 574	94 84
SHZ-2	2	Copley Greenstone metasedimentary and metavocanic	Dcs	Slate	Slate, actual composition of the matrix was too fine-grained to determine from thin-section analysis alone. S-C foliation, sigma clasts, aligned minerals, and deformed quartz veins. Foliation defined by aligned elongate fine-grained minerals of actinolite, chlorite, epidote. Sigma clasts are microcrystalline clasts with intergrown epidote group minerals. Quartz veins account for 15% of volume, intrude parallel or oblique to foliation. In outcrop, slat has two pervasive cleavage planes (bedding was not determined) striking N80E and dipping 25N and striking N26W and dipping 21S.	Upper Plate	UTM	10 T	5 45	479 556	66 89

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 5 of 7.

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
SHZ-3	2	Fault Rocks (mapped as part of Trinity terrane)	Oum	mylonite	consists mainly of fine-grained white mica, serpentine, chlorite, tremolite, and opaque minerals. Texture defined by very strong compositional layering, very strong shape-preferred orientation o minerals, and sigma clasts. In outcrop, displays a strong foliation striking N41E and dipping 35N.	Lower plate	UTM	10 T	5 45	479 556	66 89
SHZ-4	4	Fault Rocks (mapped as part of Trinity terrane)	Oum	mylonite	consists of white mica, talc, fibrous tremolite, opaque minerals surrounded by serpentine, and chlorite. Strong foliation and mineral alignment of elongate minerals and by compositional banding of tremolite rich layers, white mica, and talc. Opaque minerals form augins with diffuse boundaries. In outcrop, mylonit is pale green, fine-grained.	Lower plate	UTM	10 T	5 45	466 574	94 84
SHZ-5	3	Fault Rocks (mapped as part of Trinity terrane)	Oum	fault breccia	consists mainly of white mica, talc, and serpentine with some tremolite and chlorite. Clasts are mainly plagiogranite, amphibole and diorite. Quartz veins are folded and boudinage. Texture includes faint mineral alignment (defined by the serpentine, white mica, and talc), ghost augins, and cracks in the tremolite. Strong foliation is prominant in outcrop, stiking N74W and dipping 68 In thin-section, the foliation is harder to differentiate because of the fine-grain nature of the sample; however, faint mineral bandin comprised primarily of talc and white mica define alignment.	Lower plate	UTM	10 T	5 45	452 559	25 06
SHZ-6	1	Copley Greenstone	Fault	Greenstone	very fine-grained chlorite, quartz, clinozoisite, and fine-grained clays and amphiboles. Faint mineral alignment defined by elonga grains of chlorite and amphibole. Highly fractured. Several different quartz veining events, chlorite and quartz sections between fractured sections of rock, and some calcite along vein edges.	Upper plate	UTM	10 T	5 45	479 519	30 19

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 6 of 7.

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
SHZ-7	1	Fault Rocks (mapped as part of Trinity terrane)	Fault	mylonite	comprised mainly of talc, white micas, serpentine, chlorite, actinolite, and fine grained clays. Exhibits mineral banding, mineral alignment defining a faint s-c fabric, and porphyroclasts o relic hornblendes forming sigma clasts. Relict hornblende altered to actinolite. Outcrop exhibits strong foliation striking N10W ar dipping 43SW.	Lower plate	UTM	10 T	5 45	479 519	30 19
SHZD-8	1		Dike	rhyolite	consists mainly of strongly aligned, poikilitic plagioclase containing fine-grained epidote group inclusions, and quartz; wi lesser amounts of orthoclase feldspar, chlorite, fine-grained white micas, fine-grained clays, and saussurite. Anastomozing and moderately rough foliation, defined by thin bands of white mica and quartz, flows around the plagioclase crystals creating augens Veins intersect the foliation perpendicularly.	Intrusive/ cogenetic with Shear zone	UTM	10 T	5 45	479 519	30 19
SHZ-9	2	Fault Rocks (mapped as part of Trinity terrane)	Oum	Fault breccia	comprised of a serpentine fault breccia with felsic and mafic clasts ranging up to boulder size in a serpentine, quartz, chlorite, and smectite matrix. Matrix consists of serpentine flows around angular plutonic clasts, creating planar crystal alignment. Clasts are plagiogranite, amphibolite, and serpentine. Exhibits pulled apart clasts with quartz fibers between fragments.	Lower plate	UTM	10 T	5 45	479 556	66 89
SHZ-10	2	Fault Rocks (mapped as part of Trinity terrane)	Oum	Fault breccia		Lower plate	UTM	10 T	5 45	479 556	66 89

Appendix A: Table of sample locations, GPS locations, mineralogy, rock type, and interpretation. Page 7 of 7

Sample Name	Field Map Loc.	Formation	Map Unit	Rock Type	Mineralogy and texture	Interpret-ation	GPS Location				
Lower Plate											
D-3	4	Trinity terrane	SDd	porphyritic hornblende andesite	porphyritic pluton with euhedral hornblende up to 3 mm in lengt (altered to fine-grain amphiboles, chlorite, and calcite); euhedral mm plagioclase (altered to saussurite and fine-grained clay); and minor cubic pyrite. The fine-grained groundmass consists of microcrystalline quartz, plagioclase, chlorite, and small laths of clinozoisite.	Lower plate	UTM	10 T	5 45	466 574	94 84
D-4		Trinity terrane	Ogd			Lower plate	none				
UM-1		Trinity terrane	Oum			Lower plate	UTM	10 T	5 45	420 565	23 73
UM-2	A	Trinity terrane	Oum	serpentinized peridotite	dark to blackish green serpentinized peridotite. Complete psuedomorphic alteration to serpentine and magnetite, forming serpentinite. Opaque minerals, faintly aligned in hand sample, preserve original grain boundaries and idiomorphic granular texture.	Lower plate	UTM	10 T	5 45	462 517	77 52
UM-3	B	Trinity terrane	Oum	serpentinized peridotite		Lower plate	UTM	10 T	5 45	454 579	50 65
UM-4	B	Trinity terrane	Oum	serpentinized peridotite		Lower plate	UTM	10 T	5 45	454 579	50 65

- USGS Open-File Report 91-595 discussing gold-bearing quartz veins in the Klamath Mountains.

U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGIC SETTING, CHARACTERISTICS, AND GEOCHEMISTRY OF GOLD-BEARING QUARTZ VEINS IN THE KLAMATH MOUNTAINS IN THE REDDING 1 x 2 DEGREE QUADRANGLE, NORTHERN CALIFORNIA

by

Miles L. Silberman[1] and Joanne Danielson[2]

Open-File Report 91-595

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

[1]U.S. Geological Survey, Denver, Colorado 80225
[2]Shasta College, Redding, California 96003

Geologic Setting, Characteristics and Geochemistry of Gold-Bearing Quartz Veins in the Klamath Mountains in the Redding 1 x 2 Degree Quadrangle, Northern California

Miles L. Silberman, U.S. Geological Survey, Denver, CO 80225
Joanne Danielson, Shasta College, Redding, CA 96003

ABSTRACT

More than three million ounces of gold have been produced from several geological terranes of the Eastern Klamath Mountains in the Redding, California 1 x 2 degree quadrangle. The most common lode-gold deposits are mesothermal-type quartz or quartz-carbonate veins which are hosted by a variety of rock types including meta-sedimentary, meta-volcanic and granitic rocks. There is a spatial association between significant gold deposits and granitic plutons or hypabyssal intrusions that are related to the plutons. The gold-bearing quartz veins have similar physical characteristics and mineralogy, but they occur in at least seven different geologic settings. Distinct trace element compositions occur in veins hosted by different rock types.

REGIONAL GEOLOGY

The southern Klamath Mountains in the Redding 1 x 2 degree quadrangle consist of a series of lithotectonic units or belts of rock that form thrust plates in a generally eastward-dipping sequence (Irwin, 1981). These "terranes," as they are now referred to, and their structural and tectonic evolution, have been described by Irwin (1981; 1985). They consist of island-arc volcanic and sedimentary rocks and oceanic crust and upper mantle rocks (now ophiolites) that formed during Ordovician through Jurassic time. The Eastern Klamath Terrane (fig. 1), the nucleus of the Klamath Mountains to which the other terranes were joined, was formed during long standing volcanic-arc activity that extended from the Devonian through the Jurassic (Irwin, 1981). This Eastern Klamath Terrane (EKT) was built on Ordovician oceanic crust and upper mantle, now represented by the Trinity Terrane (TT). Along the western edge of the EKT, the Central Metamorphic Terrane (CMT; fig. 1) developed during Devonian subduction beneath the TT. Subsequently, during middle to late Jurassic time, the Northfork (NFT), Hayfork (EHT and WHT), Rattlesnake Creek (RCT), and Western Jurassic Terranes (WJT) were then amalgamated and (or) accreted to the combined EKT and CMT by successive subduction events (Irwin, 1981; 1985).

The terrane boundaries are thrust faults, many of which commonly contain serpentinized ultramafic bodies. Most of the serpentinites are parts of ophiolites which were deformed during terrane amalgamation and (or) accretion. Deformation led to dismemberment, remobilization, and emplacement of the serpentinites along the regional terrane boundaries and other thrust faults. The serpentinites are strongly magnetic and their subsurface extent, which in many areas is much larger than their outcrop areas, is well delineated on aeromagnetic maps (Griscom, 1991, in press).

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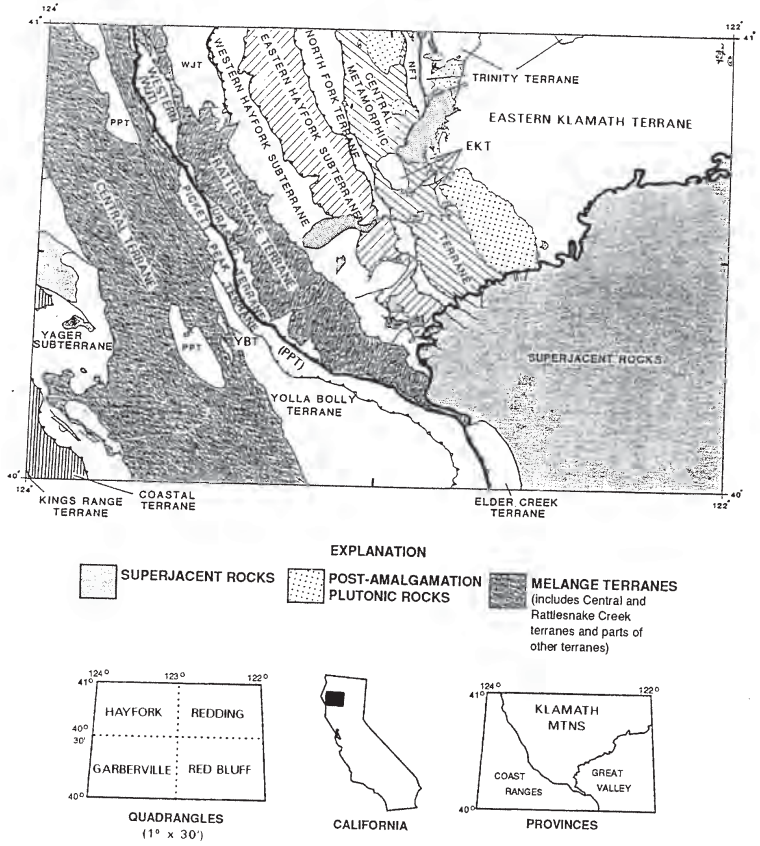

Figure 1. Generalized geologic map of the Redding 1 x 2 degree quadrangle showing physiographic provinces and geologic terranes. Modified from Fraticelli and others, 1987.

Granitic plutons and associated hypabyssal rocks of Devonian through Cretaceous age intrude the rocks of all of the terranes. They occur in belts of equivalent age that generally follow the overall trends of the amalgamated terranes (Irwin, 1985; fig. 2). Some plutons and plutonic belts were emplaced before the host terrane was attached to an adjacent terrane and are hence, "pre-amalgamation." Most of these are parts of ophiolites or are co-magmatic with volcanic rock sequences that formed in the same island arc. An example of this is the Ironside Mountain batholith belt (fig. 2) in the WHT which is co-magmatic with the Hayfork Bally meta-andesite, which underlies a large part of the terrane (Irwin, 1985).

There are plutons and plutonic belts that are clearly post-amalgamation, as they are significantly younger than their wall rocks in their host terranes, based on isotopic ages, or they cut across terrane boundaries (Irwin, 1985). The Shasta Bally batholith, and the belt of plutons in which it occurs are post-amalgamation (Irwin, 1985; fig. 2).

Regional metamorphic grade of the volcanic and sedimentary rocks of the terranes ranges from unmetamorphosed, through greenschist facies to almandine-amphibolite facies (Davis, 1966). Metamorphosed rocks of variable grade are present in all of the terranes. Contact metamorphism has affected rocks adjacent to plutons, particularly post-amalgamation intrusions, as exemplified by the banded gneiss zones along the contacts of the Shasta Bally batholith with its wall rocks (Albers, 1964).

Superjacent rocks that overlie the amalgamated terranes include the Great Valley Sequence sedimentary rocks of Cretaceous age, and other sedimentary and volcanic rocks of Cretaceous and Tertiary age. Most of these occur in the Great Valley Physiographic Province (fig. 1).

Most of the terranes of the Klamath Mountains Province contain similar lithologies, including sandstone, mudstone, shale, greenstone, minor limestone, and their metamorphosed equivalents. A few, such as the RCT and the CMT are unique. The former is largely dismembered ophiolite, the latter is a complex of mafic and felsic gneisses and schists. Some terranes such as the NFT and EHT are melanges or contain a significant melange component. The melanges are chaotic mixtures of varied oceanic or island-arc lithologies in a shaley matrix. Fraticelli and others (1987) describe individual formations, including plutons, in the terranes. Their geologic map was the basis for figure 1.

LODE GOLD DEPOSITS

Geologic setting, relationship to plutonic belts, plutons and hypabyssal intrusions:

Gold in the Klamath Mountains has been produced from a variety of deposit types including placer deposits, gold-bearing quartz veins, Cu-Zn massive sulfide deposits, and sulfide disseminations and sulfide-rich veins in ultramafic rocks. More than half of the

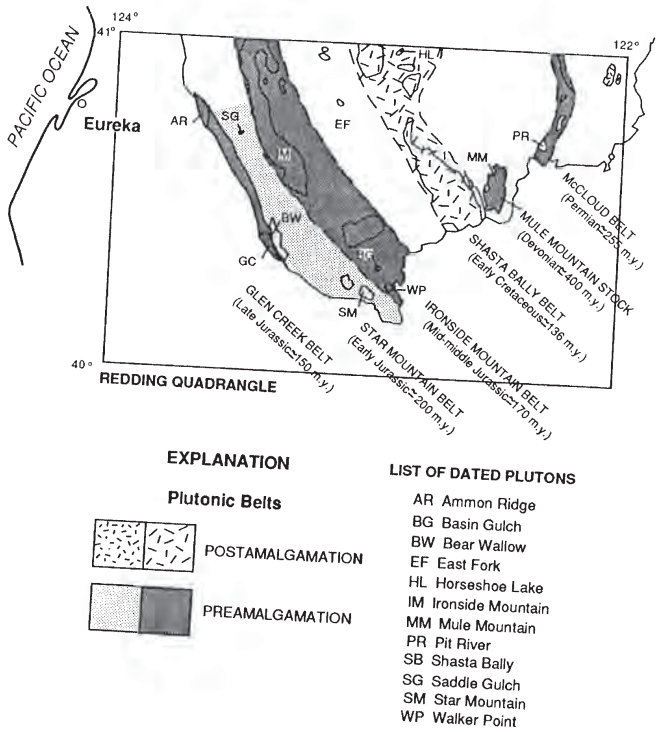

Figure 2. Map of the Klamath Mountains in the Redding 1 x 2 degree quadrangle province showing outlines of major plutons and trends of plutonic belts. Modified from Irwin, 1985.

gold (64%) was produced from placers. Gold rich quartz veins produced about 27 percent and the remainder, about 9 percent, was produced as a by-product of Cu- and Zn-rich massive-sulfide deposits. There are no reliable figures for gold production from ultramafic rocks (Irwin, 1960; Albers, 1964). The most common lode deposits are Au and Au/Ag-rich quartz and quartz-carbonate veins similar to those found along the Mother Lode Belt in central California (Landefield and Silberman, 1987; Danielson and Silberman, 1988; Elder and Cashman, 1991).

Danielson and Silberman (1988) suggested that most of the productive gold-bearing quartz vein districts are situated between pre- and post-amalgamation pluton belts, and are within a few kilometers, at most, of the contact between their host rocks and one or more granitic plutons of either association (figs. 2 and 3). The observation appears to work best in the EKT where many of the districts are located between the Cretaceous Shasta Bally belt and either the Devonian Mule Mountain Stock or plutons belonging to the Permian McCloud belt (figs. 2 and 3). In the CMB, the districts occur within the Shasta Bally belt; in the Hayfork Terrane, the districts occur within the Ironside Mountain belt.

Lanphere and others (1968) plotted the distribution of lode gold deposits which produced greater than $100,000 (approximately 5,000 oz) in the California part of the Klamath Mountains. They concluded that there was a strong association between gold mineralization and the youngest (now called post-amalgamation) plutons (fig. 4). Both of these interpretations could be correct, although some deposits such as those in the Hayfork and Harrison Gulch districts are clearly in the Ironside Mountain belt, which is pre-amalgamation.

Most of the gold-mining districts have two or more petrographically distinct sets of intermediate to felsic hypabyssal intrusions that are spatially associated with the gold-bearing quartz veins. These dikes and sills are believed to be offshoots of the larger plutonic bodies (Hotz, 1971; Danielson and Silberman, 1988). The French Gulch-Deadwood district, which was the largest gold producer in the Klamath Mountains, and nearby Whiskeytown district (table 1) are good examples of the relationships between plutonic belts, plutons and hypabyssal intrusions. The most productive mines in these districts are situated between the pre-amalgamation, Devonian Mule Mountain stock and the post-amalgamation, Early Cretaceous Shasta Bally batholith. The gold-bearing quartz veins are closely associated with dikes and sills of quartz porphyry, dacite, quartz diorite and diorite (Albers, 1965; Danielson and Silberman, 1988). The "Birdseye" porphyry described by Albers (1961; 1965) that is so frequently associated with gold-bearing quartz veins at French Gulch-Deadwood and other districts in the EKT ranges in composition from dacite to diorite, and may be of several different ages (Danielson, 1988).

Districts such as South Fork, Canyon Creek-East Fork, Hayfork, and Harrison Gulch appear to occur within individual plutonic belts rather than between them. However, in the more productive districts, there is an association with at least two petrographically distinct hypabyssal intrusions. At Canyon Creek-East Fork, for

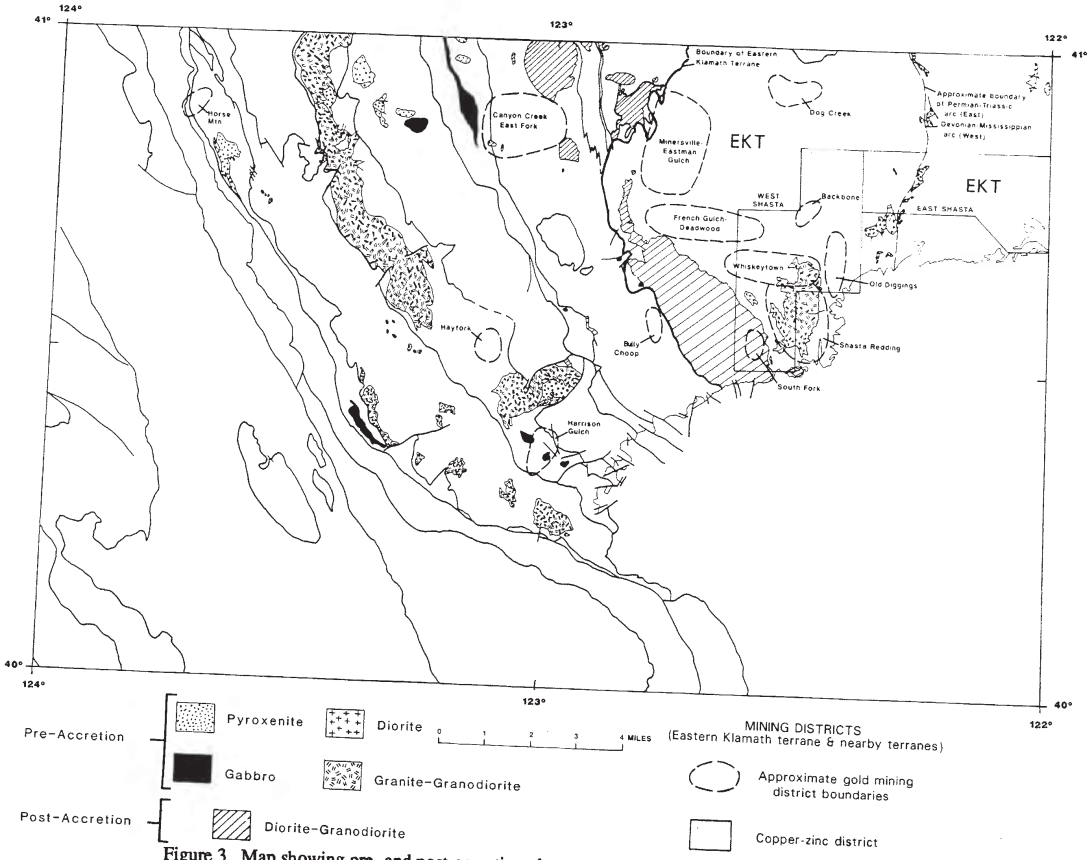

Figure 3. Map showing pre- and post-accretion plutons and lode gold mining districts in the Redding 1 x 2 degree quadrangle. Modified from Fraticelli and others, 1987.

EKT = Eastern Klamath Terrane

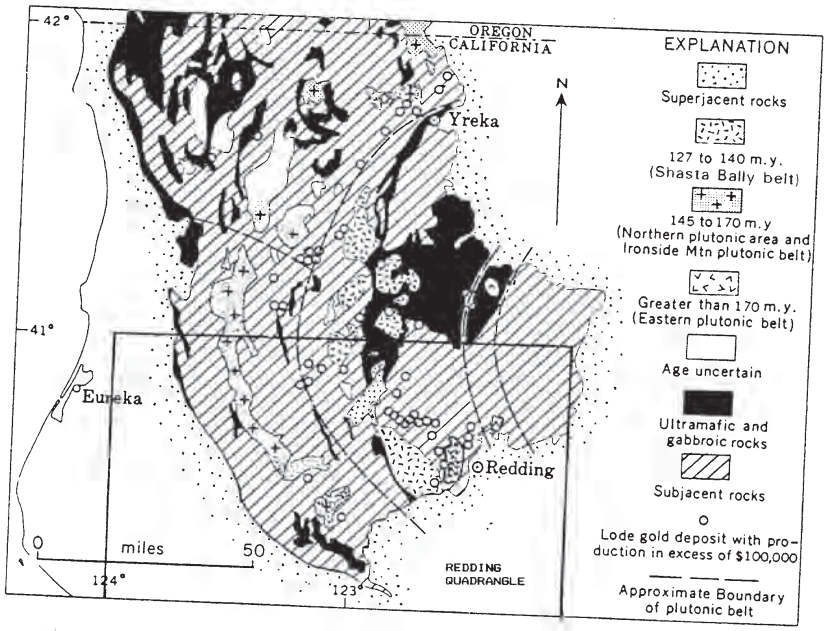

Figure 4. Map showing distribution of granitic plutons and lode gold deposits with greater than $100,000 (5,000 oz) production in the Klamath Mountains. Modified from Lanphere and others, 1968.

Table 1. Lode gold production from mining districts and terranes of the Klamath Mountains

[EKT = Eastern Klamath Terrane, CMB = Central Metamorphic Terrane, HT = Hayfork Terrane. Harrison Gulch and Hayfork are at or near boundary of Eastern and Western Hayfork subterranes. 1. Hotz, 1971; 2. Clark, 1970; 3. Albers, 1965; 4. Hotz and others, 1972. [1]Mostly by-product from massive sulfide deposits, East and West Shasta districts.]

District	Terrane	Au (oz)	Reference
French Gulch-Deadwood	EKT	800,000 1,500,000	1. 2.
Minersville	EKT	39,000	1.
Whiskeytown	EKT	54,000 70,000	1. 3.
Backbone	EKT	50,000	1.
Shasta-Redding	EKT	25,000	1., 2.
Old Diggings	EKT	200,000	1.
Shasta Cu-Zn belt[1]	EKT	560,000	2.
Canyon Creek-East Fork	CMB	192,000	1., 4.
Harrison Gulch	HT	200,000	1.
Hayfork	HT	5,000	1.

example, quartz porphyry, pegmatite, aplite, and diorite are associated with many of the quartz veins (Hotz, 1971; Hotz and others, 1972).

The Old Diggings district which is located between the Devonian Mule Mountain Stock and the Permian McCloud belt plutons, including the Pit River stock (figs. 2 and 3), appears to corroborate the suggestion of important districts being located between plutonic belts. However, a recent K-Ar age determination on sericitic alteration adjacent to one of the large veins at the Reid mine in the district shows that the mineralization was Devonian in age, and approximately the same age as the Mule Mountain stock (Danielson and Silberman, 1990).

Production

More than 7 million ounces of gold have been produced from lode and placer deposits in the Klamath Mountains (Hotz, 1971). The most common lode deposits are mesothermal-type, quartz veins similar to those along the Mother Lode belt. A variety of host rocks and three geologic terranes of the eastern Klamath Mountains contain the veins (Danielson and Silberman, 1988). Significant gold has also been produced, mostly as a by-product, from Cu-Zn massive sulfide deposits, particularly in the Shasta Copper-Zinc belt (Clark, 1970). During the 1860's Au and Ag were originally mined from gossans in these districts (Clark, 1970). Elsewhere in the Klamath Mountains, auriferous massive sulfide deposits have also produced Au. For example, the Siskon mine in the Happy Camp district, near Yreka produced more than 180,000 oz of Au from ferruginous gossan ore, which resulted from the weathering of a massive sulfide body (Hotz, 1971).

French Gulch-Deadwood, with an estimated production of 800,000 oz Au (Hotz, 1971) or 1.5 million ounces Au (Clark, 1970), was the most productive district in the Klamath Mountains. Based on Au production figures given by Clark (1970), Hotz (1971), and Albers (1965), we estimate that the total lode gold produced from mining districts of the Klamath Mountains in the Redding quadrangle exceeds 2 million ounces (table 1).

Because we lack adequate data for smaller, but still productive mines, and from many of the smaller districts, such as Dog Creek and Bully Choop, and the fact that much of the data from Hotz (1971) are minimum estimates, the summary figure for Au production can be considered a lower limit. Table 1 gives an estimate of 1.6 million ounces of Au production from quartz veins, with another 560,000 oz from by-product of massive sulfide deposits. The minimum lode production of the Redding quadrangle is thus 2.1 million ounces of Au (using the lower estimate for French Gulch-Deadwood).

Placer Au production from the entire Klamath Mountains and the Redding quadrangle is much more difficult to estimate. There are few good production summaries in the literature, and much of the Au was produced early in the mining history, before good records were kept. Placer gold mining was the principal industry in Trinity County, which occupies a good part of the Redding quadrangle, from 1849 until World War II (O'Brien, 1965). The La Grange mine, in the CMT, was one of the largest

placer mines in the U.S. and was active from 1851 through the 1940's. It produced approximately 390,000 oz of Au (Clark 1970). No adequate data exist from most of the rest of the placer mines, but we suggest that their aggregate production was at least the equivalent of the La Grange.

Adding these estimates, results in a suggested minimum figure of Au production for the Redding quadrangle of about 3 million ounces accounting for nearly one-half the production of the Klamath Mountains. The great preponderance of the Au came from the EKT, followed by the Hayfork Terrane, and the CMT. Although significant lode gold deposits have not been found in other terranes of the Klamath Mountains and Coast Ranges in the Redding quadrangle, geochemical anomalies, of Au and other elements associated with gold-bearing deposits in this region are present in rocks and stream-sediment samples throughout the quadrangle (Silberman and others, 1991; Smith and others, 1990; 1991).

Geologic settings of gold-bearing quartz veins and gold-mining districts in the Klamath Mountains in the Redding Quadrangle:

Gold-bearing quartz veins occur in a variety of host rocks and geologic settings throughout the Klamath Mountains, but the largest deposits and the most productive districts are located in the EKT, CMT, and the Hayfork Terranes (fig. 3). We define seven common geologic settings in which gold-bearing quartz veins occur. The distinctions are based on our observations and on published descriptions. It is likely that additional work, particularly detailed work, will revise this classification.

1. Steeply dipping veins in greenstone with or without meta-rhyolite of Devonian age. The host rocks are within the greenschist facies. Examples are the Old Diggings and Dog Creek districts (Hotz, 1971), in the EKT.

2. Steeply dipping veins in graywacke and argillite of late Devonian to Early Carboniferous age, and moderately dipping quartz veins along the thrust contact of the graywacke-argillite rocks and underlying Devonian greenstone. Both sets of veins are associated with dikes and sills of quartz-porphyry, and "Birdseye" porphyry of diorite to dacite composition (Albers, 1965; Hotz, 1971). Examples are French Gulch-Deadwood, Eastman Gulch, Minersville, and parts of the Whiskeytown district, in the EKT.

3. Steeply dipping quartz veins in the Devonian Mule Mountain stock and co-magmatic meta-rhyolite and greenstone near the contacts of these rocks with the stock. Examples are the Shasta-Redding, and parts of the Whiskeytown districts (Albers, 1965; Hotz, 1971; Lydon and O'Brien, 1967). The Backbone district has quartz veins hosted in a Devonian meta-rhyolite intrusion some distance from the contact of the Mule Mountain stock (Lydon and O'Brien, 1967), but we include it in this category.

4. Steeply dipping Ag-rich quartz veins in the Early Cretaceous Shasta Bally batholith. The South Fork district is an example, the only precious metal, quartz-vein

district in the Klamath Mountains that was Ag rich, with little Au production (Tucker, 1926; Albers, 1965; Hotz, 1971).

5. Low and moderate to steeply dipping quartz veins in amphibolite facies grade schists and gneisses. The steeper veins appear to be associated with pegmatite, aplite, and quartz porphyry dikes. Examples are the Canyon Creek-East Fork and Bully Choop districts in the CMB (Ferguson, 1914; Hotz, 1971; Averill, 1941; O'Brein, 1965).

6. Steeply dipping quartz veins in argillites and cherts of late Paleozoic or Jurassic age near the contact with Hayfork Bally Meta-andesite of Jurassic age. Examples are Hayfork and Harrison Gulch districts (Hotz, 1971), in the Hayfork Terrane.

7. Gold-bearing quartz veins which contain copper sulfides, and (or) disseminated copper sulfides and carbonates in serpentinite, diorite, and gabbro in ultramafic rock complexes (Eric, 1948). These deposits have not been described in the recent literature. They are common in many of the terranes of the Redding quadrangle, including the Franciscan terranes, Josephine Ophiolite at the WJT, TT of the EKT, north of the Redding Quadrangle, and in other terranes that contain serpentinites and dismembered ophiolites such as the RCT. The only significant example of this deposit type in the Redding Quadrangle is in the Horse Mountain district (fig. 3).

Horse Mountain produced between 100,000 and 1,000,000 pounds of Cu (Eric, 1948). The district is underlain by serpentinite which is cut by dikes of diorite, gabbro and felsite (Laizure, 1925) which we found to be plagiogranite. Lowell (1916) and Laizure (1925) report the occurrence of chalcopyrite, bornite, chalcocite, native copper, cuprite and copper carbonates. Gold is reported to be present (Lowell, 1916; Laizure, 1925) but the few samples collected during the course of our work did not contain detectable Au, although one sample had 5 ppm Ag, along with greater than 2 percent Cu. No quartz veining is present at Horse Mountain, but small veins of chalcocite were seen in serpentinite. Descriptions of other "Horse Mountain" type deposits indicate the presence of quartz veining in some of them (Hotz, 1971; Eric, 1948).

Descriptions of the quartz veins, alteration and mineralogy are taken mostly from Hotz (1971), modified by our own observations. Quartz veins in all of these settings are medium to coarse grained and contain variable amounts of wall rock fragments and subordinate calcite. Ribbon texture is common in the veins. The sulfide mineral content is generally low, from less than 3 percent to approximately 5 percent. Sulfides are usually concentrated in wall rock inclusions and the wall rocks immediately adjacent to the veins. Pyrite is the most abundant sulfide mineral. Others are arsenopyrite (particularly common in argillite-graywacke-hosted veins), galena, sphalerite, chalcopyrite, pyrrhotite, and molybdenite (Hotz, 1971). Gold tellurides are present in veins hosted in greenstones (MacDonald, 1986). Elemental gold occurs in quartz and within sulfides, mainly pyrite (Hotz, 1971). The Au/Ag, based on analyses of quartz-vein samples collected during this study is usually 1 or more, except for the Ag-rich South Fork District.

Wall rock alteration adjacent to the quartz veins depends on host rock lithology. In greenstone, meta-rhyolite and granitic rock, including dikes and sills, sericitic alteration is most common. Chloritic alteration and carbonate enrichment may also occur. Dikes and sills adjacent to veins generally are silicified and have sericitic alteration assemblages slightly further from the veins. Albitic alteration and carbonatization are also common and some paragonite is reported adjacent to some veins (Ferguson, 1914; Albers, 1965; Hotz, 1971). Wall-rock alteration in argillite and graywacke is not obvious, although local silicification occurs immediately adjacent to veins. Petrographic study of wall rocks at the Summit Mine in French Gulch however, shows that sericite and chlorite alteration minerals and thin calcite or ankerite veins are commonly developed within a few meters of the larger Au-bearing quartz veins in those host rocks (H. Folger, written commun., 1986). Hornblende schist is usually chloritized adjacent to veins.

Trace element content of mineralized quartz veins does not show a consistent relationship to host rock chemistry. However, quartz veins hosted in different lithologies do tend to have different overall trace element compositions. Ag content of mineralized quartz veins is generally less than 10 ppm, with Au/Ag usually greater than 1. The South Fork district is an exception, with Ag content of samples from the base metal-silver veins ranging from 50 to 5,000 ppm and Au/Ag less than .01. Arsenic content is highest (>1,000 ppm) in veins hosted by argillite and graywacke. Te (2-20 ppm) and B (50-300 ppm) are highest in veins hosted by greenstone. Cu (10-100 ppm), and Pb and Zn (both 10-1,000 ppm) contents are highest outside of the South Fork district in veins hosted by hornblende schist in the Canyon Creek-East Fork mining district. These veins also contain an average of 1.2 ppm Hg, much higher than gold-rich veins from other lithologies, and other mining districts. At Horse Mountain mineralized rocks contain greater than 2 percent Cu and high amounts of Ni and Cr (1,500-2,000 ppm). Ag (5 ppm) is anomalous.

An appendix follows the main text of this report. It summarizes the geological and geochemical characteristics of many of the mining districts discussed above and shown on figure 3.

Origin of the gold-bearing quartz veins:

The petrography, textures and associated alteration of their wall rocks suggests that these veins are typical mesothermal gold-bearing veins similar to those found along the Mother Lode belt of California to the southeast of the Klamath Mountains. We lack the fluid inclusion and light-stable isotope data that would enable us to specify the conditions of formation of the veins, although a few stable isotope analyses are currently in progress. Stable isotope studies of the mother lode veins suggest that they were formed from two different fluids, an early, isotopically heavy, CO_2-bearing fluid of deep origin followed by an isotopically light fluid of permiable meteoric origin (Böhlke and Kistler, 1986).

Elder and Cashman (1991) suggest, on the basis of fluid inclusion data, that mineralized quartz-carbonate veins at Quartz Hill, Oro Fino district, central Klamath Mountains, north of Redding, were formed by partial mixing of two fluids, one of metamorphic origin, and the other possibly of meteoric origin. They have submitted a detailed study of this area for publication (Elder and Cashman, in press). The veins at Quartz Hill are associated with a major transcurrent fault (Elder and Cashman, 1991) and are not spatially associated with granitic plutons or hypabyssal intrusions, as are many of the mineralized Redding Quadrangle examples. We need isotopic-age data on the veins, their spatially associated hypabyssal igneous rocks, and fluid inclusion and stable isotope data before we can launch into a discussion of genesis. We are hopeful of obtaining those data in the future.

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APPENDIX A

SUMMARY OF CHARACTERISTICS AND GEOCHEMISTRY OF GOLD-BEARING QUARTZ VEINS IN SOME OF THE LODE GOLD MINING DISTRICTS IN THE KLAMATH MOUNTAINS IN THE REDDING 1 x 2 DEGREE QUADRANGLE

Old Diggings district

- Terrane: Eastern Klamath
- Host rock lithology: Meta-andesite and -dacite of Copley Greenstone and meta-rhyolite of Balaklala Rhyolite
- Vein characteristics: Parallel to subparallel massive quartz veins from a few inches to 25 ft wide, which strike north to northeast, and dip vertical to steep east. The average width of veins is 10 ft at the Reid mine, the largest in the district (Averill, 1933). Quartz is very clean and was used as smelter fluxing ore (Hotz, 1971).
- Igneous rocks: District occurs between Mule Mountain stock (Devonian), and Pit River stock (Permian), however, K-Ar age of quartz-paragonite adjacent to quartz vein is 396 ± 9 Ma, which is the age of the Mule Mountain stock (Danielson and others, 1990).
- Geochemical characteristics: Mineralized veins have moderate Ag content, high B content (geometric mean of 56), and elevated Te (6-21 ppm) in samples with greater than 1 ppm Au. Base metal content is very low, with Cu being highest on average, reflecting greenstone host rocks. Cu and Zn contents are both lower than wall and host rocks. Hg is relatively high, but not as high as Canyon Creek-East Fork. In the veins, gold correlates well with Ag and Te, less well with B, not at all with Cu, Pb, or Zn (table 3).
- Production: Approximately 200,000 oz Au (Hotz, 1971).
- Mineralogy: Pyrite, chalcopyrite, Au- and Ag-bearing tellurides, free gold (Hotz, 1971; MacDonald, 1986).
- Au/Ag = 1.0 (9 samples).

French Gulch-Deadwood (includes Minersville and Eastman Gulch) district

- Terrane: Eastern Klamath

- Host Rock Lithology: Argillite and graywacke of Mississippian Bragdon Fm., metavolcanic rocks of the Copley Greenstone and Balaklala Rhyolite, Dikes and sills of feldspar porphyry, quartz porphyry and "Birdseye" porphyry (Albers, 1965).

- Vein Characteristics: Quartz and quartz-calcite veins several inches to tens of feet in width. Moderate dip along thrust contact of Bragdon and Copley or steeply dipping within Bragdon. Latter type are most productive. Major zone of production is along an E-W fracture system which contains dikes and sills of felsic to intermediate composition (Albers, 1961; 1965).

- Igneous Rocks: Gold-bearing veins are closely associated with dikes and sills of a variety of compositions, and frequently cut them. Among the most common dikes are "Birdseye" porphyry, which vary in composition from dacite to quartz dacite and diorite. All compositional varieties are characterized by large plagioclase feldspar phenocrysts--the "Birdseyes" (Albers, 1965). Quartz porphyry dikes are also associated with quartz veins (Albers, 1965). Preliminary K-Ar ages suggest at least some quartz porphyry dikes are about 135 Ma, and that some varieties of Birdseye porphyry are about 160 Ma. Several other petrographic varieties of dikes are present in the area (Albers, 1964; 1965; Danielson, 1988) but their relationship to gold mineralization is uncertain. Dikes represent hypabyssal equivalents of the Shasta Bally and probably Permian and (or) Devonian plutons.

- Geochemical Characteristics: Most productive veins have very high As content. Wall rocks, particularly dikes, have strongly elevated As and anomalous Au relative to background. Cu, Pb, and Zn contents are low, generally below those of host rocks, except for greenstone-hosted veins. B is moderate, Ba relatively high, but both are below host rock levels. Hg is very low, and below host rock content. Proximal host rocks (wall rocks) have lower Cu, Pb, Zn, Hg, and B than distal host rocks (tables 4 and 5). Sb is below detection in nearly all rocks.

- Production: Between 800,000 oz Au (Hotz, 1971) and 1,500,000 oz Au (Clark, 1963).

- Mineralogy: Pyrite, galena, sphalerite, arsenopyrite, and rare chalcopyrite. Free gold in quartz and in sulfides (Hotz, 1971; Albers, 1961; 1965).

- Au/Ag = 8.9 (10 samples)

Canyon Creek-East Fork mining district

- Terrane: Central Metamorphic

- Host Rock Lithology: Hornblende gneiss and schist and interbedded argillite of the Salmon Formation.

- Vein Characteristics: Quartz veins, a few inches to 6 ft in width at low to moderate dips in much of the district. Some veins, particularly in the north, are considerably wider and steeper (Ferguson, 1914; O'Brien, 1965).

- Igneous Rocks: Canyon Creek trondjhemite pluton is just north of the district. Quartz porphyry, pegmatite, and aplite dikes are associated with some of the deposits, particularly those in the northern and eastern parts (Ferguson, 1914; Averill, 1941; Hotz, 1971).

- Geochemical characteristics: Geochemically complex. Very high grade gold. Moderately high As, but lower than French Gulch. Hg is high, at 1.2 ppm (geom. mean), higher than most other gold districts. Moderately high Ag, but Au/Ag = 2.4. Pb and Zn are elevated, up to 2,000 and 1,500 ppm, although geometric means are much lower (table 6). Pb content of veins higher than host rocks, Cu and Zn lower (on average). Au correlates well with As, Ag, Pb, and Zn in the veins, somewhat the same in wall rocks. Au, Ag, and As averages drop off from veins through wall rocks to host rocks. Low level Au anomaly present in host and district igneous rocks, well above crustal average.

- Production: 192,000 oz Au (Hotz, 1971; Hotz and others, 1972).

- Mineralogy: Pyrite, galena, sphalerite, free gold in quartz, and also associated with sulfides (Ferguson, 1914; O'Brien, 1965).

- Au/Ag = 2.4 (11 samples).

Harrison Gulch mining district

- Terrane: Hayfork
- Host Rock Lithology: Cherts and slaty argillites of the middle unit of the Hayfork Terrane of probable Permian age (Irwin, 1981), at or near contact with Hayfork Bally meta-andesite which underlies the sedimentary rocks. Fraticelli and others (1987) now consider these rocks to be Jurassic.
- Vein Characteristics: Two or more parallel quartz veins, which strike NW and dip moderately to steeply SW. Approximately 1- to 3-ft wide. The two main productive veins are along the contact between meta-andesite and sedimentary rocks, and within the sedimentary rocks respectively. Irregular, though nonproductive veinlets occur in the andesite (Kramm, 1913; Brown, 1916).
- Igneous Rocks: District occurs near Wildwood pluton, a quartz diorite-syenodiorite mass. Small bodies of intrusive granite and serpentinite are exposed near the Midas mine. Other prospects in the district are reportedly adjacent to diabase and quartz porphyry dikes (Hotz, 1971).
- Geochemical Characteristics: High As (250-400 ppm), low base metals, moderate to low Ag (2-7 ppm). Generally similar to French Gulch, except lower As and higher Ag (table 2).
- Production: Approximately 200,000 oz Au (Hotz, 1971).
- Mineralogy: Pyrite, tetrahedrite, free gold alloyed with some silver, minor chalcopyrite (Kramm, 1913).
- Au/Ag = 3.1 (very limited data; 2 samples).

Hayfork mining district

- Terrane: Hayfork
- Host Rock Lithology: Argillite, siliceous argillite, and chert of the middle unit of the Hayfork Terrane of probable Permian age (Irwin, 1981). Veins occur near the contact with underlying Hayfork Bally meta-andesite. These rocks are now considered to be Jurassic (Fraticelli and others, 1987).
- Vein Characteristics: Stringers of quartz in slate. Gold occurs in the quartz associated with pyrite, arsenopyrite, and galena (Averill, 1941).
- Igneous Rocks: None reported (limited data), but district occurs near the Wildwood pluton, a diorite-syenodiorite body.
- Geochemical Characteristics: Generally similar to French Gulch, high As (200-600 ppm), low base metals, very low Ag. Very high grade gold (table 2).
- Production: Approximately 5,000 oz Au (Hotz, 1971).
- Mineralogy: Pyrite, galena, arsenopyrite. Free gold in quartz, some in pyrite (Hotz, 1971; Averill, 1941).
- Au/Ag = >20 (very limited data; 2 samples, very low Ag).

South Fork mining district

- Terrane: Eastern Klamath
- Host Rock Lithology: Granitic rock of the Shasta Bally batholith where it intrudes Copley Greenstone.
- Vein Characteristics: Roughly parallel series of quartz veins striking NE and dipping steeply SE to vertical, 1- to 8-ft wide (Tucker, 1926).
- Geochemical Characteristics: Base metal-silver association. Very high Ag, up to 5,000 ppm. High Pb and Zn (1,000-10,000 ppm, and 800 to >10,000 ppm, respectively). High Cu (up to 1,500 ppm) and Mo (up to 1,000 ppm). Hg content highest found in the Klamath districts, many at >10 ppm level. Relatively low Au, although one high grade Ag sample had 4.3 ppm (table 2).
- Production: Approximately $1,000,000, mostly from Ag. Low Au production.
- Mineralogy: Tetrahedrite, galena, small amounts of pyrite, sphalerite, some chalcopyrite, with small amounts of Au (Hotz, 1971; Tucker, 1926).
- Au/Ag = 0.005 (6 samples).

APPENDIX B

GEOCHEMICAL DATA FOR QUARTZ VEINS AND HOST ROCKS FROM SOME LODE GOLD DISTRICTS IN THE KLAMATH MOUNTAINS IN THE REDDING 1 x 2 DEGREE QUADRANGLE*

Table 2. Geochemistry of selected high grade quartz-vein samples from lode gold districts of the Klamath Mountains, California

[-- indicates not analyzed]

Mine	Au ppm	Ag ppm	As ppm	Hg ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Old Diggings district									
Reid	70	50	<5	0.7	21	200	<5	<5	300
French Gulch-Deadwood district									
Summit	75	70	1,100	<0.02	2.1	5	20	10	50
Brown Bear	50	5	>10,000	<0.02	0.7	5	20	<5	20
Canyon Creek-East Fork district									
Enterprise	86	23	658	1.8	--	21	267	165	20
Ozark	76	27	3,126	1.0	--	12	60	56	<10
Harrison Gulch district									
Midas	34	7	400	0.1	1.0	20	15	<5	10
Hayfork district									
Kelly	22	0.5	190	0.06	1.0	<5	30	5	10
South Fork district									
Crystal	4.3	300	10	>10	<0.05	700	1,000	10,000	10
Crystal	0.4	5,000	10	0.2	<0.05	70	2,000	>10,000	30

Table 3. Geochemical summary, Old Diggings district

[Values are geometric means. Number in paranetheses is number of samples used to calculate mean. [1]Samples of unaltered greenstone were collected in the French Gulch and Shell Mountain quadrangles, west of the Old Diggings district.]

Rock type	Au ppm	Ag ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Quartz vein (11)	0.9	1.5	<5	0.14	12	<10	<5	56
Wall rock greenstone (13)	0.07	0.4	<5	0.02	67	<10	45	47
Host rock greenstone[1] (23)	<0.05	<0.5	2	0.02	58	<10	49	15

Table 4. Geochemical summary, French Gulch district--quartz veins

[Values are geometric means. West (Br.B.) is the Brown Bear mine, the largest in the Klamath Mountains, with approximate production of 500,000 oz Au. Number in parentheses represents number of samples analyzed from each area. MNVL = Minersville, Gy = Graywacke, Arg = Argillite, Grnst = Greenstone, Dk = Dike]

Area	Au ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm	Host rock
Center (21)	0.2	225	0.02	11	10	12	28	Arg/Gy/Dk
East (4)	0.5	478	0.02	6	7	5	14	Arg/Gy/Dk
West (Br.B.) (3)	2.1	8,772	0.02	11	27	2	37	Arg/Gy/Dk
Eastman Gulch (2)	10	30	0.06	39	77	58	12	Grnst/Dk
Mnvl (10)	0.04	4	<0.02	7	6	6	17	Arg/Gy/Grnst

Table 5. Geochemical summary, French Gulch mining district wall rocks and host rocks

[Values are geometric means. Number in parentheses is number of smaples used to calculate mean. Background refers to samples collected away from areas of quartz veins. Wall rock includes samples adjacent to and within a few meters to tens of meters from quartz veins.]

Rock type	Au ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Argillite (49) (Background)	<0.05	4.5	0.09	41	21	82	99
Argillite (23) (Wall rock)	<0.05	56	0.04	32	17	68	77
Graywacke (26) (Background)	<0.05	2.6	0.05	28	13	54	58
Graywacke (9) (Wall rock)	<0.05	16	0.03	28	13	36	50
Greenstone (23) (Background)	<0.05	2	0.02	58	6	49	15
Greenstone (8) (Wall rock)	<0.05	8	0.01	50	6	44	13
Dike-Fspr (9) (Background)	<0.05	10	0.03	15	15	42	54
Dike-Fspr (4) (Wall rock)	0.05	98	0.03	10	13	31	34
Dike-qtz (1) (Background)	<0.05	10	0.02	15	30	30	150
Dike-qtz (9) (Wall rock)	0.21	512	0.02	6	13	17	73

Table 6. Geochemical summary, Canyon Creek-East Fork district

[Values are geometric means. Number in parentheses is number of samples used to calculate mean. Host rock is background, as in table 5. Igneous rock refers to samples of dikes collected within district.]

Rock type	Au ppm	Ag ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Quartz vein (12)	2.5	1.5	45	1.2	12	17	30	13
Wall rock gneiss (12)	0.03	0.09	6.1	0.9	34	2.6	55	14
Host rock gneiss (9)	0.02	0.04	2.4	<0.5	33	1.5	27	22
Igneous rock (7)	0.01	0.06	2.3	<0.5	17	1.7	14	16

*Analytical data and methods of analyses reported in Hassemer and others (in press).

Appendix B

Boring Logs and Field Notes

BROWN AND CALDWELL

BORING LOG

Project Name: **Moody Creek** Project Number: **137108**

Soil Boring [X] Hand Auger Boring [ ] Monitoring Well [X] Boring/Well Number: **B-1** Sheet **1** of **1**

Boring Location: **Redding/Mountain Gade**		Elevation and Datum: **Approx: 1115 feet msl**	
Drilling Contractor: **WDC**	Driller: **Joe Zimmer**	Date Started: **5/1/2009**	Date Finished: **5/1/2009**
Drilling Equipment: **Arch**	Borehole Diameter: **10"**	Completed Depth: (feet) **50.0**	Water Depth (Feet): Static/First Encountered **17.95/30.0**
Sampling Method: **Grab**		WELL CONSTRUCTION	
Drilling Method: **Air Rotary**	Drilling Fluid: **Air**	Type and Diameter of Well Casing: **6" Steel and 2" PCV**	
Backfill Material: **Bentonite chips**		Slot Size: **0.02**	Filter Material: **Bentonite chips**
Logged By: **Tim Godwin**	Checked By: **Tim Godwin**	Development Method: **N/A**	

Depth (feet)	USCS Soil Type	Description (group name, gradation [%gravel, %sands, %fines] munsell color, color, soil characteristics)	Blow Counts	Sample No.	Sample	Graphic Log: Lithology	Graphic Log: Boring/Well Completion	PID Readings PPM	Remarks
5	CL	Soils - silty clay, moist, very dark red, fill from road cut, highly weathered							10" borehole from 0 to 20 feet bgs with 6" steel conductor casing, annulus sealed with hydrated bentonite chip according to Shasta County specifications.
10		Weathered bedrock - light reddish brown, sandy clayey soils and rock fragments							
15		More competent							
20		Basaltic rock							Static water level = 17.95 feet bgs 6" borehole from 20 to 50 feet bgs. with 2" PVC casing from 0 to 50 feet bgs no filter pack, free standing in open borehole. PCV 0.020" slot screen from 30 to 50 feet bgs.
25		More competent, fine grain, dark black/green with minor phenocrysts (plagioclase), some weathering.							
30									First encountered groundwater = 29 feet bgs Minor water, cuttings wet, no runoff during drilling.
35									Low water production, 1 gpm.
40		Greenstone/andesite - light green with moderate quartz phenocrysts, and trace pyrite							
45									
50		Total depth of boring = 50 feet bgs							

BORING LOG MOODY CREEK.GPJ 6/30/09

BROWN AND CALDWELL

BORING LOG

Project Name: **Moody Creek** Project Number: **137108**

Soil Boring [x] Hand Auger Boring [ ] Monitoring Well [x] Boring/Well Number: **B-2** Sheet **1** of **1**

Boring Location: **Redding/Mountain Gade**		Elevation and Datum: **Approx: 1150 feet msl**	
Drilling Contractor: **WDC**	Driller: **Joe Zimmer**	Date Started: **4/28/2009**	Date Finished: **4/29/2009**
Drilling Equipment: **Arch**	Borehole Diameter: **8"**	Completed Depth: (feet) **50.0**	Water Depth (Feet): Static/First Encountered **NA/NA**
Sampling Method: **Grab**		WELL CONSTRUCTION	
Drilling Method: **Air Rotary**	Drilling Fluid: **Air**	Type and Diameter of Well Casing: **6" Steel and 2" PCV**	
Backfill Material: **Granular bentonite**		Slot Size: **0.02**	Filter Material: **Granular bentonite**
Logged By: **Tim Godwin**	Checked By: **Tim Godwin**	Development Method: **NA**	

Depth (feet)	USCS Soil Type	Description (group name, gradation [%gravel, %sands, %fines] munsell color, color, soil characteristics)	Blow Counts	Sample No.	Graphic Log: Sample	Graphic Log: Lithology	Graphic Log: Boring/Well Completion	PID Readings PPM	Remarks
	ML	Silt, red							8" borehole from 0 to 20 feet bgs with 6" steel conductor casing, annulus sealed with hydrated bentonite chip according to Shasta County specifications.
5		Weathered Bedrock - Green andesite with minor euhedral quartz, some surfaces weathered with red oxidation stains.							
10									
15									
20									6" borehole from 20 to 50 feet bgs. with 2" PVC casing from 0 to 50 feet bgs no filter pack, free standing in open borehole. PCV 0.020" slot screen from 30 to 50 feet bgs.
25		Andesite - fine grained with phenocrysts of quartz and plagioclase, minor reddish oxidation on fracture surfaces, trace pyrite or chalcopyrite (very fine grained).							
30									
35		-Color change to darker green; pyrite not observed.							
40		-Quartz veins, massive.							
45		-No quartz veins, phenocrysts.							
50		Total depth of boring = 50 feet bgs							

BORING LOG MOODY CREEK.GPJ 6/30/09

BROWN AND CALDWELL

BORING LOG

Project Name: **Moody Creek** Project Number: **137108**

Soil Boring [x] Hand Auger Boring [ ] Monitoring Well [x] Boring/Well Number: **B-3** Sheet **1** of **1**

Boring Location: **Redding/Mountain Gade**		Elevation and Datum: **Approx: 1200 feet msl**	
Drilling Contractor: **WDC**	Driller: **Joe Zimmer**	Date Started: **4/30/2009**	Date Finished: **5/1/2009**
Drilling Equipment: **Arch**	Borehole Diameter: **10"**	Completed Depth: (feet) **50.0**	Water Depth (Feet): Static/First Encountered **NA/NA**
Sampling Method: **Grab**		WELL CONSTRUCTION	
Drilling Method: **Air Rotary**	Drilling Fluid: **Air**	Type and Diameter of Well Casing: **6" Steel and 2" PCV**	
Backfill Material: **Bentonite chips**		Slot Size: **0.02**	Filter Material: **Bentonite chips**
Logged By: **Tim Godwin**	Checked By: **Tim Godwin**	Development Method: **NA**	

Depth (feet)	USCS Soil Type	Description (group name, gradation [%gravel, %sands, %fines] munsell color, color, soil characteristics)	Blow Counts	Sample No.	Graphic Log: Sample	Graphic Log: Lithology	Graphic Log: Boring/Well Completion	PID Readings PPM	Remarks
		Soil/weathered rock, strongly oxidized and weathered, rock is possibly andesite and/or basalt.							10" borehole from 0 to 20 feet bgs with 6" steel conductor casing, annulus sealed with hydrated bentonite chip according to Shasta County specifications.
5		Weathered Basalt - weathered, reddish oxidation staining, blocky fracturing, minor quartz veining.							
10									
15		Andesitic Basalt - Light green andesitic basalt composition, much more competent, still lightly weathered.							
20		Andesitic Basalt - competent, fine grained, minor/trace phenocrysts of quartz; weathered surfaces are dark red to black.							6" borehole from 20 to 50 feet bgs. with 2" PVC casing from 0 to 50 feet bgs no filter pack, free standing in open borehole. PCV 0.020" slot screen from 30 to 50 feet bgs.
25		Andesite, light green, fine grained with moderate phenocrysts composed of quartz, plagioclase, mafics (hornblende).							
30		-Quartz veining present.							
35									
40									
45		-Trace quartz veining.							
50		Total depth of boring = 50 feet bgs							

BORING LOG MOODY CREEK.GPJ 6/30/09

BROWN AND CALDWELL

BORING LOG

Project Name: **Moody Creek** Project Number: **137108**

Soil Boring [x] Hand Auger Boring [ ] Monitoring Well [x] Boring/Well Number: **MW-1** Sheet **1** of **1**

Boring Location: **Redding/Mountain Gade**		Elevation and Datum: **Approx: 1200 feet msl**	
Drilling Contractor: **WDC**	Driller: **Joe Zimmer**	Date Started: **4/29/2009**	Date Finished: **4/30/2009**
Drilling Equipment: **Arch**	Borehole Diameter: **10"**	Completed Depth: (feet) **100.0**	Water Depth (Feet): Static/First Encountered **22.86/NA**
Sampling Method: **Grab**		WELL CONSTRUCTION	
Drilling Method: **Air Rotary**	Drilling Fluid: **Air**	Type and Diameter of Well Casing: **6" Steel and 2" PCV**	
Backfill Material: **Bentonite chips**		Slot Size: **0.02**	Filter Material: **Bentonite Chips**
Logged By: **Tim Godwin**	Checked By: **Tim Godwin**	Development Method: **N/A**	

Depth (feet)	USCS Soil Type	Description (group name, gradation [%gravel, %sands, %fines] munsell color, color, soil characteristics)	Blow Counts	Sample No.	Graphic Log: Sample	Graphic Log: Lithology	Graphic Log: Boring/Well Completion	PID Readings PPM	Remarks
	ML	Soils and fill from road cut, silty sands, highly weathered rock, very red oxidized soils, clasts are andesite.							10" borehole from 0 to 20 feet bgs with 6" steel conductor casing, annulus sealed with hydrated bentonite chip according to Shasta County specifications.
5		Weathered Andesite - fine grained, blocky fracture, weathered reddish oxidation staining.							
10									
15		- More competent bedrock							
20		- More competent bedrock							6" borehole from 20 to 50 feet bgs. with 2" PVC casing from 0 to 50 feet bgs no filter pack, free standing in open borehole. PCV 0.020" slot screen from 30 to 50 feet bgs. Static Water = 22.86 feet below ground surface.
		Andesite - fine grained, light green in color, moderate phenocrysts to 3 mm, quartz, plagioclase							
25									
30									
35									
40									
45		-Color change to darker green, finer grained less phenocrysts.							
50									
55		-Approximately 40% quartz.							
60		-Fine quartz veins, approximately 10% to 15% and 0.5 cm wide.							
65		-Very dark green, trace quartz vein fragments, andesite is very fine grained, approximately 10% non-distinguishable phenocrysts (possibly plagioclase).							
70		-Dark mafic minerals 1 to 2 mm and are subhedral to euhedral.							
75									
80									
85									
90									
95									
100		Dark green in color. Total depth of boring = 100 feet bgs							
105									

BORING LOG MOODY CREEK.GPJ 6/30/09

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TG	4/27/09		1

Project	Subject
Moody Creek	Well Installation

References/Notes

930 Arrived on-site, Frank Borden on-site, equipment operators (LePage) Jim (owner) & Kevin (operator). Site prepared and ready.

945 Driller not on-site, calling for status.

11^00 WDC was unable to get bond (required) to Shasta County to secure permit so they didn't mobilize to site. Determining when they will be on-site.

11^10 Tim G. leaving site. LePage staying to complete tasks for Frank Borden. Checking on permits with County.

13^30 Conference call w/ WDC Orville, Brian Cook, and Joe Zimmer (Driller). Will have bond in place tomorrow, will mobilize to site tomorrow arrival between 10 and 11.

13^45 Notified Frank of plan for Tuesday. Off site for day. Staying in Redding based on Drillers arrival.

Tim Godwin

#1590-4/10" sq.

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TG	4/28/09		1

Project	Subject
Moody Creek	Well Installation

References/Notes

10:00 On-site waiting for drillers. LePage (Kevin) and Frank on-site.

10:30 Receive call from Joe Zimmer (WDC), had to replace tires on truck will be leaving shortly. Told Kevin (LePage) to come back at 1:30 - Kevin off-site. Called County to check on Permits they are ready and approved.

11:00 Inspection all drilling locations.

12:30 Brian Cook at Shell Station, going out to meet. Waiting on drillers.

13:30 Drillers arrive, Kevin on-site, review site conditions and mobilizing to B-2

15:30 All Equipment up the hill and setting up.

16:30 Start Drilling 8" conductor/seal boring. Drilled to 20 ft. bgs. Called Regulator (County) Mark Kramer for AM.

17:30 Cleaning up and heading out.

18:30 Tim Godwin last out and locked all gates.

Tim Godwin

#1590-1/10" sq.

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TG	4/29/09		1

Project	Subject
Moody Creek	Well Installation

References/Notes

7:00 On site LePage & WDC here. Mobilize to site B-2.

8:00 Reviewed HASP and begin prep for today.

8:30 Tim out to pick up County Inspector Mark Kramer. Called Mark regarding 8 in hole and 6 in casing, he indicated we could still seal 1 in annulus if we used granular bentonite. Asked him to reschedule inspection.

8:45 Drillers off-site to pick up granular bentonite from Ted Oglivie @ Diamond Core Drilling. Rescheduled with Mark for 9:30 @ Shell.

9:30 Picked up Mark. Mobelize to site.

10:00 Casing in hole and ready, tagged annulus bottom at 18 ft. begin filling with bentonite granules and hydrating every-other bag. Mark did not require hydration.

10:45 Taking regulator out.

11:45 Back at B-2 and drilling again.

13:30 TD=50' in B-2 installed 20' 0.020 slot PVC screen and 30' blank. No water observed.

14:00 Mobilizing to MW-1.

15:00 Set up and ready to drill on hold waiting for Brian Cook with 10" drill bit.

16:45 Brian on-site with bit, fit to drill stem.

17:00 Begin drilling at MW-1.

18:15 Drilled 9 feet working well. Start again in morning. Clean site and out.

18:50 Tim Godwin off-site all gates locked.

111 1/2 ⇒ 3.5 bags bentonite

Tim Godwin

#1590-1/10" sq.

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TL	4/30/09		1

Project	Subject
Moody Creek	Well Installation

References/Notes

6:50 On-site opening gates.
7:00 WDC on-site mobilizing to MW-1
7:15 Find gate at RR Tracks open, lock broken
7:30 At MW-1, drillers find items have been stolen off trucks
8:00 Items stolen include coat, coveralls, keys to WDC truck, hard hat. No critical items short of keys for truck, not necessary until we leave. Setting up to drill. Calling County Inspector - will be here at 10.
8:30 Mark Kramer (County) calls ask to move earlier will met at Shell at 9 AM. Depth drilled 20 ft. to find competent rock.
9:00 Pick up Mark head back to site
9:30 Ready to seal using bentonite chips, ADD seal and hydrate. Taking Mark out.
10:00 Drop Mark at Shell.
10:30 Back out at site drillers at 35' bgs with samples collected for me at 25, 30.
13:00 At TD=100 pulling Rod.
13:30 Built casings and in hole 20' 0.020 Slot Sch. 40 PVC 80' of blank. Turner called he is at Shell and coming in.
14:00 Mobilizing to B-3
14:30 Called County to request inspection
15:00 Set-up to drill B-3 target 50 ft. bgs.
15:30 Mark Kramer called and said he wouldn't make it up and to go ahead and place seal consistent with others.
17:00 Cleaning site after placing seal.
17:30 Check water at MW-1 99.17'
18:00 Off-site all gates secure.

~~IIII~~ IIII = 9 bags Bentonite Chips Pure Gold Medium
1/2 bag granular

9 bags chips
1 bag granular

Tim Cook

#1590-1/10" sq.

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TL	5/1/09		1

Project	Subject
Moody Creek	Well Installation

References/Notes

7:00 On-site mobilizing out to site WDC, LePage, Turner all present.
7:30 Measured B-2 ⇒ No water ; MW-1 = 95.45 to water.
9:45 Completed boring at B-3, installing casing 20' 0.020 slot and 30' blank Sched. 40 PVC.
10:25 Mobilizing to site B-1.
11:30 Mobilized all equipment starting to drill
12:30 Joe Turner off site
13:00 Placing casing to 18' sealing with bentonite chips
13:30 Proceeding with drilling 6" borehole
14:00 Water - minor amounts at 28' cuttings moist, no run-off. Poor air return ~ to 2 gpm.
14:10 Pulling rods to check bit, called Joe - NA called Andy to discuss depth requirement. Top of Casing elevation ~ 1115 drilled to 1085 now.
14:30 Talked to Andy - Proceed to 50 if possible. Bit plugging with cuttings. Could be poor air circ. due to irregular borehole surface.
15:00 Back in hole operating well.
15:15 Pulling again due to poor air circulation.
15:45 Cleaned Drill head out, grout chuck blocking passageway.
16:15 Start drilling again, collect 35 foot sample and take Kevin to front to drop water tank and truck
16:45 Return to drilling @ 47', drilling very slow.
17:00 At TD=50 placing casing cleaning and securing equipment. Too wet and raining too hard to attempt getting out this late.
17:15 Walked back for WL 38 ft to water recovering at rate of 0.3' per minute.
17:30 Mobilizing out
17:45 Kevin done repairing RR Gate hole.
18:15 Off-site; gates locked.

0
95.45

#1590-1/10" sq.

Appendix C

Water Sampling Analytical Results and Field Notes

CALIFORNIA LABORATORY SERVICES

3249 Fitzgerald Road Rancho Cordova, CA 95742

April 07, 2009

CLS Work Order #: CSC1078
COC #: 103359

Joseph Turner
Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project Name: 3M Redding Quarry

Enclosed are the results of analyses for samples received by the laboratory on 03/31/09 09:30. Samples were analyzed pursuant to client request utilizing EPA or other ELAP approved methodologies. I certify that the results are in compliance both technically and for completeness.

Analytical results are attached to this letter. Please call if we can provide additional assistance.

Sincerely,

James Liang, Ph.D.
Laboratory Director

CA DOHS ELAP Accreditation/Registration number 1233

Brown & Caldwell-Rancho Cordova	Project: 3M Redding Quarry	
10540 White Rock Rd. Suite 180	Project Number: 137108	**CLS Work Order #: CSC1078**
Rancho Cordova, CA 95670	Project Manager: Joseph Turner	COC #: 103359

CLS - Labs

CHAIN OF CUSTODY

CLS ID No.: CSC1078

LOG NO. 103359

REPORT TO:

NAME AND ADDRESS: Tim Godwin - Brown & Caldwell, 10540 White Rock Rd #180, Rancho Cordova, CA 95670

PROJECT MANAGER: Joe Graner PHONE#: 853-5331

PROJECT NAME: 3M Redding Quarry

SAMPLED BY: T. Godwin

JOB DESCRIPTION: Surface Water Sampling

SITE LOCATION

CLIENT JOB NUMBER: 137108

DESTINATION LABORATORY#: ✓ CLS (916) 638-7301, 3249 FITZGERALD RD. RANCHO CORDOVA, CA. 95742

☐ OTHER

ANALYSIS REQUESTED

GEOTRACKER: EDF REPORT ☐ YES ☐ NO

GLOBAL ID:

COMPOSITE:

FIELD CONDITIONS:

TURN AROUND TIME: 1 DAY, 2 DAY, 5 DAY, 10 DAY

SPECIAL INSTRUCTIONS: OR ALT. ID:

DATE	TIME	SAMPLE IDENTIFICATION	MATRIX	CONTAINER NO.	CONTAINER TYPE	PRESERVATIVES N/A HCL	Metals (6010/6020/7470)*	Alkalinity (total/carb/bicarb)	TDS (160.1)	Spec. Cond. (150.1)	Anions**	Hardness (130.2)	5 DAY
3/30/09	1230	SW-3	H_2O	3	Poly		X	X	X	X	X	X	X
	1315	SW-2					X	X	X	X	X	X	X
	1425	SW-1					X	X	X	X	X	X	X
	1430	DUP					X	X	X	X	X	X	X

Tim Godwin

* METALS - Hg, Al, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, K, Ag, Na, Zn, Sb, As, Pb, Se, Tl, V

** ANIONS - AMMONIUM AS N, NITRATE AS N, NITRITE AS N, BROMIDE, CHLORIDE, FLOURIDE, SULFATE.

INVOICE TO:

P.O. #

QUOTE #

SUSPECTED CONSTITUENTS

PRESERVATIVES: (1) HCL (2) HNO_3 (3) = COLD (4) = NaOH (5) = H_2SO_4 (6) = $Na_2S_2O_3$ (7) =

RELINQUISHED BY (SIGN)	PRINT NAME / COMPANY	DATE / TIME	RECEIVED BY (SIGN)	PRINT NAME / COMPANY
Tim Godwin	Tim Godwin-BC	3/30/09 1610		
Will Orellana		3/31/09 0930		

RECEIVED AT LAB BY: Will Orellana DATE / TIME: 3/31/09 0930 CONDITIONS / COMMENTS: 1106°C

SHIPPED BY: ☒ FED X ☐ UPS ☐ OTHER AIR BILL #

LAB ORIGIN

Brown & Caldwell-Rancho Cordova	Project: 3M Redding Quarry	
10540 White Rock Rd. Suite 180	Project Number: 137108	**CLS Work Order #: CSC1078**
Rancho Cordova, CA 95670	Project Manager: Joseph Turner	COC #: 103359

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SW-3 (CSC1078-01) Water Sampled: 03/30/09 12:30 Received: 03/31/09 09:30									
Total Alkalinity	**38**	5.0	mg/L	1	CS02394	03/31/09	03/31/09	SM2310B	
Bicarbonate as CaCO3	**38**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS02425	04/01/09	04/01/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Chloride	**0.83**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**110**	1.0	µmhos/cm	"	CS02411	04/01/09	04/01/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Total Hardness as CaCO3	**42**	1.0	"	"	CS02415	04/01/09	04/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**15**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**75**	10	"	"	CS02380	03/31/09	04/01/09	SM2540C	
SW-2 (CSC1078-02) Water Sampled: 03/30/09 13:15 Received: 03/31/09 09:30									
Total Alkalinity	**38**	5.0	mg/L	1	CS02394	03/31/09	03/31/09	SM2310B	
Bicarbonate as CaCO3	**38**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS02425	04/01/09	04/01/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Chloride	**0.82**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**100**	1.0	µmhos/cm	"	CS02411	04/01/09	04/01/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Total Hardness as CaCO3	**40**	1.0	"	"	CS02415	04/01/09	04/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**13**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**65**	10	"	"	CS02380	03/31/09	04/01/09	SM2540C	

CA DOHS ELAP Accreditation/Registration Number 1233

3249 Fitzgerald Road Rancho Cordova, CA 95742 www.californialab.com 916-638-7301 Fax: 916-638-4510

CALIFORNIA LABORATORY SERVICES

 04/07/09 16:43

Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: 3M Redding Quarry
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSC1078
COC #: 103359

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SW-1 (CSC1078-03) Water Sampled: 03/30/09 14:25 Received: 03/31/09 09:30									
Total Alkalinity	**96**	5.0	mg/L	1	CS02394	03/31/09	03/31/09	SM2310B	
Bicarbonate as CaCO3	**96**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS02425	04/01/09	04/01/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Chloride	**1.0**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**200**	1.0	µmhos/cm	"	CS02411	04/01/09	04/01/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Total Hardness as CaCO3	**88**	1.0	"	"	CS02415	04/01/09	04/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**7.6**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**130**	10	"	"	CS02380	03/31/09	04/01/09	SM2540C	
DUP (CSC1078-04) Water Sampled: 03/30/09 14:30 Received: 03/31/09 09:30									
Total Alkalinity	**97**	5.0	mg/L	1	CS02394	03/31/09	03/31/09	SM2310B	
Bicarbonate as CaCO3	**97**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS02425	04/01/09	04/01/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Chloride	**1.0**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**200**	1.0	µmhos/cm	"	CS02411	04/01/09	04/01/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Total Hardness as CaCO3	**87**	1.0	"	"	CS02415	04/01/09	04/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS02408	04/01/09	04/01/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**7.6**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**130**	10	"	"	CS02380	03/31/09	04/01/09	SM2540C	

CALIFORNIA LABORATORY SERVICES

 04/07/09 16:43

Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: 3M Redding Quarry
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSC1078
COC #: 103359

Metals by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SW-3 (CSC1078-01) Water Sampled: 03/30/09 12:30 Received: 03/31/09 09:30									
Mercury	ND	0.20	µg/L	1	CS02439	04/01/09	04/02/09	EPA 7470A	
Aluminum	ND	50	"	"	CS02415	04/01/09	04/01/09	EPA 6010B	
Barium	**22**	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**9900**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**4100**	1000	"	"	"	"	"	"	
Manganese	ND	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**2900**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Antimony	ND	6.0	"	"	CS02414	04/01/09	04/01/09	EPA 6020/7000	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	
Vanadium	ND	20	"	"	"	"	"	"	

CA DOHS ELAP Accreditation/Registration Number 1233

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CALIFORNIA LABORATORY SERVICES

 04/07/09 16:43

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COC #: 103359

Metals by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SW-2 (CSC1078-02) Water Sampled: 03/30/09 13:15 Received: 03/31/09 09:30									
Mercury	ND	0.20	µg/L	1	CS02439	04/01/09	04/02/09	EPA 7470A	
Aluminum	ND	50	"	"	CS02415	04/01/09	04/01/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**9000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**4100**	1000	"	"	"	"	"	"	
Manganese	ND	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**2800**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Antimony	ND	6.0	"	"	CS02414	04/01/09	04/01/09	EPA 6020/7000	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	
Vanadium	ND	20	"	"	"	"	"	"	

CALIFORNIA LABORATORY SERVICES

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Metals by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
SW-1 (CSC1078-03) Water Sampled: 03/30/09 14:25 Received: 03/31/09 09:30									
Mercury	ND	0.20	µg/L	1	CS02439	04/01/09	04/02/09	EPA 7470A	
Aluminum	ND	50	"	"	CS02415	04/01/09	04/01/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**21000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**8500**	1000	"	"	"	"	"	"	
Manganese	ND	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**3900**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Antimony	ND	6.0	"	"	CS02414	04/01/09	04/01/09	EPA 6020/7000	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	
Vanadium	ND	20	"	"	"	"	"	"	

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Metals by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
DUP (CSC1078-04) Water Sampled: 03/30/09 14:30 Received: 03/31/09 09:30									
Mercury	ND	0.20	µg/L	1	CS02439	04/01/09	04/02/09	EPA 7470A	
Aluminum	ND	50	"	"	CS02415	04/01/09	04/01/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**21000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**8300**	1000	"	"	"	"	"	"	
Manganese	ND	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**3900**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Antimony	ND	6.0	"	"	CS02414	04/01/09	04/01/09	EPA 6020/7000	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	
Vanadium	ND	20	"	"	"	"	"	"	

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Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02380 - General Preparation										
Blank (CS02380-BLK1)				Prepared: 03/31/09 Analyzed: 04/01/09						
Total Dissolved Solids	ND	10	mg/L							
Duplicate (CS02380-DUP1)	**Source: CSC1041-02**			Prepared: 03/31/09 Analyzed: 04/01/09						
Total Dissolved Solids	702	10	mg/L		696			0.9	20	
Batch CS02394 - General Preparation										
Blank (CS02394-BLK1)				Prepared & Analyzed: 03/31/09						
Total Alkalinity	ND	5.0	mg/L							
Bicarbonate as CaCO3	ND	5.0	"							
Carbonate as CaCO3	ND	5.0	"							
Hydroxide as CaCO3	ND	5.0	"							
Duplicate (CS02394-DUP1)	**Source: CSC1078-01**			Prepared & Analyzed: 03/31/09						
Total Alkalinity	39.4	5.0	mg/L		38.4			3	20	
Bicarbonate as CaCO3	39.4	5.0	"		38.4			3	20	
Carbonate as CaCO3	ND	5.0	"		ND				20	
Hydroxide as CaCO3	ND	5.0	"		ND				20	
Batch CS02408 - General Prep										
Blank (CS02408-BLK1)				Prepared & Analyzed: 04/01/09						
Chloride	ND	0.50	mg/L							
Sulfate as SO4	ND	0.50	"							
Fluoride	ND	0.10	"							
Bromide	ND	0.10	"							
Nitrite as N	ND	0.10	"							
Nitrate as N	ND	0.50	"							

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Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02408 - General Prep										
LCS (CS02408-BS1)				Prepared & Analyzed: 04/01/09						
Sulfate as SO4	5.20	0.50	mg/L	5.00		104	80-120			
Bromide	1.91	0.10	"	2.00		95	80-120			
Chloride	1.96	0.50	"	2.00		98	80-120			
Fluoride	1.93	0.10	"	2.00		97	80-120			
Nitrate as N	0.460	0.50	"	0.451		102	80-120			
Nitrite as N	0.609	0.10	"	0.610		100	80-120			
LCS Dup (CS02408-BSD1)				Prepared & Analyzed: 04/01/09						
Sulfate as SO4	5.18	0.50	mg/L	5.00		104	80-120	0.4	20	
Chloride	1.93	0.50	"	2.00		97	80-120	1	20	
Fluoride	2.10	0.10	"	2.00		105	80-120	8	20	
Bromide	1.90	0.10	"	2.00		95	80-120	0.4	20	
Nitrite as N	0.599	0.10	"	0.610		98	80-120	2	20	
Nitrate as N	0.459	0.50	"	0.451		102	80-120	0.3	20	
Matrix Spike (CS02408-MS1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Sulfate as SO4	20.6	0.50	mg/L	5.00	15.2	107	75-125			
Chloride	2.56	0.50	"	2.00	0.825	87	75-125			
Fluoride	2.09	0.10	"	2.00	ND	104	75-125			
Bromide	1.90	0.10	"	2.00	ND	95	75-125			
Nitrite as N	0.599	0.10	"	0.610	ND	98	75-125			
Nitrate as N	0.460	0.50	"	0.451	ND	102	80-120			
Matrix Spike Dup (CS02408-MSD1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Sulfate as SO4	20.6	0.50	mg/L	5.00	15.2	107	75-125	0	25	
Fluoride	2.15	0.10	"	2.00	ND	108	75-125	3	25	
Chloride	2.59	0.50	"	2.00	0.825	88	75-125	1	25	
Bromide	1.94	0.10	"	2.00	ND	97	75-125	2	25	
Nitrate as N	0.469	0.50	"	0.451	ND	104	80-120	2	20	
Nitrite as N	0.611	0.10	"	0.610	ND	100	75-125	2	25	

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Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02411 - General Preparation										
Blank (CS02411-BLK1)				Prepared & Analyzed: 04/01/09						
Specific Conductance (EC)	ND	1.0	µmhos/cm							
Batch CS02415 - EPA 3010A										
Blank (CS02415-BLK1)				Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	ND	1.0	mg/L							
LCS (CS02415-BS1)				Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	56.8	1.0	mg/L	66.2		86	80-120			
LCS Dup (CS02415-BSD1)				Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	57.6	1.0	mg/L	66.2		87	80-120	1	20	
Matrix Spike (CS02415-MS1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	99.0	1.0	mg/L	66.2	41.7	87	75-125			
Matrix Spike (CS02415-MS2)		**Source: CSC1082-03**		Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	305	1.0	mg/L	66.2	250	83	75-125			
Matrix Spike Dup (CS02415-MSD1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	98.4	1.0	mg/L	66.2	41.7	86	75-125	0.6	25	
Matrix Spike Dup (CS02415-MSD2)		**Source: CSC1082-03**		Prepared & Analyzed: 04/01/09						
Total Hardness as CaCO3	306	1.0	mg/L	66.2	250	85	75-125	0.4	25	
Batch CS02425 - General Preparation										
Blank (CS02425-BLK1)				Prepared & Analyzed: 04/01/09						
Ammonia as N	ND	0.10	mg/L							

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Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02425 - General Preparation										
LCS (CS02425-BS1)				Prepared & Analyzed: 04/01/09						
Ammonia as N	0.433	0.10	mg/L	0.500		86	80-120			
LCS Dup (CS02425-BSD1)				Prepared & Analyzed: 04/01/09						
Ammonia as N	0.443	0.10	mg/L	0.500		89	80-120	2	25	
Matrix Spike (CS02425-MS1)		**Source: CSC1049-01**		Prepared & Analyzed: 04/01/09						
Ammonia as N	0.427	0.10	mg/L	0.500	ND	85	75-125			
Matrix Spike Dup (CS02425-MSD1)		**Source: CSC1049-01**		Prepared & Analyzed: 04/01/09						
Ammonia as N	0.433	0.10	mg/L	0.500	ND	86	75-125	1	25	

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Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02414 - EPA 3020A										
Blank (CS02414-BLK1)				Prepared & Analyzed: 04/01/09						
Antimony	ND	6.0	µg/L							
Arsenic	ND	5.0	"							
Lead	ND	5.0	"							
Selenium	ND	5.0	"							
Thallium	ND	1.0	"							
Vanadium	ND	20	"							
LCS (CS02414-BS1)				Prepared & Analyzed: 04/01/09						
Antimony	115	6.0	µg/L	100		115	80-120			
Arsenic	107	5.0	"	100		107	80-120			
Lead	105	5.0	"	100		105	80-120			
Selenium	108	5.0	"	100		108	80-120			
Thallium	108	1.0	"	100		108	80-120			
Vanadium	110	20	"	100		110	80-120			
LCS Dup (CS02414-BSD1)				Prepared & Analyzed: 04/01/09						
Antimony	116	6.0	µg/L	100		116	80-120	0.7	20	
Arsenic	107	5.0	"	100		107	80-120	0.06	20	
Lead	105	5.0	"	100		105	80-120	0.6	20	
Selenium	105	5.0	"	100		105	80-120	3	20	
Thallium	107	1.0	"	100		107	80-120	1	20	
Vanadium	111	20	"	100		111	80-120	0.5	20	
Matrix Spike (CS02414-MS1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Antimony	112	6.0	µg/L	100	0.580	111	75-125			
Arsenic	106	5.0	"	100	0.910	105	75-125			
Lead	103	5.0	"	100	ND	103	75-125			
Selenium	106	5.0	"	100	ND	106	75-125			
Thallium	106	1.0	"	100	0.250	106	75-125			
Vanadium	112	20	"	100	0.980	111	75-125			

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Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02414 - EPA 3020A										
Matrix Spike (CS02414-MS2)		**Source: CSC1082-02**		Prepared & Analyzed: 04/01/09						
Antimony	115	6.0	µg/L	100	ND	115	75-125			
Arsenic	107	5.0	"	100	1.54	106	75-125			
Lead	105	5.0	"	100	ND	105	75-125			
Selenium	107	5.0	"	100	ND	107	75-125			
Thallium	110	1.0	"	100	ND	110	75-125			
Vanadium	110	20	"	100	3.02	107	75-125			
Matrix Spike Dup (CS02414-MSD1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Antimony	115	6.0	µg/L	100	0.580	114	75-125	3	25	
Arsenic	108	5.0	"	100	0.910	107	75-125	2	25	
Lead	106	5.0	"	100	ND	106	75-125	3	25	
Selenium	107	5.0	"	100	ND	107	75-125	1	25	
Thallium	108	1.0	"	100	0.250	108	75-125	2	25	
Vanadium	112	20	"	100	0.980	111	75-125	0.4	25	
Matrix Spike Dup (CS02414-MSD2)		**Source: CSC1082-02**		Prepared & Analyzed: 04/01/09						
Antimony	116	6.0	µg/L	100	ND	116	75-125	0.4	25	
Arsenic	112	5.0	"	100	1.54	111	75-125	5	25	
Lead	108	5.0	"	100	ND	108	75-125	2	25	
Selenium	111	5.0	"	100	ND	111	75-125	4	25	
Thallium	112	1.0	"	100	ND	112	75-125	2	25	
Vanadium	114	20	"	100	3.02	111	75-125	3	25	
Batch CS02415 - EPA 3010A										
Blank (CS02415-BLK1)				Prepared & Analyzed: 04/01/09						
Aluminum	ND	50	µg/L							
Antimony	ND	50	"							
Barium	ND	20	"							
Beryllium	ND	5.0	"							
Cadmium	ND	10	"							
Calcium	ND	1000	"							
Chromium	ND	10	"							

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Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02415 - EPA 3010A										
Blank (CS02415-BLK1)				Prepared & Analyzed: 04/01/09						
Cobalt	ND	20	µg/L							
Copper	ND	10	"							
Iron	ND	100	"							
Magnesium	ND	1000	"							
Manganese	ND	20	"							
Molybdenum	ND	20	"							
Nickel	ND	20	"							
Potassium	ND	1000	"							
Silver	ND	10	"							
Sodium	ND	1000	"							
Zinc	ND	20	"							
Boron	ND	50	"							
LCS (CS02415-BS1)				Prepared & Analyzed: 04/01/09						
Aluminum	1660	50	µg/L	2000		83	80-120			
Antimony	437	50	"	500		87	80-120			
Barium	1880	20	"	2000		94	80-120			
Beryllium	46.4	5.0	"	50.0		93	80-120			
Cadmium	48.3	10	"	50.0		97	80-120			
Calcium	9280	1000	"	10000		93	80-120			
Chromium	192	10	"	200		96	80-120			
Cobalt	475	20	"	500		95	80-120			
Copper	236	10	"	250		94	80-120			
Iron	828	100	"	1000		83	80-120			
Magnesium	8160	1000	"	10000		82	80-120			
Manganese	475	20	"	500		95	80-120			
Molybdenum	416	20	"	500		83	80-120			
Nickel	473	20	"	500		95	80-120			
Potassium	9060	1000	"	10000		91	80-120			
Silver	58.2	10	"	50.0		116	80-120			
Sodium	8550	1000	"	10000		85	80-120			

CA DOHS ELAP Accreditation/Registration Number 1233

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Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: 3M Redding Quarry
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSC1078
COC #: 103359

Metals by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02415 - EPA 3010A										
LCS (CS02415-BS1)				Prepared & Analyzed: 04/01/09						
Zinc	467	20	µg/L	500		93	80-120			
Boron	2350	50	"	2500		94	80-120			
LCS Dup (CS02415-BSD1)				Prepared & Analyzed: 04/01/09						
Aluminum	1670	50	µg/L	2000		84	80-120	0.6	20	
Antimony	423	50	"	500		85	80-120	3	20	
Barium	1910	20	"	2000		95	80-120	1	20	
Beryllium	47.2	5.0	"	50.0		94	80-120	2	20	
Cadmium	50.4	10	"	50.0		101	80-120	4	20	
Calcium	9410	1000	"	10000		94	80-120	1	20	
Chromium	189	10	"	200		95	80-120	1	20	
Cobalt	481	20	"	500		96	80-120	1	20	
Copper	238	10	"	250		95	80-120	0.8	20	
Iron	820	100	"	1000		82	80-120	0.9	20	
Magnesium	8280	1000	"	10000		83	80-120	1	20	
Manganese	481	20	"	500		96	80-120	1	20	
Molybdenum	417	20	"	500		83	80-120	0.3	20	
Nickel	473	20	"	500		95	80-120	0.06	20	
Potassium	9130	1000	"	10000		91	80-120	0.8	20	
Silver	58.5	10	"	50.0		117	80-120	0.5	20	
Sodium	8650	1000	"	10000		86	80-120	1	20	
Zinc	475	20	"	500		95	80-120	2	20	
Boron	2390	50	"	2500		96	80-120	2	20	
Matrix Spike (CS02415-MS1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Aluminum	1680	50	µg/L	2000	ND	84	75-125			
Antimony	443	50	"	500	ND	89	75-125			
Barium	1900	20	"	2000	21.6	94	75-125			
Beryllium	47.4	5.0	"	50.0	0.440	94	75-125			
Cadmium	50.1	10	"	50.0	ND	100	75-125			
Calcium	19300	1000	"	10000	9920	94	75-125			
Chromium	190	10	"	200	ND	95	75-125			

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Project: 3M Redding Quarry
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Project Manager: Joseph Turner

CLS Work Order #: CSC1078
COC #: 103359

Metals by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02415 - EPA 3010A										
Matrix Spike (CS02415-MS1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Cobalt	477	20	µg/L	500	ND	95	75-125			
Copper	236	10	"	250	ND	94	75-125			
Iron	817	100	"	1000	ND	82	75-125			
Magnesium	12300	1000	"	10000	4100	82	75-125			
Manganese	477	20	"	500	ND	95	75-125			
Molybdenum	427	20	"	500	ND	85	75-125			
Nickel	477	20	"	500	ND	95	75-125			
Potassium	9160	1000	"	10000	275	89	75-125			
Silver	58.5	10	"	50.0	ND	117	75-125			
Sodium	11400	1000	"	10000	2930	85	75-125			
Zinc	473	20	"	500	9.80	93	75-125			
Boron	2370	50	"	2500	30.7	94	75-125			
Matrix Spike (CS02415-MS2)		**Source: CSC1082-03**		Prepared & Analyzed: 04/01/09						
Aluminum	1810	50	µg/L	2000	130	84	75-125			
Antimony	446	50	"	500	ND	89	75-125			
Barium	2020	20	"	2000	130	95	75-125			
Beryllium	47.3	5.0	"	50.0	ND	95	75-125			
Cadmium	51.8	10	"	50.0	4.50	95	75-125			
Calcium	42800	1000	"	10000	33700	91	75-125			
Chromium	196	10	"	200	ND	98	75-125			
Cobalt	476	20	"	500	ND	95	75-125			
Copper	237	10	"	250	ND	95	75-125			
Iron	965	100	"	1000	163	80	75-125			
Magnesium	48100	1000	"	10000	40200	79	75-125			
Manganese	481	20	"	500	ND	96	75-125			
Molybdenum	432	20	"	500	ND	86	75-125			
Nickel	477	20	"	500	ND	95	75-125			
Potassium	11500	1000	"	10000	2380	91	75-125			
Silver	54.1	10	"	50.0	4.10	100	75-125			
Sodium	71300	1000	"	10000	62600	86	75-125			

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Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: 3M Redding Quarry
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSC1078
COC #: 103359

Metals by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02415 - EPA 3010A										
Matrix Spike (CS02415-MS2)		**Source: CSC1082-03**		Prepared & Analyzed: 04/01/09						
Zinc	491	20	µg/L	500	ND	98	75-125			
Boron	4730	50	"	2500	2390	94	75-125			
Matrix Spike Dup (CS02415-MSD1)		**Source: CSC1078-01**		Prepared & Analyzed: 04/01/09						
Aluminum	1670	50	µg/L	2000	ND	84	75-125	0.5	25	
Antimony	449	50	"	500	ND	90	75-125	1	25	
Barium	1890	20	"	2000	21.6	93	75-125	0.6	25	
Beryllium	47.2	5.0	"	50.0	0.440	94	75-125	0.4	25	
Cadmium	49.7	10	"	50.0	ND	99	75-125	0.8	25	
Calcium	19300	1000	"	10000	9920	93	75-125	0.5	25	
Chromium	194	10	"	200	ND	97	75-125	2	25	
Cobalt	478	20	"	500	ND	96	75-125	0.1	25	
Copper	236	10	"	250	ND	94	75-125	0	25	
Iron	809	100	"	1000	ND	81	75-125	1	25	
Magnesium	12200	1000	"	10000	4100	81	75-125	0.8	25	
Manganese	477	20	"	500	ND	95	75-125	0.1	25	
Molybdenum	429	20	"	500	ND	86	75-125	0.5	25	
Nickel	471	20	"	500	ND	94	75-125	1	25	
Potassium	9180	1000	"	10000	275	89	75-125	0.2	25	
Silver	58.5	10	"	50.0	ND	117	75-125	0	25	
Sodium	11300	1000	"	10000	2930	84	75-125	0.7	25	
Zinc	474	20	"	500	9.80	93	75-125	0.06	25	
Boron	2370	50	"	2500	30.7	93	75-125	0.08	25	
Matrix Spike Dup (CS02415-MSD2)		**Source: CSC1082-03**		Prepared & Analyzed: 04/01/09						
Aluminum	1850	50	µg/L	2000	130	86	75-125	2	25	
Antimony	457	50	"	500	ND	91	75-125	2	25	
Barium	2040	20	"	2000	130	95	75-125	0.8	25	
Beryllium	47.8	5.0	"	50.0	ND	96	75-125	1	25	
Cadmium	52.2	10	"	50.0	4.50	95	75-125	0.8	25	
Calcium	43000	1000	"	10000	33700	93	75-125	0.4	25	
Chromium	202	10	"	200	ND	101	75-125	3	25	

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Project: 3M Redding Quarry
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CLS Work Order #: CSC1078
COC #: 103359

Metals by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02415 - EPA 3010A										
Matrix Spike Dup (CS02415-MSD2)		**Source: CSC1082-03**		Prepared & Analyzed: 04/01/09						
Cobalt	484	20	µg/L	500	ND	97	75-125	2	25	
Copper	240	10	"	250	ND	96	75-125	2	25	
Iron	982	100	"	1000	163	82	75-125	2	25	
Magnesium	48300	1000	"	10000	40200	81	75-125	0.4	25	
Manganese	486	20	"	500	ND	97	75-125	1	25	
Molybdenum	443	20	"	500	ND	89	75-125	3	25	
Nickel	481	20	"	500	ND	96	75-125	0.6	25	
Potassium	11600	1000	"	10000	2380	92	75-125	0.6	25	
Silver	55.7	10	"	50.0	4.10	103	75-125	3	25	
Sodium	71500	1000	"	10000	62600	88	75-125	0.3	25	
Zinc	483	20	"	500	ND	97	75-125	2	25	
Boron	4780	50	"	2500	2390	95	75-125	0.9	25	
Batch CS02439 - EPA 7470A										
Blank (CS02439-BLK1)				Prepared: 04/01/09 Analyzed: 04/02/09						
Mercury	ND	0.20	µg/L							
LCS (CS02439-BS1)				Prepared: 04/01/09 Analyzed: 04/02/09						
Mercury	5.37	0.20	µg/L	5.00		107	75-125			
LCS Dup (CS02439-BSD1)				Prepared: 04/01/09 Analyzed: 04/02/09						
Mercury	4.49	0.20	µg/L	5.00		90	75-125	18	25	
Matrix Spike (CS02439-MS1)		**Source: CSC1041-01**		Prepared: 04/01/09 Analyzed: 04/02/09						
Mercury	5.08	0.20	µg/L	5.00	ND	102	75-125			

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Project: 3M Redding Quarry
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSC1078
COC #: 103359

Metals by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS02439 - EPA 7470A										
Matrix Spike Dup (CS02439-MSD1)		**Source: CSC1041-01**		Prepared: 04/01/09	Analyzed: 04/02/09					
Mercury	5.10	0.20	µg/L	5.00	ND	102	75-125	0.4	25	

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COC #: 103359

Notes and Definitions

DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TG	3/30/09		1 / 1

Project	Subject
3M Redding Quarry	Surface Water Sampling

References/Notes

11:15 In Redding, Tim Goodwin & Joe Turner met with Frank ~~Boston~~ (Shasta Resource?) picked up keys for site.

Front Gate Combo: 1229

12:30 At First Location, road crossing creek, sample up gradient approx. 20 ft from crossing. Sample ID: SW-3, GPS point collected.

Field Meter Values:

pH 6.99
Temp 12.9 °C
EC 145 µS/cm
ORP ~~[illegible]~~ 100 mV
DO 11.31 mg/L

~~20 ft~~ 10 m × 0.5 ft deep × 7 ft wide
~~70~~ 3.5 ft²
32 sec. ~~for~~ 20 ft = 0.625 ft/sec
~2.2 cfs

13:00 SW-2 Location approx. 25 ft downstream of crossing at confluence of 2 minor streams

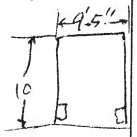
pH - 7.00
Temp - 14.62°C
EC - 200 µS/cm
ORP - 95 mV
DO - 10.3 mg/L

GPS Point Collected
SW-02 is correct
SW-2 is incorrect
~300-400 gpm

13:30 Tunnel Measurement

Measurement is concrete ignored timbers inside.

9'-5" wide
10'-0" tall



14:25 SW-1 off of White Rd after gate need key. White Road off of Digger Bay Road. Collecting Field Duplicate

pH 7.65
Temp 14.24 °C
EC 149 µS/cm
ORP 69 mV
DO 10.50 mg/L

#1580-1/8" sq.

CALIFORNIA LABORATORY SERVICES

3249 Fitzgerald Road Rancho Cordova, CA 95742

June 04, 2009

CLS Work Order #: CSE1053
COC #: 103647

Joseph Turner
Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project Name: Moody Creek

Enclosed are the results of analyses for samples received by the laboratory on 05/28/09 10:30. Samples were analyzed pursuant to client request utilizing EPA or other ELAP approved methodologies. I certify that the results are in compliance both technically and for completeness.

Analytical results are attached to this letter. Please call if we can provide additional assistance.

Sincerely,

James Liang, Ph.D.
Laboratory Director

CA DOHS ELAP Accreditation/Registration number 1233

Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

CLS - Labs

CHAIN OF CUSTODY CLS ID No.: CSE1053 LOG NO. 103647

REPORT TO:
NAME AND ADDRESS: Tim Godwin - Brown & Caldwell, 10540 White Rock Rd. #180, Rancho Cordova, CA 95670
PROJECT MANAGER: Joe Turner PHONE#: 916-853-5334
PROJECT NAME: Moody Creek
SAMPLED BY: T. Godwin
JOB DESCRIPTION: Groundwater Sampling
SITE LOCATION: Redding, CA

CLIENT JOB NUMBER: 137108
DESTINATION LABORATORY#: ☒ CLS (916) 638-7301, 3249 FITZGERALD RD. RANCHO CORDOVA, CA 95742 ☐ OTHER

GEOTRACKER: EDF REPORT ☐ YES ☐ NO
GLOBAL ID:
COMPOSITE:
FIELD CONDITIONS:

DATE	TIME	SAMPLE IDENTIFICATION	MATRIX	CONTAINER NO.	CONTAINER TYPE	PRESERVATIVES	Metals (6010/6020/7470)*	Alkalinity (Total/Carb/Bicarb)	TDS (160.1)	Specific Conductance (120.1)	Anions**	Hardness (130.2)	1 DAY	2 DAY	5 DAY	10 DAY	SPECIAL INSTRUCTIONS ALT. ID:
5/27/09	825	B-3	WATER	2	Poly ①	2/3	X	X	X	X	X	X			X		ok to run to ~~Please Hold Analysis~~
	850	MW-1					X	X	X	X	X	X			X		
	915	B-2					X	X	X	X	X	X			X		ok to run to ~~Please Hold Analysis~~
	1115	B-1					X	X	X	X	X	X			X		
	1130	DUP-1					X	X	X	X	X	X			X		

LAB

* METALS: Hg, Al, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, K, Ag, Na, Zn, Sb, As, Pb, Se, Tl, V
** ANIONS: AMMONIA AS N, NITRATE AS N, NITRITE AS N, BROMIDE, Chloride, FLOURIDE, Sulfate
① 250 ml Poly w/HNO3 was field filtered using 0.45 µm filter; 1L NON-PRESERVED NON-FILTERED.

INVOICE TO:
PO. #
QUOTE #
SUSPECTED CONSTITUENTS
PRESERVATIVES: (1) HCL (2) HNO3 (3) = COLD (4) = NaOH (5) = H2SO4 (6) = Na2S2O3 (7) =

RELINQUISHED BY (SIGN)	PRINT NAME / COMPANY	DATE / TIME	RECEIVED BY (SIGN)	PRINT NAME / COMPANY
Tim Godwin	Tim Godwin / BC	5/28/09 1030		
RECEIVED BY LAB: Will Orellana		DATE / TIME: 5/28/09 1030	CONDITIONS / COMMENTS: 3.3°C	

SHIPPED BY: ☐ FED X ☐ UPS ☐ OTHER AIR BILL #

Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

CHANGE OF STATUS

C.L.S. Lab Job No.: CSE1053

Project Name: Moody Creek

Date Sample(s) Were Received: 5/28 Original Date Due: 6/4

Tim G. (Client Contacted) of B&C (Company) called

on 5/29 (Date) at 16:57 (Time)

. . . and requested the following

Please add Mo to metals

Turnaround time requested for additional work: Same

A. Benkett (Signature) 5/29/09 (Date)

Updated lab job database and file folder by:

cc:

H:\Alyssam\samprecchangeofstat.DOC

CA DOHS ELAP Accreditation/Registration Number 1233

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10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
B-3 (CSE1053-01) Water Sampled: 05/27/09 08:25 Received: 05/28/09 10:30									
Total Alkalinity	**420**	5.0	mg/L	1	CS04006	06/01/09	06/01/09	SM2310B	
Bicarbonate as CaCO3	**420**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	**0.14**	0.10	"	"	CS03987	05/29/09	05/29/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Chloride	**5.4**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**910**	1.0	µmhos/cm	"	CS03923	05/28/09	05/28/09	EPA 120.1	
Fluoride	**0.18**	0.10	mg/L	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Total Hardness as CaCO3	**43**	1.0	"	"	CS04007	06/01/09	06/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**73**	2.5	"	5	"	"	05/29/09	"	
Total Dissolved Solids	**700**	10	"	1	CS03985	05/29/09	06/01/09	SM2540C	
MW-1 (CSE1053-03) Water Sampled: 05/27/09 08:50 Received: 05/28/09 10:30									
Total Alkalinity	**190**	5.0	mg/L	1	CS04006	06/01/09	06/01/09	SM2310B	
Bicarbonate as CaCO3	**190**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS03987	05/29/09	05/29/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Chloride	**1.2**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**370**	1.0	µmhos/cm	"	CS03923	05/28/09	05/28/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Total Hardness as CaCO3	**180**	1.0	"	"	CS04007	06/01/09	06/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**3.3**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**210**	10	"	"	CS03985	05/29/09	06/01/09	SM2540C	

Brown & Caldwell-Rancho Cordova
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Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
B-2 (CSE1053-05) Water Sampled: 05/27/09 09:15 Received: 05/28/09 10:30									
Total Alkalinity	**350**	5.0	mg/L	1	CS04006	06/01/09	06/01/09	SM2310B	
Bicarbonate as CaCO3	**350**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS03987	05/29/09	05/29/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Chloride	**3.4**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**710**	1.0	µmhos/cm	"	CS03923	05/28/09	05/28/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Total Hardness as CaCO3	**310**	1.0	"	"	CS04007	06/01/09	06/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**29**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**440**	10	"	"	CS03985	05/29/09	06/01/09	SM2540C	
B-1 (CSE1053-07) Water Sampled: 05/27/09 11:15 Received: 05/28/09 10:30									
Total Alkalinity	**120**	5.0	mg/L	1	CS04006	06/01/09	06/01/09	SM2310B	
Bicarbonate as CaCO3	**120**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS03987	05/29/09	05/29/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Chloride	**1.1**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**230**	1.0	µmhos/cm	"	CS03923	05/28/09	05/28/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Total Hardness as CaCO3	**100**	1.0	"	"	CS04007	06/01/09	06/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**4.1**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**140**	10	"	"	CS03985	05/29/09	06/01/09	SM2540C	

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Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
DUP-1 (CSE1053-09) Water Sampled: 05/27/09 11:30 Received: 05/28/09 10:30									
Total Alkalinity	**110**	5.0	mg/L	1	CS04006	06/01/09	06/01/09	SM2310B	
Bicarbonate as CaCO3	**110**	5.0	"	"	"	"	"	"	
Carbonate as CaCO3	ND	5.0	"	"	"	"	"	"	
Hydroxide as CaCO3	ND	5.0	"	"	"	"	"	"	
Ammonia as N	ND	0.10	"	"	CS03987	05/29/09	05/29/09	SM4500-NH3C	
Bromide	ND	0.10	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Chloride	**1.1**	0.50	"	"	"	"	"	"	
Specific Conductance (EC)	**230**	1.0	µmhos/cm	"	CS03923	05/28/09	05/28/09	EPA 120.1	
Fluoride	ND	0.10	mg/L	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Total Hardness as CaCO3	**100**	1.0	"	"	CS04007	06/01/09	06/01/09	SM 2340B	
Nitrate as N	ND	0.50	"	"	CS03918	05/28/09	05/29/09	EPA 300.0	
Nitrite as N	ND	0.10	"	"	"	"	"	"	
Sulfate as SO4	**4.1**	0.50	"	"	"	"	"	"	
Total Dissolved Solids	**140**	10	"	"	CS03985	05/29/09	06/01/09	SM2540C	

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Metals (Dissolved) by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
B-3 (Field Filtered) (CSE1053-02) Water Sampled: 05/27/09 08:25 Received: 05/28/09 10:30									
Mercury	ND	0.20	µg/L	1	CS03977	05/29/09	05/29/09	EPA 7470A	
Aluminum	ND	50	"	"	CS03966	05/29/09	05/29/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**15000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	A-COM
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**7700**	1000	"	"	"	"	"	"	
Manganese	**25**	20	"	"	"	"	"	"	
Molybdenum	**35**	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	**1900**	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**190000**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Vanadium	**7.0**	5.0	"	"	CS03965	05/29/09	05/29/09	EPA 7000/6020	
Antimony	**8.1**	5.0	"	"	"	"	"	"	
Arsenic	**6.2**	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	

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Metals (Dissolved) by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
MW-1 (Field Filtered) (CSE1053-04) Water Sampled: 05/27/09 08:50 Received: 05/28/09 10:30									
Mercury	ND	0.20	µg/L	1	CS03977	05/29/09	05/29/09	EPA 7470A	
Aluminum	ND	50	"	"	CS03966	05/29/09	05/29/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**48000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	A-COM
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**15000**	1000	"	"	"	"	"	"	
Manganese	**81**	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**8500**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Antimony	ND	5.0	"	"	CS03965	05/29/09	05/29/09	EPA 7000/6020	
Vanadium	ND	5.0	"	"	"	"	"	"	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	

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Metals (Dissolved) by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
B-2 (Field Filtered) (CSE1053-06) Water Sampled: 05/27/09 09:15 Received: 05/28/09 10:30									
Mercury	ND	0.20	µg/L	1	CS03977	05/29/09	05/29/09	EPA 7470A	
Aluminum	ND	50	"	"	CS03966	05/29/09	05/29/09	EPA 6010B	
Barium	**38**	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**77000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	A-COM
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	**150**	100	"	"	"	"	"	"	
Magnesium	**30000**	1000	"	"	"	"	"	"	
Manganese	**150**	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**34000**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Vanadium	ND	5.0	"	"	CS03965	05/29/09	05/29/09	EPA 7000/6020	
Antimony	ND	5.0	"	"	"	"	"	"	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	

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Project Manager: Joseph Turner

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COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
B-1 (Field Filtered) (CSE1053-08) Water Sampled: 05/27/09 11:15 Received: 05/28/09 10:30									
Mercury	ND	0.20	µg/L	1	CS03977	05/29/09	05/29/09	EPA 7470A	
Aluminum	ND	50	"	"	CS03966	05/29/09	05/29/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**28000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	A-COM
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**8800**	1000	"	"	"	"	"	"	
Manganese	**31**	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**5700**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Antimony	ND	5.0	"	"	CS03965	05/29/09	05/29/09	EPA 7000/6020	
Vanadium	ND	5.0	"	"	"	"	"	"	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	

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CLS Work Order #: CSE1053
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Metals (Dissolved) by EPA 6000/7000 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
DUP-1 (Field Filtered) (CSE1053-10) Water Sampled: 05/27/09 11:30 Received: 05/28/09 10:30									
Mercury	ND	0.20	µg/L	1	CS03977	05/29/09	05/29/09	EPA 7470A	
Aluminum	ND	50	"	"	CS03966	05/29/09	05/29/09	EPA 6010B	
Barium	ND	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**30000**	1000	"	"	"	"	"	"	
Chromium	ND	10	"	"	"	"	"	"	A-COM
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	ND	100	"	"	"	"	"	"	
Magnesium	**9100**	1000	"	"	"	"	"	"	
Manganese	**26**	20	"	"	"	"	"	"	
Molybdenum	ND	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	ND	1000	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**5800**	1000	"	"	"	"	"	"	
Zinc	ND	20	"	"	"	"	"	"	
Vanadium	ND	5.0	"	"	CS03965	05/29/09	05/29/09	EPA 7000/6020	
Antimony	ND	5.0	"	"	"	"	"	"	
Arsenic	ND	5.0	"	"	"	"	"	"	
Lead	ND	5.0	"	"	"	"	"	"	
Selenium	ND	5.0	"	"	"	"	"	"	
Thallium	ND	1.0	"	"	"	"	"	"	

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Project: Moody Creek
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CLS Work Order #: CSE1053
COC #: 103647

Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03918 - General Prep										
Blank (CS03918-BLK1)				Prepared & Analyzed: 05/28/09						
Sulfate as SO4	ND	0.50	mg/L							
Fluoride	ND	0.10	"							
Chloride	ND	0.50	"							
Bromide	ND	0.10	"							
Nitrate as N	ND	0.50	"							
Nitrite as N	ND	0.10	"							
LCS (CS03918-BS1)				Prepared & Analyzed: 05/28/09						
Sulfate as SO4	4.76	0.50	mg/L	5.00		95	80-120			
Fluoride	1.95	0.10	"	2.00		98	80-120			
Chloride	1.93	0.50	"	2.00		97	80-120			
Bromide	2.00	0.10	"	2.00		100	80-120			
Nitrite as N	0.582	0.10	"	0.610		95	80-120			
Nitrate as N	0.449	0.50	"	0.451		100	80-120			
LCS Dup (CS03918-BSD1)				Prepared & Analyzed: 05/28/09						
Sulfate as SO4	4.80	0.50	mg/L	5.00		96	80-120	0.7	20	
Fluoride	1.99	0.10	"	2.00		100	80-120	2	20	
Chloride	1.94	0.50	"	2.00		97	80-120	0.6	20	
Bromide	2.02	0.10	"	2.00		101	80-120	1	20	
Nitrite as N	0.590	0.10	"	0.610		97	80-120	1	20	
Nitrate as N	0.459	0.50	"	0.451		102	80-120	2	20	
Matrix Spike (CS03918-MS1)		**Source: CSE1042-01**		Prepared & Analyzed: 05/28/09						
Bromide	2.06	0.10	mg/L	2.00	ND	103	75-125			
Fluoride	2.10	0.10	"	2.00	0.112	99	75-125			
Sulfate as SO4	13.3	0.50	"	5.00	8.34	99	75-125			
Chloride	7.00	0.50	"	2.00	5.30	85	75-125			
Nitrate as N	6.89	0.50	"	0.451	6.72	38	80-120			QM-4X
Nitrite as N	0.589	0.10	"	0.610	ND	97	75-125			

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Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03918 - General Prep										
Matrix Spike Dup (CS03918-MSD1)		**Source: CSE1042-01**		Prepared & Analyzed: 05/28/09						
Chloride	7.03	0.50	mg/L	2.00	5.30	86	75-125	0.4	25	
Bromide	2.09	0.10	"	2.00	ND	104	75-125	1	25	
Fluoride	2.08	0.10	"	2.00	0.112	99	75-125	0.6	25	
Sulfate as SO4	13.4	0.50	"	5.00	8.34	102	75-125	1	25	
Nitrate as N	6.90	0.50	"	0.451	6.72	40	80-120	0.1	20	QM-4X
Nitrite as N	0.598	0.10	"	0.610	ND	98	75-125	2	25	
Batch CS03923 - General Preparation										
Blank (CS03923-BLK1)				Prepared & Analyzed: 05/28/09						
Specific Conductance (EC)	ND	1.0	µmhos/cm							
Batch CS03985 - General Preparation										
Blank (CS03985-BLK1)				Prepared: 05/29/09 Analyzed: 06/01/09						
Total Dissolved Solids	ND	10	mg/L							
Duplicate (CS03985-DUP1)		**Source: CSE1049-02**		Prepared: 05/29/09 Analyzed: 06/01/09						
Total Dissolved Solids	530	10	mg/L		504			5	20	
Batch CS03987 - General Preparation										
Blank (CS03987-BLK1)				Prepared & Analyzed: 05/29/09						
Ammonia as N	ND	0.10	mg/L							

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Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03987 - General Preparation										
LCS (CS03987-BS1)				Prepared & Analyzed: 05/29/09						
Ammonia as N	0.450	0.10	mg/L	0.500		90	80-120			
LCS Dup (CS03987-BSD1)				Prepared & Analyzed: 05/29/09						
Ammonia as N	0.450	0.10	mg/L	0.500		90	80-120	0	25	
Matrix Spike (CS03987-MS1)		**Source: CSE1075-01**		Prepared & Analyzed: 05/29/09						
Ammonia as N	0.507	0.10	mg/L	0.500	0.0339	95	75-125			
Matrix Spike Dup (CS03987-MSD1)		**Source: CSE1075-01**		Prepared & Analyzed: 05/29/09						
Ammonia as N	0.507	0.10	mg/L	0.500	0.0339	95	75-125	0	25	
Batch CS04006 - General Preparation										
Blank (CS04006-BLK1)				Prepared & Analyzed: 06/01/09						
Total Alkalinity	ND	5.0	mg/L							
Bicarbonate as CaCO3	ND	5.0	"							
Carbonate as CaCO3	ND	5.0	"							
Hydroxide as CaCO3	ND	5.0	"							
Duplicate (CS04006-DUP1)		**Source: CSE1049-01**		Prepared & Analyzed: 06/01/09						
Total Alkalinity	145	5.0	mg/L		145			0.1	20	
Bicarbonate as CaCO3	145	5.0	"		145			0.1	20	
Carbonate as CaCO3	ND	5.0	"		ND				20	
Hydroxide as CaCO3	ND	5.0	"		ND				20	
Batch CS04007 - 6010A/No Digestion										
Blank (CS04007-BLK1)				Prepared & Analyzed: 06/01/09						
Total Hardness as CaCO3	ND	1.0	mg/L							

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Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS04007 - 6010A/No Digestion										
LCS (CS04007-BS1)				Prepared & Analyzed: 06/01/09						
Total Hardness as CaCO3	58.9	1.0	mg/L	66.2		89	80-120			
LCS Dup (CS04007-BSD1)				Prepared & Analyzed: 06/01/09						
Total Hardness as CaCO3	58.7	1.0	mg/L	66.2		89	80-120	0.4	20	
Matrix Spike (CS04007-MS1)		**Source: CSE0895-01**		Prepared & Analyzed: 06/01/09						
Total Hardness as CaCO3	81.9	1.0	mg/L	66.2	30.4	78	75-125			
Matrix Spike Dup (CS04007-MSD1)		**Source: CSE0895-01**		Prepared & Analyzed: 06/01/09						
Total Hardness as CaCO3	84.0	1.0	mg/L	66.2	30.4	81	75-125	3	25	

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10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03965 - EPA 3020A										
Blank (CS03965-BLK1)				Prepared & Analyzed: 05/29/09						
Vanadium	ND	5.0	µg/L				80-120		20	
Antimony	ND	5.0	"				80-120		20	
Arsenic	ND	5.0	"							
Lead	ND	5.0	"							
Selenium	ND	5.0	"							
Thallium	ND	1.0	"							
LCS (CS03965-BS1)				Prepared & Analyzed: 05/29/09						
Antimony	109	5.0	µg/L	100		109	80-120		20	
Vanadium	105	5.0	"	100		105	80-120		20	
Arsenic	100	5.0	"	100		100	80-120			
Lead	99.8	5.0	"	100		100	80-120			
Selenium	99.9	5.0	"	100		100	80-120			
Thallium	104	1.0	"	100		104	80-120			
LCS Dup (CS03965-BSD1)				Prepared & Analyzed: 05/29/09						
Vanadium	105	5.0	µg/L	100		105	80-120	0.05	20	
Antimony	108	5.0	"	100		108	80-120	1	20	
Arsenic	101	5.0	"	100		101	80-120	0.8	20	
Lead	98.4	5.0	"	100		98	80-120	1	20	
Selenium	102	5.0	"	100		102	80-120	2	20	
Thallium	105	1.0	"	100		105	80-120	0.2	20	
Matrix Spike (CS03965-MS1)	**Source: CSE1042-02**			Prepared & Analyzed: 05/29/09						
Antimony	107	5.0	µg/L	100	0.430	106	80-120		20	
Vanadium	108	5.0	"	100	7.68	101	80-120		20	
Arsenic	98.9	5.0	"	100	1.50	97	75-125			
Lead	98.3	5.0	"	100	0.260	98	75-125			
Selenium	98.5	5.0	"	100	ND	99	75-125			
Thallium	103	1.0	"	100	ND	103	75-125			

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Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03965 - EPA 3020A										
Matrix Spike (CS03965-MS2)	**Source: CSE1053-02**			Prepared & Analyzed: 05/29/09						
Vanadium	113	5.0	µg/L	100	6.97	106	80-120		20	
Antimony	123	5.0	"	100	8.06	115	80-120		20	
Arsenic	111	5.0	"	100	6.23	105	75-125			
Lead	106	5.0	"	100	0.280	106	75-125			
Selenium	107	5.0	"	100	3.22	104	75-125			
Thallium	113	1.0	"	100	ND	113	75-125			
Matrix Spike Dup (CS03965-MSD1)	**Source: CSE1042-02**			Prepared & Analyzed: 05/29/09						
Antimony	114	5.0	µg/L	100	0.430	114	80-120	7	20	
Vanadium	113	5.0	"	100	7.68	106	80-120	4	20	
Arsenic	106	5.0	"	100	1.50	104	75-125	7	25	
Lead	104	5.0	"	100	0.260	103	75-125	5	25	
Selenium	106	5.0	"	100	ND	106	75-125	8	25	
Thallium	111	1.0	"	100	ND	111	75-125	7	25	
Matrix Spike Dup (CS03965-MSD2)	**Source: CSE1053-02**			Prepared & Analyzed: 05/29/09						
Vanadium	112	5.0	µg/L	100	6.97	105	80-120	0.2	20	
Antimony	123	5.0	"	100	8.06	115	80-120	0.2	20	
Arsenic	108	5.0	"	100	6.23	101	75-125	3	25	
Lead	105	5.0	"	100	0.280	104	75-125	2	25	
Selenium	106	5.0	"	100	3.22	103	75-125	1	25	
Thallium	110	1.0	"	100	ND	110	75-125	2	25	
Batch CS03966 - EPA 3010A										
Blank (CS03966-BLK1)				Prepared & Analyzed: 05/29/09						
Aluminum	ND	50	µg/L							
Barium	ND	20	"							
Beryllium	ND	5.0	"							
Cadmium	ND	10	"							
Calcium	ND	1000	"							
Chromium	ND	10	"							
Cobalt	ND	20	"							

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10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03966 - EPA 3010A										
Blank (CS03966-BLK1)				Prepared & Analyzed: 05/29/09						
Copper	ND	10	µg/L							
Iron	ND	100	"							
Magnesium	ND	1000	"							
Manganese	ND	20	"							
Molybdenum	ND	20	"							
Nickel	ND	20	"							
Potassium	ND	1000	"							
Silver	ND	10	"							
Sodium	ND	1000	"							
Zinc	ND	20	"							
LCS (CS03966-BS1)				Prepared & Analyzed: 05/29/09						
Aluminum	2410	50	µg/L	2000		121	80-120			QM-1
Barium	1910	20	"	2000		95	80-120			
Beryllium	46.9	5.0	"	50.0		94	80-120			
Cadmium	60.0	10	"	50.0		120	80-120			
Calcium	9750	1000	"	10000		98	80-120			
Chromium	183	10	"	200		92	80-120			
Cobalt	493	20	"	500		99	80-120			
Copper	243	10	"	250		97	80-120			
Iron	853	100	"	1000		85	80-120			
Magnesium	9470	1000	"	10000		95	80-120			
Manganese	484	20	"	500		97	80-120			
Molybdenum	442	20	"	500		88	80-120			
Nickel	482	20	"	500		96	80-120			
Potassium	9550	1000	"	10000		96	80-120			
Silver	56.6	10	"	50.0		113	80-120			
Sodium	10500	1000	"	10000		105	80-120			
Zinc	495	20	"	500		99	80-120			

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CLS Work Order #: CSE1053
COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03966 - EPA 3010A										
LCS Dup (CS03966-BSD1)				Prepared & Analyzed: 05/29/09						
Aluminum	2380	50	µg/L	2000		119	80-120	1	20	
Barium	1890	20	"	2000		94	80-120	1	20	
Beryllium	46.5	5.0	"	50.0		93	80-120	0.9	20	
Cadmium	59.3	10	"	50.0		119	80-120	1	20	
Calcium	9640	1000	"	10000		96	80-120	1	20	
Chromium	188	10	"	200		94	80-120	3	20	
Cobalt	489	20	"	500		98	80-120	0.8	20	
Copper	256	10	"	250		102	80-120	5	20	
Iron	840	100	"	1000		84	80-120	2	20	
Magnesium	9400	1000	"	10000		94	80-120	0.7	20	
Manganese	478	20	"	500		96	80-120	1	20	
Molybdenum	442	20	"	500		88	80-120	0	20	
Nickel	473	20	"	500		95	80-120	2	20	
Potassium	9730	1000	"	10000		97	80-120	2	20	
Silver	59.5	10	"	50.0		119	80-120	5	20	
Sodium	10400	1000	"	10000		104	80-120	0.8	20	
Zinc	488	20	"	500		98	80-120	1	20	
Matrix Spike (CS03966-MS1)		**Source: CSE1042-02**		Prepared & Analyzed: 05/29/09						
Aluminum	2430	50	µg/L	2000	ND	122	75-125			
Barium	2000	20	"	2000	68.0	96	75-125			
Beryllium	48.1	5.0	"	50.0	ND	96	75-125			
Cadmium	61.6	10	"	50.0	5.60	112	75-125			
Calcium	35100	1000	"	10000	24800	103	75-125			
Chromium	190	10	"	200	10.3	90	75-125			
Cobalt	493	20	"	500	ND	99	75-125			
Copper	250	10	"	250	ND	100	75-125			
Iron	893	100	"	1000	29.7	86	75-125			
Magnesium	21700	1000	"	10000	12000	97	75-125			
Manganese	488	20	"	500	ND	98	75-125			
Molybdenum	446	20	"	500	ND	89	75-125			

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CALIFORNIA LABORATORY SERVICES

Brown & Caldwell-Rancho Cordova
10540 White Rock Rd. Suite 180
Rancho Cordova, CA 95670

Project: Moody Creek
Project Number: 137108
Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03966 - EPA 3010A										
Matrix Spike (CS03966-MS1)		**Source: CSE1042-02**		Prepared & Analyzed: 05/29/09						
Nickel	476	20	µg/L	500	ND	95	75-125			
Potassium	12500	1000	"	10000	2740	98	75-125			
Silver	63.6	10	"	50.0	ND	127	75-125			QM-7
Sodium	19900	1000	"	10000	10700	93	75-125			
Zinc	499	20	"	500	ND	100	75-125			
Matrix Spike (CS03966-MS2)		**Source: CSE1053-02**		Prepared & Analyzed: 05/29/09						
Aluminum	2450	50	µg/L	2000	ND	123	75-125			
Barium	1960	20	"	2000	7.30	97	75-125			
Beryllium	48.5	5.0	"	50.0	ND	97	75-125			
Cadmium	63.7	10	"	50.0	ND	127	75-125			QM-7
Calcium	25000	1000	"	10000	15400	96	75-125			
Chromium	195	10	"	200	ND	97	75-125			
Cobalt	502	20	"	500	ND	100	75-125			
Copper	261	10	"	250	ND	104	75-125			
Iron	886	100	"	1000	7.30	88	75-125			
Magnesium	17100	1000	"	10000	7690	94	75-125			
Manganese	516	20	"	500	24.6	98	75-125			
Molybdenum	490	20	"	500	34.9	91	75-125			
Nickel	486	20	"	500	ND	97	75-125			
Potassium	11800	1000	"	10000	1860	99	75-125			
Silver	62.0	10	"	50.0	ND	124	75-125			
Sodium	198000	1000	"	10000	193000	50	75-125			QM-7
Zinc	502	20	"	500	ND	100	75-125			
Matrix Spike Dup (CS03966-MSD1)		**Source: CSE1042-02**		Prepared & Analyzed: 05/29/09						
Aluminum	2470	50	µg/L	2000	ND	124	75-125	2	25	
Barium	1990	20	"	2000	68.0	96	75-125	0.2	25	
Beryllium	48.0	5.0	"	50.0	ND	96	75-125	0.2	25	
Cadmium	65.4	10	"	50.0	5.60	120	75-125	6	25	
Calcium	35000	1000	"	10000	24800	102	75-125	0.3	25	
Chromium	189	10	"	200	10.3	90	75-125	0.5	25	

CALIFORNIA LABORATORY SERVICES

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Project: Moody Creek
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Project Manager: Joseph Turner

CLS Work Order #: CSE1053
COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03966 - EPA 3010A										
Matrix Spike Dup (CS03966-MSD1)		**Source: CSE1042-02**		Prepared & Analyzed: 05/29/09						
Cobalt	490	20	µg/L	500	ND	98	75-125	0.6	25	
Copper	253	10	"	250	ND	101	75-125	1	25	
Iron	895	100	"	1000	29.7	86	75-125	0.2	25	
Magnesium	21600	1000	"	10000	12000	96	75-125	0.5	25	
Manganese	489	20	"	500	ND	98	75-125	0.2	25	
Molybdenum	453	20	"	500	ND	91	75-125	1	25	
Nickel	488	20	"	500	ND	98	75-125	3	25	
Potassium	12500	1000	"	10000	2740	98	75-125	0.2	25	
Silver	63.0	10	"	50.0	ND	126	75-125	0.9	25	QM-7
Sodium	20000	1000	"	10000	10700	93	75-125	0.2	25	
Zinc	498	20	"	500	ND	100	75-125	0.08	25	
Matrix Spike Dup (CS03966-MSD2)		**Source: CSE1053-02**		Prepared & Analyzed: 05/29/09						
Aluminum	2450	50	µg/L	2000	ND	123	75-125	0	25	
Barium	1960	20	"	2000	7.30	98	75-125	0.2	25	
Beryllium	48.4	5.0	"	50.0	ND	97	75-125	0.2	25	
Cadmium	65.0	10	"	50.0	ND	130	75-125	2	25	QM-7
Calcium	25300	1000	"	10000	15400	99	75-125	1	25	
Chromium	188	10	"	200	ND	94	75-125	3	25	
Cobalt	500	20	"	500	ND	100	75-125	0.3	25	
Copper	254	10	"	250	ND	101	75-125	3	25	
Iron	874	100	"	1000	7.30	87	75-125	1	25	
Magnesium	17200	1000	"	10000	7690	95	75-125	0.6	25	
Manganese	518	20	"	500	24.6	99	75-125	0.4	25	
Molybdenum	499	20	"	500	34.9	93	75-125	2	25	
Nickel	495	20	"	500	ND	99	75-125	2	25	
Potassium	11700	1000	"	10000	1860	98	75-125	0.6	25	
Silver	59.7	10	"	50.0	ND	119	75-125	4	25	
Sodium	201000	1000	"	10000	193000	84	75-125	2	25	
Zinc	505	20	"	500	ND	101	75-125	0.6	25	

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Brown & Caldwell-Rancho Cordova	Project: Moody Creek	
10540 White Rock Rd. Suite 180	Project Number: 137108	**CLS Work Order #: CSE1053**
Rancho Cordova, CA 95670	Project Manager: Joseph Turner	COC #: 103647

Metals (Dissolved) by EPA 6000/7000 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CS03977 - EPA 7470A										
Blank (CS03977-BLK1)				Prepared & Analyzed: 05/29/09						
Mercury	ND	0.20	µg/L							
LCS (CS03977-BS1)				Prepared & Analyzed: 05/29/09						
Mercury	4.62	0.20	µg/L	5.00		92	75-125			
LCS Dup (CS03977-BSD1)				Prepared & Analyzed: 05/29/09						
Mercury	4.19	0.20	µg/L	5.00		84	75-125	10	25	
Matrix Spike (CS03977-MS1)		**Source: CSE1053-02**		Prepared & Analyzed: 05/29/09						
Mercury	4.76	0.20	µg/L	5.00	ND	95	75-125			
Matrix Spike Dup (CS03977-MSD1)		**Source: CSE1053-02**		Prepared & Analyzed: 05/29/09						
Mercury	4.79	0.20	µg/L	5.00	ND	96	75-125	0.6	25	

Brown & Caldwell-Rancho Cordova	Project: Moody Creek	
10540 White Rock Rd. Suite 180	Project Number: 137108	**CLS Work Order #: CSE1053**
Rancho Cordova, CA 95670	Project Manager: Joseph Turner	COC #: 103647

Notes and Definitions

QM-7	The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS/LCSD recovery.
QM-4X	The spike recovery was outside of QC acceptance limits for the MS and/or MSD due to analyte concentration at 4 times or greater the spike concentration. The QC batch was accepted based on LCS and/or LCSD recoveries within the acceptance limits.
QM-1	The spike recovery was outside acceptance limits for the LCS or LCSD. The batch was accepted based on acceptable MS/MSD recoveries & RPD's.
A-COM	Reported by ICP-MS(EPA 6020).
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
			TG/JT	5/26/09		1

Project	Subject
Moody Creek	GW Sampling

References/Notes

15 30 On-site, Joe & Tim To purge MW-1 to allow recovery sample tomorrow

15 50 MW-1 22.86' DTW.

16 22 24.32' Q = 0.42 gpm, poor flow pulled pump and check.

16 56 33.00' Q = 2.5 gpm Volts = 36.3 → PVC particles caused jam,
pH = 8.34 Cond = ~~300~~ 353 µS
Temp = 18.1°C ORP = -33 mV

16 59 37.00'
17 04 43.00'
17 05 44.90' pH = 8.35 Cond = 354 µS
Temp = 18.1 °C ORP = +35 mV
17 10 51.00
17 18 60.00'
17 25 67.50'
17 29 71.00'
17 37 79.00 pH = 8.37 Cond = 339 µS
Temp = 21.0 °C ORP = -11 mV
17 51 89.00' pH = 7.32 Cond = 345 µS
Temp = 18.7 ORP = -15 mV

18 05 Collected Sample using 0.45 µm filter for both bottles 1- PRES w/HNO3 1- NO PRES.

18 35 Heading out

19 00 Off-site All gates secure

#1590-1/10" sq.

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TG/JT	5/27/09		1 2

Project	Subject
Moody Creek	GW Sampling

References/Notes

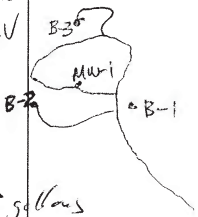
7 20 On-site

7 45 B-3 DTW 48.82' Top PVC.
49.90' TD

8 25 Collected sample B-3 pH = 8.29 Cond = 573.8 µS
Filtered Metals bottle w/HNO3 Temp = 22.5 °C ORP = -30 mV
General Non-Filtered.

8 35 DTW = 93.35 TD = 99.70' MW-1

8 50 Sample Collected MW-1 pH: 6.19 Cond. 351 µS
Metals Filtered w/HNO3 Temp = 18.6 °C ORP: 40 mV
Anions/Cations Not Filt or Pres.



9 05 B-2 DTW = 48.03' TD = 49.95'

9 15 Sample collected pH 7.74 Cond = 650 µS
Metals Filtered w/HNO3 Temp = 18.7 °C ORP = 4 mV
General/s Nonfilt Nonpres

9 35 B-1 DTW = 17.95' TD = 49.8 3CV = 143.3 gallons

10 15 Restart after clearing pump intake Q = 3.2 gpm
10 19 DTW = 21.70'
~~DTW = 25.00'~~

10 23 DTW - 25.00'
10 25 DTW - 26.00'
10 27 00 DTW - 27.00'
10 28 26 DTW - 28.00' → 1 26 min
10 29 51 DTW - 29.00' → 1 25 min → pH = 8.18 Cond = 202 µS
10 31 16 DTW - 30.00 → 1 25 min Temp = 20.4 °C ORP = -28 mV
10 32 48 DTW - 31.00 → 1 32
10 34 02 DTW - 32.00 → 1 14 min
10 35 21 DTW - 33.00 → 1 19 min
10 36 34 DTW - 34.00 → 1 13 min
10 38 09 DTW - 35.00 → 1 35 min
10 39 42 DTW - 36.00 → 1 33 min
10 40 50 DTW - 37.00 → 1 08 min pH - 8.08 Cond = 179 µS
10 41 54 DTW - 38.00 → 1 04 min → Temp 18.4 °C ORP = -37 mV
10 43 06 DTW - 39.00 → 1 12 min → Cascading water

#1590-1/10" sq.

BROWN AND CALDWELL

Date Checked	Checked By	Job Number	By	Date	Calc. No.	Sheet No.
		137108	TG/JT	5/27/09		2 2

Project	Subject
Moody Creek	Groundwater Sampling

10:50 DTW = 42.00 pH = 7.99 COND = 204
TEMP = 18.9 ORP = -30 mV

11:00 Pumped down to 45.80' pump could not keep up due to muddy conditions. Allowing RECOVERY PRIOR to collecting sample.

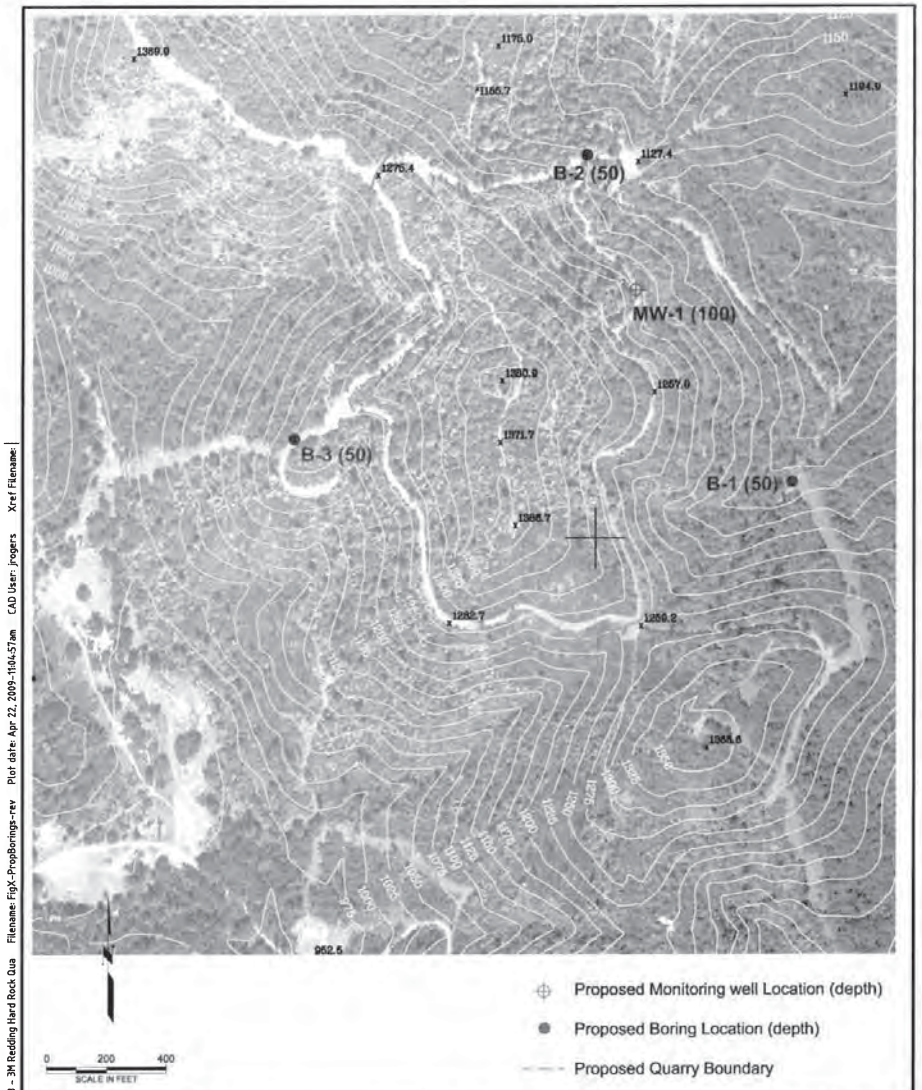
11:15 Sample B-~~1~~ B-1 pH = 8.14 Cond = 210 µS
Metals filtered ~~pre~~ HNO3 TEMP = 17.8 °C ORP = -42 mV
General non-filt non-pres.

11:30 Collect DUP-1 @ B-1

12:30 OFF-SITE Locked all gates.

References/Notes

#1590-1/10" sq.



Path: P:\37000\137108 - 3M Redding Hard Rock Qua Filename: Fig X-PropBorings-rev Plot date: Apr 22, 2009-11:04:57am CAD User: jrogers Xref Filename:

BROWN AND CALDWELL

DATE 4-22-09
PROJECT 137108-003

3M Quarry, Shasta, California

Aerial/Topo Map Showing Proposed Boring Locations

FIGURE X

CLS - Labs

CHAIN OF CUSTODY

CLS ID No.: _____

LOG NO. 103647

REPORT TO:

NAME AND ADDRESS: [illegible]

PROJECT MANAGER: [illegible] PHONE#: [illegible]

PROJECT NAME: [illegible] Creek

SAMPLED BY: [illegible]

JOB DESCRIPTION: [illegible]

SITE LOCATION: [illegible], CA

CLIENT JOB NUMBER: 137108

DESTINATION LABORATORY

☑ **CLS (916) 638-7301**
3249 FITZGERALD RD.
RANCHO CORDOVA, CA.
95742

☐ **OTHER**

PRESERVATIVES

ANALYSIS REQUESTED

GEOTRACKER:
EDF REPORT ☐ YES ☐ NO
GLOBAL ID: _____

COMPOSITE:

FIELD CONDITIONS:

DATE	TIME	SAMPLE IDENTIFICATION	MATRIX	CONTAINER NO.	CONTAINER TYPE	PRESERVATIVES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 DAY	2 DAY	5 DAY	10 DAY	SPECIAL INSTRUCTIONS OR ALT. ID:
[illegible]	[illegible]	B-3	[illegible]	3	[illegible]	[illegible]	X	X	X	X	X	X			X		[illegible]
	950	MW-1					X	X	X	X	X	X			X		
	915	B-2					X	X	X	X	X	X			X		[illegible]
	11:15	B-1					X	X	X	X	X	X			X		
	11:10	DUP-1					X	X	X	X	X	X			X		

* Metals: [illegible] V, Mo V=CAM O=EPA

** Prior Fuel: [illegible] Nitrate as N, Nitrite as N, Bromide, Chloride, Fluoride, Sulfate

① [illegible] with NaOH and Field Filtered using 0.45 µm filter, if Non-Preserved NOT Filtered.

INVOICE TO:

P.O. #

QUOTE #

SUSPECTED CONSTITUENTS

PRESERVATIVES: (1) HCL (2) HNO_3 (3) = COLD (4) = NaOH (5) = H_2SO_4 (6) = $Na_2S_2O_3$ (7) =

RELINQUISHED BY (SIGN)	PRINT NAME / COMPANY	DATE / TIME	RECEIVED BY (SIGN)	PRINT NAME / COMPANY
[illegible]	Tim Scowcroft / BC	5/28/09 [illegible]		

REC'D AT LAB BY: [illegible] DATE / TIME: [illegible] CONDITIONS / COMMENTS: [illegible]

SHIPPED BY: ☐ FED X ☐ UPS ☐ OTHER _____ AIR BILL #