Hydrothermal Zoning in the Copper-Molybdenum System beneath Red Cone Peak, Colorado

A Senior Thesis

Presented in Partial Fulfillment of the Requirements for

The Degree Bachelors of Science Degree

of The Ohio State University

By

Corey B. McCudden

*****

The Ohio State University

2006

Approved by

Douglas E. Pride

Advisor

Department of Geology

Abstract

Red Cone Peak is about 50 miles southwest of Denver, Colorado, and five miles south of the town of Montezuma. The Red Cone igneous complex centered approximately 0.5mi. south of the Continental Divide is within the Colorado Mineral Belt, a zone of igneous bodies and associated hydrothermal mineralization that crosses the mountainous part of Colorado from southwest to northeast. Mineralization within the Mineral Belt is associated with igneous activity that likely accompanied east-directed subduction of the Farallon Plate beneath North America as the Rocky Mountain Cordillera of western North America formed. This research addresses a fundamental question: was there an early copper-rich event in the Mineral Belt that has gone unrecognized, and which may be related genetically to the well known molybdenum event that to date has characterized large-scale mineralization in the Mineral Belt? The Red Cone complex intruded from 41 to 37 million years ago, which was 5 to 10 million years before the formation of the world-class molybdenum deposits at Climax (15mi. to the southwest southwest of Red Cone) and Henderson (12mi. to the northeast). The timing of the intrusion of at Red Cone Peak, and the characteristics of the hydrothermal mineralization likely put it in a category that is unique from the Climax and Henderson deposits.

Samples from a 2000 foot drill core at Webster Pass, a little over 0.5 miles northwest of Red Cone Peak have been used to characterize the lateral extent of the

hydrothermal mineralization, and the presence of vertical zoning within the margin of the Red Cone complex. Rocks in the vicinity have been pervasively mineralized with pyrite, and polished thin sections were made from samples collected at nine locations down the core. Copper and other trace elements (including molybdenum and gold) were analyzed for in the polished thin sections using scanning electron microscope (SEM) techniques. The analysis focused on individual pyrite grains with the thought that trace element variation, such as copper, might reveal subtle metal zoning in this part of the Red Cone System. Zoning with depth was not revealed in the WP-1 core. These data document variations in the trace element compositions of pyrite with depth in the igneous and hydrothermal systems.

The Red Cone complex displays characteristics of a large porphyry-type metal system. The Climax and Henderson deposits are two of the richest molybdenum deposits in the world, and they provide clues to understanding the emplacement and zoning of the rocks at Red Cone Peak, clues that will help to understand the porphyry mineralization and its place in the evolution of the Colorado Mineral Belt.

ACKNOWLEDGEMENTS

I would like to first thank my advisor, Dr. Douglas Pride, for all of his support, guidance, and patience through this study and for letting me have to opportunity to do this research in the most beautiful state in the country.

To the faculty at the Dept. of Geological sciences for their support, teaching, and knowledge. Also to friends, both grad and undergrad, that I have met through the years and mean so much to me, you guys have been great buddies.

Thanks my parents, David and June, for all of their support during the past 5 years. They made it possible for me to be at this point in my life. And to my brother who has made so many Spring Breaks in Colorado, the best skiing experiences of my life.

Finally I would like to thank Signe McLaughlin for all of her love and support and for giving me the drive and desire during all those hard times over the past 3 years. There is no way I could have done this without you.

TABLE OF CONTENTS

CHATER 1

INTRODUCTION

CHAPTER 2

METHODS AND OBSERVATIONS

CHAPTER 3

DISCUSSION AND CONCLUSIONS

LIST OF FIGURES

CHAPTER 1

Introduction

1.1 GEOLOGY OF THE MONTEZUMA QUADRANGLE

Webster Pass lies in the southeast quarter of the Montezuma 15 minute quadrangle, which was mapped by Lovering (1935). The area was revisited by Lovering and Goddard (1950) as part of an extensive mapping project of Front Range geology and its ore deposits. These two publications provide a detailed explanation of the geologic background of the Webster Pass vicinity and the surrounding Front Range region.

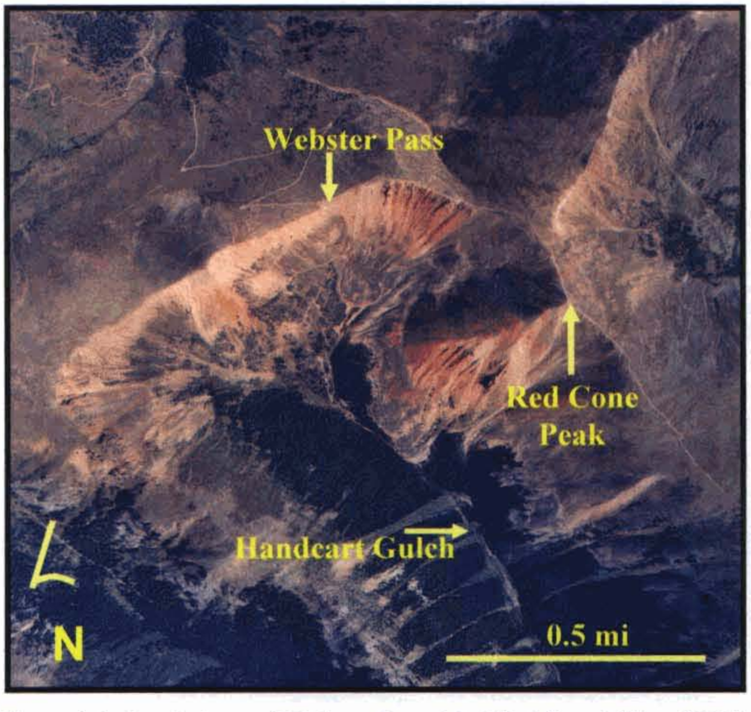


Figure 1.1. Areal photo of Webster Pass, Modified from Millan (2004)

Within the quadrangle Precambrian intrusives, gneisses, and schists cover a majority of the area. Paleozoic rocks are have not been identified within the quadrangle, and Mesozoic sedimentary and metamorphic rocks generally are limited to the southwest portion of the quadrangle and are not mapped in the vicinity of Webster Pass. Abundant Tertiary intrusives within the quadrangle have been suggested to be the source of nearly all of the important mineralization within the Front Range portion of the Colorado Mineral Belt. In the Montezuma quadrangle, Tertiary intrusive rocks cross the southwest to the northeast.

1.1.1 PRECAMBRIAN META-SEDIMENTARY ROCKS

The Precambrian meta-sedimentary rocks of the Montezuma Quadrangle and most of the Front Range are comprised of one dominant unit, the Idaho Springs Formation, named for outcrops near Idaho Springs just east of the Montezuma quadrangle. The word formation is defined by Lovering (1935) as:

> "...a laterally extensive assemblage of foliated rocks of complex but fairly distinctive lithology and fabric formed by the high-grade regional metamorphism of a thick sequence of clastic, relatively non-calcareous sedimentary rocks..."

rather than the tradition definition of the term.

The formation consists of a mixture of schists and highly complex gneisses and comprises most of the eastern third of the Montezuma Quadrangle. The schists compositions vary and range from quartz, quartz-biotite, and quartz-biotite-garnet, to quartz-biotite-sillimanite schists. Gneisses of the region range from quartz, quartz-biotite, and quartz-magnetite, to forms of granite gneisses. Both schist and gneiss bodies are intruded by aplites, pegmatites, and granites of Precambrian ages.

In the area of Webster Pass and Red Cone Peak, Idaho Springs rocks vary from quartz-sericite schist to a schistose quartzite and trend northward for several miles. Minor lime silicate lenses also are present in the Idaho Springs Formation. Lovering and

Goddard (1950) estimated that the thickness of the Idaho Springs Formation was about 15,000 feet.

1.1.2 PRECAMBRIAN META-IGNEOUS AND IGNEOUS ROCKS

Meta-igneous rocks within the Montezuma Quadrangle are dominated by the Swandyke hornblende gneiss, named after the abandoned town of Swandyke four miles west-southwest of Webster Pass. These rocks consist of hornblende gneisses and minor schists with interlayered quartz schists. The gneiss contains alternating bands of feldspar and hornblende while schist layers within the gneiss occur in lenticular masses ranging from five to 100 feet think with quartz and feldspathic quartz-biotite schist plus hornblende varieties (Lovering, 1935). Lovering suggested that the Swandyke gneiss and schist rocks are of metamorphosed intermediate igneous rock ranging in composition from gabbro to diorite. Later work done by Lovering and Goddard (1950) suggested that the Swandyke gneiss is dominantly quartz diorite in origin.

Gneiss and schist of the Swandyke lay conformably above the Idaho Springs Formation. It formed extrusively over the Idaho Springs Formation in flowing bands. The Swandyke also is affected by the Precambrian aplite, pegmatite, and granite that intrudes the Idaho Springs and comprises of nearly 50 percent of Swandyke outcrops (Lovering, 1935).

Precambrian intrusive bodies within the Montezuma Quadrangle generally are limited to two major types, Pikes Peak Granite and Silver Plume Granite. Minor bodies of quartz-diorite, basalt, quartz monzonite gneiss, and granite gneiss are scattered throughout the region but are quite sparse.

The Pikes Peak Granite forms a large batholithic body, approximately 10-30 miles wide that forms smooth contacts with surrounding gneisses. The margins rarely contain dikes or sills but do contain pegmatite "limbs" that extend outward and assimilate with schists. The granite is composed of microcline, orthoclase, quartz, and minor biotite and it typically is coarse grained. A small body of the Pikes Peak Granite is present in the extreme southeast portion of the Montezuma Quadrangle.

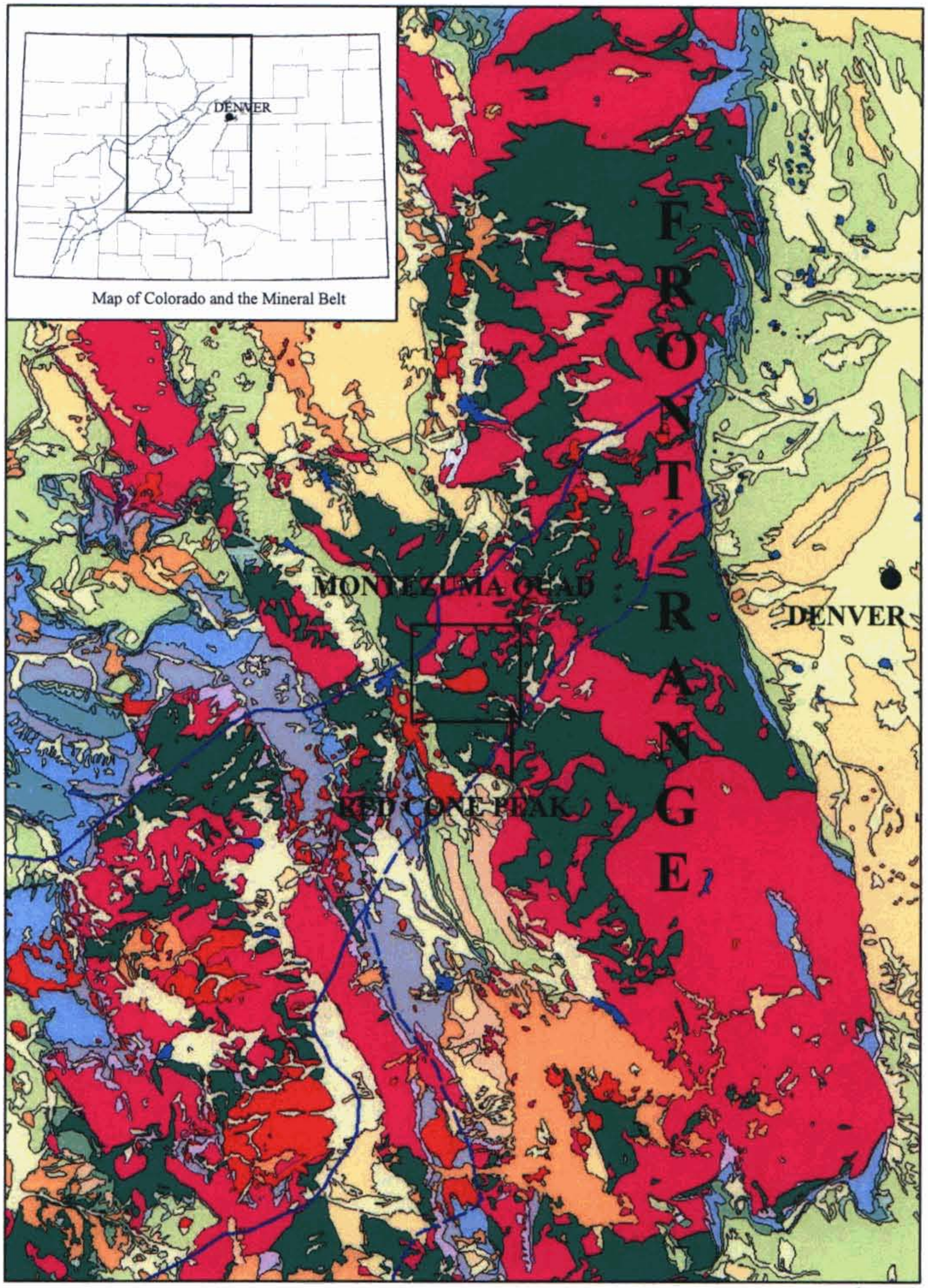
The Silver Plume Granite is older and much more common within the Montezuma Quadrangle than the Pikes Peak. Unlike the Pikes Peak Granite, the Silver Plume exhibits sharp contacts with the country rock it intrudes and according to Lovering and Goddard (1950) intruded as small batholithic bodies from a larger source through existing faults planes and fracture zones. All of these small batholiths have similar ages and compositions which link them together to the same common parental body. Lovering and Goddard (1950) described it as a pinkish gray, slightly porhyritic biotite granite with abundant pink feldspars and smokey quartz. Feldspars uniquely display flow orientation whereas mica crystals rarely align. In the Montezuma Quadrangle, the Silver Plume Granite generally limited to the northern half of the map area with sparse occurrences in the southern region.

1.1.3 TERTIARY IGNEOUS ROCKS IN THE MONTEZUMA REGION

Lovering (1935) determined that there were a total of 13 major porphyry intrusive events during Tertiary time across the entire Front Range, six of which directly affected rocks in the Montezuma Quadrangle. The following descriptions of Tertiary igneous rocks are from Lovering's (1935) publication.

Early Tertiary igneous activity in the Montezuma Quadrangle is marked by the occurrence of augite diorite and diorite. These rocks vary in texture but generally occur as dikes or small irregular masses. Plagioclase and augite are abundant with varying amounts of hornblende and biotite. Olivine is not uncommon in more ferromagnesian versions of these rocks while diotite is almost granodioritic in composition. These rocks occur mainly in the southwest region of the quadrangle.

The Montezuma Stock occurs just north of the town of Montezuma and is a quartz monzonite. The body is said by Lovering (1935) to correlate with the Lincoln porphyry of the Leadville district, and volumetrically it is the largest Tertiary intrusional igneous body in the region. Although these rocks occur mainly as large stocks, they can be found in dikes as well. Similar sodic quartz monzonite occurs sparsely within the Montezuma Quadrangle in short dikes that differ from the Montezuma stock in being much less silicic and more sodic in composition.



(cont.)

Figure 1.2. Geologic map of central Colorado and the Colorado Mineral Belt. Explanation on p. 8. Wilson & Sims (2002) and modified from Millan (2005).

Figure 1.2. (cont.) Map explanation. Modified from Wilson and Sims (2002).

Cenozoic	⬜	Quaternary, unconsolidated
	🟪	Quaternary, basalt
	🟨	Tertiary, unconsolidated
	🟥	Cretaceous-Tertiary, plutonic rocks
	🟧	Tertiary, volcanic rocks
	🟧	Tertiary, volcano-clastic rocks
	🟨	Tertiary, sedimentary rocks
Mesozoic	🟩	Cretaceous, sedimentary rocks
	🟩	Cretaceous-Jurassic, sedimentary rocks
	🟩	Jurassic, sedimentary rocks
	🟩	Jurassic-Triassic, sedimentary rocks
	🟦	Triassic, sedimentary rocks
	🟦	Triassic-Permian, sedimentary rocks
	🟦	Triassic-Pennsylvanian, sedimentary rocks
Paleozoic	🟦	Permian, sedimentary rocks
	⬜	Mesozoic, sedimentary rocks, undifferentiated
	🟦	Permian-Pennsylvanian, sedimentary rocks
	🟪	Pennsylvanian, sedimentary rocks
	🟪	Mississippian-Cambrian, sedimentary rocks
	🟫	Cambrian, sedimentary rocks
	🟩	Cambrian, intrusive rocks
Precambrian	🟫	Precambrian, sedimentary rocks
	🟥	Precambrian, igneous rocks
	🟩	Precambrian, meta-sedimentary and meta-igneous
	⬛	Archean, metamorphic rocks

Colorado Mineral Belt

— approx. inner boundary

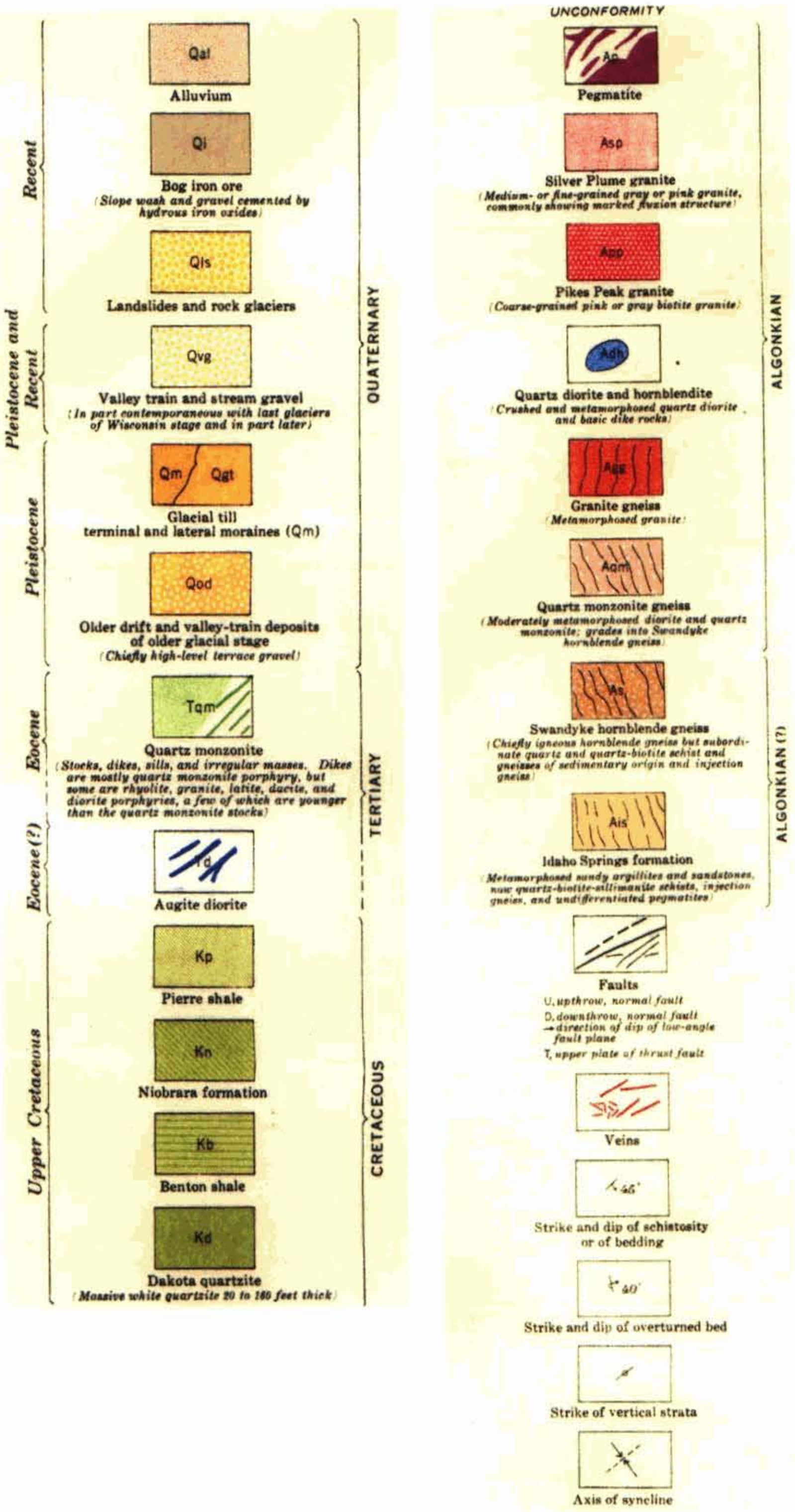
- - approx. outer boundary

1.2 GEOLOGY OF THE WEBSTER PASS/RED CONE PEAK VICINITY

Rocks in and around Webster Pass range from Precambrian meta-sedimentary rocks, meta-igneous rocks, and igneous intrusives to Tertiary intrusives. Also unique quaternary deposits can be found in the gullies on either side of Webster Pass (Fig. 1.3).

Figure 1.3. Geologic map of the Webster Pass – Red Cone Peak area.
Explanation is on p. 9. Modified from Lovering (1935).

Figure 1.3. (cont.) Map explanation. Modified from Lovering (1935).



Precambrian meta-sedimentary rocks within the study area are primarily Idaho Springs Formation and Swandyke gneiss and schist. The contact between the two rock groups trends northwest and is irregular. Idaho Springs Formation largely occurs on the eastern side and outcrops atop Webster Pass while Swandyke rocks outcrop to the west.

Precambrian meta-igneous and igneous rocks include the Pikes Peak granite, Silver Plume granite, and scattered pegmatites. The Pikes Peak granite occurs in the far southeastern portion of the area and quadrangle near the mouth of Bruno Gulch. The Silver Plume granite outcrops to the north-northeast of Webster Pass further along the continental divide and has not effected rocks in the Webster Pass vicinity.

Tertiary intrusive rocks are present 0.5 miles south along the Continental Divide from Webster Pass as well as within Handcraft Gulch and in outcrops on the south side of Red Cone Peak. These rocks have been linked to the Montezuma Stock and its Lincoln type porphyries in the area. Age dating by Crook (2004) indicates that these porphyrys were emplaced between 37and 39ma. K-feldspar and hornblende dates from the same area yield ages up to 42ma. and 54ma., respectively.

Quaternary deposits within the area consist of typical glacial, colluvial, and alluvial sediments plus very interesting occurrences of ferricrete on both sides of Webster Pass. According to Lovering (1935) and Perse (2000) these deposits are mostly ferric iron but also contain several trace metals, e.g. gold, silver, copper, molybdenum, lead, and zinc (Perse, 2000). Recent work (Robinson, personal communication) suggests that alone, a minimum of 5 million tons of pyrite would have to be completely oxidized to create the ferricrete deposits found in Handcraft Gulch

1.3 STRUCTURES

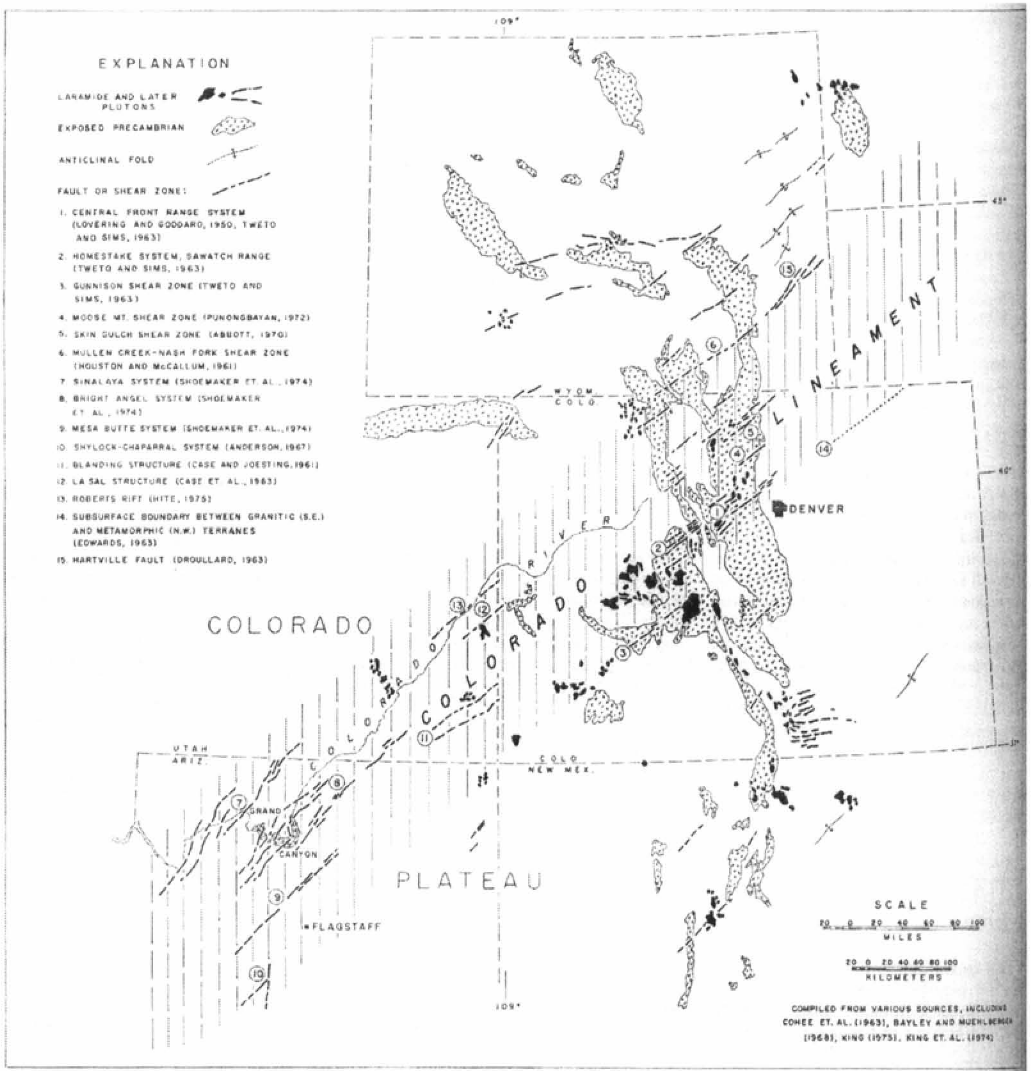
A variety of structures are found within the Montezuma Quadrangle and the Front Range with ages that range from Precambrian to Early Cenozoic. These structures help the high peaks develop, and also the placement of the rich ore deposits the Colorado Mineral Belt.

The Front Range is a long stretch of high peaks that stretches from Canyon City, Colorado northward into Wyoming. It resembles a broad antiform of mostly Precambrian metamorphic rocks. A majority of the major structure in the region was developed during the Precambrian, but was later reactivated during the Laramide orogeny at the end of the Mesozoic and into the Cenozoic. Many workers believe that these structures created the pathways for intrusive activity and ore fluids to make their way toward the surface.

1.3.1 PRECAMBRIAN STRUCTURE

During the Precambrian, a broad northeast trending belt of shearing was developed from Arizona, across the Colorado Plateau and through the central Front Range to the northern Great Plains. This shear zone was referred to by Warner (1980) as the Colorado Lineament and he described the system as a wrench fault system characteristic of a continental plate margin, similar to the present San Andreas Fault system along the western margin of North America.

Tweto and Sims (1963) described the shear zone as a series of northeast-trending faults along with north-northeast, north and northwest trending shear zones with echelon characteristics. Within the zone itself, cataclasis, granulation, mylonites, mylonite gneiss, and pseudotachylyte display various conditions of shearing that give time, temperature and pressure information. Zones up to 0.6 miles wide can be traced for several miles, and are separated by zones of unsheared rock (Warner, 1980). Both Warner, and Tweto and Sims suggest that the shearing occurred at high temperatures and pressures deep below the surface.



COMPILED FROM VARIOUS SOURCES, INCLUDING COHEE ET. AL. (1963), BAYLEY AND MUEHLBERGER (1968), KING (1975), KING ET. AL. (1974)

Figure 1.4. Position of the Colorado Lineament in Colorado and surrounding states. From Warner (1980)

1.3.2 LARAMIDE STRUCTURES

In the time between the Precambrianand the beginning of the Laramide orogeny, these shear zones experienced little to no major activity. However, when the Laramide orogeny commenced about 72 ma., many of these zones were reactivated and other new fault systems were developed.

The Laramide orogeny lasted from ~72-35ma and worked with preexisting structures to account for compressional stresses. An initial stage of the orogeny created the broad doming of Precambrianrocks and then was followed by northwest trending folding and faulting (Lovering and Goddard, 1950). One of the largest thrusts, the Williams Range thrust, developed at this time and cuts across the southwest portion of the Montezuma quadrangle.

As the mountain building process continued northeast and east-northeast trending transverse faulting developed, creating fracture zones in which early lead-silver ores were deposited. This marks the early stages of the depositing of the Colorado mineral belt. Further development of these structures across the state gave way to the deposition of nearly all the mineral resources in the belt today.

1.4 THE COLORADO MINERAL BELT

The Colorado Mineral Belt is a zone of mineralization that trend southwest to northeast from the La Plata Mountains in the south to just north of Boulder, Colorado. It is about 250 miles long and varies from 10-35 miles wide. A majority of the mineralization is a result of the invasion of igneous bodies throughout the Laramide orogeny with some younger events during Pliocene time.

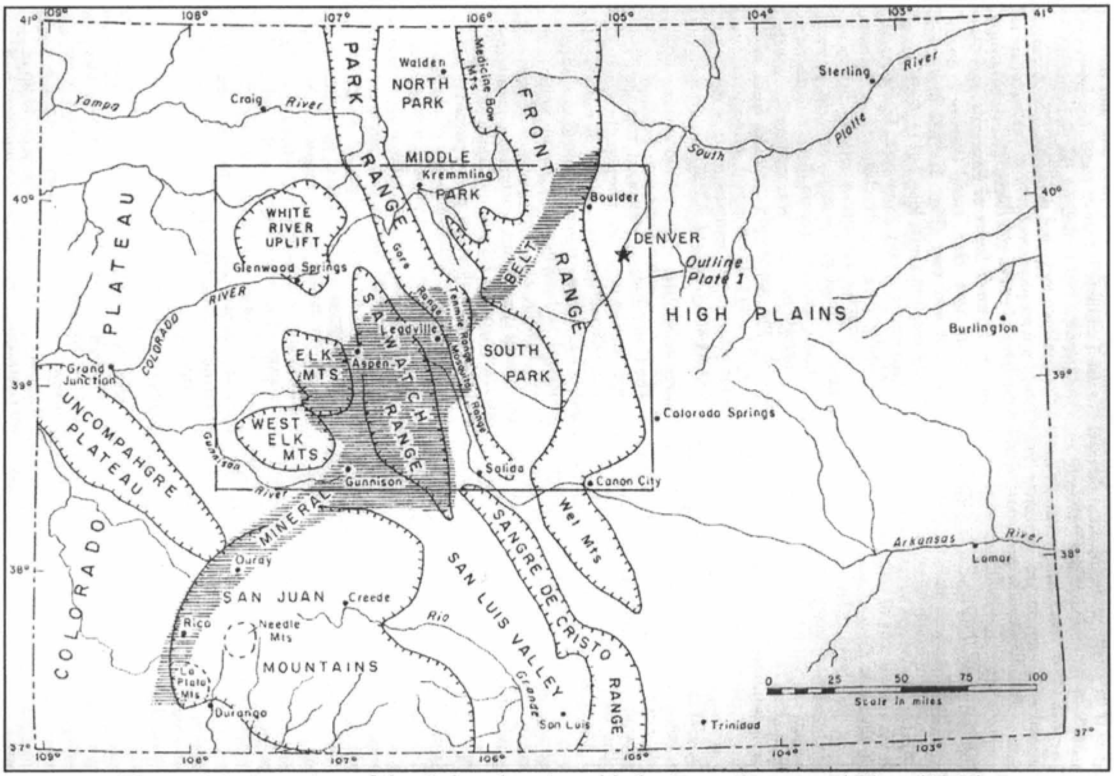


Figure 1.5. Location of the Colorado mineral belt. From Tweto and Sims (1963).

As mentioned, these deposits run along the Precambrian shear zone of the Colorado Lineament, which was reactivated, altered, and cut by faults during the Laramide orogeny. Rocks within the mineral belts generally consist of Precambrianmetamorphic and igneous rocks as well as Tertiary intrusive rocks which have been linked to the mineralization source.

Curtis (1997) described five major categories of mineralization in the belt: (1) Precambrianmassive sulfide deposits; (2) Early to mid-Tertiary veins in Precambrianrocks; (3) Veins and replacement deposits in Paleozoic and Mesozoic sedimentary rocks; (4) Disseminated and stockwork molybdenum mineralization in mid-Tertiary porphyritic stocks; (5) Precious base-metal veins in volcanic rocks. Interestingly, deposits of the mineral belt have produced about 400 mineral species, of which 42 were unknown prior to the discovery and mining.

Many researchers believe that the belt itself is related to a single intrusive body or smaller similar bodies that lie beneath the region. Tweto and Sims (1963) have referred to this as the mineral belt batholith. The exact origin of the mineralization is still under debate but for the most part been limited to tectonic activity related to Laramide and younger magmatic events.

1.5 MAJOR MINING DISTRICTS NEAR RED CONE PEAK

Most of the deposits in the region of Red Cone Peak consist of high concentrations of base-metal sulfides with gold and silver. Mineralization usually occurs wherever there is open space for fluids to fill. The spaces were created by veins, joints, and faults, and by vein and fault intersections that localize ore shoots. Extreme changes in dip of faults and foliation also provide space for mineralization (Millan, 2005). Additionally areas of igneous activity, whether it is intrusive or extrusive, can create the needed space for mineralization to be localized.

Mining districts near Red Cone are located within regions with multiple intrusion histories cycle shown as sequences of ore deposition. Igneous emplacement often began with silicic andesite, followed by augite diorite, and finally silicic magmas that range from alkalic monzonites to quartz monzonites and rhyolites (Millan, 2005).

Major economic deposits in the mineral belt often have a large component of vein mineralization, and coarse stockworks and ore shoots that were occasionally enriched by surficial processes (Lovering and Goddard, 1950). Mineralization also occurs as replacement deposits, and within the wallrock close to veins. Such deposits rarely are economic.

Residual and supergene enrichment are common forms of mineralization within the mineral belt. Oxidized zones rich in gold, silver, and lead generally are located in the uppermost 100 to 150 feet of the profile, whereas secondary copper sulfides and associated native silver are concentrated beneath the oxidized zone and near the paleo-water table (Millan, 2005). Many of the zones of significant enrichment are quite shallow and gold deposits may be as close as 25 feet below the present surface (Lovering & Goddard, 1950). Major mining districts of the Mineral Belt are shown in Fig. 1.4.

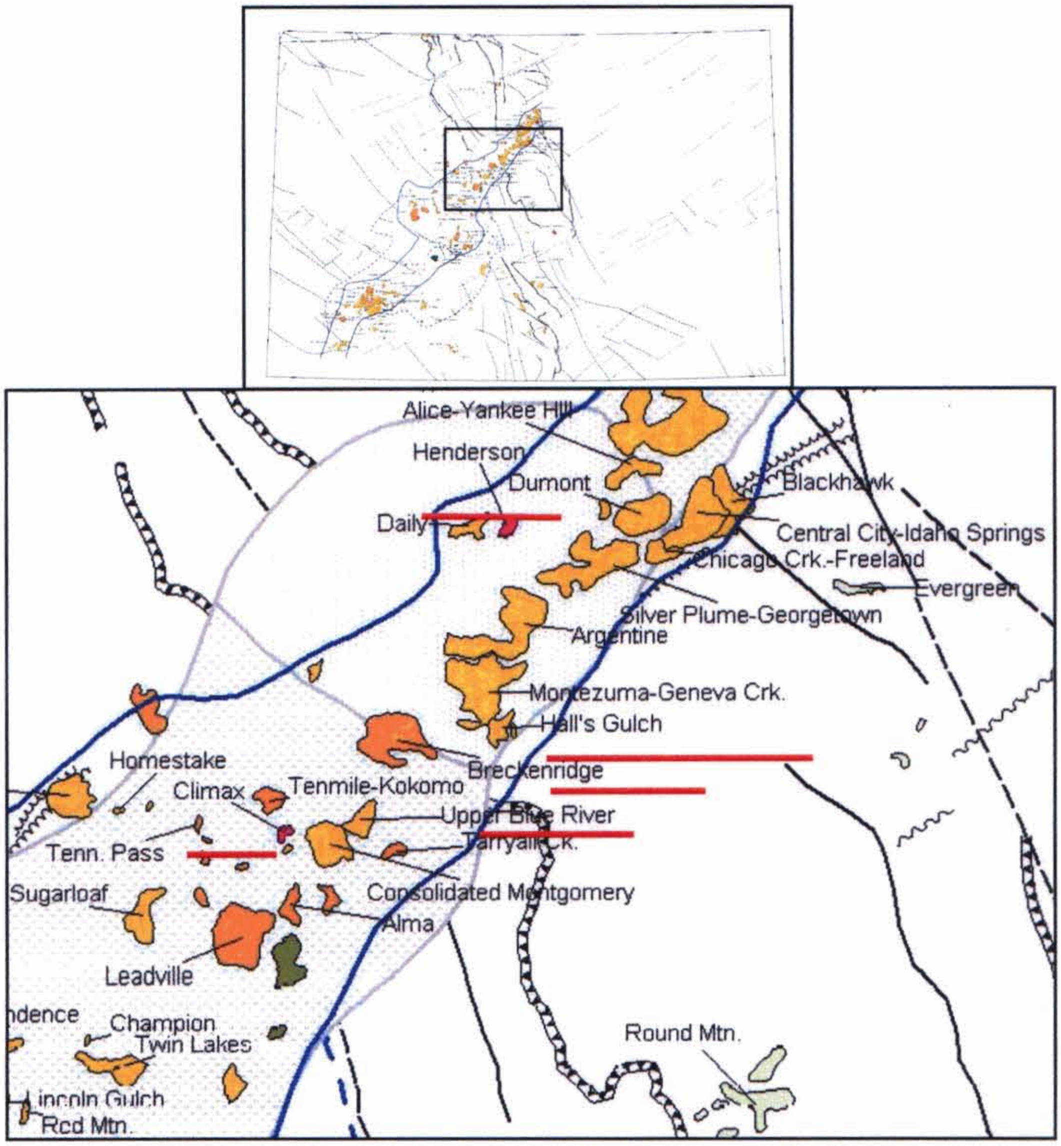


Figure 1.6. Colorado mineral belt, inferred batholiths and metallic mineral districts. Modified from Millan and (2005) Wilson & Sims (2002).

1.5.1 URAD/HENDERSON MINE

The Urad/Henderson mine is located about 45 miles west of Denver on the eastern edge of the Continental Divide and western edge of the Colorado Mineral Belt. The two mines share the north and south sides of Red Mountain, Henderson lying to the north and Urad the south. These deposits are part of the Dailey-Jones district and combined comprise the second largest molybdenum deposits in the world, Climax being the largest.

Like Climax, these deposits result from multiple intrusions that began in the Oligocene, about 33m.a., and range from breccias to porphyrys to granite rhyolite bodies. The ore body at Urad occurs in stockwork veining of a porhyritic rhyolite, and at Henderson is related to the intrusion and micro-fracturing of the Henderson granite (Millan, 2005). Of the two, Henderson is the larger and formed at depth below than the smaller Urad deposit. Mineralization within the complex occurs as veins and veinlets with high level altered igneous intrusions and in intrusive brecciated zones. The dominant ore produced in both mines is molybdenite (MoS_2), but also contains pyrite and small amounts of, rhodochrosite, galena, and sphalerite (Wallace, 1978).

1.5.2 CLIMAX MINING DISTRICT

The Climax mining district is located about 62 miles southwest of Denver and just southwest 15 miles from Red Cone Peak. The mining operation at Climax is the largest in the state of Colorado and is the largest molybdenum deposit of its type in the world. Like the Ural/Henderson mines, the ore at Climax consists of quartz-pyrite-molybdenite . Copper is not present at all in either deposit.

The age of the Climax district is approximately 25m.a. placing it after major Laramide orogenic activity and makes it some of the youngest material within the Mineral Belt. The mineralization at Climax consists of three major ore bodies, coinciding with three of the multiple intrusions within the complex. Each intrusion occurs at deeper depths than the previous. These roughly circular ore bodies are about 0.6 to 0.8 miles across and appear as inverted bowls in cross section, each being about 200m thick (Guilbert and Park, 1986).

Wallace et al. (1968) suggest that the intrusive bodies were connected to a deep magma reservoir and each of the ore-related intrusion brought with it a flux of volatile rich fluids that interacted with country rock and precipitated the mineralization. The ore formed in fractures in the country rock and in places within overlying intrusion.

1.5.3 BRECKENRIDGE MINING DISTRICT

The Breckenridge district is located approximately 60 miles west-southwest of Denver, between the Front Range and the Tenmile Range. It was made famous in 1859 for its placer and lode gold deposits, but the district has also produced significant amounts of zinc, lead, and silver ores.

Contact metamorphic ores, coarse stockworks, blanket replacement ores, and veins, and placer deposits have all be described in the district with the later two contributing the most economically (Lovering and Goddard, 1950). Ransome (1911) suggested that the bedrock ores developed along fractures that were associated with the Williams Range thrust fault. Laramide-age mineralization in the Breckenridge district most likely was related to solidification of quartz monzonite porphyry intrusives, followed by supergene enrichment (Lovering and Goddard, 1950). Hornblende monzonite occurs as sills throughout the district, but it is cross-cut by Lincoln type quartz monzonite stocks, dikes and sills plus various alkalic rhyolite intrusives and intrusive breccias especially in the northern half of the district (Lovering & Goddard, 1950).

According to Lovering (1935), the high-grade lead ores in these deposits are due to hydrothermal leaching of sphalerite and pyrite, whereas the rich gold ores are due to supergene enrichment. According to Pride and Robinson (1978), Cocker (1978), and Cocker and Pride (1978), the Breckenridge district is underlain by a stock that spawned satellite composite intrusions and intrusive breccias that likely generated the mineralization of the district.

1.5.4 MONTEZUMA MINING DISTRICT

The Montezuma district is located ~50 miles west of Denver, on top of and to the west of the Continental Divide. It is comprised of several sub-districts, Swan River, Geneva Creek, and the Hall Valley, but is generally referred to mining activity between the Breckinridge district to the southwest and the West Argentine district to the northeast.

This district is known for its lead-zinc-silver ore, as well as for some gold and bismuth (Lovering, 1935). In general, economical deposits within the district are mesothermal veins that of often been enriched by supergene alteration. It is no question that the source of the majority of mineralization is due to the large Lincoln-type, Montezuma Stock and perhaps related intrusive activity that invaded the region during the Laramide orogeny just north of the town of Montezuma. Much of the deposits of economical value are found on the south where country rock is more highly fractured and faulted. North of the stock, the country rocks are significantly less deformed.

The Hall Valley deposits occur just south of Red Cone Peak, and they may have some similarities with Red Cone. Lovering and Goddard (1950) described Hall Valley deposits as veins running north-northeast and intersecting with the Hall Valley Fault, which trends north-northwest. The veins are rich in bismuth and silver with lesser lead. Tetrahedrite and tennantite are common and usually are accompanied by low grade pyritic gold (Lovering, 1935). Lovering and Goddard include the Hall Valley deposits with the Montezuma mining district because the geology, structure, lithologies, and characteristics of the mineralization are similar.

The richest veins in the Montezuma district are lead, silver, and zinc and are present in the northeastern part of the Montezuma quadrangle. Native silver-bearing minerals are present in the southern part of the quadrangle, and these deposits also contain gold and some zinc and lead.

CHAPTER 2

METHODS AND OBSERVARIONS

2.1 INITIAL OBSERVATION OF WEBSTER PASS AND RED CONE PEAK AREA

In 1997, studies by Robinson, Pride, and Faure were studying the presence of and on of heavy metals in the Snake River valley, to the north of Webster Pass. The focus of the study was ferricrete deposits mapped in the area by Lovering (1935). Similar ferricrete deposits on the south side of Webster Pass in Handcraft Gulch was the focus of M.S. research by Perse (2000)(Fig. 2.1). These deposits were also mapped by Lovering (1935) as part of the Montezuma 15 minute quadrangle. Robinson and Pride visited the area and sampled the ferricrete in Handcraft Gulchin 1998. this work identified heavy metals and gold in the ferricrete at the surface. Samples of highly altered Tertiary intrusives were

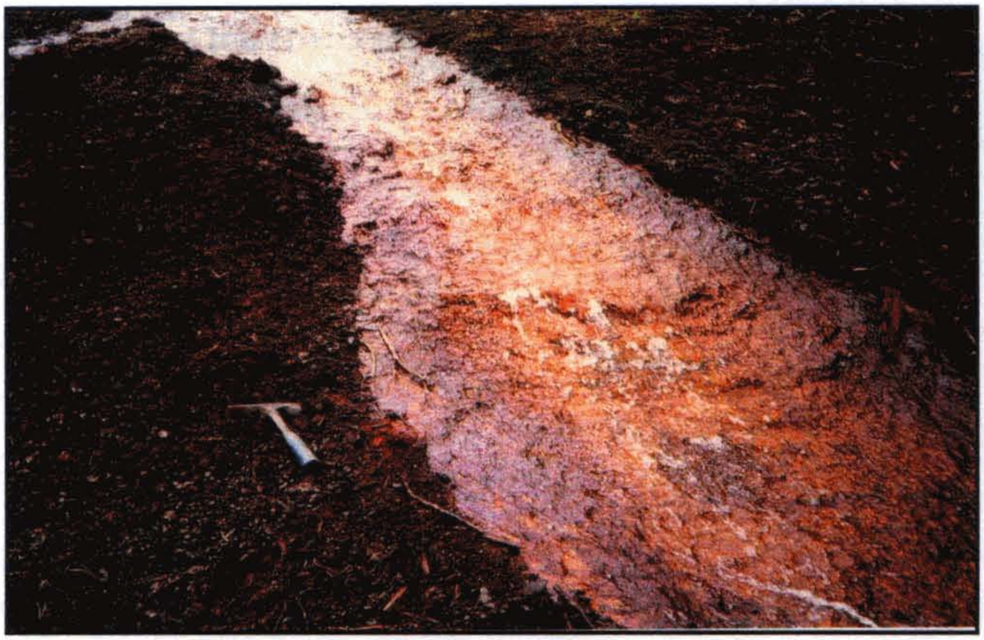


Figure 2.1. Ferricrete deposit. Modifited from Perse (2000).

Figure 2.2 . Ferricrete deposit in Handcraft Gulch, Red Cone Peak top right (photo by D.E. Pride, 2001)

Figure 2.3. Ferricrete deposit near the Snake River (photo by D.E. Pride, 2001)

Figure 2.4. Ferricrete outcrop near the Snake River (photo by D.E. Pride, 2001)

collected during these early studies, and as a result of these investigations, several claims were posted in the area, and funding for further sampling and diamond core drilling was acquired from a group of private individuals in Denver, CO.

In the late summer and early fall of 2001, the first drilling was conducted at Webster Pass on the Continental Divide, to determine the geometry and composition of the igneous system that was thought to lie beneath the pass. The first core was assigned the name WP-1 and penetrated about 2,000 feet of metamorphic and igneous rocks. In the following year, cores, WP-2, WP-3, and WP-4, were drilled on the southwestern slopes of Red Cone Peak. These cores vectored into what is thought to be the center of the igneous activity in the Webster Pass/Red Cone Peak area.

After mapping, geochemical, and further geophysical studies in the area, it has been determined that a porphyry-type system does lie beneath the Webster Pass/Red Cone Peak area. The exact geometry, shape, and extent of mineralization is yet to be determined, but examination of drill core from the complex can provide valuable clues in determining these characteristics.

Figure 2.5. Drilling of WP-1 on Webster Pass (photo by D.E. Pride, 2001)

2.1.1 MACROSCOPIC DESCRIPTIONS OF WP-1

The purpose of this study is to describe mineralization in core WP-1 and to place the core within the porphyry setting. Macroscopic descriptions were done by D.E. Pride and C.S. Robinson who first logged the core itself. According to these writers, the upper 962 feet of the core is mostly silicified quartzite with interlayered beds of sillimanite gneiss. This quartzite and sillimanite gneiss belong to the Idaho Springs Formation. Disseminated and vein/veinlet pyrite become more abundant with depth from top to bottom. Visible metallic minerals include pyrite, chalcopyrite, and occasional molybdenite.

Below 962 feet the country the quartzite gneiss is intruded by Lincoln type, quartz monzonite porphyry. This rock continues to the bottom of the core and it contains abundant veins, veinlets, and fracture filling of pyrite, chalcopyrite, plus more minor molybdenite. Sphalerite and galena, who are also present, appear toward the bottom of the core.

Figure 2.6. WP-1 cores (photo by D.E. Pride, 2001)

2.1.2 INITIAL GEOCHEMICAL ANALYSIS OF WP-1

Initial geochemical results from the WP-1 core show the presence of several elements of possible economic interests. Copper, molybdenum, lead, and zinc percentages all increase with depth. Copper and molybdenum spikes show slight inversions: as one increases in percentage the other drops slightly. Gold, silver, sulfur, and fluorine generally remain constant with depth. The "nugget effect" may be present in gold and silver quantities, leaving the exact proportions difficult to determine. Also gold, silver, and copper have been highly affected by percolating meteoric waters in the first 200 feet of the core.

2.2 REFLECTED LIGHT MICROSCOPIC ANALYSIS OF DRILL CORE WP-1

Nine polished thin sections were made from samples of various depths of the core (see Fig. 2.1). Reflected light microscopy was done to observe the characteristics of pyrite grains, mineral texture of the rock, and the intensity of mineralization. The researcher has made detailed notes of each surface, and from these notes has determined what slides and which pyrite crystals within those slides would likely display down core hydrothermal zoning. Factors used in determining which slides to be used include depth in the core, abundance of disseminated pyrite crystals, and abundance of ore minerals such as chalcopyrite, molybdenite, magnetite, and sphalerite. Gold is present only as trace amounts

Sample Depth	
Slide	**Depth**
PMC 2	**88 ft.**
PMC 3	**440 ft.**
PMC 4	**777 ft.**
PMC 5	**969 ft.**
PMC 6	**1160 ft.**
PMC 7	**1377 ft.**
PMC 8	**1719 ft.**
PMC 9	**1903 ft.**
PMC 10	**1964 ft.**

Figure 2.7. Shows depth within the core of each slide.

2.2.1 REFLECTED LIGHT MICROCOPIC OBSERVATIONS

As mentioned, the country rock in the upper 962 feet of drill core WP-1 consists of quartzite and schistose quartzite. Three slides were made of rocks in this portion of the column: PMC 2 is quartzite, and PMC 3 and PMC 4 are generally sillimanite gneiss. PMC 2 contains disseminated pyrite that has completely oxidized to limonite and hematite through interaction with downward percolating meteoric waters. PMC 3 and 4 are very much alike, containing nearly equivalent amounts of disseminated pyrite: however, PMC 3 contains a narrow veinlet of pyrite, whereas PMC 4 contains a vein of pyrite which is nearly 3mm wide at its widest. Both veins in PMC 3 and PMC 4 cross-cut foliation in the quartzite country rock. Disseminated pyrite grains are anhedral to subhedral. Some subhedral chalcopyrite is present near the veins in both PMC 3 and PMC 4; and other minerals present are hematite and sphalerite.

Below 962 feet in the core, the country rock changes to quartz monzonite. The rock is clearly prophyritic and contains varying amounts of disseminated pyrite and other metallic minerals, plus veinlets and of pyrite veins ranging from 1 to 2mm wide. PMC 5 through PMC 8 contains disseminated pyrite ranging from 0.2 to 2mm, plus chalcopyrite as disseminated grains, within veinlets, or within pyrite crystals. Below PMC 8 (1719 feet), disseminated subhedral pyrite becomes much finer grained, but is much more abundant. A pyrite vein 5mm wide cuts across PMC 9 inclosing euhedral feldspars. Disseminated magnetite and veinlets of magnetite also are present below PMC 5 enclosing crystals of pyrite and chalopyrite (PMC 10).

What is apparent in all nine of the polished this sections signs of multiple mineralization events. The disseminated pyrite represents the pyrite shell that develops in the early stages of a porphyry copper system (Fig. 2.8). Following this disseminated mineralization if the cross-cutting veins and veinlets of quartz- pyrite and pyrite-molybdenite. Signs of significant alteration of feldspar crystals in the monzonite, with crystals being completely replaced by sericite in some places. The images were taken of mineralization in PMC 5, PMC 7, PMC 8, and PMC 10.

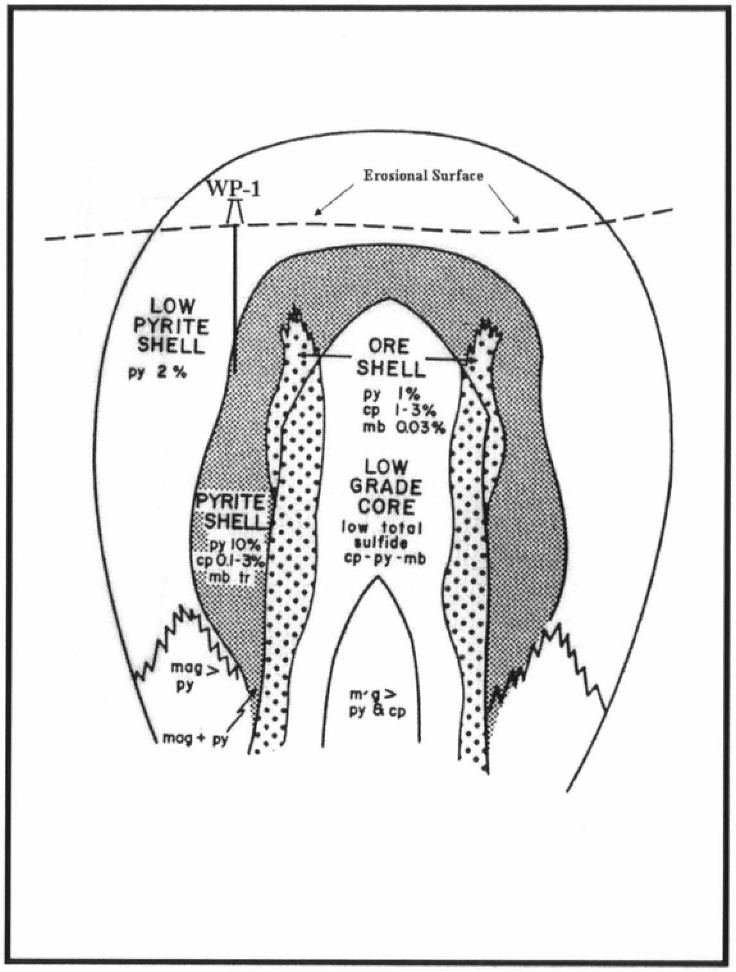


Figure 2.8. Erosional level and trace of drill hole WP-1 in hypothesized porphyry Cu-Mo setting at Red Cone, CO. (Model modified from Lowell and Gilbert 1970)

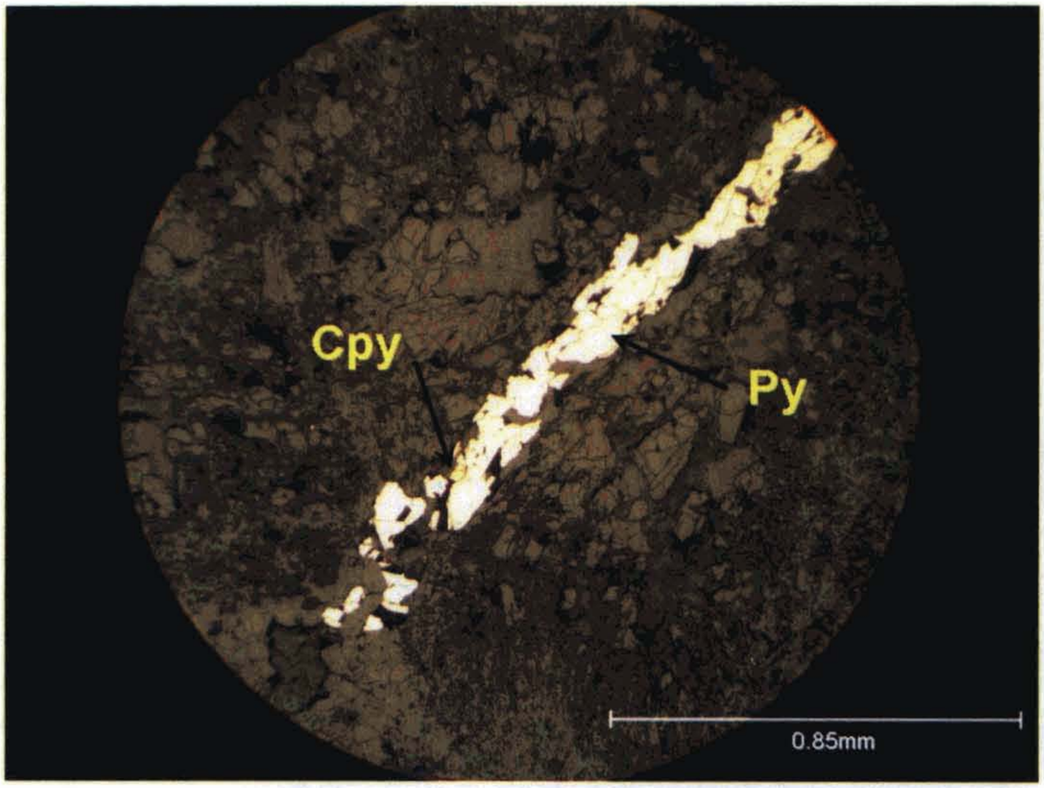


Figure 2.9. PMC 5 showing a pyrite vein with chalcopyrite.

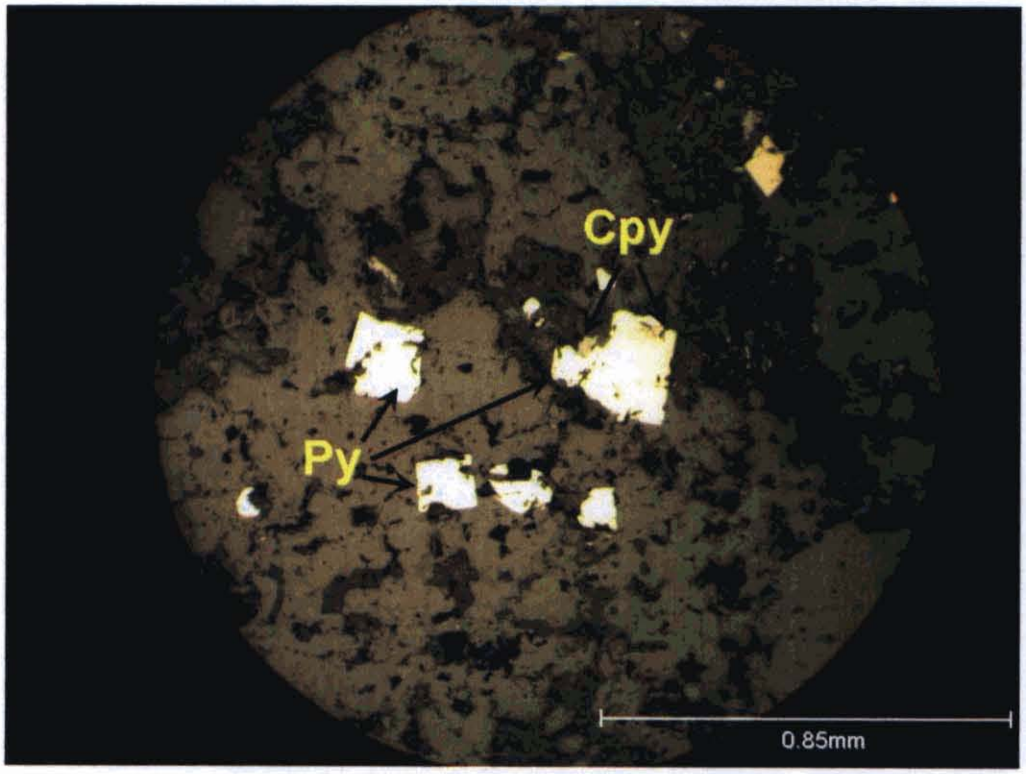


Figure 2.10. PMC 7 showing euhedral pyrite w/ some chalcopyrite.

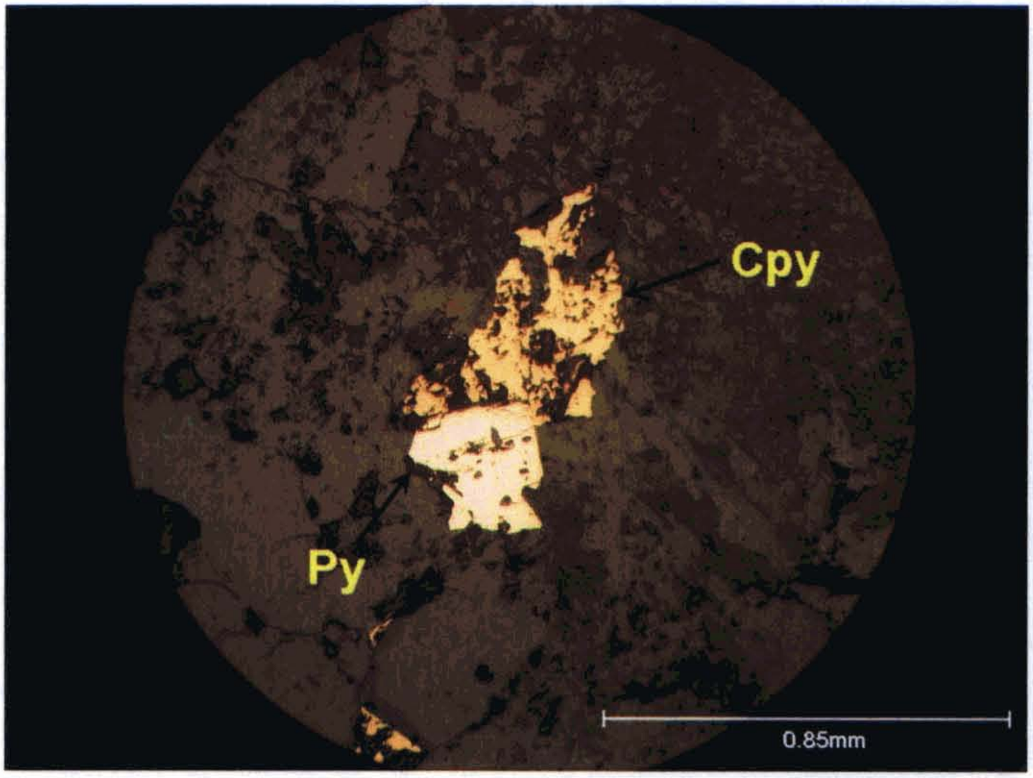


Figure 2.11. PMC 8 showing pyrite w/ chalcopyrite.

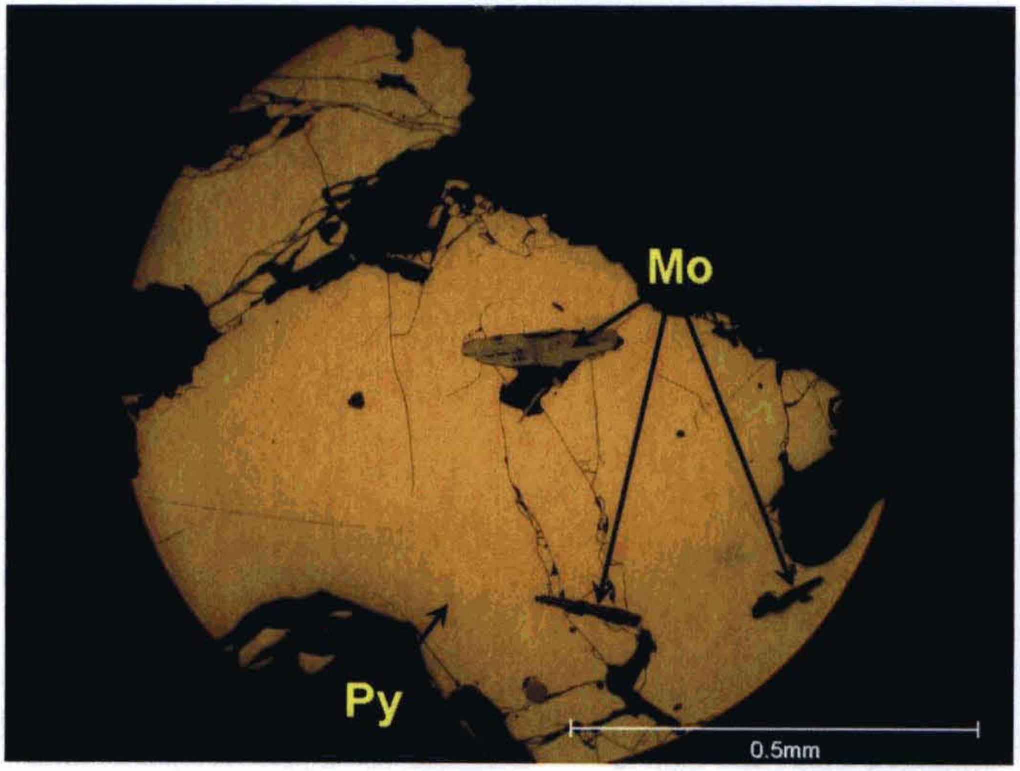


Figure 2.12. PMC 8 showing bladed molybdenite enclosed in pyrite.

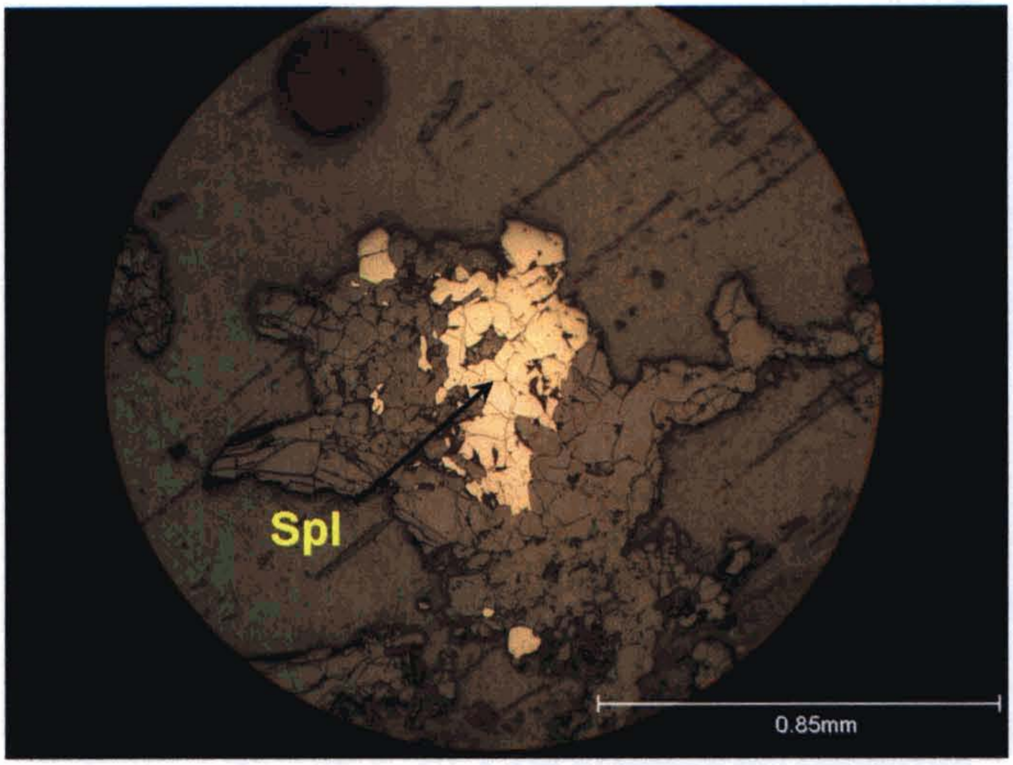


Figure 2.13. PMC 8 showing sphalerite.

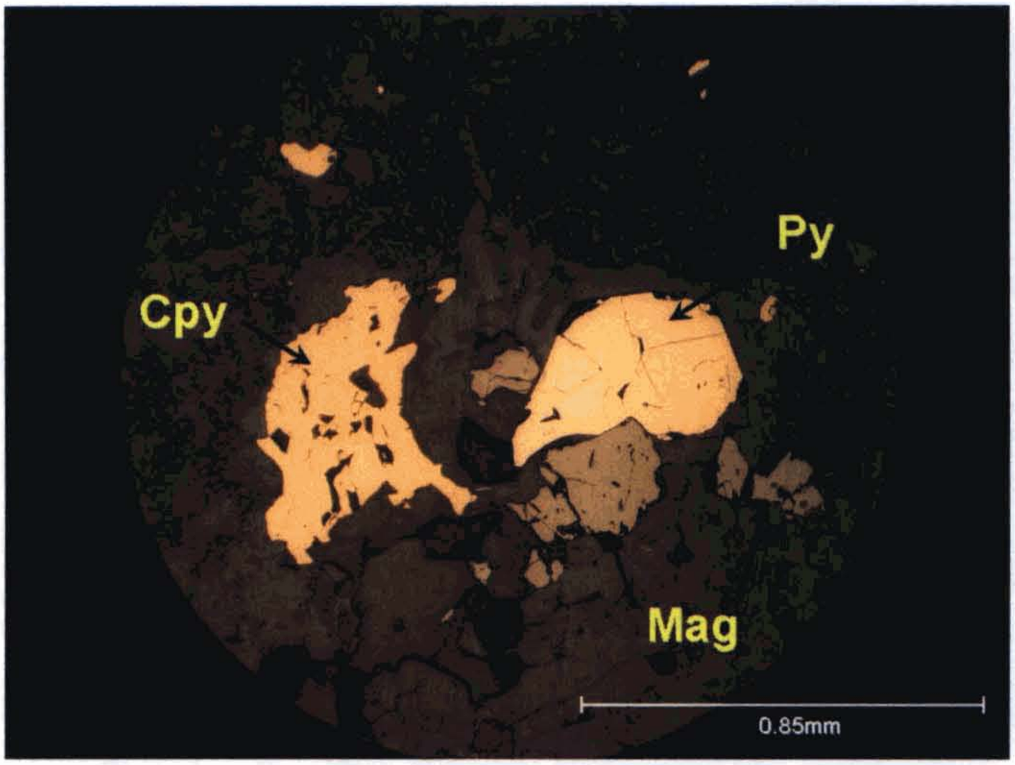


Figure 2.14. Disseminated pyrite, chalcopyrite, and magnetite in PMC 10.

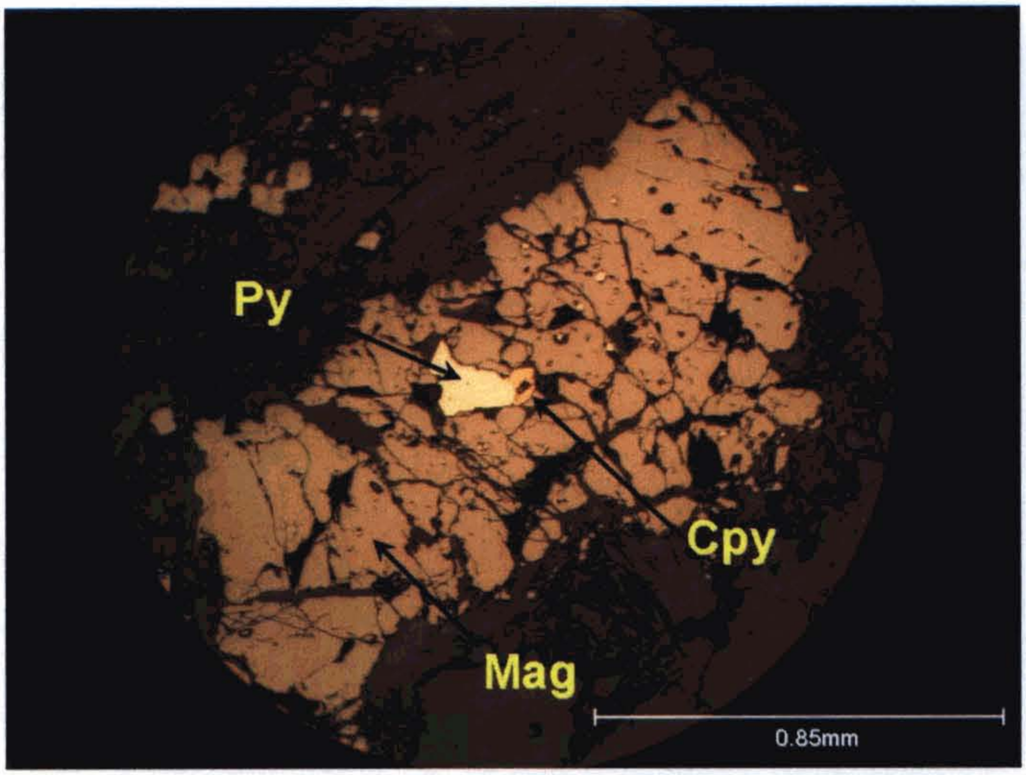


Figure 2.15. Magnetite vein containing pyrite and chalcopyrite in PMC 10.

2.3.2 HYDROTHERMAL ZONING ANALYSIS

A scanning electron microscope (SEM) at the Microscopic and Chemical Analysis Research Center (MARC) of the Ohio State University, Department of Geological Science with lab assistance by Sreenivas Bhattiprolu was used for zoning analysis. This analytical tool provided the feather to individually analyze each pyrite or chalcopyrite grain one at a time for to determine its exact chemical composition. If hydrothermal zoning does occur, the x-ray mapping feature would show the location and abundance of elements such as gold and silver that could be contained within sulfide mineral grains.

Possible hydrothermal zoning within drill core WP-1 was done using a scanning electron microscope equipped for backscatter x-ray mapping and spectrum analysis.

These techniques can be used to analyze a field or can be focused on specific crystals; in the present study analysis was used to look at disseminated pyrite and in some occasions chalcopyrite to determine if there were any variations in copper or gold with depth in the core.

Three slides, PMC 3 (440'), PMC 7 (1377'), and PMC 10 (1964'), were selected for this study. Grains were selected based on the shape and "inconsistencies" or variation, with their reflected light color.

After analyzing several pyrite crystals on each surface, no signs of hydrothermal zoning in pyrite or chalcopyrite were noted. This likely is a result of the position of the drill core in relationship to the center of the porphyry system, or no zoning within the complex at all. Further investigation of this type on cores drilled on Red Cone Peak should yield better results of zoning. The following images are just a few of the mapping and spectrum analysis done on PMC 3 and PMC 10.

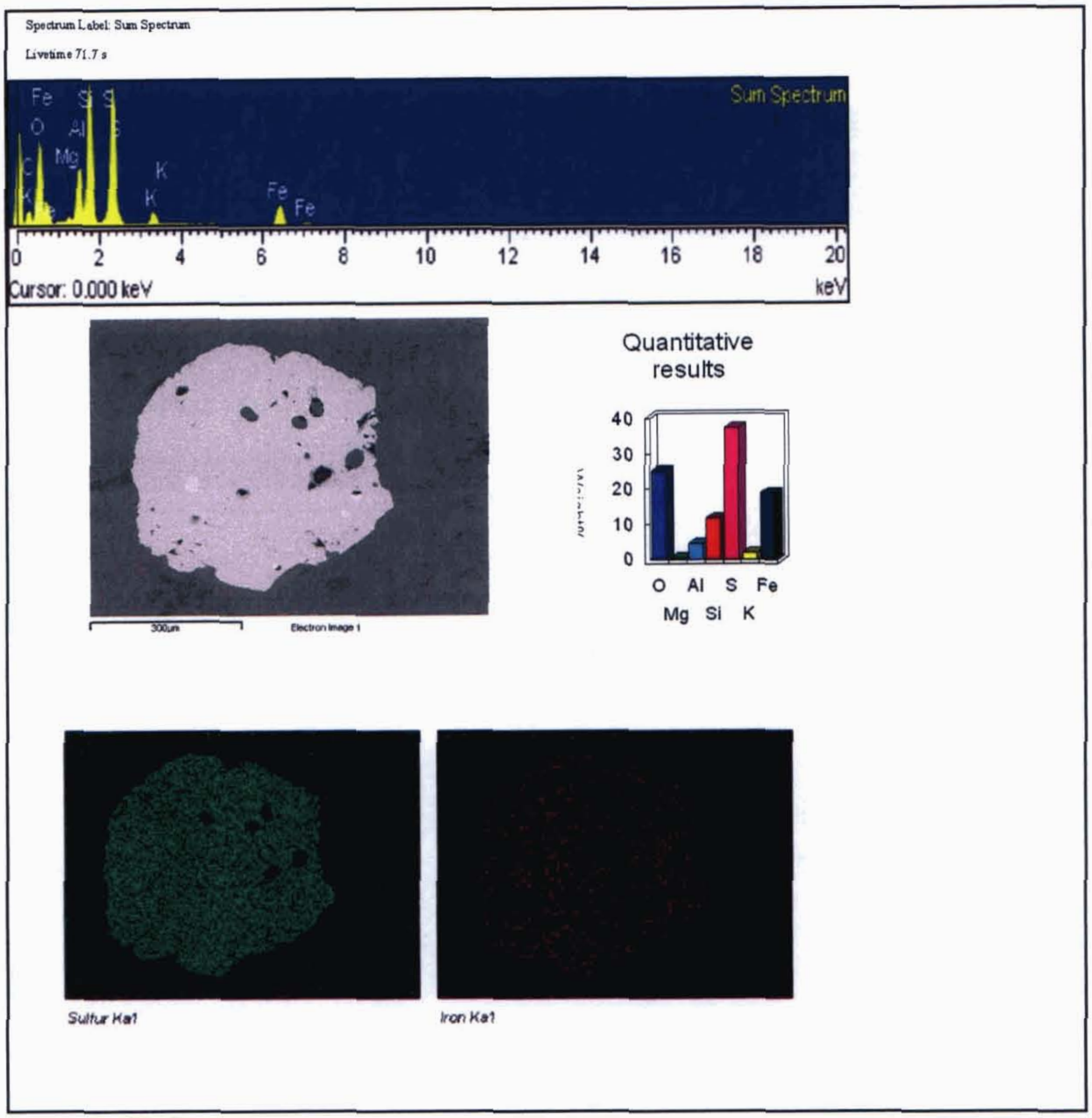


Figure 2.16. Mapping of a pyrite crystal in PMC 3.

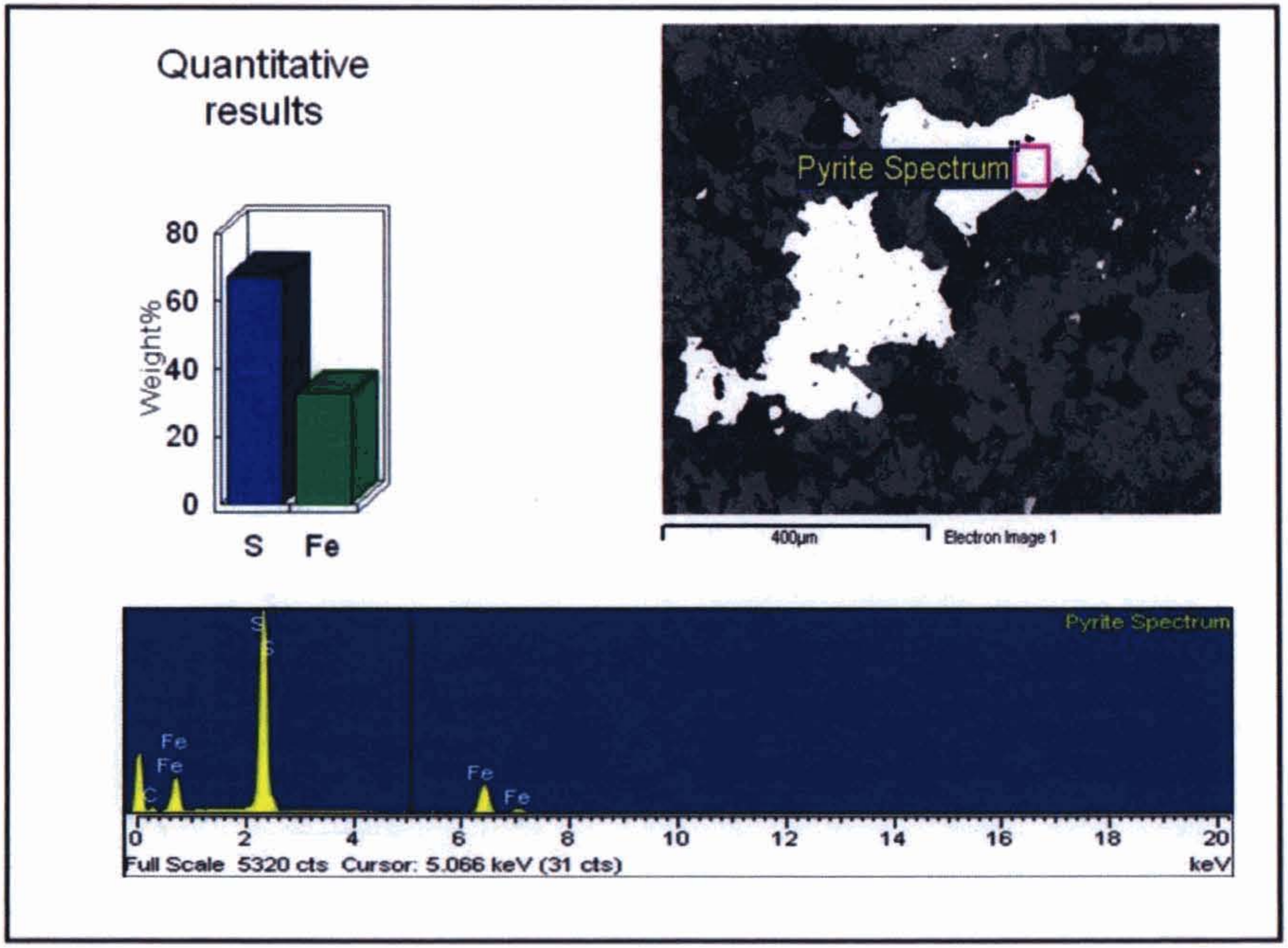


Figure 2.17. Spectrum analysis of pyrite crystal in PMC 10.

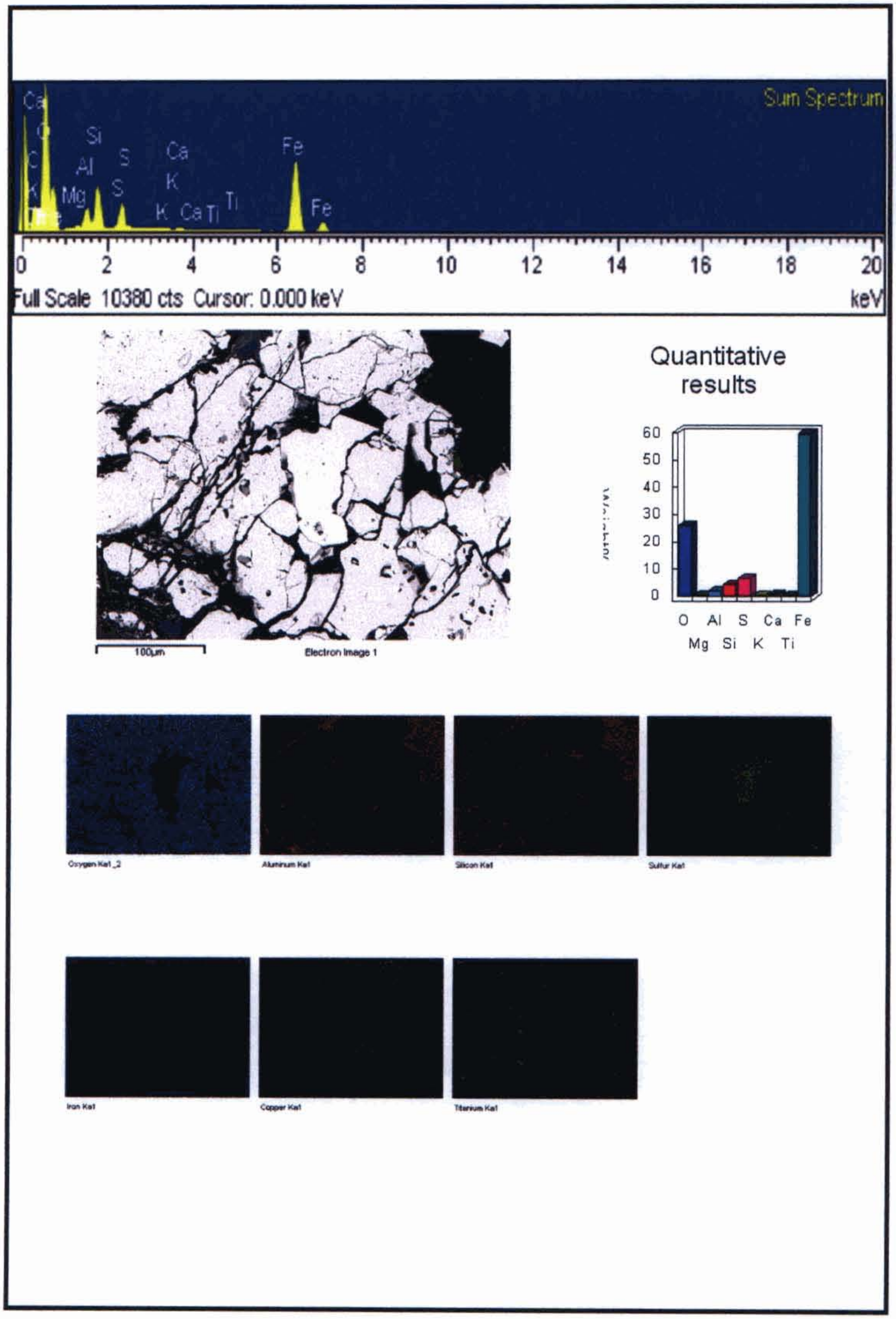


Figure 2.18. Mapping of a magnetite vein containing pyrite and chalcopyrite in PMC 10.

CHAPTER 3

CONCLUSION AND DISCUSSION

Porphyry copper and Climax-type porphyry molybdenum systems develop in different tectonic settings: molybdenum above shallow subduction dettigns that produce tensional forces, whereas copper-rich systems usually form above convergent margins where subduction is steeper, e.g. Andean style subduction systems. Also, copper-rich systems are develop from intermediate magmas, whereas molybdenum mineralization is associated with more silicious, granite rhyolite systems.

During the formation of the Colorado Mineral Belt, intrusive activity changed character as the Laramide orogeny progressed. Early intrusive activity along the belt generally was intermediate in composition, but developed into more highly eveolved silica-rich systems in mid to late Tertiary time (Lovering, 1935). In addition, copper deposits were much more important during the earlier stages of the mineral belt. Dating of Lincoln-type porphyry intrusives in the Red Cone complex (Crook, 2004) puts the time of emplacement from 41 to 37m.a., whereas the Climax and Henderson deposits to the southwest and northeast of Red Cone Peak were emplaced generally from 33 to 26m.a. and 24m.a. respectively (Gilbert and Park, 1986). From 41 to about 33m.a., stresses in the western Cordilllera changed from compressional to tensional, and this fact along with the evolution of magma at at certain locations within the Belt may provide an explanation for the differences in magma composition and associated mineralization in this part of the Mineral Belt.

Both copper and molybdenum are present within the porphyry complex at Red Cone Peak. The simplest explanation is that the mineralization at Red Cone formed in an early intrusive event with porphyry copper affinities, an event that preceded the now famous porphyry molybdenum mineralization for which Colorado is famous.

Although this study failed to produce signs of hydrothermal zoning with depth in the WP-1 core, it did provide valuable information about the complex itself. It is clear there is a multi-event igneous body below Red Cone Peak. The lack of zoning in the mineralization in core WP-1 suggests that the core penetrated the periphery of the outer pyrite shell of a porphyry metal system. Work by Millan (2004) suggests that the core of the system, and the center of mineralization may lie beneath the southern slope of Red Cone Peak, below what is referred to as the "Alligator". This outcrop is 0.5 miles southeast of Webster Pass.

Detailed study cores WP-2, WP-3, and WP-4 will shed light on the overall characteristics of the Red Cone complex. It appears there is a copper-molybdenum system beneath the Red Cone complex, and studies of existing cores, plus perhaps additional drilling will provide a much better understanding of its structure and economic potential.

REFERENCES

Cocker, M.D., 1978, Multiple Intrusion, Hydrothermal Alteration and Related Mineralization in the Northern Breckenridge Mining District, Summit Co., Colorado: unpublished Ph.D. Thesis, The Ohio State University, Columbus, Ohio, 288p.

Cocker, M.D., and Pride, D.E., 1979, Hydrothermal alteration-mineraization of a subvolcanic-volcanic complex, Breckenridge mining district, Colorado. Fifth International Association Genesis Ore Deposits Quadrennial Symposium, p. 141-149.

Crook, J., 2004, Personal Communication for M.S. Thesis at New Mexico School of Mines, Socanro, New Mexico.

Curtis, G.R., 1997, The Colorado Mineral Belt, in Sonnenberg, S.A., and Bolyard, D.W., ed., Geologic History of the Colorado Front Range, 1997 RMS-AAPG Field Trip #7, 189p.

Guilbert, J.M., and Park, C.F., 1986, *The Geology of Ore Deposits*, W.H. Freeman and Company 985p.

Lovering, T.S., 1935, Geology and Ore Deposits of the Montezuma Quadrangle, Colorado. U.S. Geological Survey Prof. Paper 178, 119p.

Lovering, T.S., and Goddard, E.N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geological Survey Prof. Paper 223, 319 p.

Millan, C., 2005, Origin and significance of intrusive breccias at Red Cone Peak, Park County, Colorado, unpublished M.S. Thesis, The Ohio State University, Columbus, Ohio, 83p.

Perse, J.D., 2000, Geology and significance of a large ferricrete deposit in Handcart Gulch, Park County, Colorado, unpublished M.S. Thesis, The Ohio State University, Columbus, Ohio, 88p.

Ransome, F.L., 1911, Geology and ore deposits of the Breckenridge district, Colorado. U.S: Geological Survey Professional Paper 75, 187p.

Rice, C.M., and Parry, S.F., 2002, Webster Pass Geological Mapping and Sampling Projects, July 2001: Report for Mineral Systems, Inc., unpublished, 19p.

Robinson, C. S., Pride, D. E., and Rice, C. M., 2002, Geology and Mineralization of the Webster Pass Prospect Summit and Park Counties, Colorado. Report for Mineral Systems, Inc., unpublished 74 p.

Robinson, C.S., Pride, D.E., and Jemielita, R.A., 2004 Summary Report, Mineral Exploration, Webster Pass area, Summit and Park Counties, Colorado: Report for Mineral Systems, Inc., unpublished, 37p.

Sonnenberg, S.A., and Bolyard, D.W., 1997, Tectonic history of the Front Range in Colorado, in Sonnenberg, S.A., and Bolyard, D.W., eds., Geologic History of the Colorado Front Range, 1997 RMS-AAPG Field Trip #7, 189p.

Tweto, O.L., and Sims, P.K., 1963, Precambrian ancestry of the Colorado mineral belt: Geological Society of America Bulletin, v. 74, p. 991-1014.

Wahlstrom, E.E., and Kim, O.J., 1959, Precambrian rocks of the Hall Valley area, Front Range Colorado: Geological Society of America Bulletin, v. 70, p. 1217-1244.

Wallace, S.R., MacKenzie, W.B., Blair, R.G., and Muncaster, N.K., 1978, Geology of the Urad and Henderson Molybdenite deposits, Clear Creek county, Colorado, with a section on a comparison of these deposits with those at Climax, Colorado: Economic Geology, v. 73, p. 325-368.

Warner, L.A., 1980, The Colorado Lineament: A middle Precambrian wrench fault system: Geological Society of America Bulletin, v. 89, p. 161-171

Wilson, A.B., and Sims, P.K., 2003, Colorado Mineral Belt Revisited – An Analysis of New Data: U.S. Geological Survey Open-File Report 03-046. http://pubs.usgs.gov/of/2003/ofr-03-046/