Investigation of Mineralization Related to Detachment Faulting
Northeastern Sacramento Mountains, Ca

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Abstract

Copper and gold mineralization was first reported in the Sacramento Mountains of south-eastern California in the late 1800's (Desert Fever, 1980). It was suggested that oxides of copper and gold occurred in a 4000 foot long quartz vein. This research examines the northern portion of a metamorphic core complex in the Sacramento range for occurrences of base and precious metal mineralization. Host rock and intrusive dikes were examined both geochemically with X-ray fluorescence (XRF) and petrographically. The intrusive dikes were thought to occur along high angle faults associated with detachment faulting (Spencer, 1986), as displayed in the model of Figure 4 (See Detachment Fault Model) . Results of these analyses were used to compare the different lithologies and alteration, where present. The geochemical study quantified major elements through a whole rock analysis. The alternating gneissic units were notably similar in chemical composition with minor differences in the amount of quartz, feldspar and iron oxide, while the intrusive dikes ranged from basaltic to rhyolitic in composition. Copper mineralization was found in a barite dike as well as in tailings from previous exploration workings. The copper mineralization occurred both as an oxide, chrysocolla, and as a sulfide, chalcopyrite. Gold assays were minimal and silver only a minor constituent. Petrography revealed that most of the host rock had undergone some form of alteration. This alteration can be attributed to circulating meteoric water interacting with deep fluids. This research does not support a likely relationship of the Josie K vein to detachment, as had been previously proposed.

Introduction

The Sacramento Mountains have been explored for mineral resources for over a century, but

with little success. The range has also been the site for an array of studies focusing on the

Precambrian gneiss complex

and its exhumation. The

following research encompasses

the metamorphic core complex

outcropping in the northeastern

Sacramento Mountains. The

investigation was to find

evidence of mineralization

related to the detachment fault

in the area. There have been

Figure 1: Copper cost in USD/pound over the past thirty years.
Source: Global Financial Data

multiple papers published dealing with the detachment fault itself (Pease, Davis), but there are

few publications relating the detachment fault to mineralization.

Although base and precious metals have been sought after for centuries, there has been a

considerable increase in exploration for gold and copper in recent years as the prices have

steadily risen. Economic copper-bearing minerals are generally found as sulfides, but if the

grade is high enough to be considered ore, copper oxide minerals are also viable. The most

common copper ore is chalcopyrite ($CuFeS_2$). Figure 1 shows the copper price trend over the

past thirty years.

The objectives of this thesis are to:

1. Examine host rock lithology and alteration present.

2. Identify mineralization and attempt to relate it to the detachment fault model if possible.

Location and Accessibility

The Josie K property is situated in the northeastern Sacramento Mountains, San Bernardino County, CA about 140 kilometers south of Las Vegas, NV and 370 kilometers east of Cal Poly Pomona. The nearest city is Needles, CA, 6 kilometers to the east of the prospect site
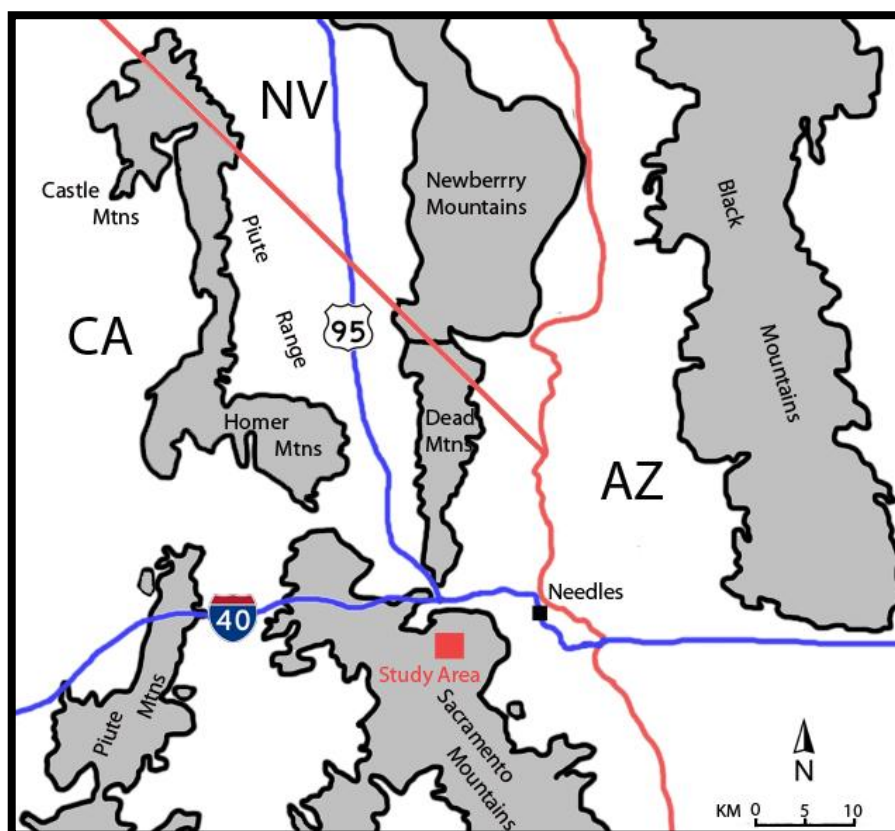

Figure 2: Index map showing location of project study area with nearby mountain range along the California/Arizona/Nevada borders.

(Figure 2). The Josie K lies along the east flank of the Sacramento Mountains. The Sacramento Mountains range stretches approximately 26 kilometers in a northwest/southeast direction and is about 16 kilometers in width. Access from Cal Poly Pomona is via Interstate 15 North to

Interstate 40 East to the West Park Road exit about three kilometers north of Needles, CA. From there one drives a short distance west on Park Road, thence east on Old National Trails Road, turning off (west) on series of unpaved gravel roads and dry washes to the prospect. The unpaved gravel road requires 4WD during periods of poor weather. This research was confined to gold and copper mineralization within the Josie K property area. The area lies within the Needles SW US Geologic Survey 7.5' topographic quadrangle and includes portions of Sections 29 and 30 of R.22E. T.9 N.

Climate and Physiography

The Mojave Desert is located south of the Basin and Range physiographic province. This area is comprised of northwest-trending mountains ranges bordered by basins filled with alluvial fan gravels. The Basin and Range and Mojave Desert provinces have similar pre-Cenozoic stratigraphic units and structural features, although they are less preserved in the Mojave
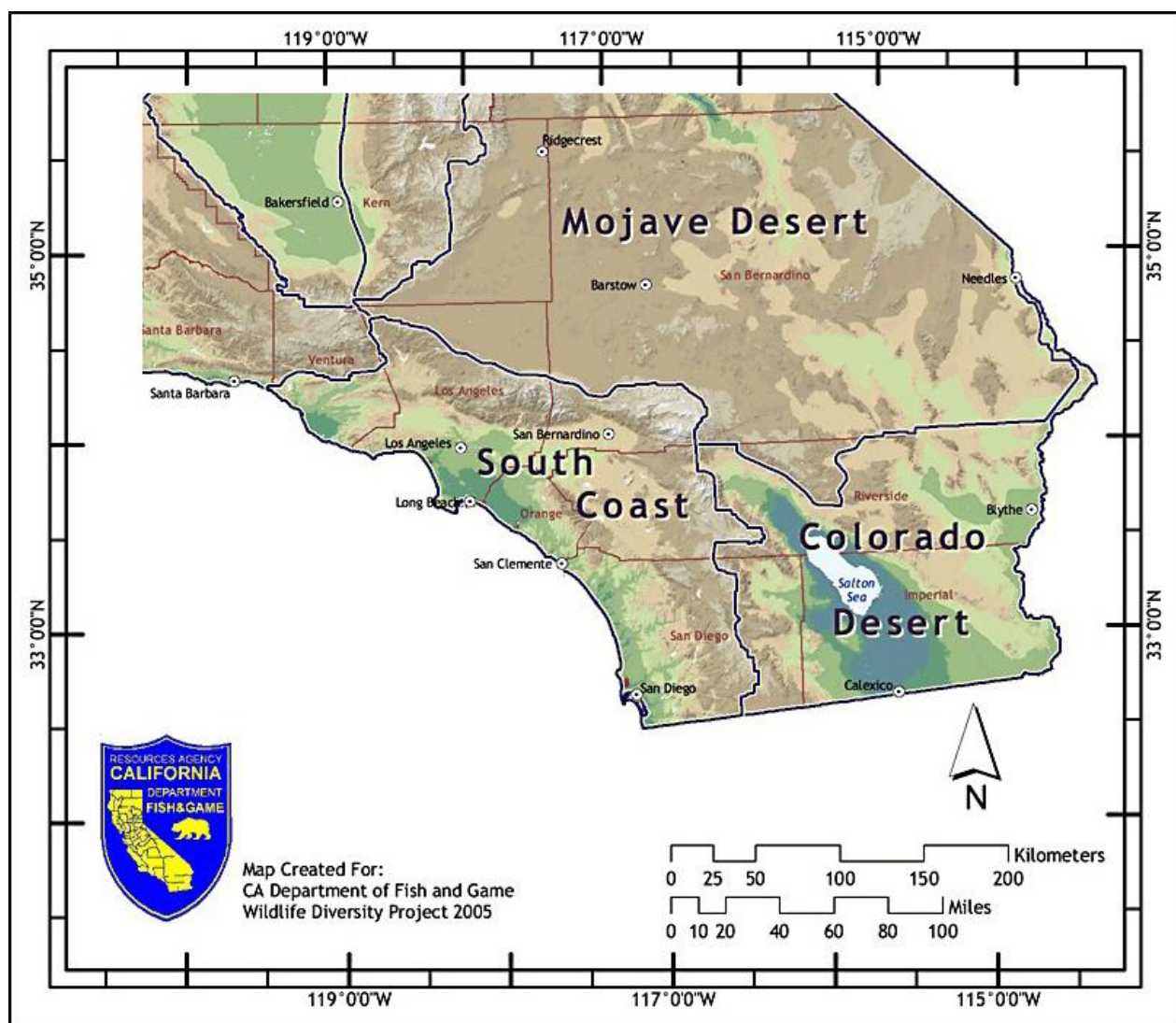

Figure 3: Physiographic map displaying the Mojave Desert relative to other southern California geographic provinces.

Source: CA Department of Fish and Game (edited)

Desert. The Mojave Desert province extends east and northward from the San Andreas Fault to the approximate longitude of Las Vegas, Nevada. The northern boundary is marked by the Garlock Fault. To the south the boundary with the Sonora Desert is less distinct, but is generally marked by a change in elevation from "High Desert" to "Low Desert". The Sacramento Mountains are located southwest of Needles, east of the Piute Mountains, and northwest of the Chemehuevi Mountains. The tallest peak in the range is Eagles Mountain at an elevation of 1100 meters above sea level. Drainage is to the southwest into the Chemehuevi Wash and Chemehuevi Valley which in turns drains southeasterly into the Colorado River. Alternatively, this region along the California-Arizona border is often termed the Colorado River Trough (CRT). In general, the CRT is characterized by mountain ranges comprised of Proterozoic core complexes of gneissic rock overlain by Tertiary volcanics with valleys consisting of recent gravel deposits associated with the Colorado River. The CRT has undergone significant deformation associated with Tertiary-Recent strike—slip (San Andreas style) faulting. Areas of fault stepover have created accommodation zones characterized by detachment faults high angle normal faults.

Average annual precipitation in the Mojave is approximately 3.65 inches (9.25cm) (Source: Western Regional Climate Center), but is highly variable due to the sporadic monsoonal weather during the summer months July through September. This region has very low humidity for the majority of the year. High temperatures in the summer exceed 120 °+F, and the record low is 20 °F (NOAA). Daytime high temperatures can be drastically different than nighttime lows. Vegetation consists of desert shrubs and bushes with limited ground cover.

Mining History

There is limited literature regarding exploration and mining within the Sacramento Mountains, and few reports give insight into the exploration of ranges even within close proximity. The Bannock Prospect of Echo Bay Exploration lies to the northwest of the Josie K property. In a guidebook for the Society of Economic Geologists (Saunders 1996), discusses extensive exploration using the detachment fault model in search for a concealed deposit. Rock chip sampling of the Bannock property defined multiple economic targets from gold, silver, and copper anomalies thought to be associated with detachment faulting. There were three target areas within the Bannock property; Big Boy Prospect, Black Calcite Prospect, and Big Hill Prospect. Although an extensive drilling program was launched, it yielded less than favorable results.

Other junior exploration companies reportedly staked and explored areas along the Sacramento Mountains detachment fault west and north of Needles in the late 1980s and early 1990s [D. Jessey, 2012, pers. comm.]. However, nothing was published on their efforts and there is no evidence of current activity.

The Josie K site was prospected and mined in 1908 by the Kane Copper Company (Desert Fever, 1980). The prospectors worked multiple quartz, calcite, and copper bearing veins in search of gold. Gold was claimed to be present near an 87 foot shaft, which drew considerable attention in 1908. Today the property is dotted with small prospect pits and shallow shafts. However, there is a noticeable absence of significant tailings or mine infrastructure leading to the conclusion actual production was small to even nonexistent.

Geology

There is a controversy in the scientific community as to whether the Sacramento Mountains

metamorphic core complex (SDF) mineralization is detachment fault related or simply located

around an unconformity. Multiple papers have been published defending either side of the

argument, but this specific paper does not address which model is more correct.

Detachment Fault Model

Detachment faulting is thought to have played an important role in the Tertiary evolution of the

Sacramento Mountains, so it is necessary to expand upon a simple reference to the process. As

first described by Greg Davis (circa, 1982) for the Whipple Mountains; a listric normal fault

forms in the upper crust, flattening as it extends laterally and creates a weak zone along the

brittle-ductile transition. The hanging wall is commonly referred to as the upper-plate rock,

while the footwall is referred to as the lower-plate rock. As uplift of the plastic zone begins, the head of the listric fault will begin to rotate and decrease its dip angle (Figure 4). As the uplift continues to occur, the listric fault creates a new, more favorable high-angle
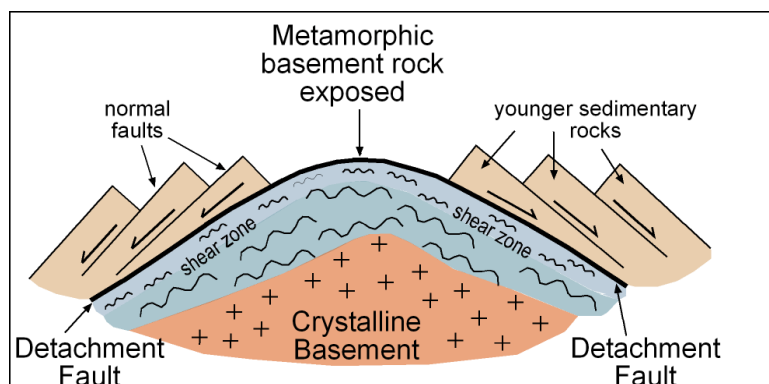

Figure 4: Detachment fault model displaying exhumed basement rock with nearby normal faults in overlying displaces layers.

Source: Idaho State University

fault. The deformation created in the upper-plate is a result of the brittle deformation by the

extension process. This process repeats itself, continuing to rotate the inactive and newly

created normal faults. The steepest fault will be the youngest and most active in the series. The result is a domino style chain of tilted blocks with a metamorphic core exposed after erosion has taken its toll on the landscape. Due to the rotation of the faults in the upper-plate, this model has effectively been called the "rolling hinge model" (Fossen, 2010). Mylonitization and brecciation are both common along the detachment fault plane and can range from centimeters to meters thick. The favored model for the Sacramento Mountain Detachment fault follows a three-plate model (Fedo, 1992); a lower plate basement of gneiss; a middle plate consisting of alternating tuff units, including the Peach Springs Tuff, with alternating sandstones and conglomerates; and an upper plate of immature sediments. The middle plate is reported to be between 200-300 m thick in some sections, and correlates rather well with widely recognized dating of the Peach Springs Tuff at 18.5 Ma (Fredo, 1992). Although these plates are found throughout the Sacramento Mountains along the detachment fault, only the basement lower plate and intruding dikes were present in the researched field area due to its location in the heart of the metamorphic core complex. It should be noted that although the Whipple Detachment fault has been well documented, other detachment faults are less definitive. This is particularly true for the SDF (Fig. 5). Simpson, et. al (1991) challenge the detachment fault interpretation and suggest the Proterozoic/Miocene contact is an erosional unconformity rather than a fault contact. This has important implications for exploration in the area. Much of the precious and base metal exploration and subsequent drilling have been driven by the
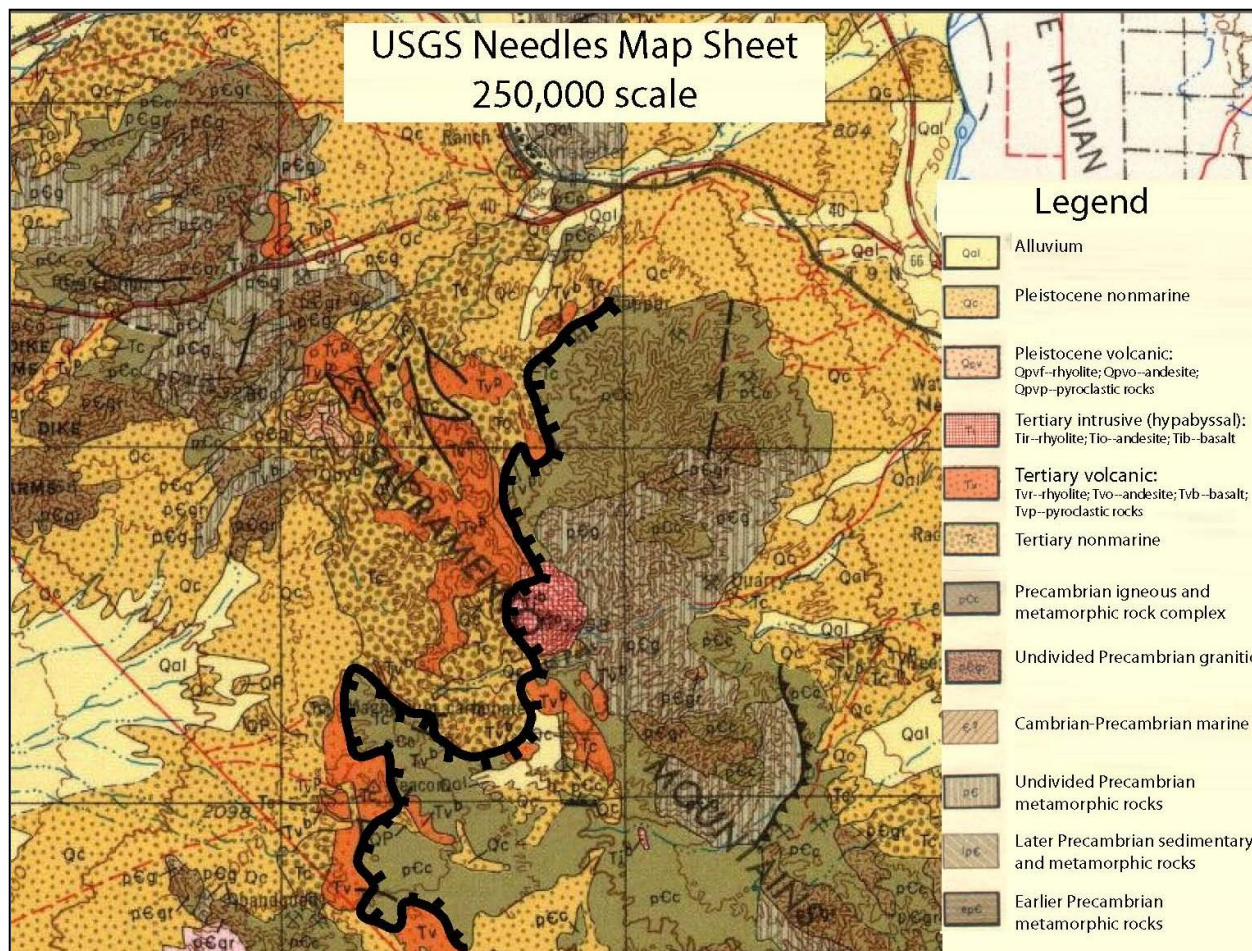
Figure 5: Edited geologic map of study area. Map showing R.19-21E T. 7-9N of USGS Needles Map Sheet 250,000 scale. Detachment fault is outlined on the western flank of the Sacramento Mountains.

detachment fault model. If this model is incorrect, it follows that exploration activities have

perhaps focused on the wrong targets. This must be considered when evaluating the Josie K

property. The southern Mojave was also subjected to Basin and Range extension during the

Cenozoic. The Sacramento Mountains lie within the extensional area known as the Colorado

River extensional corridor, which underwent as much as 50 km of extension (Fedo, 1992).

The northern Sacramento Mountains are comprised of quartzo-feldspathic gneiss basement

rocks intruded by mid-Tertiary dikes with subordinate Tertiary gravels and cataclastites

(Drobeck, 1986). The gneissic rocks comprise the lower plate of the Sacramento Detachment

Fault (SDF). They are commonly amphibolites-grade mylonitic gneiss featuring northeasterly

lineation (Lingrey, 1980). These rocks are overlain by Miocene volcanics that presumably form

the upper plate of the detachment. Lineations within the gneiss suggest transport of the

hanging wall rock (upper plate) in a N60°E direction. The gneissic unit has been referred to as

"Fenner Gneiss" in various publications. This is a loose term for 1.70 Ga gneisses that outcrop

throughout the eastern Mojave Desert. Although the bulk of the rocks in the lower plate of the

SDF are Proterozoic, multiple studies (Simpson 1991, Pease, 1999) have shown that rocks as

young as Cretaceous occur within the lower plate. The characteristic green coloration of the

gneissic units is attributed to alteration of micas, amphiboles and plagioclase to epidote and

chlorite (Simpson, 1991). The gneisses are overlain by mid-Tertiary volcanic and Colorado River

clastic sediments. The volcanics are known to be of rhyodacite composition dated at 14.3 MA

(Simpson, 1991, Pease, 1999). In contrast to the gneiss, volcanics and sedimentary rocks of the

upper plate have undergone oxidation of iron-bearing mineral phases to create a red to burnt

orange coloration. The overall result is a red-on-green color contrast that supposedly marks

the location of detachment faults throughout the region.

The volcanism in this area is typical of an extensional environment. The Mojave province in

general, is characterized by volcanics that range in composition from basalt to rhyolite (Winter,

2001). The latter dominate in the northern Sacramento Mountains. The feeder dikes have been

intruded along vertical fracture planes and high angle normal faults which are a consequence of

regional extension. The dikes are generally undeformed and strike almost north-south. They

rarely exceed one meter in thickness (Simpson, 1991). Because these dikes are undeformed,

this leads to the assumption that the volcanism was one of the last stages in structural

development in the area. Simpson (1991) speculates that this magmatism occurred when pull-

apart basins created during Tertiary extension allowed heat to escape from the asthenosphere

melting the overlying crust to create the silicic magmas. At times, melted asthenosphere was

able to rise along the faults generating the basaltic rocks of the area and more particularly to

the west in the Cima and Amboy volcanic fields.

Mineralization

Widespread oxide and sulfide mineralization has been reported in the Sacramento Mountains (Saunders, 1996, Spencer, 1986)(Fig. 6). The mineralization occurs adjacent to the detachment fault plane in the lower plate gneissic rocks, as well as along veinlets, and
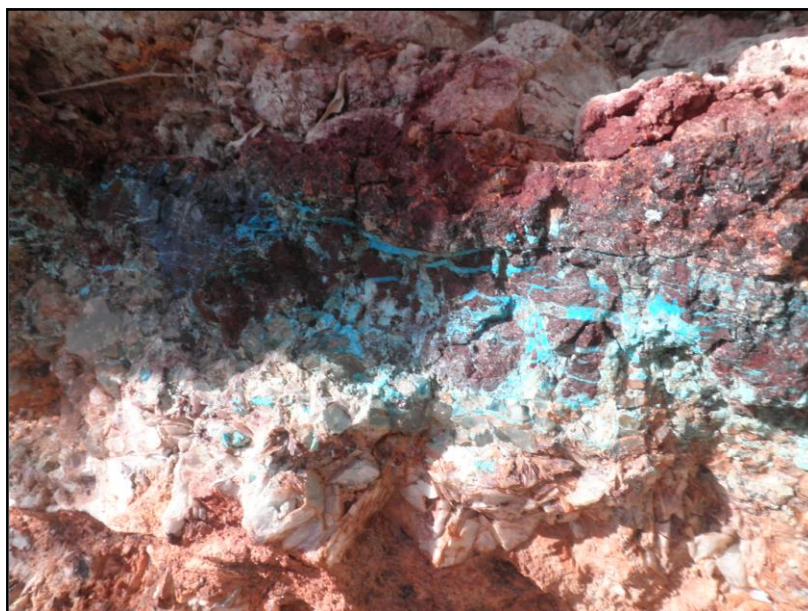

Figure 6: Chrysocolla mineralization in barite vein, Josie K property. Sample number JK 2.2

disseminations throughout the upper-plate. The sulfide mineralization is thought to predate the

oxide mineralization. This is evidenced by younger fracture surfaces coated by hematite

(Spencer, 1986). He suggested that sulfide mineral deposition occurred when reduced fluids

circulating in the lower plate cooled during uplift. Movement of these fluids into the upper-

plate rocks is said to be a source of the disseminated sulfides hosted by those rocks (Spencer, 1986).

Spencer felt that formation of typical copper oxides and carbonates such as chrysocolla and malachite by simple weathering and oxidation was not an adequate explanation for their occurrence in the Sacramento Mountains. He noted they occurred as fracture fillings rather than oxide crusts and proposed they were the product of mixing of meteoric water with the deep circulating fluids responsible for sulfide deposition along the high angle faults created during extension and detachment. The gangue minerals present are large amounts of quartz, with barite and calcite (Spencer, 1986). Abundant chlorite is also known to be present due to the mylonitization along the detachment fault.

Field Work

Visits to the site were conducted in mid-November 2011 and mid-February 2012. The host rock in the area is consists of alternating lenses of felsic and mafic gneiss. There are multiple dacitic and basaltic dikes (See Analytical Section) with a predominant northeast strike crosscutting the gneiss. There is evidence, in the area, to associate mineralization with these dikes. A chrysocolla vein was found near an adit with a N35°E strike dipping to the northwest at 65 degrees. The copper concentration was 2.8% in the vein (Table 1, sample JK2.2).

 The vein can be followed along the surface for approximately several hundred meters, but then disappears beneath mine talus and alluvium. Therefore, overall strike length is largely a matter of conjecture. The vein appears to occur along a fault, due to the presence of fine-grained fault gouge on either side of the mineralization. However, no offset is visible across the fault to determine sense of movement or total displacement. This vein is in close proximity to a basalt dike with the same bearing. Traversing further to the west, gneissic rocks are cut by

Table 1: Notable samples with copper concentration analysis determined from XRF SemiQ analysis								
Sample	Na2O	Al2O3	SiO2	K2O	Fe2O3	Ba	Cu	TiO2	Field Name
JK2.2	1.609	1.69	13.682	0.073	6.572	58.122	2.829	0	Chrysocolla
JK2.5	0.917	1.064	96.383	0.129	0.453	0	0.012	0	Quartz vein in prospect
JK2.9	2.497	3.021	68.562	0.187	15.319	0	1.332	0.221	Py, Cp, Chys, calcite in tailings
JK2.12	1.51	1.396	5.014	0.043	11.106	67.193	0.015	0	Barite with Fe oxide

unmineralized andesite and basaltic dikes. These dikes can be seen to be cut by younger faults.

There are multiple prospects located throughout the field area, most of which follow various vein types within the gneiss host rock. In a larger prospect area with extensive workings, the tailings contain abundant pyrite, with lesser chalcopyrite and chrysocolla (Fig. 7). A sample was taken from these tailings for copper and gold analysis. This specific prospect working is located along a quartz vein which can be followed for hundreds of meters along the surface. In this specific location, there is a notable amount of hydrothermal alteration. This alteration appears

younger than the unmineralized andesite dikes, as they appear to also have been altered.
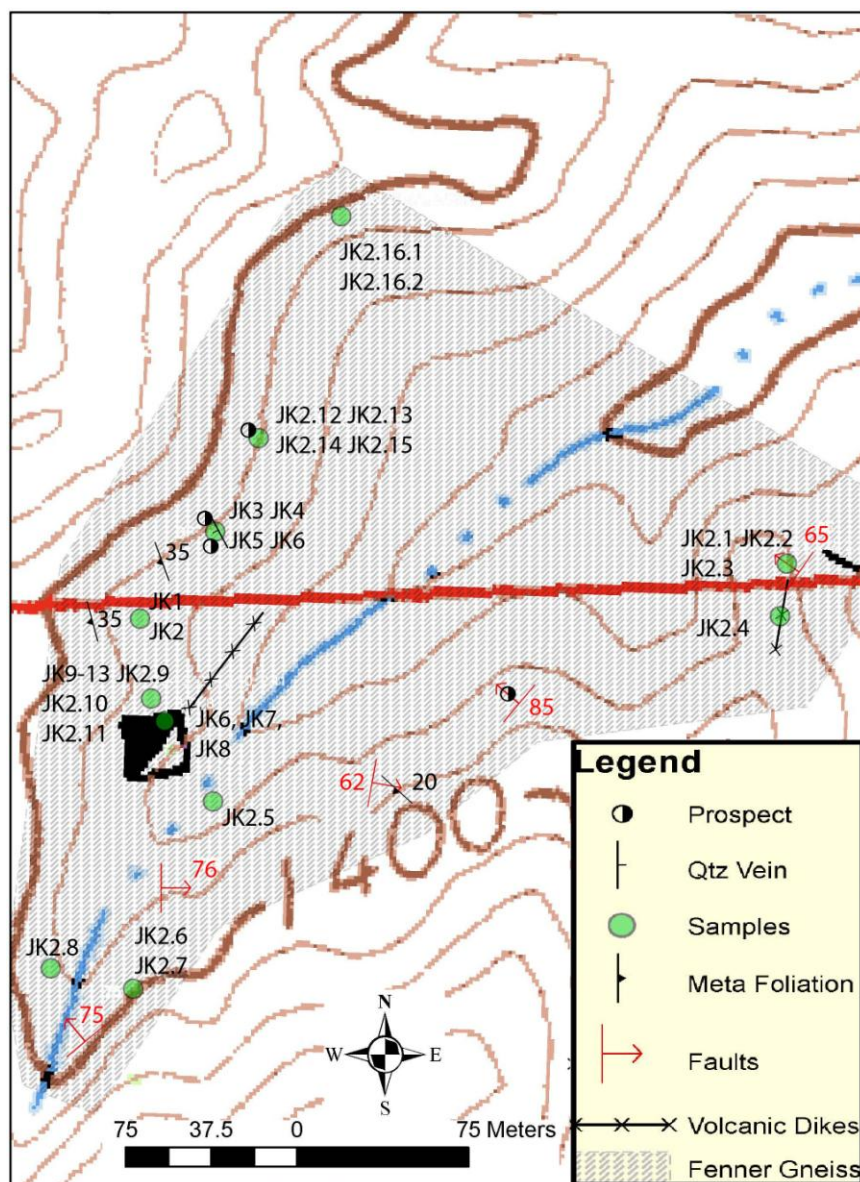

Figure 7: Field map of Josie K site. Map generated from 7.5' USGS Needles SW quadrangle.

Assay samples were also taken from a barite, iron-oxide rich vein. This vein was of interest due

to its high barite and iron-oxide content and the possibility of similarities to the barite-silver

mineralization in the Calico Mountains.

Research

Samples collected from the site were prepared in various ways for different techniques used in the research involved in the project. Thin sections were prepared by Quality Thin Sections out of Tucson, Arizona. They were later analyzed and photographed using a Nikon polarizing microscope outfitted with a digital camera.

X-ray fluorescence (XRF) analysis was performed on the California Polytechnic University Pomona campus in the Geological Sciences department with a Philips (PANanalytical) x-ray fluorescence spectrophotometer. The sample preparation involved a series of steps to achieve the "pellet" used in the XRF machine. The samples were first cut to size, using a diamond tipped saw blade, then crushed to fit into a Chipmunk jaw crusher. Once the samples had been crushed, they were placed into a ball mill for 30 minutes to create a power. After the 30 minutes had passed, the samples were sieved through a -90 micro sieve. Each sample powder was then mixed with cellulose binder and placed back into the ball mill for approximately 2 minutes for mixing. After a homogenous mixture is attained, it is pressed into a "pellet" using a press and die apparatus. An aluminum cup is placed into the steel holster and the sample mixture is poured and compacted. Once this process is completed, the result is a disc-like "pellet" which is labeled and placed into the XRF for analysis.

All samples investigated underwent whole rock analysis based upon USGS Standards. This program measures the major elements present in each samples (Si, Al, Ca, Mg, Fe, Mn, Na, K, P, and Ti). After the USGS Standards analysis was run, the next test was performed using a program called SemiQ. This analysis is semi-qualitative as it looks at all of the elements on the

periodic table and reports only the ones that are concentrated above a predefined amount in the sample. The detection limit varies by element and rarely is less than 100 ppm.

Once data had been collected for all the samples, the computer program Ig-Pet 2006 was used to plot geochemical analysis on diagrams. Although the software can plot a variety of diagrams dependent on what the user is looking for, we utilized the basic rock type diagrams to analyze the volcanic rocks in the area. There are, unfortunately as the name IgPet suggests, no diagrams available for metamorphic rock analysis with this software.

Geochemistry

The first field mapping of the area was done in the early 1900's. The complex was characterized as a Pre-Cambrian gneiss suite, but there was no discussion either of petrology or geochemistry. Due to the general absence of reports post 1900, there is little with which to compare the results of this project. To examine the basement gneiss suite and the dikes of the area, 26 samples were collected. Samples were examined with a binocular microscope to determine the mineral assemblages. In addition, rough estimates of mineral percentages were made. However, due to human bias, a more qualitative approach was also taken. Each sample was analyzed with XRF to determine the major elements percentages. Unfortunately, most of the outcropping rock in the area is basement gneiss suite, and there is no accepted diagrammatic approach to quantification of gneisses. As such, a simple spreadsheet analysis of major elements had to suffice in determining the difference between the alternating gneiss units of the area (Table 2).

Sample #	SiO$_2$	TiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	MgO	CaO	Na$_2$O	K$_2$O	Field Name/Comment
Table 2: Concentration of major elements (wt %) determined from XRF whole rock analysis									
JK1	74.979	0.1	13.709	1.274	0.488	2.498	6.324	0.598	Light Gneiss
JK2	67.329	0.44	16.601	3.173	1.898	3.617	4.687	2.015	Dark Gneiss
JK3	95.412	0.015	1.889	0.976	0.157	0.482	0.367	0.677	Quartz vein
JK4	81.725	0.06	9.575	1.354	0.334	1.411	4.491	1.016	Gneiss with quartz
JK5	67.587	0.829	16.222	6.926	2.529	1.073	1.143	3.556	Dark Gneiss
JK6	68.049	0.612	15.216	4.225	3.114	0.901	2.151	5.492	Dacite
JK7	68.889	0.68	15.226	3.755	2.623	3.92	3.937	0.92	Light Gneiss
JK8	70.594	0.497	13.68	5.69	1.236	1.109	1.611	5.432	Dacite
JK9	46.616	0.793	8.812	9.673	8.097	24.838	0.473	1.05	Altered Feldspar/Clay
JK11	50.927	1.427	17.847	20.885	3.485	1.222	2.523	0.612	Protolith before alteration (Gneiss)
JK12	52.021	1.508	20.499	18.456	2.263	1.396	0.786	1.87	Altered Feldspar/Clay next to mine shaft
JK13	50.581	1.451	19.919	17.982	4.87	2.032	1.001	1.088	Semi-altered brittle clay/host rock
JK2.1	74.689	0.092	14.387	2.374	0.289	0.188	4.848	3.1	Hanging wall of fault, clay alteration (near chrysocolla)
JK2.2	86.351	0.574	5.666	20.318	1.648	0.522	5.151	0.587	Chrysocolla
JK2.3	73.477	0.116	14.591	2.244	0.653	0.547	5.002	3.32	Footwall light gneiss
JK2.4	50.483	1.406	16.04	10.318	11.173	6.695	2.49	0.674	Basalt Dike
JK2.5	100	0	0	0	0	0	0	0	Quartz vein in prospect
JK2.6	51.95	1.07	16.917	9.131	8.303	8.821	3.068	0.393	Diorite
JK2.7	49.221	1.422	12.546	10.618	9.718	10.472	3.469	0.361	Biotite/Chlorite Gneiss
JK2.8	60.786	0.993	14.401	12.826	4.667	0.597	1.889	3.475	Dacite south of workings
JK2.9	75.303	0.047	0.928	22.773	0.815	0.136	0.315	0.195	Py, Cp, Chys, calcite in tailings
JK2.12	50.528	0.788	9.042	43.599	2.443	15.553	4.512	0.228	Calcite with Fe oxide
JK2.13	71.674	0.049	16.694	0.989	0.247	1.02	7.679	1.626	Light Gneiss
JK2.15	62.43	1.06	10.365	43.215	1.656	5.048	3.523	0.13	Black powder vein
JK2.16.1	65.68	0.006	18.225	0.895	0.007	0.069	1.399	13.714	Quartz vein with Moly (?)
JK2.16.2	46.675	1.824	10.276	10.01	9.96	14.033	2.005	2.145	Green host rock of quartz vein

The field area was largely covered by talus and alluvium from the above hillsides, but where

there were visible outcrops, the complex was composed of alternating "light" and "dark" gneiss

units. Table 2 outlines the similarities of these encountered units along with data of the

intrusive dikes. The light gneiss units generally contained much more quartz and less iron oxide

relative to the dark gneiss. The dikes in the area ranged from basaltic to rhyolitic (Figure 8).

Two locations of mineralization were found in the study: within a fault with barite and within

the tailings from previous mine activities. The fault hosting the mineralization was dominated

by oxide mineralization consisting largely of chrysocolla (Figure 6). The sample taken from this

brecciated vein assayed 58% barium oxide and 2.8% copper oxide (Table 1, JK2.2). The second

area of mineralization was found in the tailing of a quartz vein. The mineralization was largely
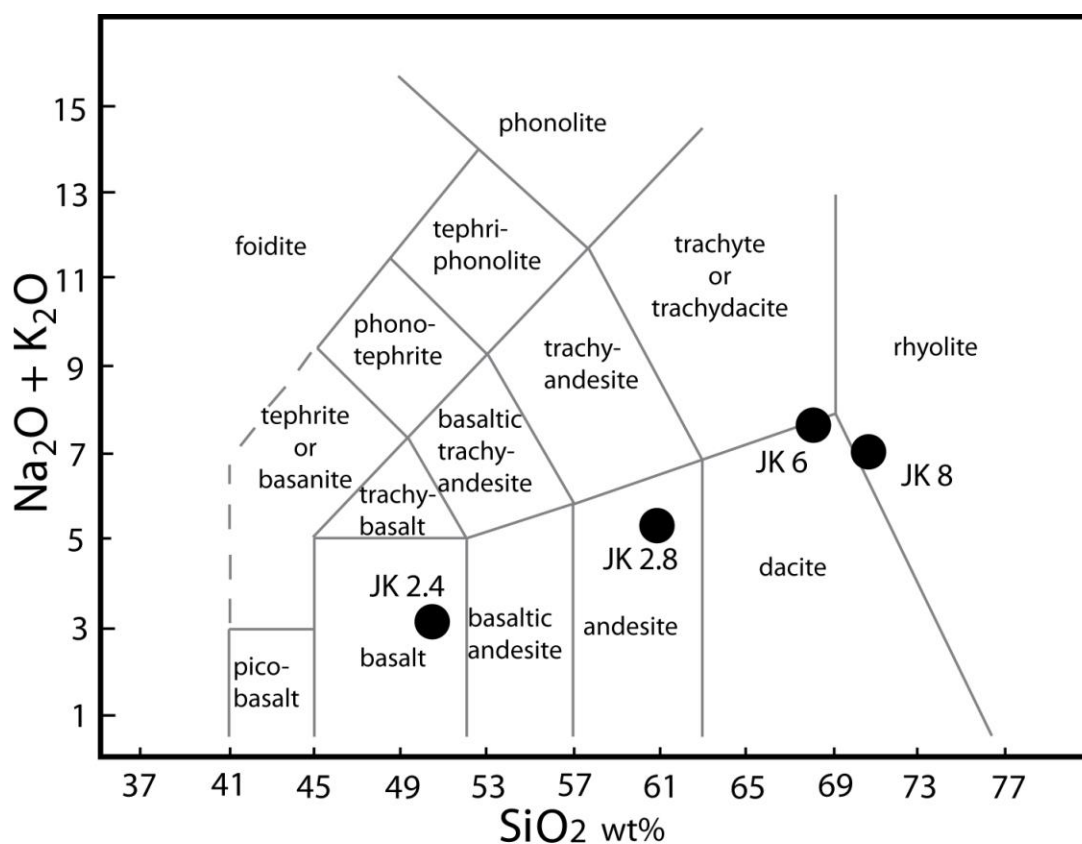

Figure 8: LeBas Volcanic diagram displaying composition of intrusive dikes in area.

disseminated sulfides, sample JK2.9. Chalcopyrite and chrysocolla were the dominant copper

bearing minerals present in JK2.9; the resulting copper assay was 1.3% (Table 1).

Once samples with higher copper concentrations were identified by XRF, they were sent off for

fire assay analysis for gold and silver to ALS Minerals of Reno, Nevada. ALS Minerals required a

100g sample of each rock per test. Two samples were identified as having a "high" copper

concentrations, JK2.2 and JK2.9. Along with these two samples, JK2.5 and JK2.12 were also sent

to ALS due to the significance in their location. On the Josie K property, there are various

prospect pits, ranging from two to four feet deep along a quartz vein. This vein is presumably

the source vein for the mine tailings sample JK2.9. From one of these prospect pits along the

quartz vein, sample JK2.5 was taken based on the assumption it might be gold bearing. In

another prospect pit further north, sample JK2.12 was taken. The justification for taking this

sample was due to a barite/iron oxide vein. The iron oxide appeared to be a resistate species

left behind as the other elements became mobile and leached out, possibly due to meteoric

fluid circulation. Therefore, other immobile elements such as gold might remain in the outcrop

material.

Fire assay data returned from ALS Minerals with the following data in Table 3. The chrysocolla/barite vein of JK2.2 held the highest concentrations of Au, while tailings sample JK2.9 help the highest concentration on Ag. Quartz vein sample JK2.5 had very disappointing results, returning values below

Table 3: Au and Ag Fire Assay Results from ALS Minerals		
Sample	Au ppm	Ag ppm
JK 2.2	0.69	6
JK 2.5	<0.05	5
JK 2.9	0.14	15
JK 2.12	<0.05	5

concentrations that would be considered economic and even below values that would warrant

additional follow-up.

Petrographic Analysis

Numerous hand samples were collected from the field site, and nine thin sections were

prepared for analysis by Quality Thin Sections in Tucson, Arizona and later examined in the

microscope lab at Cal Poly Pomona. Thin section analysis showed that the various gneiss units

in the area were generally comprised of the same mineral assemblage. Elongated quartz,

characterized by undulatory extinction, was present in every thin section viewed. This

undulatory extinction is characteristic of the amphibolites facies of metamorphism with
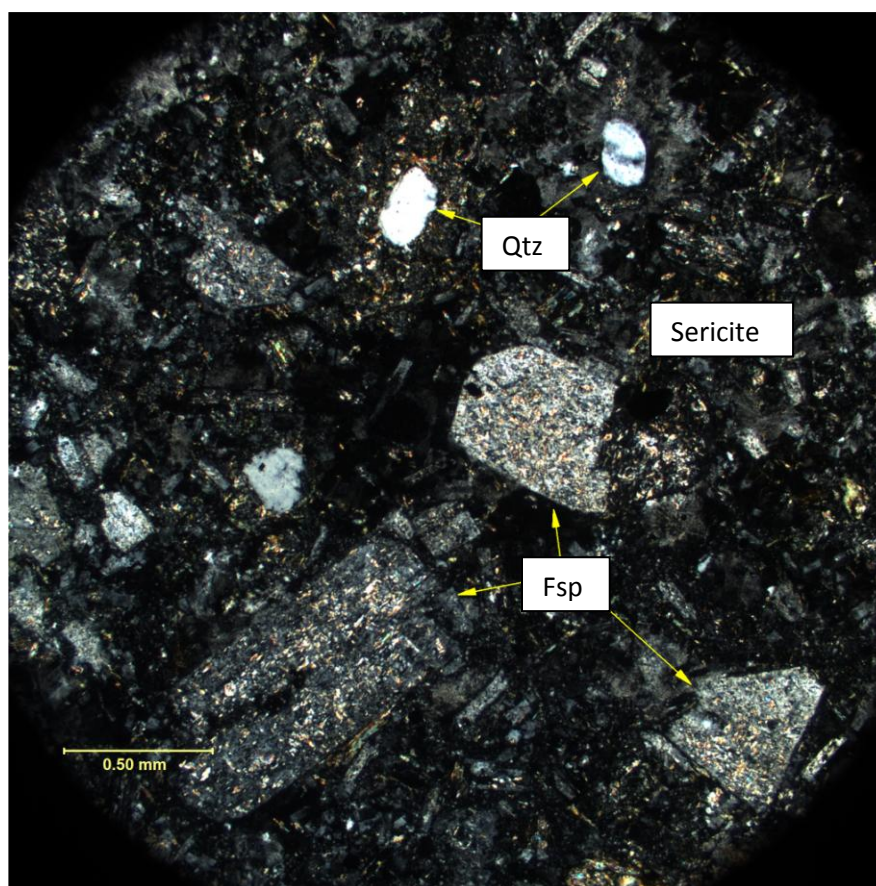
Figure 9: Thin section of sample JK6. Sericitic alteration in feldspar grains illustrates degree of alteration in the dacite dike. Rounded quartz grains are also

temperatures above 450°C (Pease, 1999). The quartz also displayed a mosaic texture, ranging in

grain sizes from 1-6 mm. Sericite (Fig. 9) is present as an alteration of plagioclase grains and is

strongly developed in those areas where we observed surface evidence of hydrothermal

alteration. This gives support to the argument there were secondary circulating meteoric or magmatic fluids. Although strongly altered it was possible to measure the An content of the plagioclase. An content was as high as 30 percent in some of the plagioclase grains from the gneisses suggesting the plagioclase is oligoclase to andesine. Albite twinning is the dominant form of twinning within the feldspar grains. There was also significant amounts of chlorite present in some of the samples, typically in association with the darker more mafic lenses of gneiss. It is also present in the lighter colored gneiss and can often be seen in hand sample with the naked eye. The chlorite was seen as a product of biotite degradation, and is typically elongated parallel to the foliation. Chlorite along with another mineral, epidote, give some of the gneissic layers a distinct greenish color.

Along with the gneiss unit, various dikes were also subjected to thin section analysis. The quartz present in the dacite dikes had very distinct characteristics. The quartz grains were often rounded rather than the typical subhedral shape. This is attributed to the quartz crystallizing out of solution at an abnormally early stage in the magma. While the quartz grains were crystallizing out, the magma was still in a mobile fluid phase, thus the grains were rolled and smoothed out during transport and movement of the magma. This process produced the rounded exterior of the quartz grains. The same effect can be found in stream beds with rounded cobbles. The quartz grains also display a glomero-porphyritic texture. This is characterized by groups of small subhedral grains within close proximity. These individual grains range from 1-2mm, but form roughly 10mm wide groups.

The dacite also contain a less identifiable groundmass. This is due to the crystal grains being much smaller relative to the quartz grains. Typically the groundmass comprised of .05-.5mm plagioclase grains. Phenocrysts of k-feldspar ranging from .2-.7mm in size were also present in some volcanic samples. These k-feldspar grains also host abundant sericite alteration. Basalt was (Fig. 8) comprised largely of a dark microcrystalline groundmass with occasional phenocrysts of altered plagioclase and perhaps some highly altered pyroxene.

Discussion

Preliminary mapping indicated that the research area consists predominantly of Proterozoic

gneissic basement rock of the metamorphic core complex, with none of the upper plate

volcanics exposed. This was also confirmed by XRF petrolographic analysis samples collected

within the research area. Furthermore, no contact separating upper plate volcanics from the

basement metamorphic core complex was identified during field mapping. However, a few

dikes of rhyolitic to andesitic composition and uncertain age were noted to cut the basement

rocks. In addition, one basaltic dike was also mapped. Mineralization was found as

disseminated sulfides in the gneissic basement rock and as fracture filling oxides within fault

zones. The oxide minerals are thought to be a product of circulating meteoric waters interacting

with magmatic waters (Spencer, 1986.

According to the prevailing model, the Josie K mineralization is related to Miocene detachment

faulting. Unfortunately, there is little evidence from this research to support that conclusion.

While the strike of the main mineralized vein is consistent with the strike one would expect for

a listric fault, the entire prospect area lies within lower plate rocks. Furthermore, the fault

hosting the vein cannot be traced into the upper plate of the detachment fault system. Also,

the style of mineralization (Cu-Ag) is more reminiscent of a typical epithermal regime than

detachment-related mineralization which rarely is characterized by appreciable copper.

If the mineralization is not related to detachment, then the major question becomes to what

tectonic event is it related? The Josie K vein/fault appears to be more "one of a kind" and not

related to the listric faults. It does not cut the upper plate and has a decidedly different strike

to mapped upper plate faults. Since it restricted to the lower plate one can only say with certainty that it is younger than the Proterozoic basement. The presence of relatively high copper values tends to suggest a relationship to Mesozoic porphyry systems, but there is an absence of porphyry stocks of compatible age nearby. The proximity of Miocene volcanics also needs to be considered. However, if the Josie K vein is not a product of the Miocene detachment thought to be related to emplacement of the volcanics, then it is difficult to envision a relationship. As Basin and Range extension generally overlaps and postdates detachment, perhaps the Josie K vein is a product of this extensional event.

Acknowledgements

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