



Geochemical and Stable Isotopic Data on Barren and Mineralized Drill Core in the Devonian Popovich Formation, Screamer Sector of the Betze-Post Gold Deposit, Northern Carlin Trend, Nevada

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Contents

Introduction.....	1
Location	1
Stratigraphy and Abbreviations	2
Methods.....	2
Drill Core, Gold, Sulfur, Carbonate, and Carbonaceous Material Analyses	2
EDS - XRF Antimony and Barium Analyses.....	3
Mixed Acid 40 Element ICP - AES	3
Tellurium Analyses.....	3
Sulfur Isotope Analyses	3
Carbonate Carbon, and Oxygen Isotope Analyses	4
Results.....	4
Geochemical Results	4
Sulfur, Carbon and Oxygen Isotope Results	4
Acknowledgments.....	5
References	5

Figures

1. Location map with mines and general geologic units and structures	6
2. Stratigraphic column with unit descriptions for the Goldstrike property	7

Tables

1. Drill-hole locations and collar elevations	8
2. Rock Formation, unit, and subunit identifications	9
3. Screamer geochemical and isotopic data.....	link

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Introduction

The Devonian Popovich Formation is the major host for Carlin-type gold deposits in the northern Carlin trend of Nevada. The Popovich is composed of gray to black, thin-bedded, calcareous to dolomitic mudstone and limestone deposited near the carbonate platform margin. Carlin-type gold deposits are Eocene, disseminated, auriferous pyrite deposits characterized by acid leaching, sulfidation, and silicification that are typically hosted in Paleozoic calcareous sedimentary rocks exposed in windows through siliceous sedimentary rocks of the Roberts Mountains allochthon (Hofstra and Cline, 2000). The Carlin trend currently is the largest gold producer in the United States. The Screamer ore zone is a tabular body on the periphery of the huge Betze-Post gold deposit. Screamer is a good place to study both the original lithochemistry of the Popovich Formation and the effects of subsequent alteration and mineralization because it is below the level of supergene oxidation, mostly outside the contact metamorphic aureole of the Jurassic Goldstrike stock (fig. 1), has small, high-grade ore zones along fractures and Jurassic dikes, and has intervening areas with lower grade mineralization and barren rock (Hofstra and others, 2011). In 1997, prior to mining at Screamer, drill core intervals from barren and mineralized Popovich Formation were selected for geochemical and stable isotope analysis. The 332, five-foot core samples analyzed are from five holes separated by as much as 2000 feet (600 meters). The samples extend from the base of the Wispy unit up through the Planar and Soft sediment deformation units into the lower part of the upper Mud unit of the Popovich Formation. The purpose of this report is to present the analytical methods and results. It is the basis for a companion report whose purpose is to interpret the data and to characterize the original geochemical and isotopic composition of the Popovich Formation and subsequent changes due to hydrothermal activity (Hofstra and others, 2011).

Location

Screamer is on the northwestern periphery of the Betze-Post gold deposit in the northern Carlin trend (fig. 1). It is located in Eureka County, Nevada, on the Rodeo Creek NW 7.5 minute quadrangle. Table 1 lists drill-hole coordinates and elevations.

Stratigraphy and Abbreviations

Figure 2 portrays the stratigraphy at the Barrick Goldstrike mine. Table 2 shows the formation, unit (informal member in fig. 2), and subunit picks for the sampled drill holes. Jurassic dikes (Ji) are divided into the following units: diorite (JDI), monzonite porphyry (JMP), lamprophyre (JLA), and biotitic lamprophyre (JBLA). Units of the Devonian Popovich Formation (DP) are abbreviated as follows: Wispy (WS), Planar (PL), Soft sediment deformation (SD), and upper Mud (UM). The Wispy unit is divided into a lower wispy subunit (WSS) and an upper wispy planar subunit (WSPL). The Planar (PL) and Soft sediment deformation (SD) units are not divided into smaller subunits, but are given the following subunit designations PLS and SDS, respectively. The upper Mud unit (UM) is divided into four subunits from bottom to top as follows: upper mud subunit (UMS), cherty lens subunit (CTL), pinstripe pyrite subunit (PIN), and the thin on thin subunit (TOT).

Methods

Drill Core, Gold, Sulfur, Carbonate, and Carbonaceous Material Analyses

Vertically oriented exploratory rock core holes were drilled, logged, photographed, and assayed for gold, sulfur, carbonate, and carbonaceous material by Barrick Gold Corporation in 1997. Five-foot core intervals were split, ground to -200 mesh (74 microns) pulps, and analyzed for gold by Barrick using in-house fire assay (FA), and atomic absorption (AA) methods. Barrick in-house LECO combustion methods were used to determine sulfur, carbonate (CO_3) and total carbonaceous matters (TCM). Pulp splits were analyzed for major, minor, and trace elements and sulfur, carbonate carbon and carbonate oxygen isotopes by the U.S. Geological Survey (USGS) between 1998 and 2007.

The fire assay gold method consists of heating an aliquot (10 to 50 grams) of the finely pulverized sample mixed with approximately three parts of a flux until the product is molten. Lead oxide in the flux is reduced to metallic lead by other constituents of the flux or the sample. The metallic lead amalgamates with the gold, silver, and small quantities of certain base metals present in the sample and falls to the bottom of the crucible to form a lead button. The bulk of the sample is converted by the flux into a glassy fluid that allows the particles of lead to fall through the molten mass. The lead button is cupelled to oxidize the lead, leaving behind a dore bead containing the precious metals.

The dore bead is transferred to a test tube, dissolved with aqua regia, diluted to a specific volume, and quantified by atomic absorption (AA) spectrophotometry. AA is a method that determines gold concentration by introducing the gold in aqua regia solution to a light beam of appropriate wavelength, causing gold atoms to absorb light. The reduction in the intensity of the light beam directly correlates with the concentration of the gold. The lower reporting level for atomic absorption was 0.001 ounce per ton gold (oz/ton Au). The upper reporting limit for AA was 0.2 oz/ton Au.

If gold is greater than 0.2 oz/ton, then a gravimetric method is used. The dore bead is instead treated with dilute nitric acid to quantitatively remove the silver. The residual mass of pure gold is then weighed and its concentration in the sample calculated. There is no upper quantitative limit to the gravimetric method.

Sulfur (S), carbonate (CO_3), and total carbonaceous matters (TCM) were determined by Barrick in-house LECO combustion methods. Carbonate was determined by weight percent loss during a hydrochloric acid digestion. Carbonaceous matters in the remaining portion of the sample were oxidized to carbon dioxide (CO_2) and sulfur was converted to sulfur dioxide (SO_2) in an induction furnace. Carbon dioxide (CO_2) and SO_2 were then measured by infrared (IR) detectors. The level of accuracy

and precision is approximately 1 percent. For additional information, see Brown and Curry (2002a and 2002b).

EDS - XRF Antimony and Barium Analyses

Antimony (Sb) and barium (Ba) were analyzed using a Kevex energy-dispersive X-ray spectrometer, interfaced to an analyzer at the USGS in Denver, Colorado. Primary excitation was supplied by an americium source. A gadolinium secondary target excited the K-alpha lines of antimony and barium. The fluoresced X-rays were detected using a Kevex energy-dispersive detector equipped with a beryllium window, and a Kevex pulse processor. Counting time was 100 seconds live time on loose powder splits of the pulped Screamer core. For a full discussion of the EDS - XRF technique see Ahmedali (1989). Lower reporting limits for both antimony and barium were 10 ppm. Upper reporting limits for both antimony and barium were somewhat greater than 50 percent. Estimated precision or reproducibility was 5 to 10 percent of the amount present (at 100 ppm) based repeated analyses of several USGS in-house standards (G.A. Desborough, written commun., 2006).

Mixed Acid 40 Element ICP - AES

Splits of the pulped Screamer core were analyzed for 40 major, minor, and trace elements by inductively coupled plasma - atomic emission spectrometry (ICP - AES) at XRAL, a contract laboratory for the USGS. Unused splits of the sample pulps are archived in Building 810 at the Denver Federal Center. Sample aliquots of 200 milligrams were decomposed using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids at 150° C. The digested samples were aspirated into the ICP - AES discharge where the elemental emission signal was measured simultaneously for the 40 elements. Calibration was performed using with a series of multielement solution standards.

Data were deemed acceptable if recovery for all 40 elements was ± 15 percent at five times the Lower Limit of Determination (LOD) and the calculated Relative Standard Deviation (RSD) of duplicate samples was no greater than 15 percent. For additional information, see Briggs (1996, 2002).

Tellurium Analyses

Tellurium was analyzed by XRAL laboratories (under USGS contract) using a separate split of the core pulps. Tellurium was determined by weighing 0.25 gram of sample into a Teflon tube, adding a mixture of nitric, hydrofluoric, and perchloric acids, and heating. After the solution cooled, hydrochloric and nitric acids were added, the solution heated again, and cooled. The samples were diluted and analyzed using hydride-generation atomic absorption spectrometry (HGAAS) with an automatic analyzer and automated data-collection system. The lower reporting limit for tellurium was 0.1 ppm.

Data for tellurium were deemed acceptable if recovery of that element was ± 20 percent at five times the LOD and the calculated percent RSD of duplicate samples was no greater than 20 percent. For additional information, see O'Leary (1996).

Sulfur Isotope Analyses

Sulfur isotope ratio analyses were carried out by a continuous flow method patterned after Giesemann and others (1994) using a Carlo Erba NC2500 elemental analyzer coupled to a Micromass Optima mass spectrometer at the USGS in Denver. Carbonate hydrochloric acid treatment: Samples containing greater than 25 percent carbonate (CO_3 by LECO analyses) were treated in 5-percent HCl to remove carbonates. Several milligrams of sample pulps were immersed in 5-percent HCl solution at

room temperature for 12 hours. The pulps were filtered and rinsed in DI water using a Millipore 0.45-micrometer vacuum filter and air-dried.

The sample pulps (acid treated and untreated) were weighed in amounts corresponding to 0.1 milligram sulfur (3.1 micromoles sulfur) based on LECO sulfur concentration measurements and were wrapped together with V₂O₅ in tin capsules. Then they were combusted in a furnace held at 1,080° C within a 5-milliliter pulse of oxygen in the elemental analyzer. All gases produced during combustion were carried on a stream of helium gas through an oxidation-reduction reactor filled with tungstic anhydride, copper oxide, and reduced copper as recommended by Carlo Erba. Sweeping all gases over heated copper oxide and reduced copper, any sulfur trioxide (SO₃) produced during combustion was converted to sulfur dioxide (SO₂) and the surplus of oxygen consumed. Water vapor was removed using a desiccant trap containing Mg(ClO₄). Finally, the gases were passed through a Poropak QS column to isolate the SO₂.

A portion of the GC column effluent was transferred through a fused silica capillary into the ion source of the mass spectrometer. Reference gas was supplied by injecting a pulse of reagent grade SO₂ into the carrier gas between the elemental analyzer and open split interface. The mass spectrometer measurements were made by isotope ratio monitoring methods. Ion currents of mass 64 and 66 were recorded over time the gas spent in the source, and the areas underneath these peaks were integrated. All results are reported in delta notation in per mil relative to Vienna Cañon Diablo Troilite (VCDT).

Sulfur isotope analyses were reproducible to within ± 0.3 per mil based on repeated analyses of standards NBS - 123 sphalerite and NBS - 127 barium sulfate.

Carbonate Carbon, and Oxygen Isotope Analyses

Carbonate carbon and oxygen stable isotope analyses were performed at the USGS in Denver. Several milligrams of powdered core from selected 5-foot intervals were digested in phosphoric acid following McCrea (1950). The resulting carbon dioxide gas was purified in a vacuum line using silver phosphate, at 25° C, to remove any hydrogen sulfide that may have evolved from trace sulfide minerals. The carbon dioxide samples were analyzed for their isotopic compositions by using a Finnigan MAT 252 mass spectrometer. The results are reported in delta notation in units of per mil relative to Vienna Pee Dee Belemnite (VPDB) for carbon and Vienna Standard Mean Ocean Water (VSMOW) for oxygen. The reported values include a correction for oxygen fractionation that was made using the dolomite fractionation factor recommended by Friedman and O'Neil (1977).

Carbonate isotope analyses were reproducible to within ± 0.1 per mil for carbon and within ± 0.4 for oxygen based on repeated analyses of standards NBS - 18 (carbonatite) and NBS - 19 (calcite).

Results

Geochemical Results

Fire assay - AA, LECO, XRF, HGAAS, and ICP - AES analytical results for each 5-foot interval of drill core are reported in table 3.

Sulfur, Carbon and Oxygen Isotope Results

The total sulfur and carbonate carbon and oxygen isotope compositions of each 5-foot interval of drill core are reported in table 3.

Interpretation of the geochemical and isotopic results is covered in a separate report by Hofstra and others (2010).

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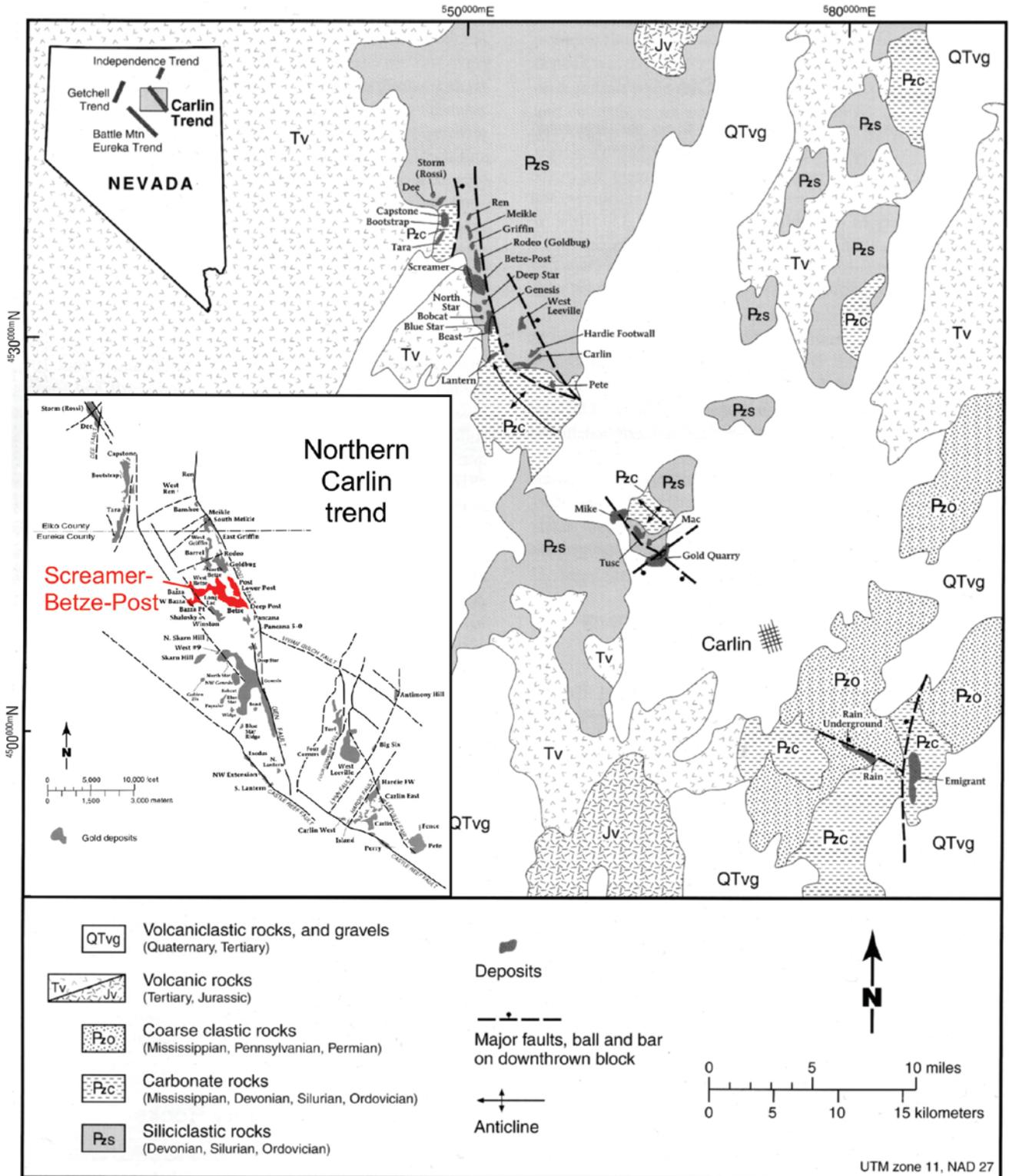


Figure 1. Location map with mines and general geologic units and structures, from Hofstra and others (2010).

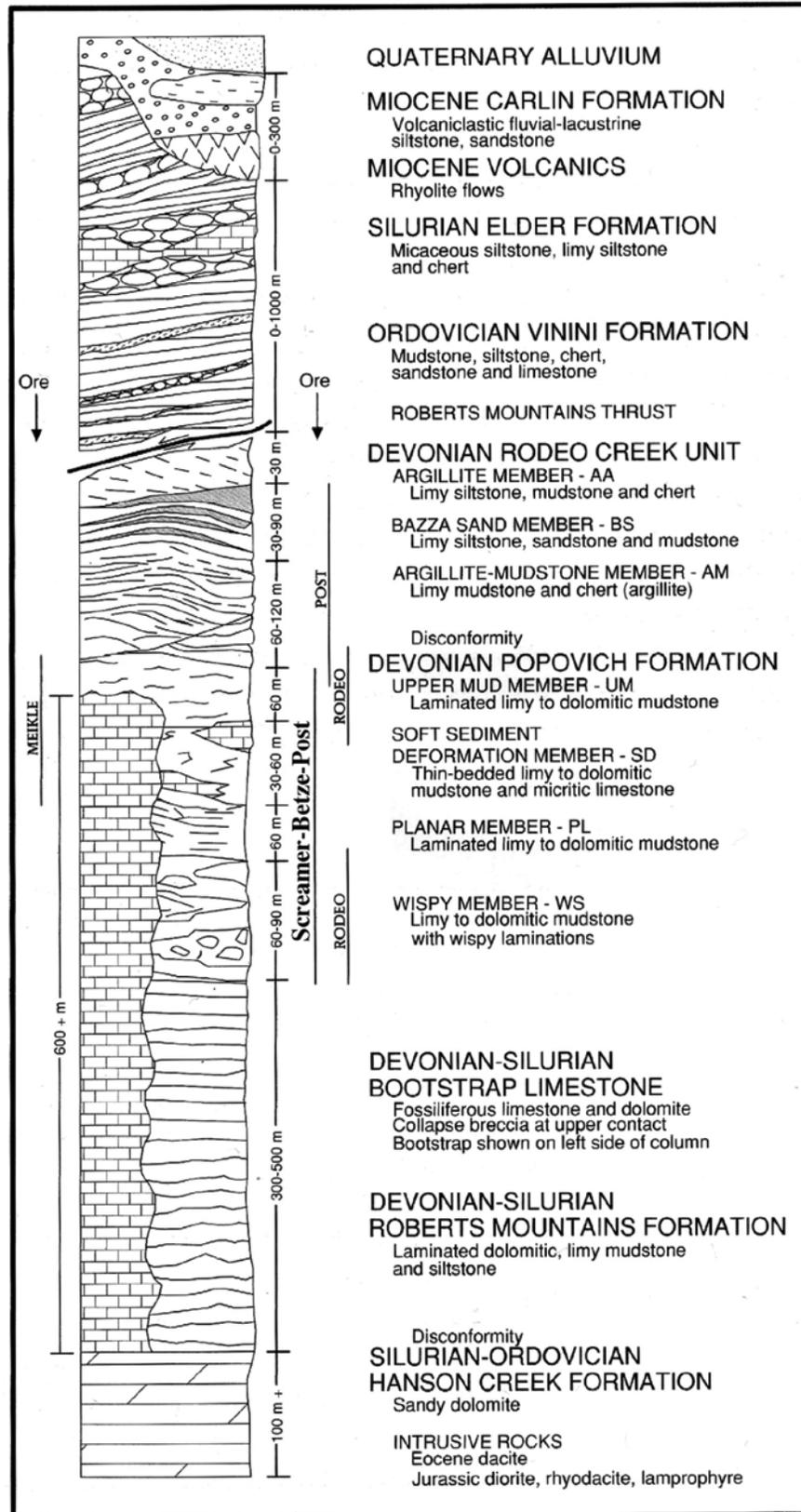


Figure 2. Stratigraphic column with unit descriptions for the Goldstrike property, from Bettles (2002).

Table 1. Drill-hole locations and collar elevations.

7.5' quad	Spheroid	Datum			
Rodeo Creek NW	Clarke 1866	NAD27			
Core hole number	Barrick grid northing (feet)	Barrick grid easting (feet)	Collar elevation (feet)	Latitude	Longitude
SJ-513C	13,478.60	7,433.20	5,467.20	40.9878	-116.3841
SJ-497C	12,679.20	5,822.90	5,360.60	40.9870	-116.3942
SJ-477C	12,910.30	6,105.40	5,359.30	40.9871	-116.3923
SJ-448C	12,139.90	7,115.10	5,490.70	40.9867	-116.3881
BZ-954C	11,406.40	6,528.10	5,460.10	40.9863	-116.3911

Table 2. Rock Formation, unit, and subunit identifications.

Drill hole	Depth interval in feet		Formation	unit	subunit
	From	To			
SJ-513C	0.0	20.0	TC	(Miocene Carlin Formation)	
SJ-513C	20.0	210.0	OV	(Ordovician Vinini Formation)	
SJ-513C	210.0	680.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-513C	680.0	700.0	DP	UM	TOT
SJ-513C	700.0	720.0	DP	UM	PIN
SJ-513C	720.0	760.0	DP	UM	CTL
SJ-513C	760.0	800.0	DP	UM	UMS
SJ-513C	800.0	895.0	DP	SD	SDS
SJ-513C	895.0	896.0	(Ji)	JDI	
SJ-513C	896.0	985.0	DP	SD	SDS
SJ-513C	985.0	1,063.0	DP	PL	PLS
SJ-513C	1,063.0	1,122.0	DP	WS	WSPL
SJ-513C	1,122.0	1,277.0	DP	WS	WSS
SJ-513C	1,277.0	1,327.3	SDRM	(D-S Roberts Mountain Fm.)	
SJ-477C	0.0	70.0	TC	(Miocene Carlin Formation)	
SJ-477C	70.0	80.0	OV	(Ordovician Vinini Formation)	
SJ-477C	80.0	490.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-477C	490.0	560.0	DP	UM	PIN
SJ-477C	560.0	595.0	DP	UM	CTL
SJ-477C	595.0	635.0	DP	UM	UMS
SJ-477C	635.0	754.6	DP	SD	SDS
SJ-477C	754.6	781.0	(Ji)	JBLA	
SJ-477C	781.0	839.5	DP	SD	SDS
SJ-477C	839.5	935.0	DP	PL	PLS
SJ-477C	935.0	988.0	DP	WS	WSPL
SJ-477C	988.0	1,068.0	DP	WS	WSS
SJ-477C	1,068.0	1,264.0	VDF	<i>Void/cavity</i>	

Formation and unit abbreviations are derived from rock units in Figure 2.

See text for Popovich Formation subunit and Jurassic dike abbreviations.

Table 2. Rock Formation, unit, and subunit identifications.—Continued

Drill Hole	Depth interval in feet		Formation	unit	subunit
	From	To			
SJ-497C	0.0	115.0	TC	(Miocene Carlin Formation)	
SJ-497C	115.0	310.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-497C	310.0	311.0	UDK	<i>Unidentified dike</i>	
SJ-497C	311.0	342.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-497C	342.0	351.0	(Ji)	JDI	
SJ-497C	351.0	405.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-497C	405.0	415.0	(Ji)	JLA	
SJ-497C	415.0	555.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-497C	555.0	590.0	DP	UM	PIN
SJ-497C	590.0	630.0	DP	UM	CTL
SJ-497C	630.0	680.0	DP	UM	UMS
SJ-497C	680.0	790.0	DP	SD	SDS
SJ-497C	790.0	795.0	NS	<i>No Sample</i>	
SJ-497C	795.0	816.0	DP	SD	SDS
SJ-497C	816.0	908.0	DP	PL	PLS
SJ-497C	908.0	910.0	(Ji)	JDI	
SJ-497C	910.0	942.0	DP	PL	PLS
SJ-497C	942.0	996.0	DP	WS	WSPL
SJ-497C	996.0	998.0	(Ji)	JMP	
SJ-497C	998.0	999.0	DP	WS	WSPL
SJ-497C	999.0	1,001.5	(Ji)	JMP	
SJ-497C	1,001.5	1,007.0	DP	WS	WSS
SJ-497C	1,007.0	1,012.2	(Ji)	JMP	
SJ-497C	1,012.2	1,193.0	DP	WS	WSS
SJ-497C	1,193.0	1,331.5	SDRM	(D-S Roberts Mountain Fm.)	
SJ-497C	1,331.5	1,332.2	(Ji)	JLA	
SJ-497C	1,332.2	1,372.3	SDRM	(D-S Roberts Mountain Fm.)	
BZ-954C	0.0	20.0	TC	(Miocene Carlin Formation)	
BZ-954C	20.0	364.0	DRC	(Devonian Rodeo Creek Unit)	
BZ-954C	364.0	366.0	(Ji)	JLA	
BZ-954C	366.0	490.0	DRC	(Devonian Rodeo Creek Unit)	
BZ-954C	490.0	505.0	TBFP?	<i>Tert. Dacite porphyry?</i>	
BZ-954C	505.0	515.0	(Ji)	JLA	
BZ-954C	515.0	565.0	DP	UM	UMS
BZ-954C	565.0	572.0	(Ji)	JLA?	
BZ-954C	572.0	730.0	DRC	(Devonian Rodeo Creek Unit)	
BZ-954C	730.0	840.0	DP	UM	UMS
BZ-954C	840.0	935.0	DP	SD	SDS
BZ-954C	935.0	1,014.0	DP	PL	PLS
BZ-954C	1,014.0	1,069.0	DP	WS	WSPL
BZ-954C	1,069.0	1,320.0	DP	WS	WSS
BZ-954C	1,320.0	1,388.0	SDRM	(D-S Roberts Mountain Fm.)	
BZ-954C	1,388.0	1,400.0	UDK	<i>Unidentified dike</i>	
BZ-954C	1,400.0	1,407.0	BXF	<i>Breccia SDRM & UDK</i>	
BZ-954C	1,407.0	1,486.0	SDRM	(D-S Roberts Mountain Fm.)	

Formation and unit abbreviations are derived from rock units in Figure 2.

See text for Popovich Formation subunit and Jurassic dike abbreviations.

Table 2. Rock Formation, unit, and subunit identifications —Continued

Drill Hole	Depth interval in feet		Formation	unit	subunit
	From	To			
SJ-448C	0.0	20.0	TC		
SJ-448C	20.0	60.0	OV	(Ordovician Vinini Formation)	
SJ-448C	60.0	75.0	UDK	<i>Unidentified dike</i>	
SJ-448C	75.0	140.0	OV	(Ordovician Vinini Formation)	
SJ-448C	140.0	205.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-448C	205.0	207.0	(Ji)	JDI	
SJ-448C	207.0	468.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-448C	468.0	485.0	(Ji)	JMP	
SJ-448C	485.0	535.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-448C	535.0	536.0	(Ji)	JMP	
SJ-448C	536.0	550.0	DRC	(Devonian Rodeo Creek Unit)	
SJ-448C	550.0	560.0	DP	UM	PIN
SJ-448C	560.0	620.0	DP	UM	CTL
SJ-448C	620.0	660.0	DP	UM	UMS
SJ-448C	660.0	899.0	DP	SD	SDS
SJ-448C	899.0	992.0	DP	PL	PLS
SJ-448C	992.0	1,029.0	DP	WS	WSPL
SJ-448C	1,029.0	1,042.4	DP	WS	WSS
SJ-448C	1,042.4	1,051.9	(Ji)	JLA	
SJ-448C	1,051.9	1,248.0	DP	WS	WSS
SJ-448C	1,248.0	1,290.0	SDRM	(D-S Roberts Mountain Fm.)	

Formation and unit abbreviations are derived from rock units in Figure 2.

See text for Popovich Formation subunit and Jurassic dike abbreviations.