

University of Nevada, Reno

**Geology, Alteration, Geochemistry, and Paragenesis of the  
Vista Vein Shear Zone Deposit,  
Humboldt County, Nevada**

A thesis submitted in partial fulfillment of the requirements  
for the degree of Masters of Science in Geology

by

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May 2015

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We recommend that the thesis  
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**KAITLYN M. BARBER**

Entitled

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Deposit, Humboldt County, Nevada**

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requirements for the degree of

**MASTER OF SCIENCE**

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## Abstract

The Vista Vein shear zone Au deposit (VVSZ) is a structurally-controlled, shear zone-hosted deposit located underneath the historic Vista Pit of the Twin Creeks Mine, which is owned and operated by Newmont Mining Corporation. The deposit is located approximately 45 miles northeast of Winnemucca, NV in the Potosi mining district of Humboldt County.

This Carlin-type gold deposit is unique in that it is hosted entirely within volcanic rocks of the Ordovician Valmy (Ov) Formation, in contrast with typical Carlin-type deposits, which are typically hosted in shelf-slope sedimentary rock environments. The upper part of the formation is dominated by pillow and massive basalts, with minor siliceous mudstones, volcanoclastic sediments, and flow breccias. Two mineralization events are recognized in this deposit: (1) a brecciated quartz-base metal vein (Galena Vein); and (2) Carlin-type Au mineralization. In the latter, gold is hosted in arsenian pyrite and marcasite disseminated through the VVSZ characterized by decarbonatization, silicification, phyllic, and argillic alteration.

The VVSZ has a mineable strike length of 4600 feet, with strikes between N40-45° E, and a dip extent length of 1000 feet with a dip of 65-70° to the NW. There is an ore shoot that has a rake of 35° to the northeast. Average gold grades range from 0.2 – 0.4 ounces per ton. The deposit is named the “Vista Vein” because of the brecciated quartz-base metal vein, known as the Galena Vein, which occurs within the shear zone of the Trench Fault. The “Vista Vein” name is misleading in that it implies a vein deposit, when in fact it is a shear zone deposit. The 1-3 foot wide Galena Vein mineralogy

includes (early to late): milky vein quartz, fractured pyrite, massive fractured sphalerite with chalcopyrite disease, subhedral-euhedral pyrite, massive fractured galena, tennantite-tetrahedrite, microcrystalline quartz, sericite, and specular hematite.

The VVSZ has been reactivated multiple times and shows strike-slip, normal, and possibly oblique displacement. Rock preparation in the VVSZ for later gold deposition included: decarbonatization, silicification, and phyllic alteration. The shear zone is brecciated and contains clasts of pervasively phyllic altered wallrock. The matrix of the fault breccia is mostly composed of microcrystalline quartz, kaolinite, and carbon. Opaque mineralogy include: pre-ore and ore-stage pyrite, ore-stage marcasite, chalcopyrite, galena, sphalerite.

Several  $114 \pm 2$  Ma porphyritic dacite dikes and sills play a significant role as secondary controls on gold mineralization in the Vista pit as well in the Vista Vein shear zone. These porphyritic dacite dikes are characterized by pervasive phyllic alteration and locally are mineralized.

The Carlin pathfinder elements that have strong positive correlations with gold include: arsenic, silver, antimony, mercury, selenium, tellurium, thallium, and tin. Arsenic, thallium, mercury, selenium, and tellurium all increase at depth to the northeast. On the opposite spectrum of the Carlin-type pathfinder elements, the base metal elements have elevated values that increase to the northeast with increasing elevation in the deposit. This suggests that these two mineralization events occurred separately.

There is no recognized “ore horizon” with the VVSZ deposit; the only constraint on the extent of gold mineralization is the surface and the 20K fault that truncates the Vista Vein deposit up dip to the northeast. The Vista Vein deposit has potential for expansion down dip and along strike.

This research has led to understanding that: (a) the porphyritic dacite dikes act as important secondary controls on mineralization, (b) steeper dips of the Vista Vein shear zone correlate with higher gold values, (c) base metals have an increase in concentrations higher in elevation, and (c) the zonation of Carlin-type pathfinder elements suggest an increase in intensity of mineralization at depth to the northeast.

## Acknowledgments

This thesis was supported by Newmont Mining Corporation, through its Vista UG Exploration project, located at the Twin Creeks mine, just north of Golconda, NV. First and foremost I would like to thank my industry mentors who have generously donated their time, help guide me in the right direction for my career, and let me bounce numerous questions and thoughts back and forth: Dr. Mike Ressel, Pat Donovan, Joe Becker, and Tom Roman. Special thanks to Dr. Tommy B. Thompson for mentoring me throughout this thesis, and for guiding me in the right direction to start my career as an Economic Geologist.

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## Chapter 1: Introduction

### *General features of Carlin-type gold deposits*

Carlin-type gold deposits (CTGD) are sedimentary rock-hosted, disseminated gold deposits that are both structurally and stratigraphically controlled. Gold occurs as submicron sized particles that are disseminated throughout arsenian pyrite and marcasite or within the host as substitutions in the lattice. These large ore bodies are concentrated in decarbonatized silty carbonate host rocks and are found in Nevada, Argentina, and Mexico. There are five major Carlin-type gold deposit trends in Nevada, which include the: Getchell, Jerritt Canyon, Carlin, Battle Mountain – Eureka, and Alligator Ridge trends (Cline et al., 2005). The discovery and continued exploration of the Long Canyon deposit suggests a sixth major CTGD trend in Nevada.

In 2012, Nevada's gold production had a value of \$9.37 billion, which accounted for 76% of the United States' total gold production for that year. This 2012 production value made the United States the fourth leading gold producer in the world (Nevada Bureau of Mines and Geology, 2014). Nevada's largest gold producing trend, the Carlin trend, reached a cumulative production of 80.5 million ounces of gold by the end of 2012 (Nevada Bureau of Mines and Geology, 2014).

Host rocks are Paleozoic carbonate rocks deposited in continental slope to continental shelf environments, with ore also present in Eocene igneous bodies. Alteration assemblages that are associated with these deposits include: decarbonatization, argillic alteration, and silicification. Typical Carlin-type ore fluids are inferred to have

been low in salinity, moderately acidic, and had low temperatures that range from 150-250 degrees Celsius.

Gold and pyrite are thought to precipitate together from H<sub>2</sub>S-rich fluids through the process of sulfidation of the host rock iron (Hofstra and Cline, 2000). Iron is considered immobile, and in addition to sulfur, Au, Sb, Tl, Hg, Ag, W, Te, and As are added to pyrite during sulfidation (Hofstra and Cline, 2000).

Groff et al. (1997), Hofstra et al. (2000), Tretbar et al. (2000), Ressel and Henry (2006) have confined the ages of Carlin-type gold deposits to 36-42 Ma. The most accurate hydrothermal mineral date still is a <sup>40</sup>Ar/<sup>39</sup>Ar date of 42.0 Ma on adularia from Newmont's Twin Creek's deposit (Groff et al., 1997). Other less precise dates were both obtained from the Getchell deposit. Galkhaite yielded a Rb-Sr isochron age of 34±11 Ma (Tretbar, 2000). Fluorite yielded a Th-Pb date of 34±11 Ma (Hofstra et al., 2000).

Even though every Carlin-type gold deposit is unique and has certain attributes that are only associated with local geology, three different models have been proposed to explain the formation of these deposits. These three models involve hydrothermal fluids from three different sources: (1) meteoric water; (2) plutons that provided the heat, fluids, and metals; and (3) a combination of metamorphic fluids or deep magmatic fluids (Heitt et al., 2003; Cline et al., 2005).



### *Objective*

The Vista Exploration Project is Newmont's underground mine associated with the Vista Vein shear zone (VVSZ) deposit. This deposit is a structurally controlled, shear-zone hosted, gold deposit located underneath the historic Vista Pit of Twin Creeks Mine (TC), which is owned/operated by Newmont Mining Corporation (NMC). The name Vista Vein is unfortunately misleading, since the deposit is really a shear zone that is locally associated with a brecciated quartz-base metal vein and is not a "vein" deposit. In early drill programs, the shear zone was called the Galena Vein. This complex structurally-controlled deposit is a wide, northeast-trending, strongly mineralized shear zone that has also been called the Trench Fault. It is hosted completely within the Ordovician Valmy Formation. It contains disseminated gold mineralization with average gold grades of 0.2 – 0.4 opt. The goal of this study is to develop an interpretation of the alteration, mineralogy, structural controls, paragenesis, and trace element zonation of the VVSZ deposit. The scope of the research for this thesis includes:

1. Petrographic analysis of alteration assemblages and base metal mineralization.
2. Creating trace element longitudinal sections along the plane of the Vista Vein deposit.
3. Analyzing the role of structure with respect to the hydrothermal systems.
4. Assessment of the spatial and temporal relationships of the porphyritic dacite dikes to precious and/or base metal mineralization.
5. Investigating the genetic relationship between the Galena Vein, the VVSZ deposit, and the bulk tonnage Carlin-type Au deposit at Twin Creeks.
6. Determining the paragenesis of the VVSZ deposit.

This research will provide a better understanding about the origin of this deposit, which in turn might help in the exploration of similar deposits distal to Carlin-type gold deposits.

### *Location*

The Twin Creeks Mine, owned and operated by NMC, is one of the largest gold producing mines in the United States. This Carlin-type gold deposit is located approximately 45 miles northeast of Winnemucca, NV in the Potosi Mining District of Humboldt County. It lies on the eastern flank of the Osgood Mountains, just northeast of the Getchell, Pinson, and Turquoise Ridge mines (Fig. 1). The Twin Creeks deposit is situated along the mineral belt of the Getchell Trend, one of the five major mineral belts in Nevada.

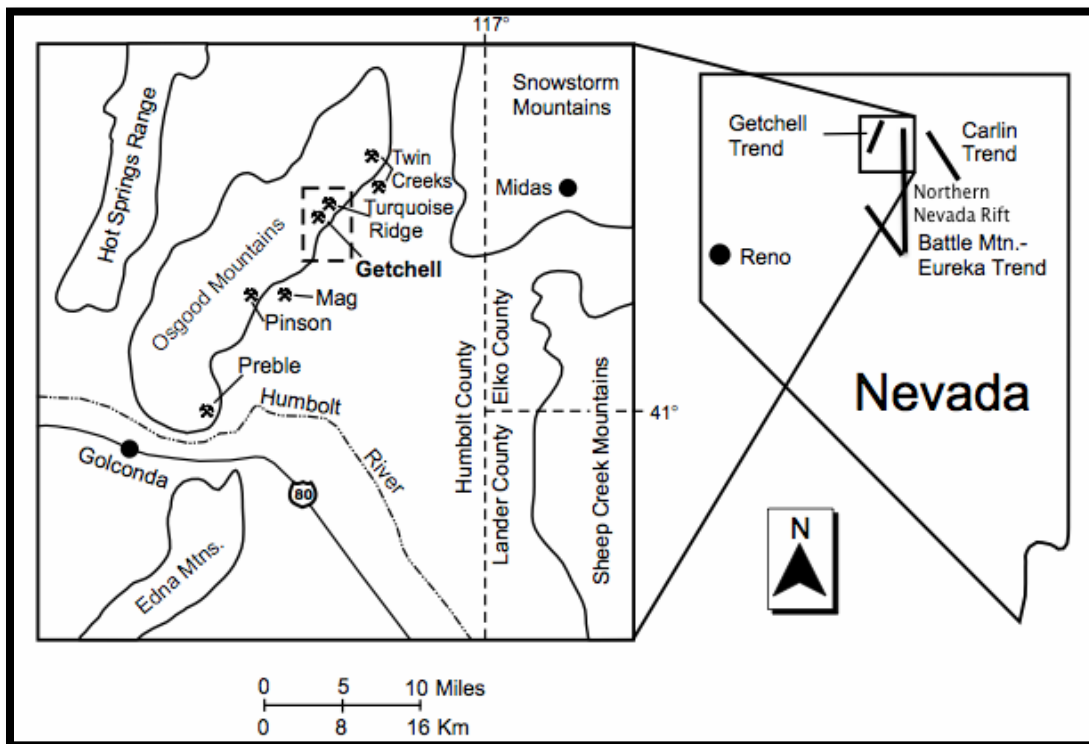


Figure 1. The location of Twin Creeks in relationship to four of the five major mineral trends of the state of Nevada (Modified from Cline, 2001).

### *Methodology*

Fieldwork was conducted during the summer of 2013, under the supervision of NMC geologists, through a summer internship at the Vista underground exploration project. The goal of this internship was to gain experience in numerous aspects of an underground mine geologist's job, while collecting pertinent information in order to write this thesis. Three weeks were spent learning how to map underground using a 1:20 scale mapping base with the Anaconda mapping method at the Midas Au-Ag mine, now owned by Klondex. The rest of the summer was spent at the Vista Project sampling, constructing longitudinal sections, and logging drill core to determine distribution of trace element zonation around the ore body and to analyze the role of structure associated with the VVSZ deposit. Twelve core drill holes distributed across the northern, central, and southern part of the deposit were logged and sampled over the summer.

In order to understand the geology of the VVSZ, careful examination of crosscutting relationships between the brecciated quartz-base metal vein and Carlin mineralization were key to developing a sense of timing in the system. Sixty polished sections were cut from drill core and were analyzed using both reflected and transmitted light microscopy. The petrographic analysis of the polished sections was used to determine the sulfide and gangue mineralogy, delineate the various alteration suites, create a paragenesis, and analyze crosscutting relationships of the VVSZ deposit.

The geochemistry of the VVSZ deposit was studied through examination of graphic reconstructions and multiple correlation matrices of trace element data. Fourteen longitudinal sections were created using ioGAS geochemical software. Twelve of the longitudinal sections of individual trace elements aided in identifying changes in

both elevation and along strike of the shear zone and relationships of elements in the ore body and structures. Two additional longitudinal sections were contoured to illustrate variations in grade-thickness and true thickness of the deposit.

Two correlation matrices using trace element data were created in ioGAS using the Spearman correlation matrix. These correlation matrices were established in order to analyze the overall geochemical signature of the Galena Vein trace element signature and then just the shear zone signature without the Galena Vein intercepts.

### *Previous Work*

There have been numerous Santa Fe Pacific Gold Company and NMC internal reports, and a few Twin Creek scientific papers that have briefly mentioned the VVSZ deposit. However, over the last 18 years, there has been limited research focused on the VVSZ deposit. Osterberg and Guilbert (1991) dated illite at 107 and 92 Ma by the K-Ar method in two samples of altered basalt near the Trench Fault from drill holes DCH-038 and DCH-182. The discovery of the VVSZ was noted in a Santa Fe internal report in April of 1995. Breit et al. (2005) dated zircons of  $114 \pm 2$  Ma by the U-Pb method in a mineralized plagioclase-biotite-quartz porphyritic dacite dike that is cut by the Trench Fault.

McComb (2010) wrote the first detailed petrographic report on 17 core samples from drill hole TWD-01372. In this petrographic report samples from TWD-01372 were submitted for SEM/EDS analysis from the interval 291.8-294.2'. Semi-quantitative SEM/EDS analysis indicated that the later brownish sulfide rimming and replacing pyrite

and marcasite had an approximate formula of  $\text{Fe}_{1.5}\text{AsS}_{2.8}$  (Fig. 2).

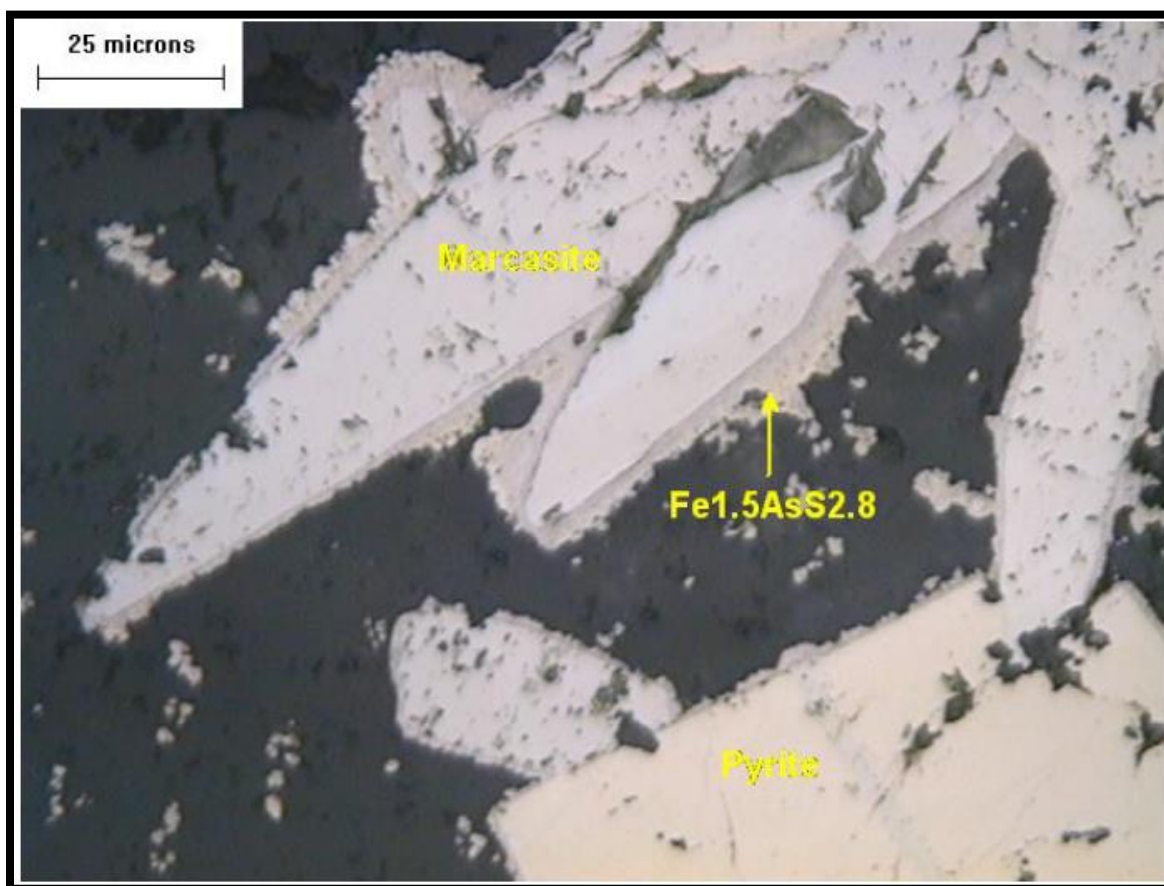


Figure 2. Photomicrograph showing a brownish sulfide that is rimming pyrite and marcasite and, as shown by SEM/EDS to have an average calculated formula of  $\text{Fe}_{1.5}\text{AsS}_{2.8}$  (McComb, 2010).

With the assumption that arsenic is substituting for sulfur, this rimming phase could be arsenian pyrite that is enriched in arsenic and possibly gold. McComb (2011) wrote a second petrographic report on 12 core samples from drill holes TWD-01539 and 01544. Gray (2011) wrote the first Newmont internal report that touched briefly on the interpretation of the entire system as well as describing the alteration, mineralogy, and structural controls.

## Chapter 2: Background

### *History of Twin Creeks and Getchell Trend*

The mining history in the surrounding area around TC dates back to 1883, when skarn deposits in the region were mined for precious metals, copper and lead. Skarn deposits are found in this area because of the contact metamorphism between the Osgood Mountain granodiorite stock, and a shale and limestone, which are locally metamorphosed to hornfels and marble (Cail and Cline, 2001). This contact metamorphic aureole extends 3 km outward from the granodiorite stock and consists of calcite-wollastonite-diopside-garnet and tremolite skarnoids (Cline et al., 2008). In 1916, tungsten was found in the skarn systems and was mined episodically for the next forty-four years. Both tungsten and copper-bearing minerals are peripheral to the Osgood Mountain stock (Cail and Cline, 2001). Tungsten mineralization occurs in andradite, diopside, scheelite, and retrograde actinolite-epidote-quartz-scheelite and sulfide assemblages (Cline et al., 2008). In 1934, the miners discovered gold, long before the original Carlin deposit was exploited. The Getchell deposit is notable for being the first Carlin-type gold deposit discovered in Nevada, although not recognized as such (Cline et al., 2008).

The first discovery of gold at TC was in December 1984 at Chimney Creek, owned by Gold Fields Mining Company (GFMC). The second major discovery of gold, made in June of 1987 by Santa Fe Pacific Gold Company (SFPGC), was just to the south of Chimney Creek. SFPGC started up the Rabbit Creek Mine two years later in 1989 (Breit et al., 2005).

Hanson Natural Resources Company (HNRC) acquired GFMC in 1991. With the exchange of assets by HNRC and SFPGC in 1993, the Rabbit Creek and Chimney Creek mines were combined to form the Twin Creeks mine. A few years later in 1997, SFPGC merged with NMC, the present owner and operator (Breit et al., 2005).

In the deposits of the Getchell Trend (Fig. 1) gold mineralization is generally associated with structural highs, N-S and NE striking faults, and distinct hydrothermal alteration. The gold occurs as sub-micron particles in arsenian pyrite, a signature characteristic of Carlin-type systems. Gold is mined in the lower Ordovician Comus Formation, Ordovician Valmy Formation, and the lower Pennsylvanian-Permian Etchart Formation. Gold in the Comus is typically stratiform and stratabound; the Valmy gold mineralization tends to be fracture controlled; and the Etchart mineralization tends to be stratiform and associated with decarbonated rocks.

#### *Discovery/exploration of the Vista Vein shear zone deposit*

The Galena Vein was discovered in April of 1995 by SFPGC. SFPGC drilled CTW-341, which targeted a down dip extension of a possible structure. This structure was originally intercepted in drill hole N92-88 (SFPGC internal report, 1995). In CTW-341, mineralization was found to be concentrated along a northeast trending structure with a dip ranging between 70 – 80° NW. The hole combined a five foot intercept of 1.294 opt gold that was concentrated within a 1 foot wide quartz, galena, sphalerite, arsenopyrite, and pyrite vein, which was given the name, Galena Vein (SFPGC internal report, 1995). The Galena Vein underground drill program was developed in March of 1996, to test the possibility of a gold-bearing high-grade structure on 200-foot centers,

and to delineate underground mineable reserves. To date, NMC has drilled a total of approximately 326 Vista Underground Core (VUC) drill holes. Two of the last three VUC holes drilled in the central and southern end of the deposit had intercepts that doubled the true thickness of the mineralized shear zone from the block model prediction. The intercepts for VUC-00324 had a true thickness of 19.5 feet at 0.450 opt gold. The intercepts for VUC-00282 had a true thickness of 10.4 feet at 0.442 opt gold. In May of 2013 the Vista underground exploration project was halted due to capital cost reductions and redirection of finances to more profitable NMC projects in Nevada.

### **Chapter 3: Regional Geology**

Twin Creeks is situated slightly northeast of the Getchell and Turquoise Ridge Joint Venture underground mines (Figs. 1 and 3). The dominant topographic feature in the Potosi Mining district is the Osgood Mountain Range. The Dry Hills are just northeast of the Osgood Mountains. Most of the rocks that underlie the Osgood Mountains and the Dry Hills are Paleozoic sedimentary rocks, with the exception of the Cretaceous Osgood Mountain pluton (Breit et al., 2005). The Getchell Trend lies on the east side of the Osgood Mountains and is one of the primary mineral belts in northern Nevada.

The Cambrian Osgood Mountains Formation comprises the oldest rocks exposed in the Potosi Mining District and is believed to have a thickness of 5,000 feet (Breit et al., 2005). The Osgood Mountains Formation is composed of quartzites that contain 90-95% quartz, with minor amounts of chert, feldspar, sericite, zircon, tourmaline, sphene and leucoxene (Willden, 1964). The upper Cambrian Preble Formation overlies the Osgood



Mountains Formation and is comprised of shale with interbedded limestone (Willden, 1964). This stratigraphy has been severely folded, faulted, and deformed during two or more major orogenies (Breit et al., 2005).

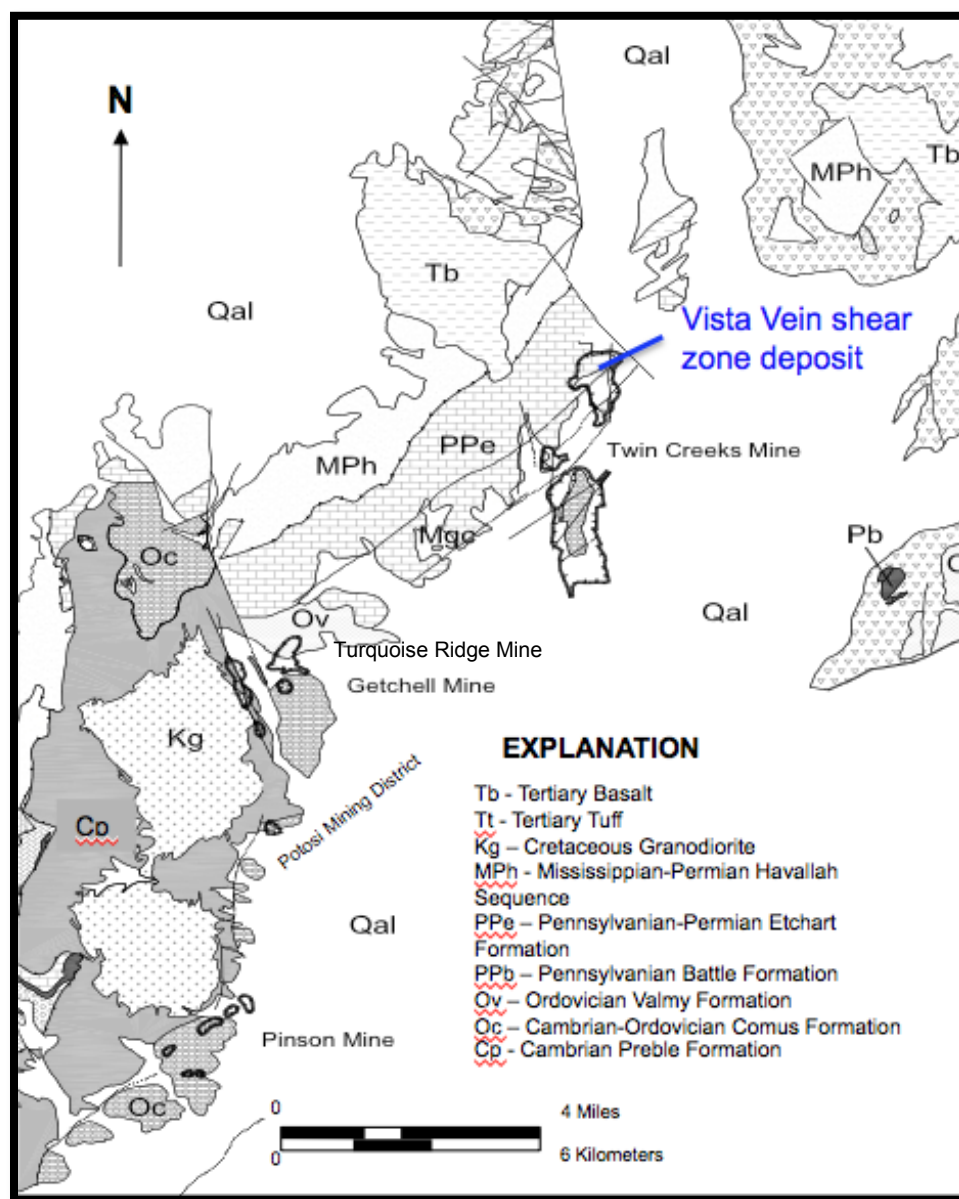


Figure 3. Regional geologic map of the Osgood Mountain and Dry Hills area where the Vista Vein shear zone deposit is located (modified from Breit et al., 2005).

The oldest rocks at Twin Creeks are the upper Cambrian Preble Formation (Fig. 4), known only from drillholes. This formation consists of limestone, phyllite, and argillite (Breit et al., 2005).

The Cambrian - Ordovician Comus Formation is composed of siltstones, silty limestone, volcanic debris flows, and tuff. The Comus sits unconformably above the Preble (Breit et al., 2005). The Ordovician Valmy Formation was thrust on top of the Comus rocks during the Mississippian along the Roberts Mountain Thrust (Breit et al., 2005). At Twin Creeks, the contact between the Valmy and Comus, is a northwest dipping fault also thought to be the Roberts Mountain Thrust (Breit et al., 2005). Valmy rocks are upper plate rocks composed of pillow basalts, massive basalt, volcanoclastic sediments, and siliceous mudstones. Lying unconformably above the Valmy Formation is the Antler overlap sequence of the Pennsylvanian-Permian Etchart Formation (Breit et al., 2005). The Mississippian-Permian Havallah Formation was placed above the Etchart rocks along the Golconda Thrust. The entire Twin Creeks deposit is overlain by 0-700 feet of Tertiary volcanics and Quaternary alluvium (Breit et al., 2005).

## **Chapter 4: Local Geology**

### *Stratigraphy*

Rocks at Twin Creeks range in age from Cambrian to Quaternary (Breit et al., 2005). The major formations that make up the stratigraphy at Twin Creeks, ranging from oldest to youngest, (Fig. 4) include: the Upper Preble, Comus, Valmy, Etchart, and Havallah Formations. The most recent geologic map of the Twin Creeks mine is shown in Figure 5.

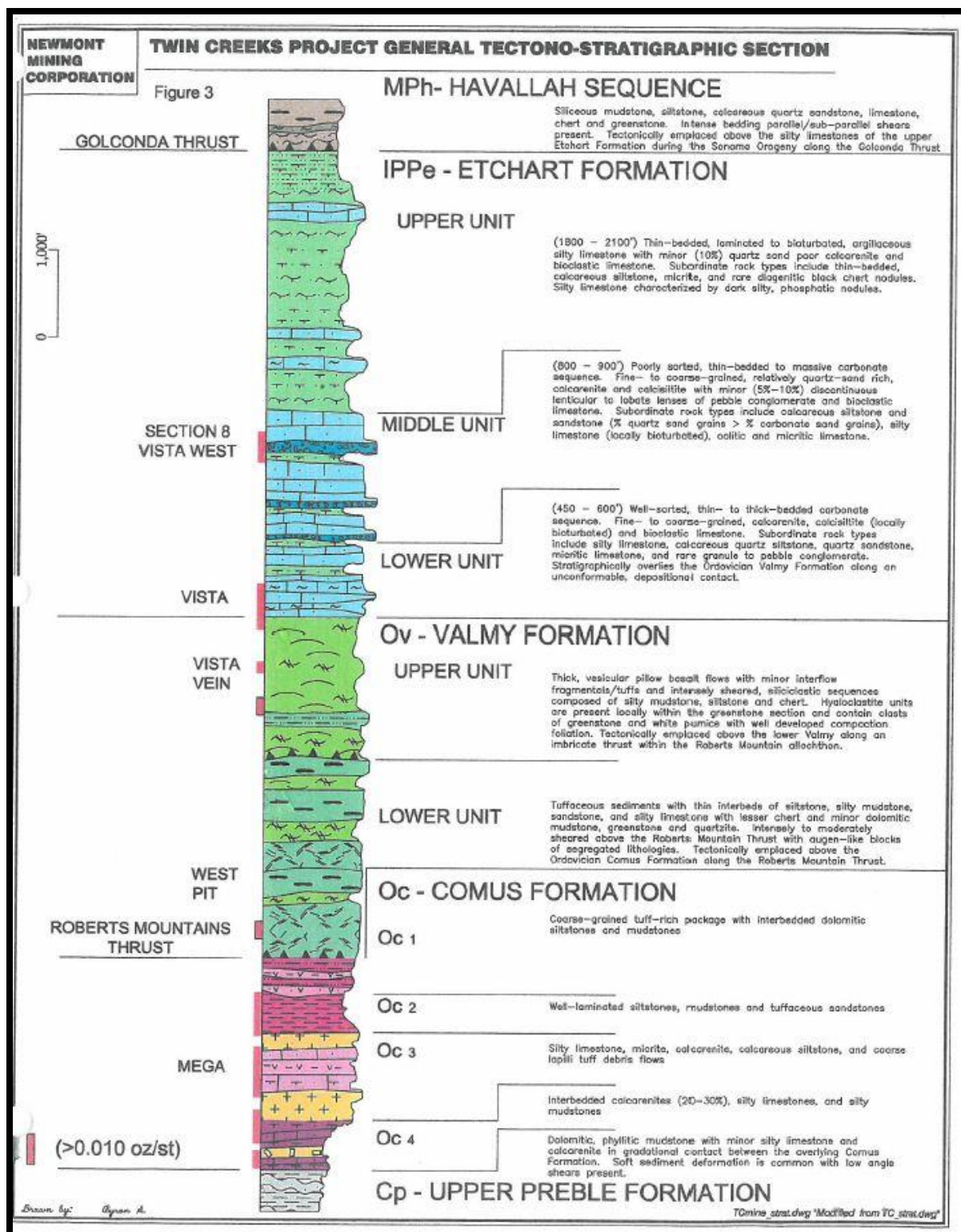


Figure 4. Stratigraphic column of Twin Creeks local geology, compiled by NMC. The short red bars to the left side of the stratigraphic column indicate the lithology in which gold mineralization is found.

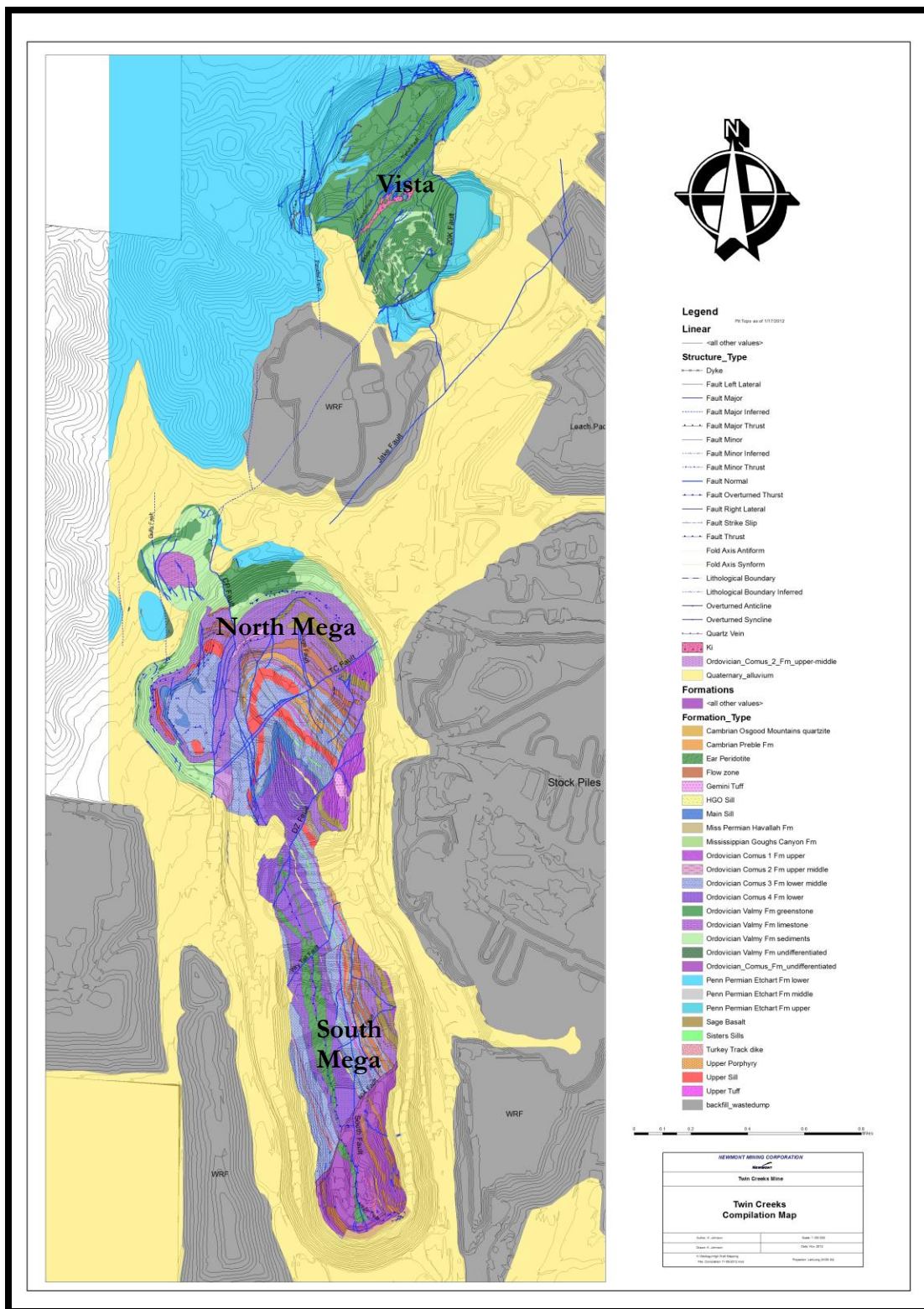


Figure 5. Most recent geologic map of Twin Creeks of the three main open pits: Vista, North Mega and South Mega (NMC).

### *Upper Preble Formation*

The Cambrian Upper Preble Formation is only known from drillhole data and is predominantly laminated silty mudstone (Breit et al., 2005).

### *Comus Formation*

The Ordovician Comus Formation is 1,500 -1,800 feet thick at Twin Creeks mine. The Comus hosted 70 percent of the pre-mine gold reserves at Twin Creeks (Breit et al., 2005). The Comus rocks tend to represent a carbonate slope to basinal plain facies, which include: siltstone, shale, and silty to fine-grained carbonate rocks (Bloomstein et al., 1990). This formation is subdivided into four units: C1, C2, C3, and C4. The lowermost unit, C4, is comprised of interbedded calcarenites, silty limestone, and silty mudstones. The C3 is the best host rock for gold mineralization in the Mega pit and is composed of silty limestone, micrite, calcarenite, calcareous siltstone, and coarse lapilli tuff debris flows (Breit et al., 2005). There are a few reasons that a large concentration of gold is located in the C3. These include numerous basaltic sills (which aided in fluid flow and mineralization dispersal), an extremely thick unit, and thin-bedded silty limestone (Breit et al., 2005). C2 is composed of well-laminated siltstones, mudstones, tuffaceous sandstones, and multiple basaltic sills. The uppermost unit, the C1, is a coarse-grained tuff-rich package with interbedded dolomitic siltstones and mudstones. The gold mineralization in the Comus is localized where the TC and DZ faults intersect at the nose of the Conelea anticline (Stenger et al., 1998). The Conelea anticline, the most important ore controlling structure of the Mega pit, is an overturned, double

plunging anticline that has an axial surface that strikes north-northwest with dips ranging between 25-45° west (Breit et al., 2005).

#### *Valmy Formation*

The Ordovician Valmy Formation is approximately 3000 feet thick, and composed dominantly of pillow basalt, massive flow basalt, siliceous mudstones, and debris flow breccias. On the mine site, the Valmy formation has been divided into two units: the Lower and the Upper. The VVSZ deposit is hosted in the upper unit of the Valmy Formation. Gold mineralization in these basalts tends to be concentrated in veins that form a sooty-sulfide stockwork system (Hall et al., 2000). The basalts of the Valmy Formation likely formed along a volcanic rift that cut across a passive abyssal plain, thus explaining the presence of minor interbedded abyssal sediments.

#### *Etchart Formation*

The Pennsylvanian-Permian Etchart Formation has a regional thickness of 3,600 feet and has been divided into three subunits (Breit et al., 2005). The lower unit, ranges from 50 – 250 feet thick and is composed of calcareous sandstone to sandy limestone, with local quartzite pebble conglomerate at the base (Breit et al., 2005; MacKerrow et al., 1997). The middle unit ranges 50-850 feet in thickness in the Vista pit and is composed of calcareous sandstone, sandy limestone, limestone, and dolomite (MacKerrow et al., 1997). The upper unit has pit exposures of 0 – 450 feet, but the regional thickness is 2000 feet (MacKerrow et al., 1997). The dominant rock types include: siltstone, sandstone, calcarenite, limestone, and conglomerate. These rock types suggest they were accumulated on high-energy continental slope and shelf environments (Breit et al., 2005).

In the Vista pit, the lower unit is the primary host for the gold mineralization (Osterberg, 1990). The distribution of the gold also tends to be closely related to the Trench and Discovery faults (Stenger et al., 1998).

#### *Havallah Formation*

The Mississippian-Permian Havallah Formation has a regional thickness of up to 650 feet (MacKerrow et al., 1997). In the Vista pit, the formation exists as erosional outliers and does not surpass 120 feet in thickness (MacKerrow et al., 1997). It is usually thin-bedded, light brown calcareous sandstone interbedded with gray, thin-bedded chert (Breit et al., 2005). North of the Vista pit on the TC mine site, the Havallah consists of sandstone, greenstone, siltstone, chert, and tuff (MacKerrow et al., 1997).

#### *Alteration*

There are four stages of alteration and mineralization represented at Twin Creeks, as shown in Figure 6 (Breit et al., 2005). The first stage is a regional propylitic alteration event that altered rocks of the Comus and Valmy Formations. Pillow basalts of the Valmy are gray black to medium green gray and have an abundance of carbonate and chlorite within the groundmass (Gray, 2011). Primary minerals such as pyroxene, olivine, and calcic plagioclase are replaced by chlorite, albite, talc, and calcite. This propylitic alteration event is possibly related to basalt interacting with seawater during emplacement (Breit et al., 2005).

Dikes cross-cutting the Etchart Formation in Vista pit express phyllic (quartz-sericite-pyrite QSP) alteration. The Valmy Formation also experienced phyllic alteration and quartz seems to be associated with higher-grade ore zones (Gray, 2011). Osterberg

and Guilbert (1991) dated sericite from a dike from Vista pit that gave  $117.3 \pm 2.7$  Ma K-Ar. Hall et al. (2000) dated illite using Ar-Ar dating and calculated ages between 105 – 107 Ma.

The third stage of alteration was silicification and decarbonatization in the Eocene. These alteration events pre-date gold mineralization. In the Comus Formation, carbonate sedimentary rocks adjacent to basaltic sills have experienced silicification. These carbonate rocks have vuggy silica textures and have ample fractures that developed normal to bedding (Breit et al., 2005). Adularia is actually found in the hanging wall of the TC fault zone, but is not noted to be found anywhere else on the property. The Etchart Formation experienced replacement silicification of carbonate units, which Osterberg (1990) referred to as bedded jasperoids.

In both the Comus and Etchart Formations, decarbonatization of carbonate rocks was an important ground-preparation event for the later gold mineralization. These decarbonatized rocks acted as porous and permeable zones that gold-rich fluids could easily flow through (Breit et al., 2005). In the Valmy Formation, stage 3 alteration exhibited a later argillic alteration event that overprinted the phyllic alteration. Pervasive argillic alteration in the Valmy basalt is concentrated near northeast-striking faults that acted as feeders for gold mineralization (Breit et al., 2005).

The fourth stage of alteration was related to supergene processes that resulted in oxidation of the Etchart Formation and the C3 and C4 units of the Comus Formation. The deep oxidation event was probably facilitated by secondary permeability of major fault zones and decarbonatized, highly porous and permeable rocks (Breit et al., 2005).



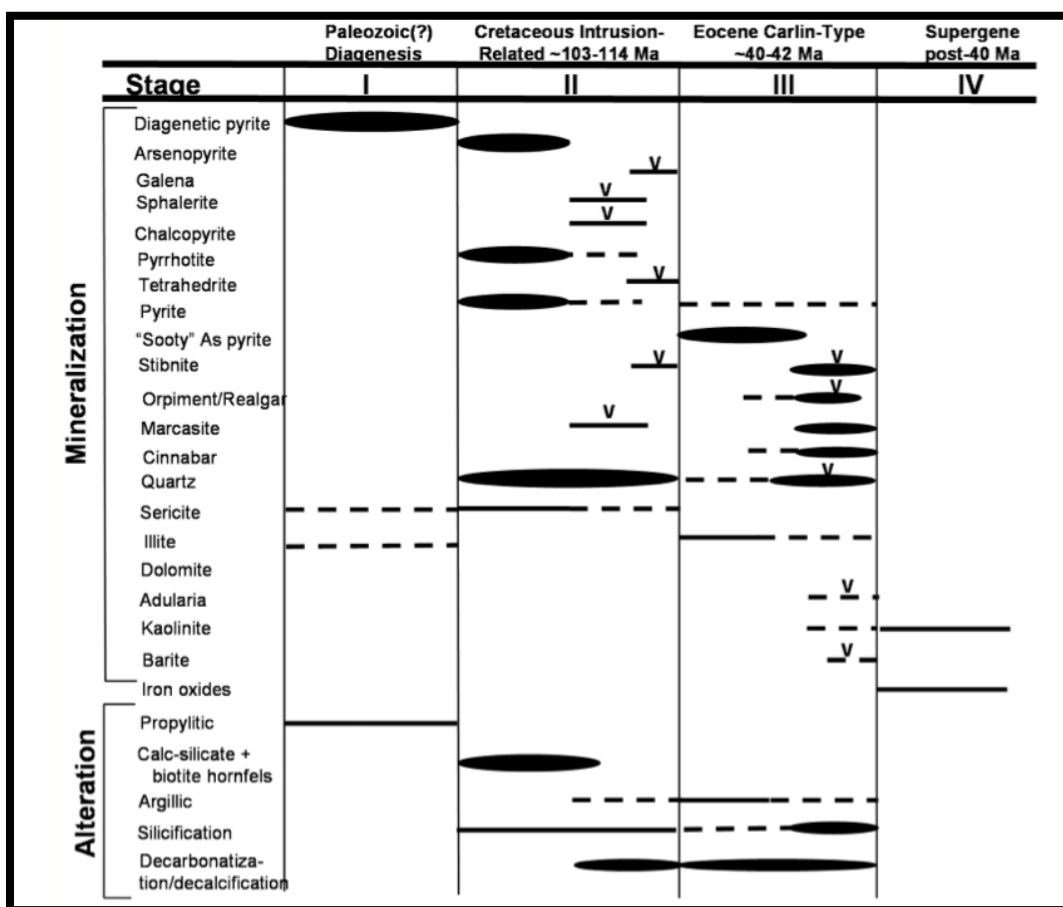


Figure 6. Four stages of alteration and mineralization of the Twin Creeks deposit (Breit et al., 2005).

## Chapter 5: Deposit Geology

The VVSZ deposit is hosted entirely within the upper unit of the Ordovician Valmy (Ov) Formation. It has a mineable strike length of 4600 feet and strikes N 40-45° E, and a dip length of 1000 feet and dips 65-70° NW. There is an ore shoot that has a rake of 35 degrees to the northeast. The ore consists of disseminated gold in arsenian pyrite and marcasite in the VVSZ, which is part of the Trench fault. The deposit is named the "Vista Vein" because of the brecciated quartz-base metal vein, historically

known as the Galena Vein that occurs within the shear zone of the Trench fault system (Fig.7).

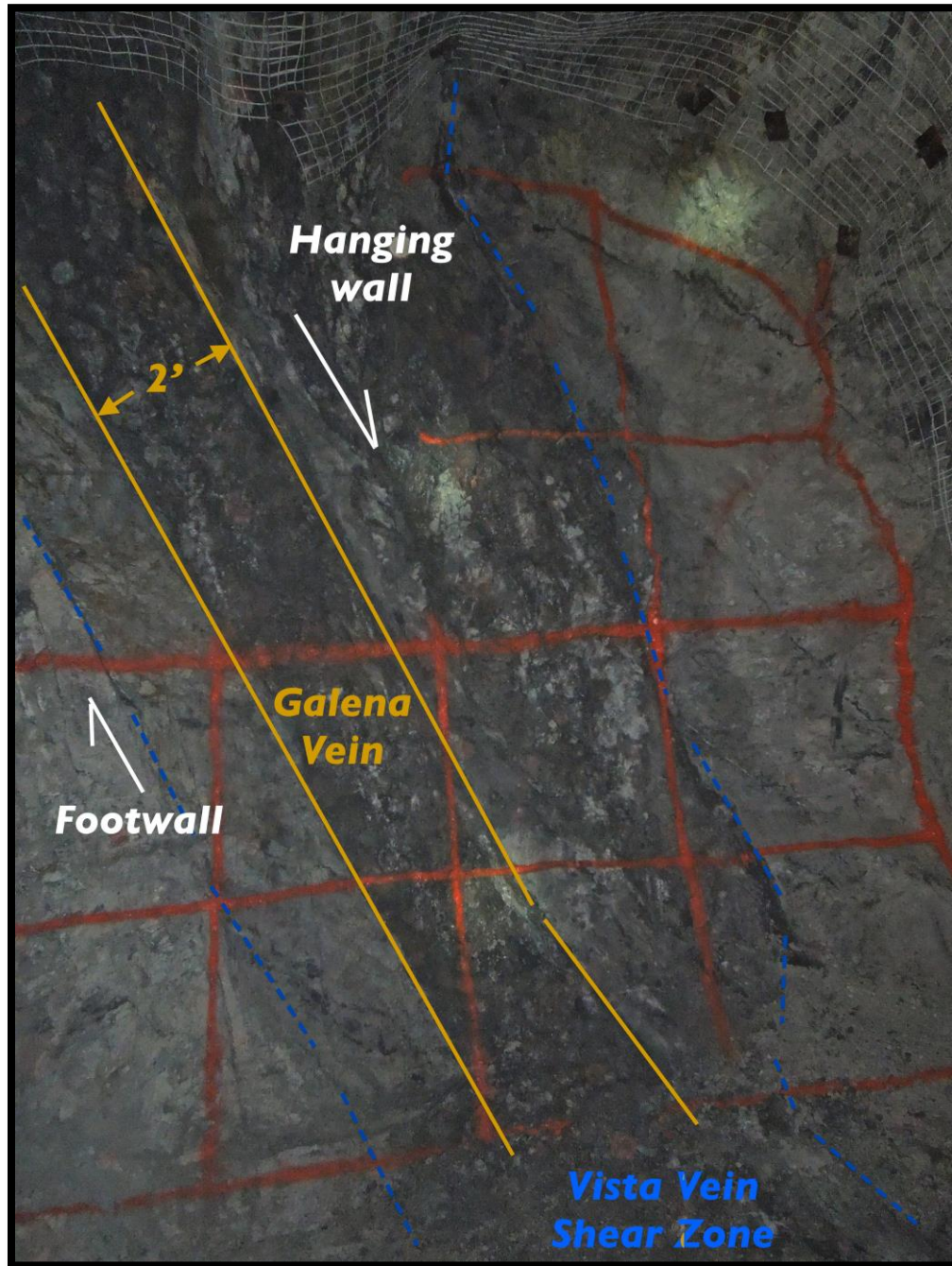


Figure 7. Underground exposure of the Vista Vein shear zone (outlined in blue). Outlined in orange is the brecciated quartz-base metal vein that is approximately 2 ft wide. This shear zone is about 8 ft wide in this photograph.

The “Vista Vein” name is misleading in that it implies a vein-hosted deposit, when, in fact, it is a shear zone hosted deposit. With the benefit of two years of drilling, it is now clear that the shear zone controls the ore (Berg, 2013). The deposit has an average true thickness of 6 to 10 feet. As of 2014, there is no recognized “ore horizon” with the VVSZ deposit; the only constraint on the extent of gold mineralization is the surface and the 20K fault that truncates the Vista Vein deposit up-dip to the northeast. The VVSZ deposit has great potential for expansion because it remains open down-dip and along strike to the north.

#### *Lithologic Descriptions*

The Ordovician Valmy Formation, approximately 3000 feet thick, belongs to the upper plate rocks of the Roberts Mountains Thrust and is divided into upper and lower units. The upper unit of the Valmy Formation is the host to the VVSZ deposit. The upper unit rock package is dominated by pillow basalts and massive basalts, with minor siliceous mudstones, debris flows, and volcanoclastic sediments.

The depositional environment of the Valmy remains to be determined. It is a marine deposit and paleogeographic reconstructions suggest it was not too distant from the western edge of the continental platform, but in a submarine volcanic setting. The lower Paleozoic margin is believed to have been a passive margin where volcanism is not a common feature. Perhaps the Valmy was formed in a localized rift near the edge of the continental rise, where submarine pillow lavas, massive sheet lavas, and debris flow breccias could have been deposited.

### *Pillow basalts*

The regional propylitically altered basalts are light to dark green gray in color with a groundmass that is aphanitic to fine grained. The mineral assemblage in the basalt groundmass consists of actinolite, calcite, chlorite, and epidote. The pillows seen in drill core (Fig. 8) tend to occur in irregular masses and/or layers within the Valmy basalts. In outcrop, pillows are rounded, aphanitic, and crowded on top of one another, and are  $\leq 2$  feet in length. Most pillow margins are zoned with a brown quenched partially devitrified palagonite rind that is  $\leq 1$  inch thick. These rocks tend to be highly reactive to HCl on account of the carbonate introduced during the propylitic alteration and weak to moderately strong calcite veining. Vesicles are found along the pillow margins and are filled with either quartz or carbonate.



Figure 8. Core box photograph from VUC-00170 of propylitically altered pillow basalt.

### *Massive basalt*

The regional propylitically altered massive basalts (Fig. 9) are light to dark green and range from finely- to coarsely- crystalline with a felty texture as seen in drill core. These massive basalts are crosscut by abundant calcite veinlets that are less than two inches in thickness. The massive basalt can also have vesicles that are filled with carbonate and quartz.



Figure 9. Core box photograph from VUC-00002 of propylitically altered massive basalt.

### *Siliceous mudstones*

Siliceous mudstones (Fig. 10) are a minor component in the upper unit, but in drill core are finely laminated, sheared, and locally brecciated. Mudstones would have been deposited during stages of quiescence, as originally suggested by Gray (2011).

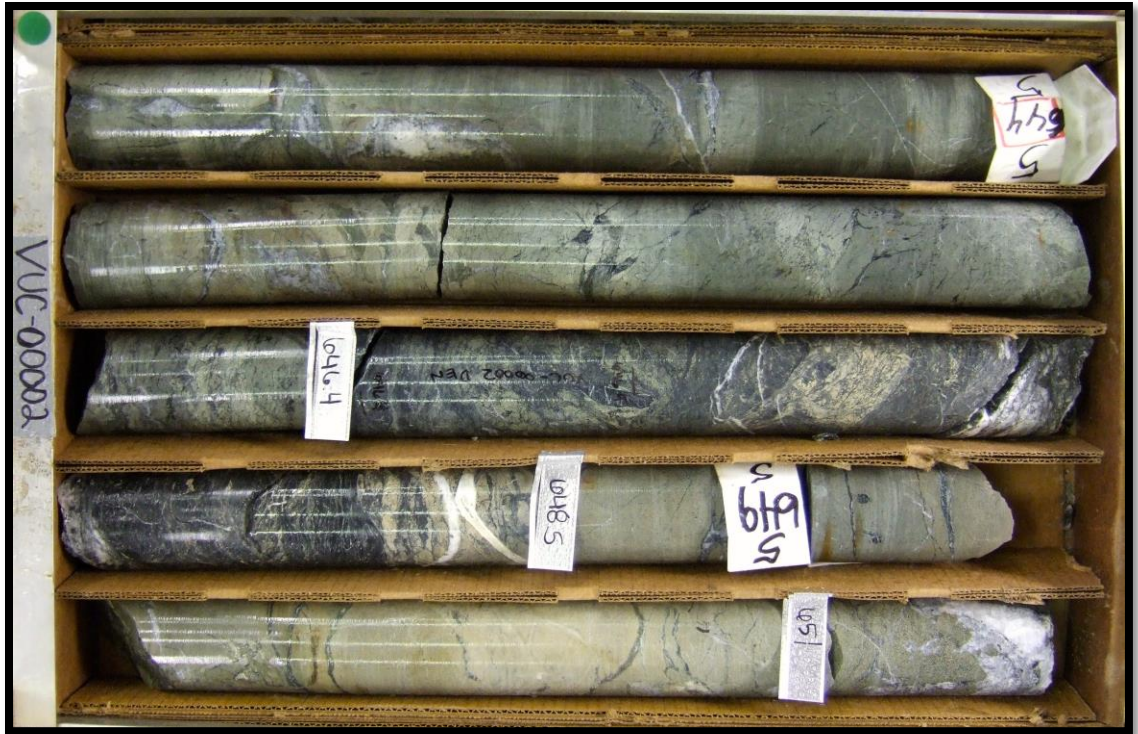


Figure 10. Core box photograph from VUC-00002 of siliceous mudstones from 646.4-648.5'.

### *Flow breccias*

Flow breccias (Fig. 11) are interlayered with the massive and pillow basalts. Flow breccias typically occur at the top of a basalt flow/ basal part of the overlying flow. These breccias result when basalt flows over solidified basalt (Gray, 2011). As the basalt flows over the older basalt, it fractures and picks up clasts to create the breccia. These flow breccias have sub-angular to angular clasts of basalt and have a fragmental matrix composed of carbonate and glass. Clasts can be up to 3 inches in length.



Figure 11. Core box photograph from VUC-00002 of a flow breccia.

## Chapter 6: Structure of the deposit

### *Methods*

Using ioGAS software three longitudinal sections were developed in order to show: gold by fire assay (AuFA) contours (Fig. 12), True Thickness contours (Fig. 13), and Grade x Thickness contours (Fig. 14) along the plane of the deposit. Two longitudinal sections along the plane of the vein were hand contoured in order to show the variation of strike and dip within the VVSZ deposit. The strikes and dips were calculated using core data and Vulcan software, which in effect solves a three-point problem between the drill hole intersections with the footwall (Figs. 14 & 15).

### *Major structures in Vista Vein shear zone vicinity*

Structural controls on mineralization in the Vista Pit area are northeast-striking faults that cut both the Valmy and Etchart Formations. The bulk of the Vista Pit gold mineralization is controlled by the Valmy-Etchart unconformity, whereas the VVSZ deposit is a fault zone-controlled high-grade ore deposit (Breit et al., 2005). Breit et al. (2005) proposed that the Trench fault acted as a feeder to the overlying disseminated gold mineralization in the Etchart Formation. The VVSZ deposit formed along the shear zone of the Trench fault, which was described by Gray (2011) as a shear zone with a set of internal sub-parallel sheeted shears. The 20,000 fault (also referred to as the 20K fault) is a low angle, east dipping normal fault that strikes north-south. The 20K fault truncates the VVSZ deposit up dip to the east, but the VVSZ deposit remains open for exploration down dip. The 20K fault cuts across the northeast side of the Vista Pit and has post-



mineral movement, down-dropping Quaternary alluvium against the lower Etchart Formation in the northeast high wall of the pit (Gray, 2011).

*Vista Vein shear zone AuFA, True Thickness, and Grade x Thickness contours*

These next three longitudinal sections shown in Figures 12 through 14 were created in ioGAS software. Three hundred and thirty-six drill holes with 337 intercepts were used for all three sections. The portion of the deposit that is measured and eligible for conversion to reserves is controlled by 65-foot drill hole spacing. The remainder of the resource has drill hole spacing between 100 and 300 feet.

The VVSZ gold (fire assay (AuFA), reported in ounces per ton) longitudinal section (Fig. 12) shows an ore shoot with a rake of approximately 35° NE. Average gold grades in the VVSZ deposit were calculated at 0.28 oz/ton. The spatial distributions of gold values greater than 0.26 oz/ton are concentrated in the northern deeper part of the deposit. The highest gold values increase at depth to the north with most values above 0.5 oz/ton and a few intercepts above 1.0 oz/ton. Less drilling has been done in the southern end of the deposit, where drill holes are farther spaced.

The VVSZ True Thickness longitudinal section (Fig. 13), reported in feet, shows thickness values increasing at depth to the north of the deposit. The calculated average thickness is 8 feet for the Vista Vein ore deposit. The longitudinal section shows a maximum thickness of 27 feet thick at an elevation of 4,110 feet above sea level. This extremely thick interval is most likely the result of multiple branches of mineralized rocks, which are separated by lower grade mineralized rock. For the model the entire

zone was grouped into one interval. The true thickness and AuFA contours show similar spatial distributions of higher gold grade and greater thicknesses at depth to the north.

The VVSZ Grade x Thickness (GT) longitudinal section (Fig. 14), reported in oz/ton x feet, shows GT values increasing at depth to the north in the deposit. The average GT value calculated was 2.3. The largest GT value contour is at 9.95. All three longitudinal sections: AuFA, True Thickness, and Grade Thickness, show promising future targets for expansion of the Vista Vein ore deposit at depth towards the north.

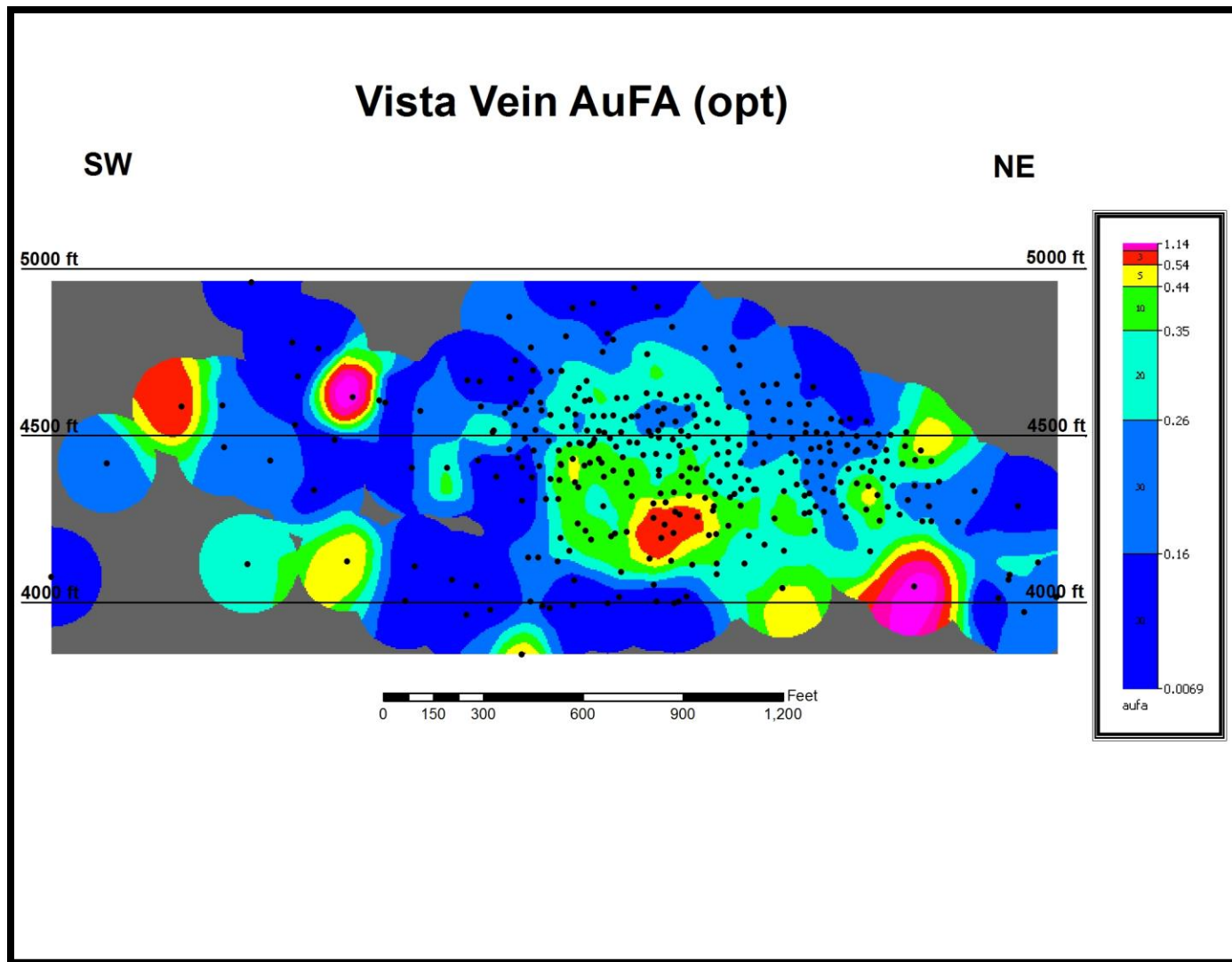


Figure 12. Gold (fire assay) contours projected onto the footwall of the Vista Vein shear zone. The black dots are drill hole pierce points. Note the northeast-plunging zone in green from middle center to lower right of the section. This represents the ore shoot with gold grades greater than 0.26 opt.

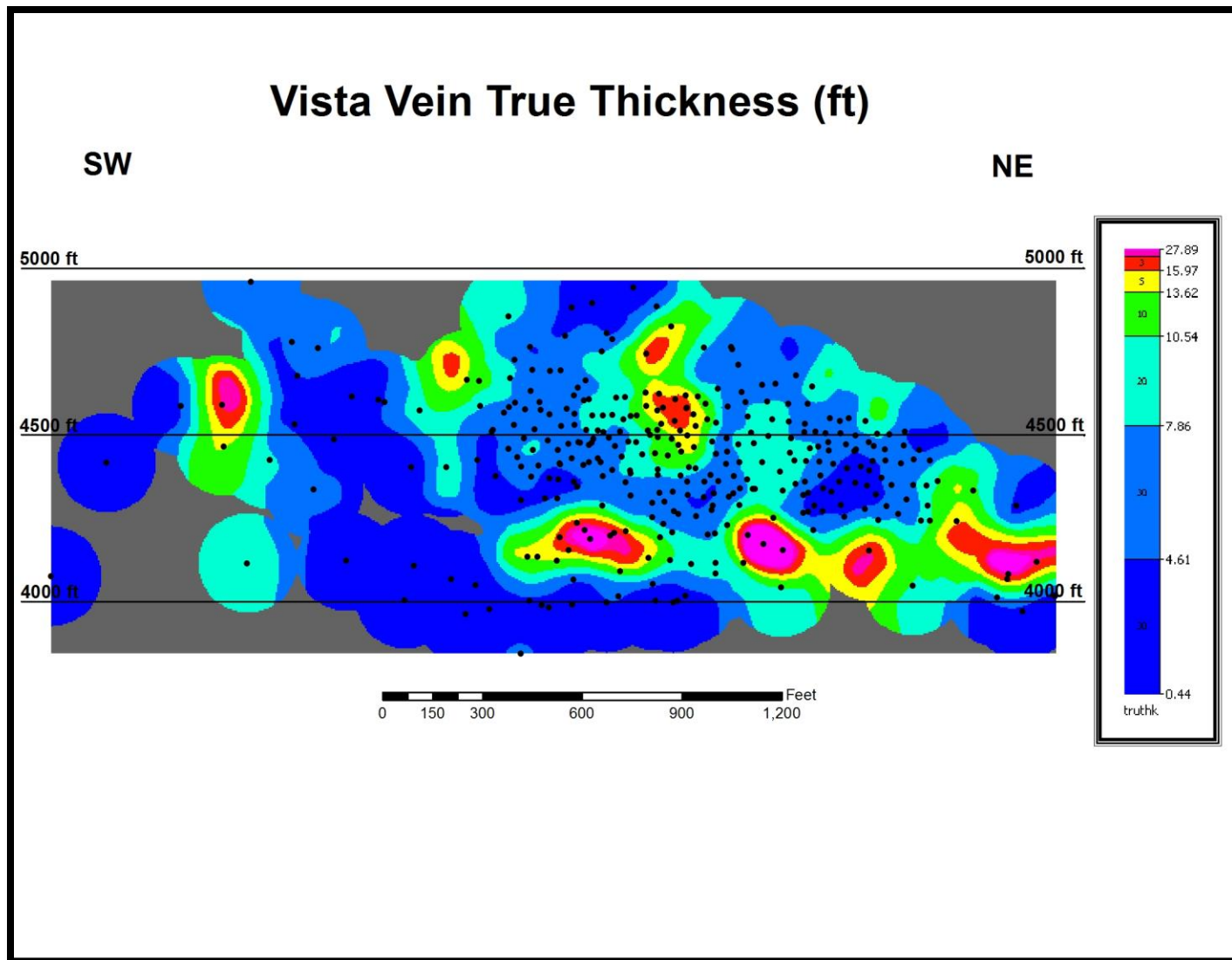


Figure 13. True Thickness contours (feet) projected onto the footwall of the Vista Vein shear zone. The black dots are drill hole pierce points. At depth to the north, the shear zone increases in thickness with values that range from 8-27 feet.

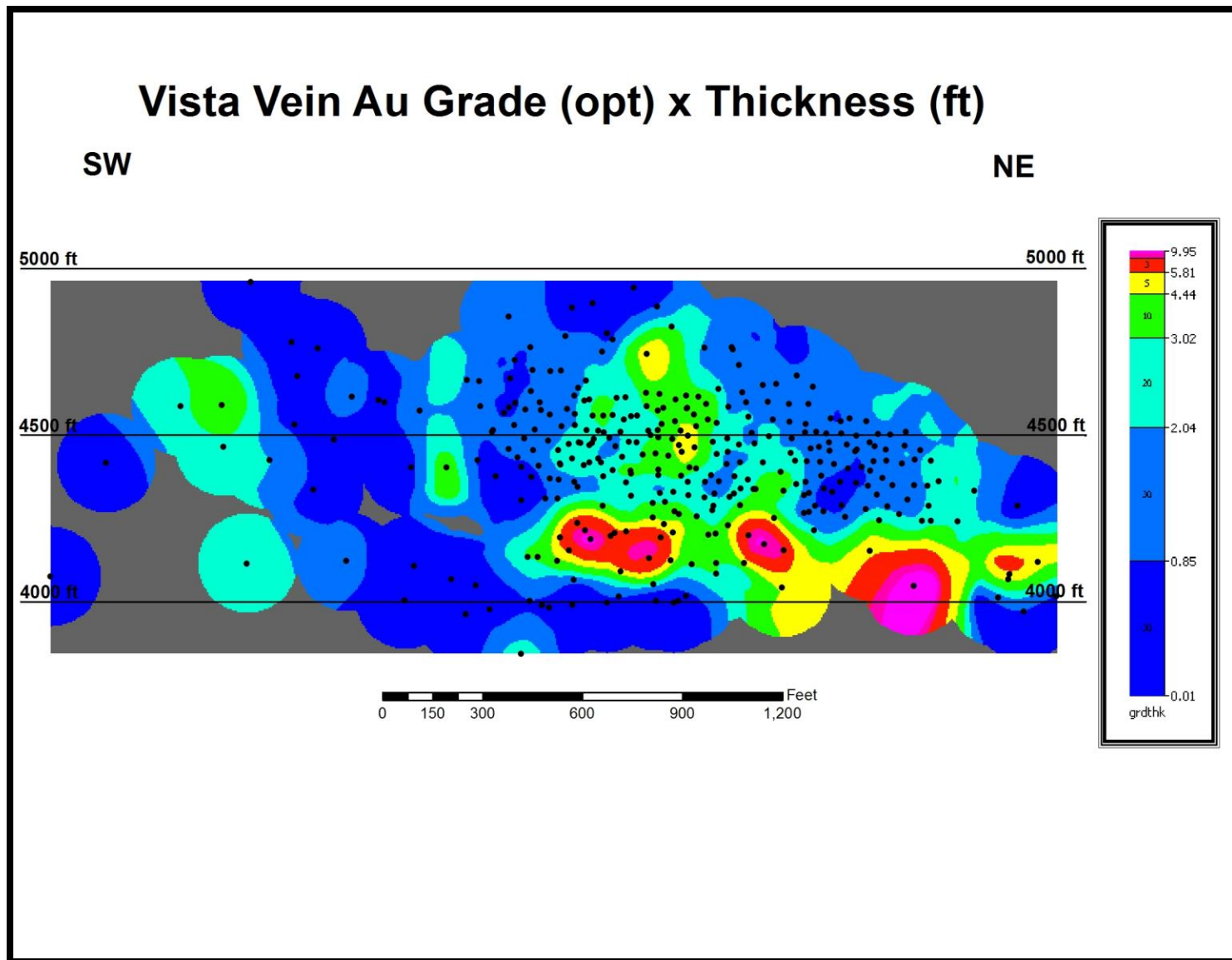


Figure 14. Grade Thickness contours projected onto the footwall of the Vista Vein shear zone. The black dots are drill hole pierce points. The shear zone increases in grade thickness at depth to the north.

*Vista Vein shear zone strike and dip variations*

The VVSZ strikes N40-45° E with an average dip of 65-70° NW. The variations of both strike and dip along the footwall of the deposit were contoured using both Vulcan software and ArcGIS (Figs. 15 and 16). The Vulcan software in effect solves the three-point problem based on the intersection of the individual core drill holes with the footwall of the Vista Vein shear zone. Comparing the values of AuFA (Fig. 12) with the dip variation longitudinal section (Fig. 16) one can conclude that higher gold values correlate with steeper dip values ranging between 70-90 degrees. The VVSZ ore shoot has a rake of 35 degrees and also correlates with the steeper dip values.

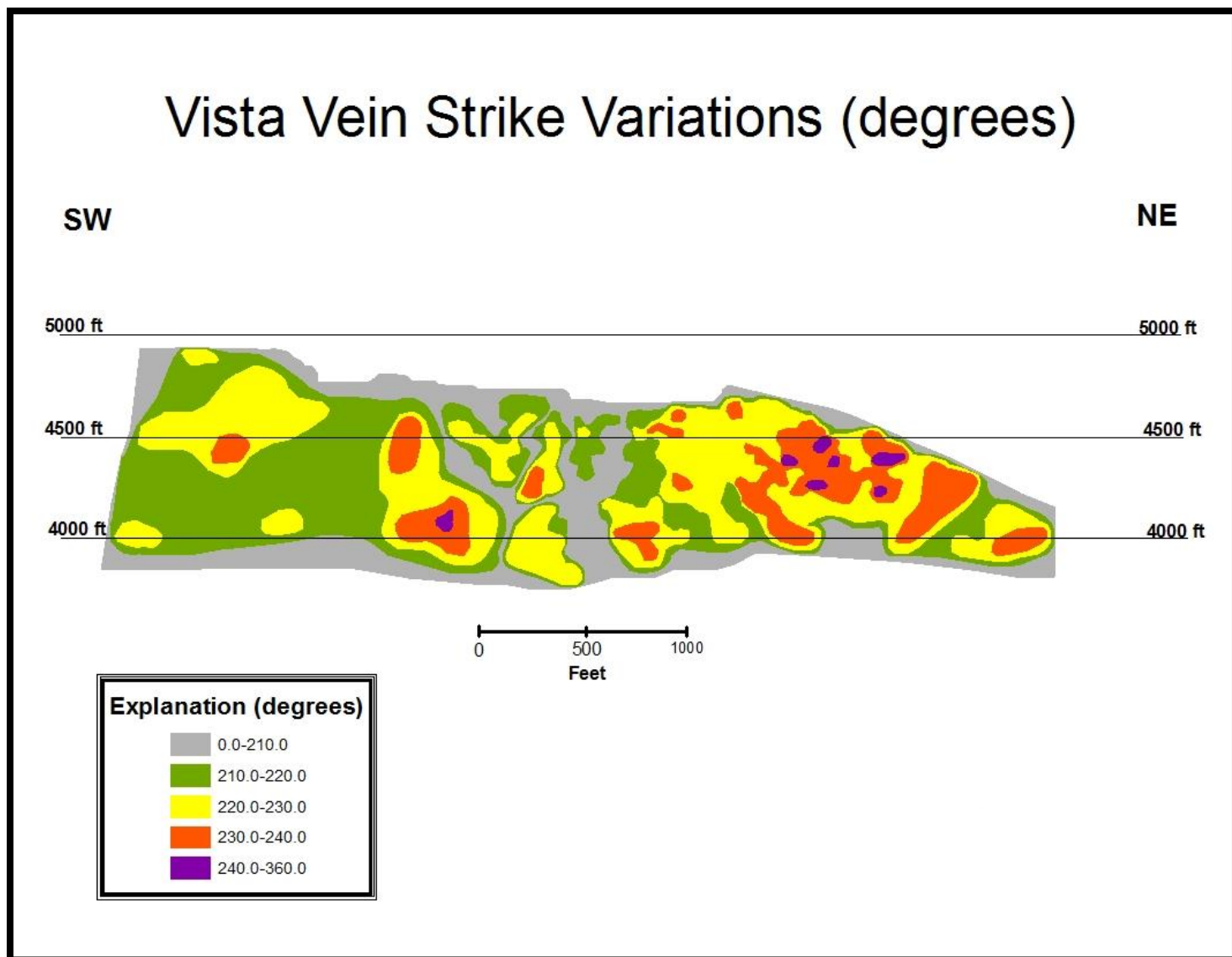


Figure 15. Contours of the variation in strike projected along the footwall of the Vista Vein shear zone. When Figures 12 and 15 are compared it is clear that the ore shoot of Figure 12 is correlative with strike directions between 230 and 240 degrees.

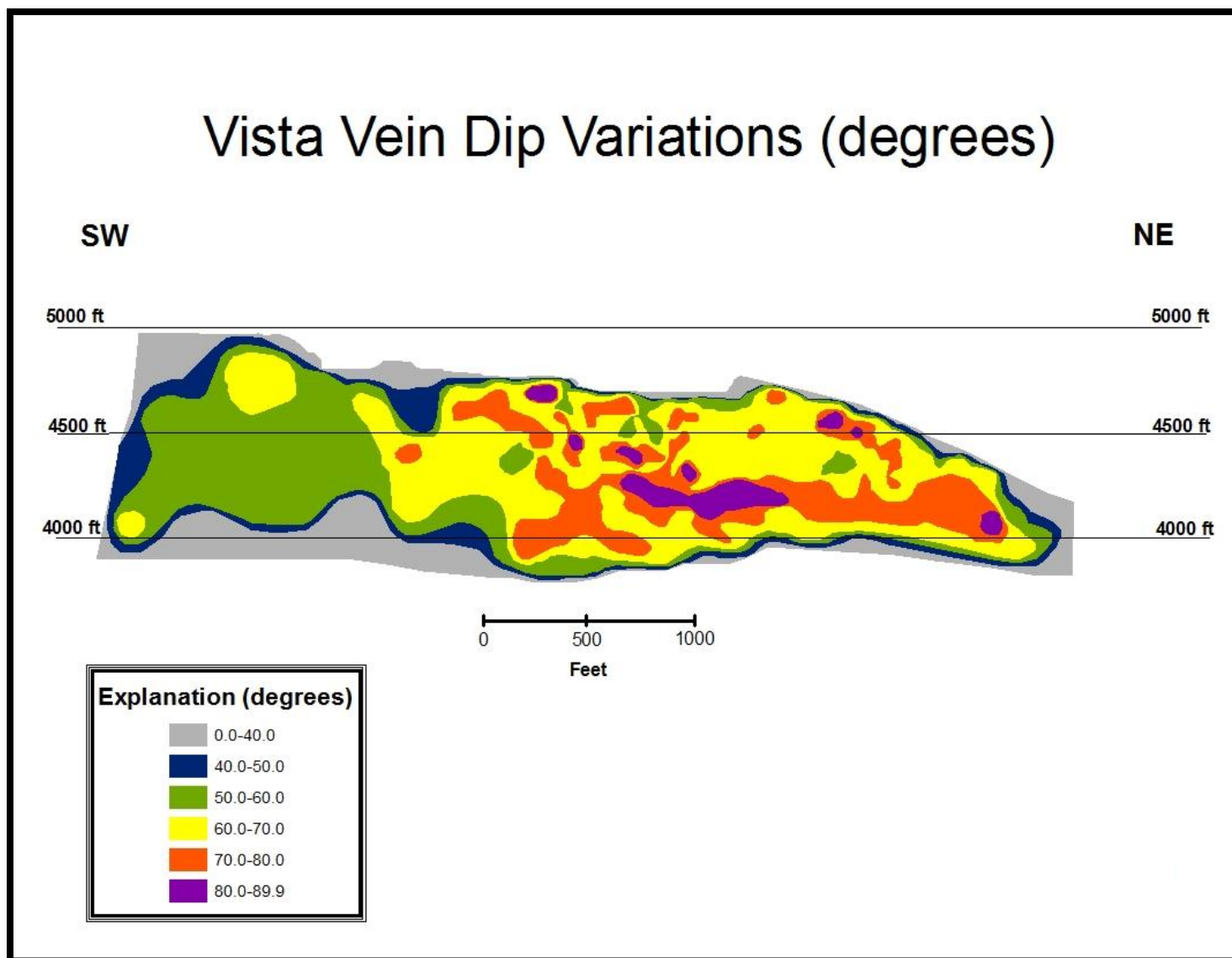


Figure 16. Contours of the variation of dips projected along the footwall of the Vista Vein shear zone. When Figures 12 and 16 are compared it is clear that the ore shoot of Figure 16 is correlative with dip angles between 70 and 80 degrees.



### *Secondary controls on mineralization*

A porphyritic dacite dike (Fig.17) that is cut by the VVSZ played a significant role as a secondary control for gold mineralization in the ore deposit.

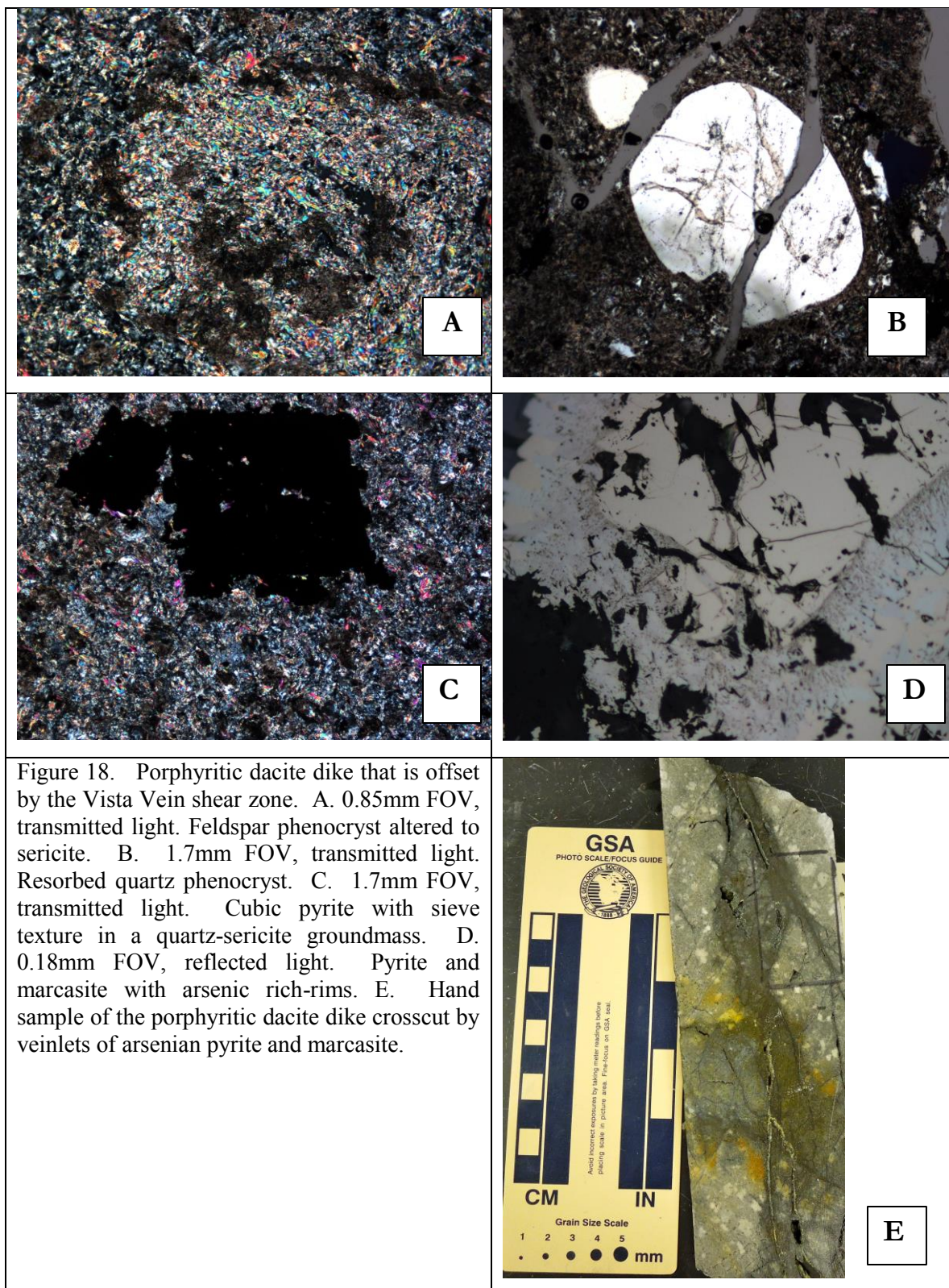


Figure 17. Porphyritic dacite dike that is offset by the Vista Vein shear zone from VUC-00171.

Four polished sections were used to analyze mineralogy, alteration, and paragenesis of the porphyritic dacite dike that is cut by the VVSZ. Similar dikes are observed throughout the Vista pit; zircons in one of these dikes were dated by Breit et al. (2005) by the U/Pb method giving a date of  $114 \pm 2$  Ma. The dike is porphyritic with phenocrysts of altered plagioclase and quartz. Feldspar phenocrysts have been altered to sericite (Fig. 18A) and do not show any remnants of original mineralogy. Quartz phenocrysts are resorbed (Fig. 18B) and are up to 1.0 cm in length. The altered groundmass is fine-grained and composed of quartz, sericite, and carbonate (Fig. 18C). Veinlets of Carlin-type gold mineralization crosscut the dike. These veinlets are  $\leq 3$  mm

in width and are filled with pyrite and marcasite (Fig.18D). The marcasite in the veinlets is subhedral-euhedral and has a feathery texture. In hand sample, the veinlets are dark-gray in color and are typically described in core logs as sooty sulfide veinlets (Fig. 18E).

The dike has phyllic alteration. Pyrite also occurs in the groundmass, where it is subhedral-euhedral in crystal shape with cubic habit,  $\leq 2.0$  mm in length, and in many instances exhibits sieve texture. Some sections have minor low temperature clay alteration. There is a later carbonate event present that is seen in veinlets cutting the dike.



This dike is offset by as much as 200 feet by the fault zone. Vulcan screenshots of the Vista Vein block model show that gold mineralization is confined dominantly to the north side of the dike (Fig. 19).

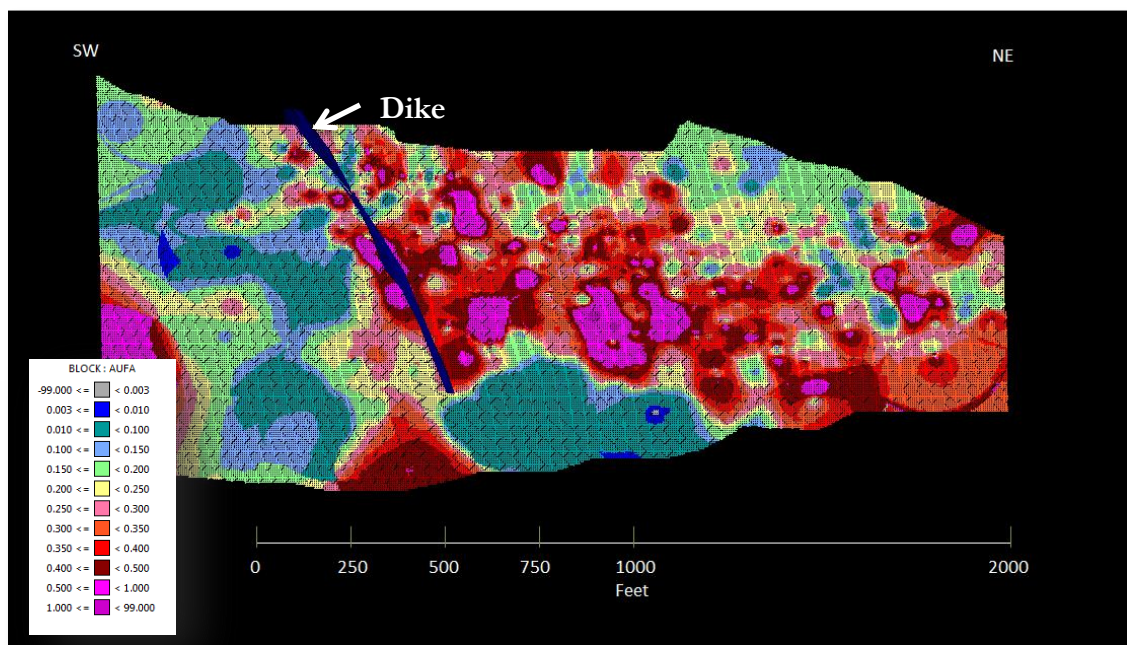


Figure 19. Modeled shape (in blue) of the porphyritic dacite dike on the footwall side of the fault zone projected in the block model. The highest grade gold zones are shown by red and pink tones, whereas the lowest grade gold zones are blue and green tones.

### *Vista Vein Shear Zone*

The VVSZ has a potential mineable strike length of 4600 feet striking N40-45°E and a down-dip extent of a 1000 feet dipping 65-70° NW. It is the zone of brecciated and sheared rock associated with the Trench fault. The shear zone's average thickness is 6-10 feet. The Galena Vein may have followed the initial plane of the Trench fault, but continued movement led to shearing of the vein and widening of the shear zone to eventually form the VVSZ.

The shear zone has been reactivated multiple times and shows strike-slip, normal, and perhaps oblique movement. The shear zone is characterized by four alteration types: phyllic, argillic, decarbonatization, and silicification. The ore in the shear zone is hosted in tectonic breccia, which is the result of rotation and shattering of wall rocks during the shearing event. In the footwall and hanging wall of the VVSZ, crackle breccias occur where the rocks did not experience severe rotational movement. Timing relationships of the tectonic brecciation in the shear zone are not well defined because of alteration and unclear cross-cutting relationships. The main brecciation event took place before silicification and after phyllic alteration (clasts were already sericitized).

The shear zone (Fig. 21) is brecciated and contains clasts of altered wallrock. Clasts of wallrock are pervasively altered to sericite, cemented by microcrystalline quartz, and show no remnants of original mineralogy or textures (Fig. 20A). Opaque mineralogy in the polished sections includes: pre-ore and ore stage pyrite, marcasite, chalcopyrite, galena, and sphalerite. Pyrite can occur as both disseminations and in veinlets. Pyrite and marcasite have arsenic-rich rims. Pyrite is anhedral-subhedral and locally exhibits cubic habit. Arsenian pyrite can also be represented as a brown very fine-grained mineral (Fig. 20B). Marcasite is subhedral-euhedral and occurs in section as feathery laths. The matrix of the fault breccia is mostly composed of microcrystalline quartz, kaolinite, and carbon. Kaolinite is the high temperature clay alteration mineral within the fault zone and is indicative of acidic fluids. Orpiment can be fracture controlled (Fig. 20C) and/or rims marcasite and pyrite (Fig. 20D). There are multiple stages of quartz in polished sections. Quartz occurs as both microcrystalline filling in fractures and/or as grains in clasts (Fig. 20E).

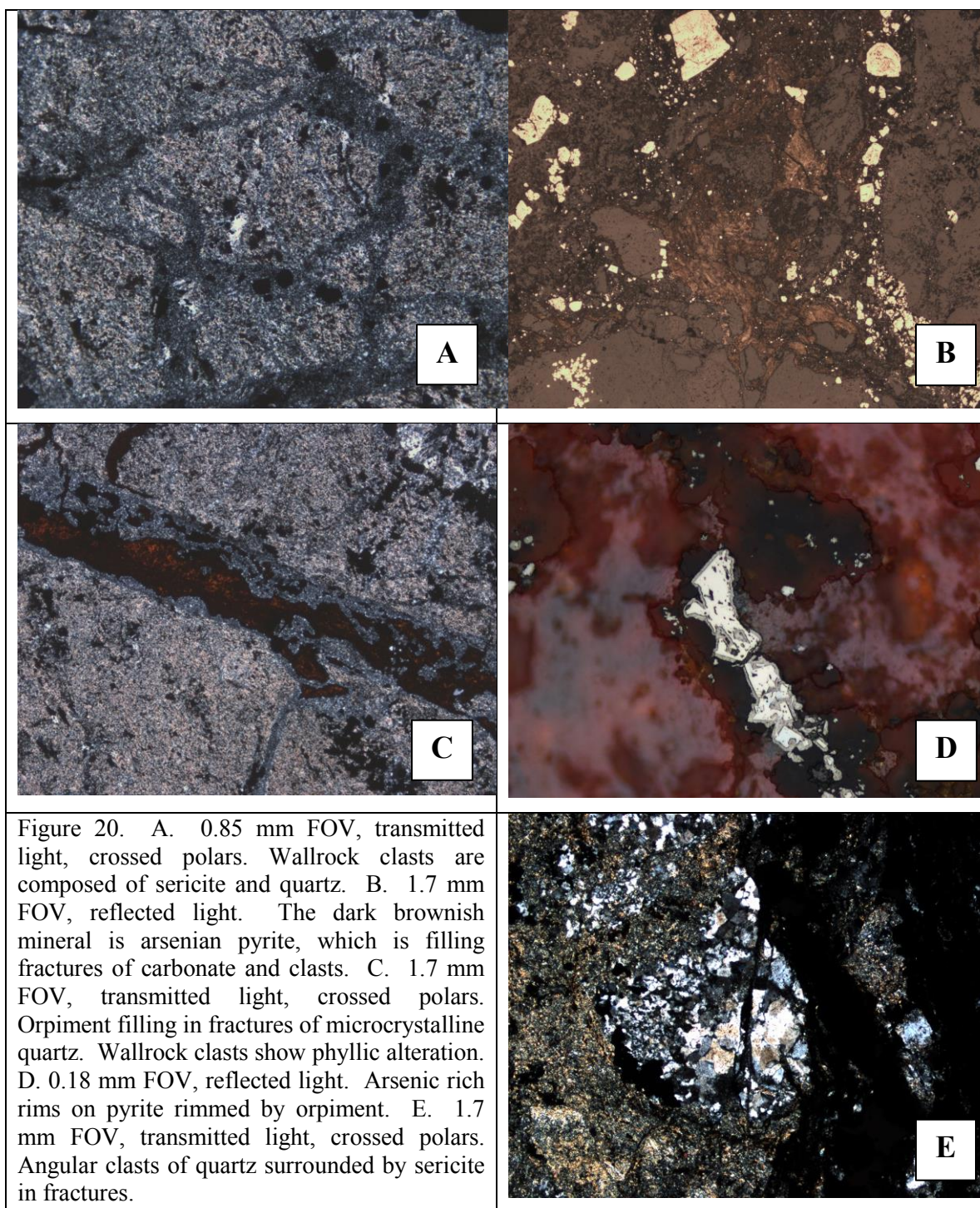




Figure 21. Complete Vista Vein shear zone intercept from VUC-00165. Gold assays for individual samples are: 476.1-477.6'=1.110 oz/ton. 477.6-481'=0.816 oz/ton. 481-483'=1.460 oz/ton. 483-485'=2.03 oz/ton. 485-488'=1.525 oz/ton. 488-491.2'=1.015 oz/ton. 491.2-493.2'=0.107 oz/ton. 493.2-496.5'=0.472 oz/ton. 496.5-498.5'=0.108 oz/ton. Blue lines indicate the extent of the VVSZ. Red lines indicate the extent of the Galena Vein. The Galena Vein is seen on the far right. Orpiment and realgar are late-stage and fill fractures. This zone was examined petrographically and has phyllic and silicic alteration and decarbonatization.

### Galena Vein



Figure 22. Core box photograph of the Galena Vein in VUC-00147. The Galena Vein is from 450.5 - 453.5 ft. The gold assay for this interval is 1.01 oz/ton. The core box is two feet long.

The Galena Vein is a 1-3 foot wide brecciated and sheared quartz-base metal vein (Fig. 22) that is locally associated with the VVSZ. Underground geologic maps of S4620N and S4620S were compiled using geologists underground face sheets to determine the spatial relationship of the Galena Vein and the VVSZ. The Galena Vein is strictly confined to the shear zone as shown in red in Figures 23, 24, and 25.

Eight polished sections were made from five different drill holes to document the mineralogy, textures, and paragenesis of the Galena Vein. Five of those polished sections were made from one intercept of the Galena vein (Fig. 26). Figures 27-31 show detailed photomicrographs and crosscutting relationships of the Galena Vein. Base metal minerals that have been identified petrographically include: pre-ore and ore-stage pyrite, ore-stage



marcasite, chalcopyrite, sphalerite, galena, and tennantite-tetrahedrite. Other minerals identified include: orpiment, realgar, quartz, sericite, hematite, and organic carbon.

Pyrite occurs as both pre-ore and ore-stage products. Pyrite is intensely fractured and occurs as disseminations and in veinlets. Pyrite ranges from anhedral to euhedral and sometimes locally exhibits cubic habit. Pyrite and marcasite cut and fill fractures in sphalerite. Galena exhibits typical triangular cleavage pits, and rims and fills in fractures in sphalerite. Chalcopyrite occurs as both “chalcopyrite disease” in sphalerite and as individual grains. Tennantite-tetrahedrite is greenish-gray in color and cuts galena and rims and replaces sphalerite.

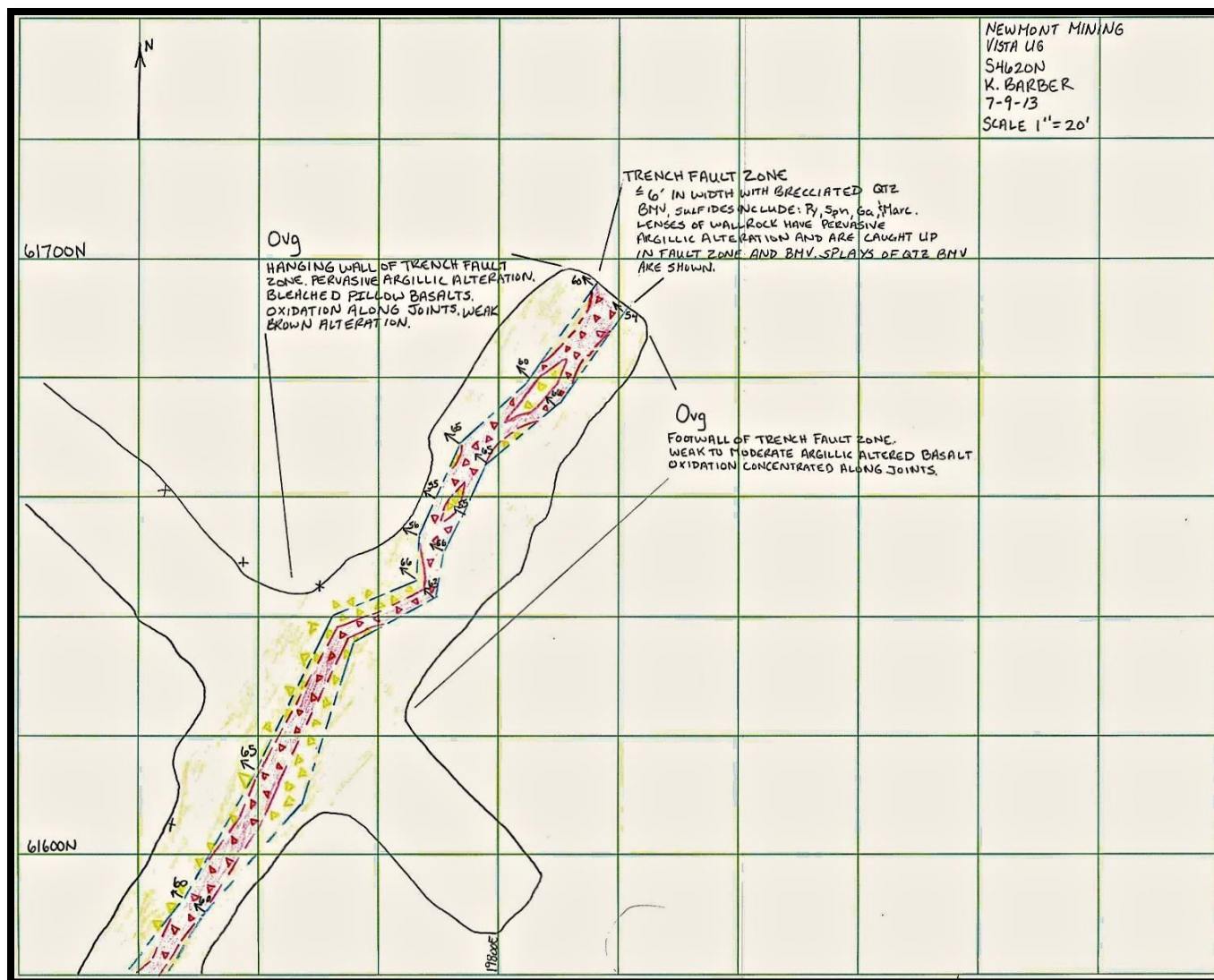


Figure 23. Map 1. Underground map compiled using face sheets of S4620N to show the relationship of the Galena Vein relative to the shear zone. Red = Galena Vein. Blue = Vista Vein shear zone. Yellow triangles = brecciation. Yellow shading = clay alteration.

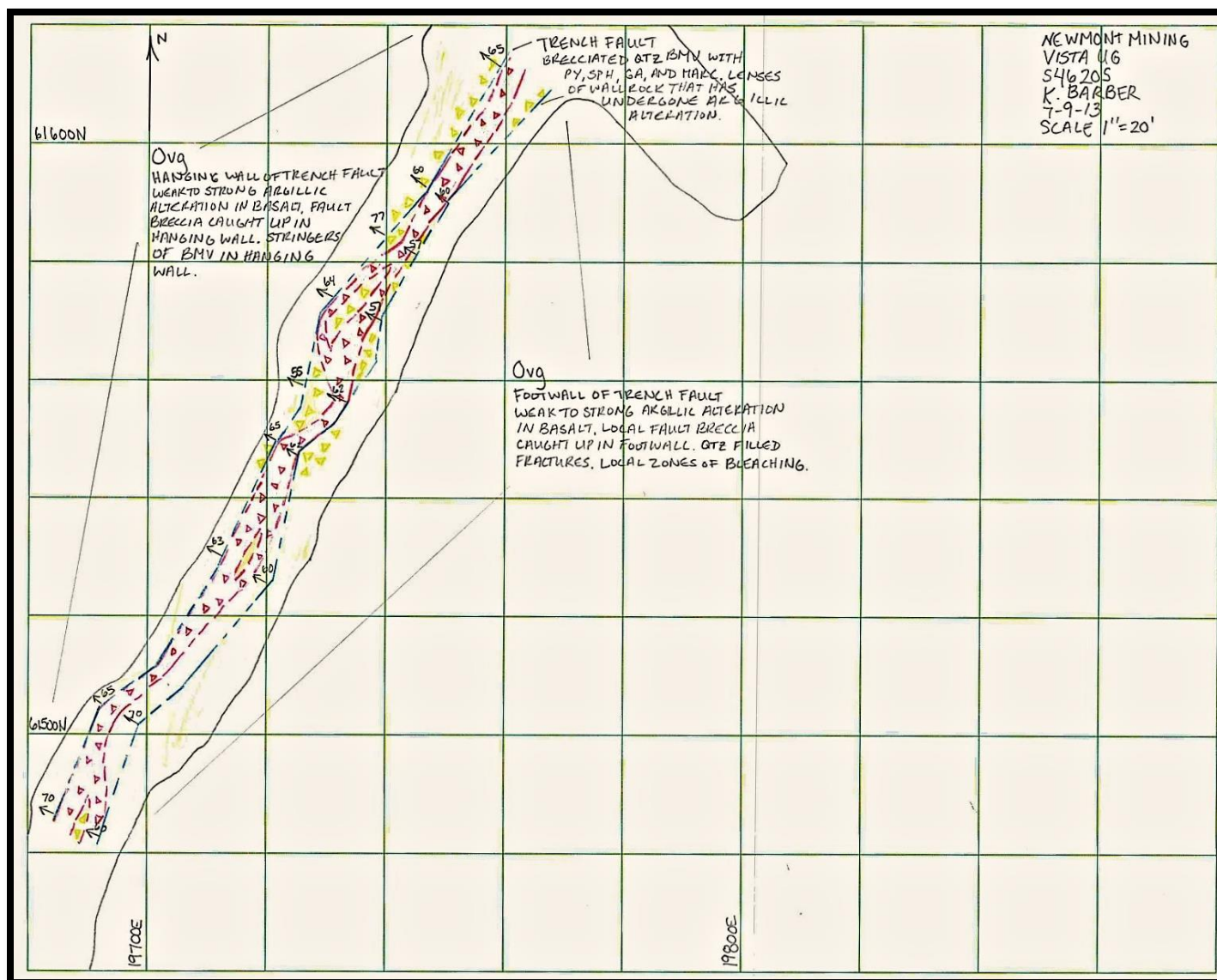


Figure 24. Map 2. Underground map continued along S4620S showing the relationship of the Galena Vein relative to the VVSZ. Red = Galena Vein. Blue = Vista Vein shear zone. Yellow triangles = brecciation. Yellow shading = clay alteration.

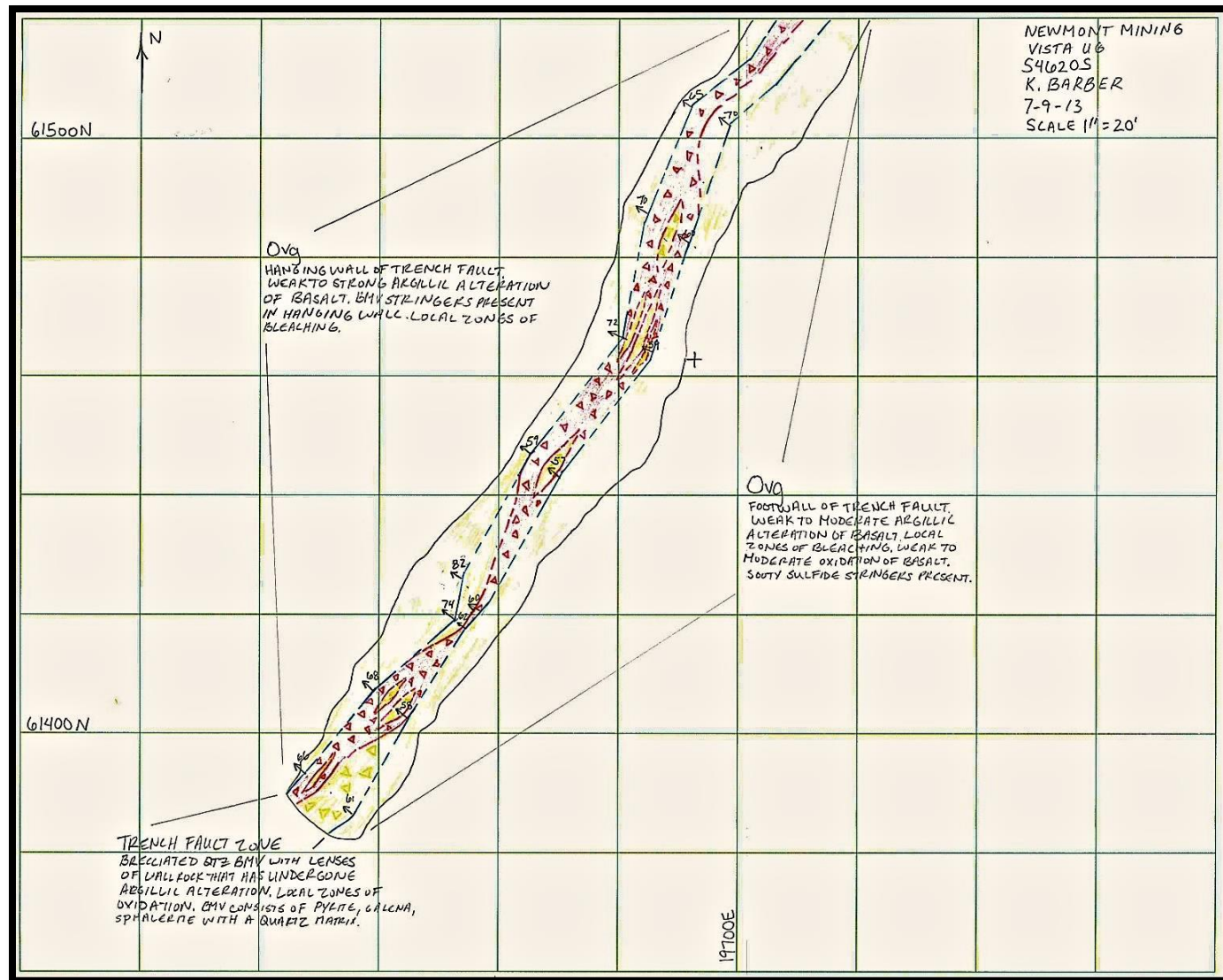


Figure 25. Map 3. Underground map continued along S4620S showing the relationship of the Galena Vein relative to the VVSZ. Red = Galena Vein. Blue = Vista Vein shear zone. Yellow triangles = brecciation. Yellow shading = clay alteration.



Figure 26. Galena Vein petrographic sections from VUC-00231 at 465.2-466.2'.

**Slide 5:** This images illustrates cross-cutting relationships of later sulfide veinlets filled with arsenian pyrite. These later sooty sulfide veinlets are cross-cutting the Galena Vein and are filled with clasts of pyrite, sphalerite, quartz, and galena.

**Slide 4:** Galena rims subhedral-euhedral pyrite. Marcasite laths are filling in the fractures with microcrystalline quartz 2. Sphalerite is earlier because of the inclusions of pyrite within it.

**Slide 3:** This image has subhedral-euhedral pyrite showing cubic crystal habit being cut by microcrystalline quartz 2 and arsenian marcasite. There is a veinlet of microcrystalline quartz 2 and feathery marcasite laths that are cutting both sphalerite and pyrite.

**Slide 2:** Within this slide there is a dark veinlet cutting the Galena Vein. This veinlet is filled with fragments of pyrite, galena, organic carbon, tennantite-tetrahedrite, quartz 1, and sphalerite, which are all cemented by microcrystalline quartz 2.

**Slide 1:** This image has arsenian pyrite within a microcrystalline quartz 2 veinlet that is cutting the milky vein quartz 1 and base metal sulfides.

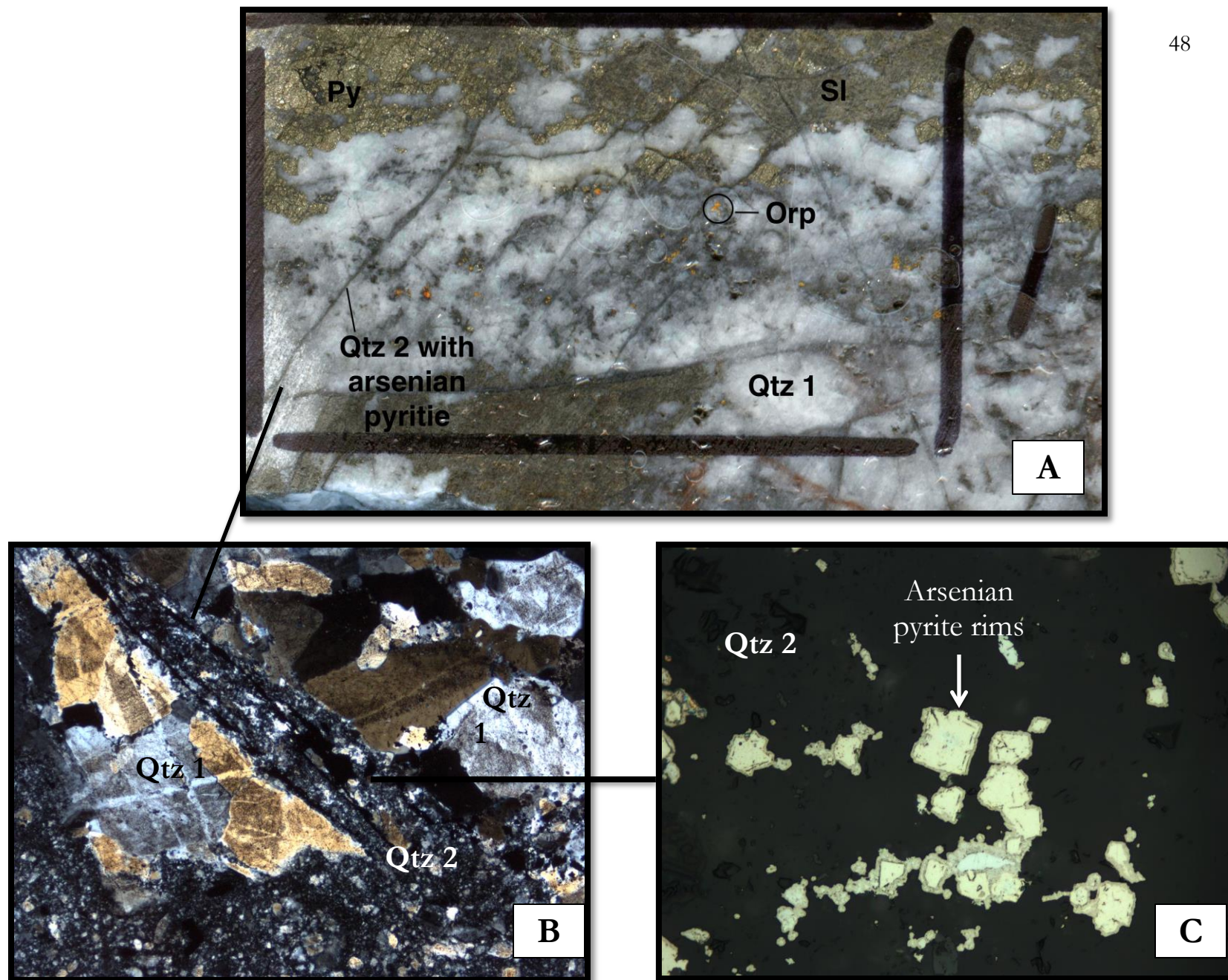
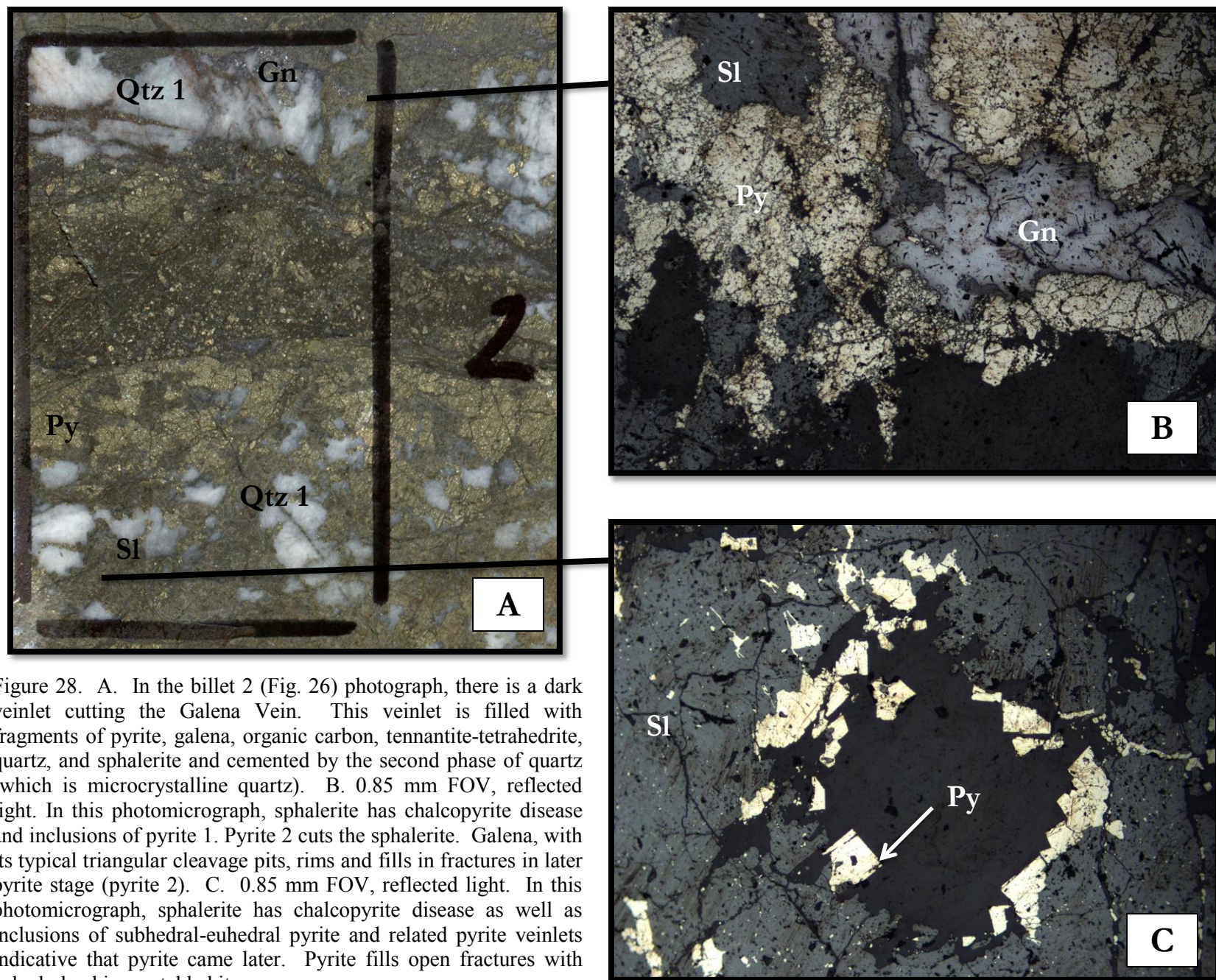


Figure 27. A. Photograph of billet 1 (Fig. 26). B. 1.7 mm FOV, transmitted light, crossed polars. The photomicrograph shows arsenian pyrite in a microcrystalline quartz 2 veinlet cutting the milky vein quartz 1. C. 0.18 mm FOV, reflected light. The photomicrograph is a close up on the arsenian pyrite in reflected light. The subhedral-euhedral pyrite has these rims of arsenian pyrite clearly visible in this photomicrograph.



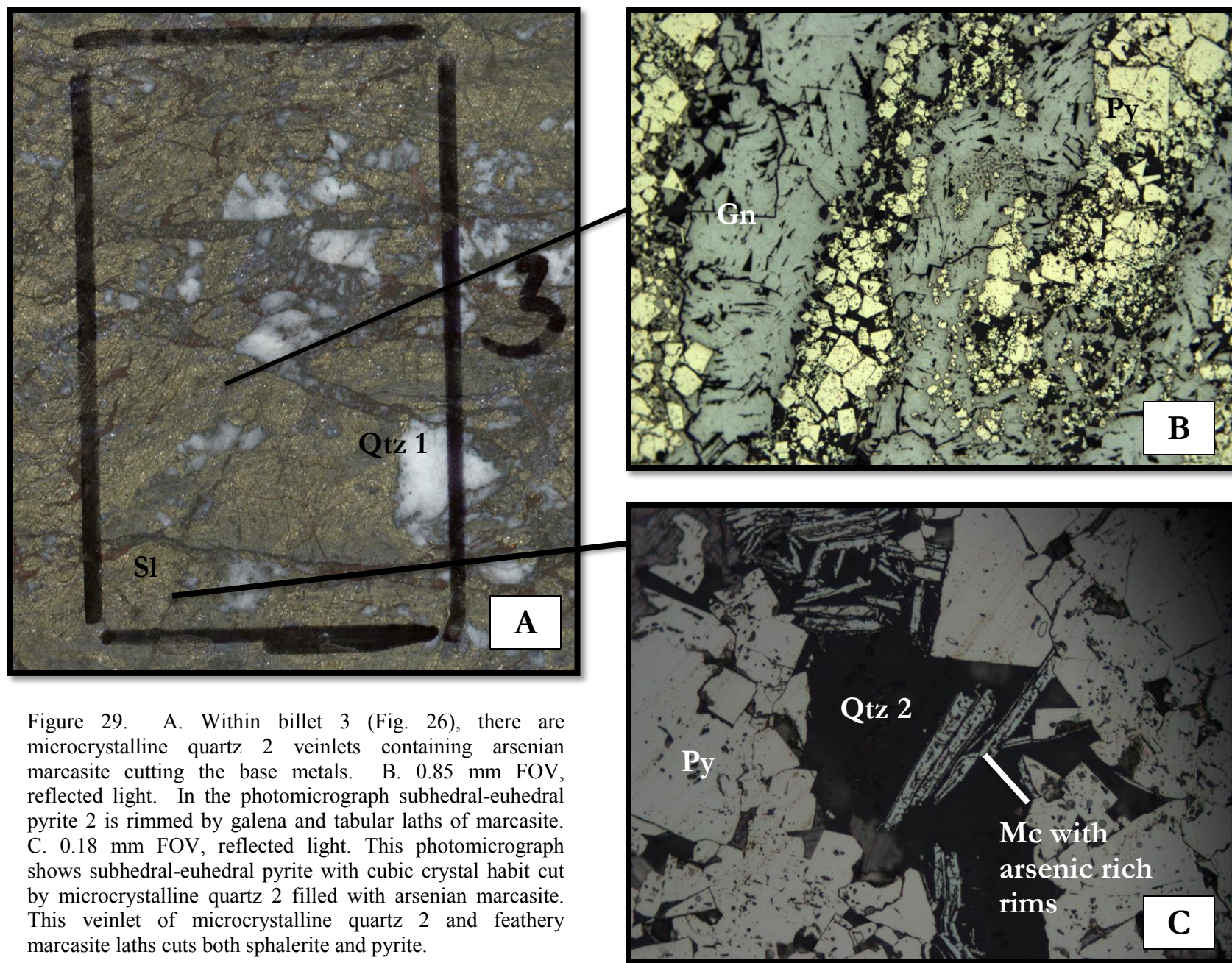


Figure 29. A. Within billet 3 (Fig. 26), there are microcrystalline quartz 2 veinlets containing arsenian marcasite cutting the base metals. B. 0.85 mm FOV, reflected light. In the photomicrograph subhedral-euhedral pyrite 2 is rimmed by galena and tabular laths of marcasite. C. 0.18 mm FOV, reflected light. This photomicrograph shows subhedral-euhedral pyrite with cubic crystal habit cut by microcrystalline quartz 2 filled with arsenian marcasite. This veinlet of microcrystalline quartz 2 and feathery marcasite laths cuts both sphalerite and pyrite.



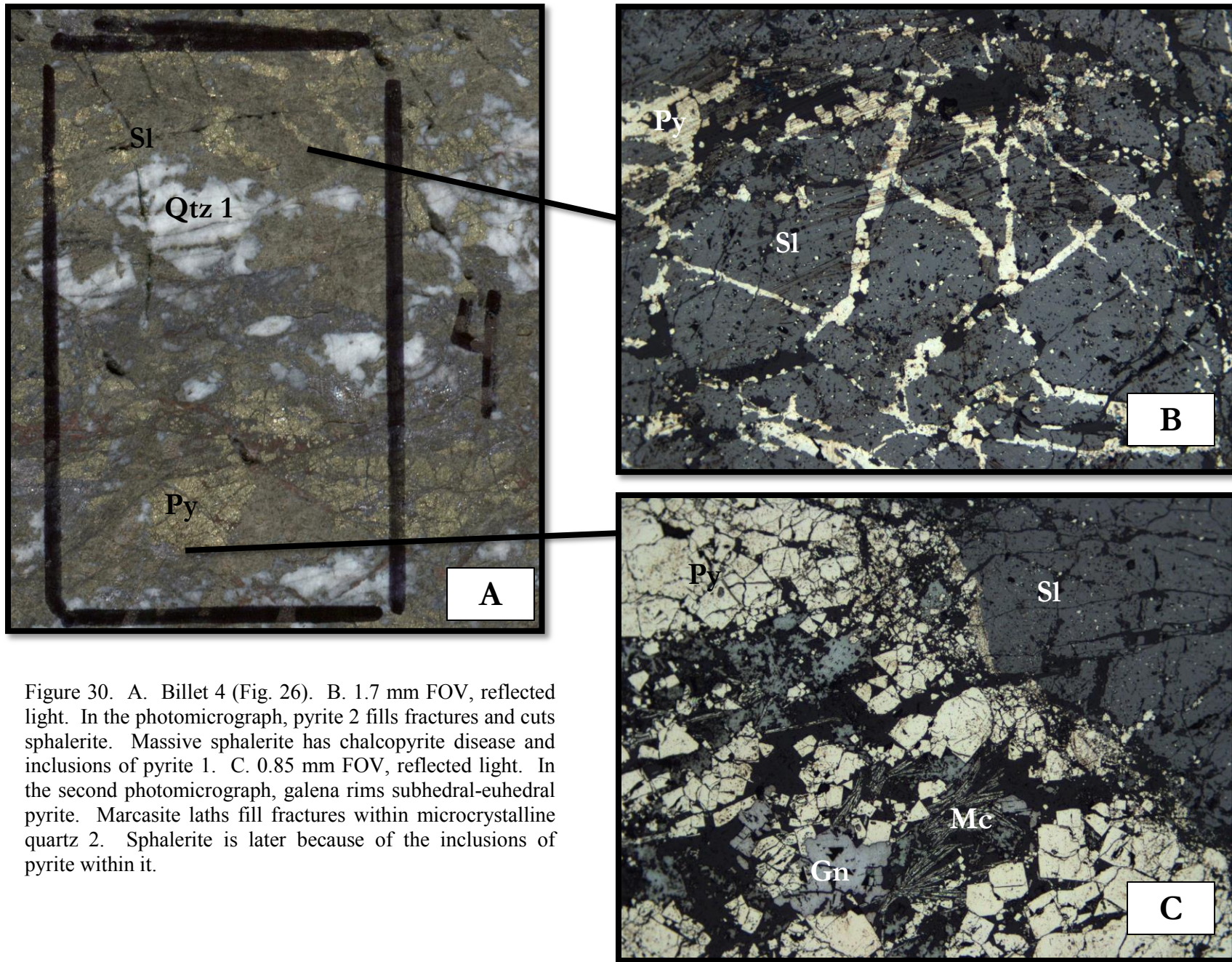


Figure 30. A. Billet 4 (Fig. 26). B. 1.7 mm FOV, reflected light. In the photomicrograph, pyrite 2 fills fractures and cuts sphalerite. Massive sphalerite has chalcopyrite disease and inclusions of pyrite 1. C. 0.85 mm FOV, reflected light. In the second photomicrograph, galena rims subhedral-euhedral pyrite. Marcasite laths fill fractures within microcrystalline quartz 2. Sphalerite is later because of the inclusions of pyrite within it.

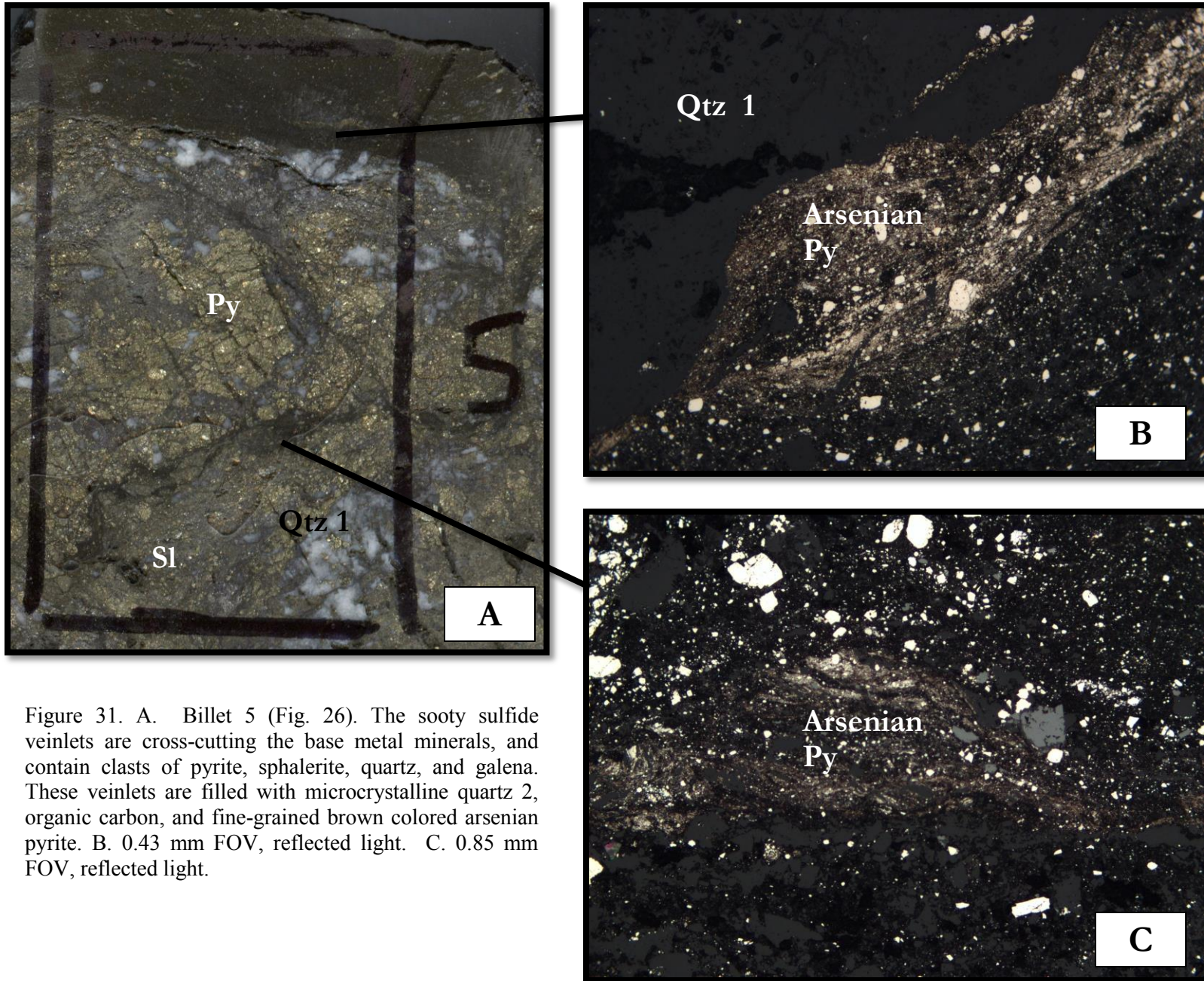


Figure 31. A. Billet 5 (Fig. 26). The sooty sulfide veinlets are cross-cutting the base metal minerals, and contain clasts of pyrite, sphalerite, quartz, and galena. These veinlets are filled with microcrystalline quartz 2, organic carbon, and fine-grained brown colored arsenian pyrite. B. 0.43 mm FOV, reflected light. C. 0.85 mm FOV, reflected light.

The paragenesis of the Galena Vein (Fig. 32) starts off with a milky vein quartz 1 that is cut by the first pyrite stage. This first pyrite is massive and has been severely fractured. Sphalerite rims and cuts the first pyrite. Sphalerite has chalcopyrite disease and is replaced by a later pyrite. That later pyrite is typically subhedral-euhedral pyrite and is rimmed by galena. The galena is replaced by tennantite-tetrahedrite. Later microcrystalline quartz 2 has filled fractures and cemented the broken sulfides. Sericite, specular hematite, and carbon are associated with microcrystalline quartz 2. Arsenian pyrite and marcasite veinlets crosscut the base metals. Late orpiment has filled fractures and cuts the base metal sulfides. Without finding a dateable mineral in the Galena Vein, there is no definitive age date for the base metal event, which is why the Galena Vein paragenetic diagram is kept separate from the VVSZ paragenetic diagram.

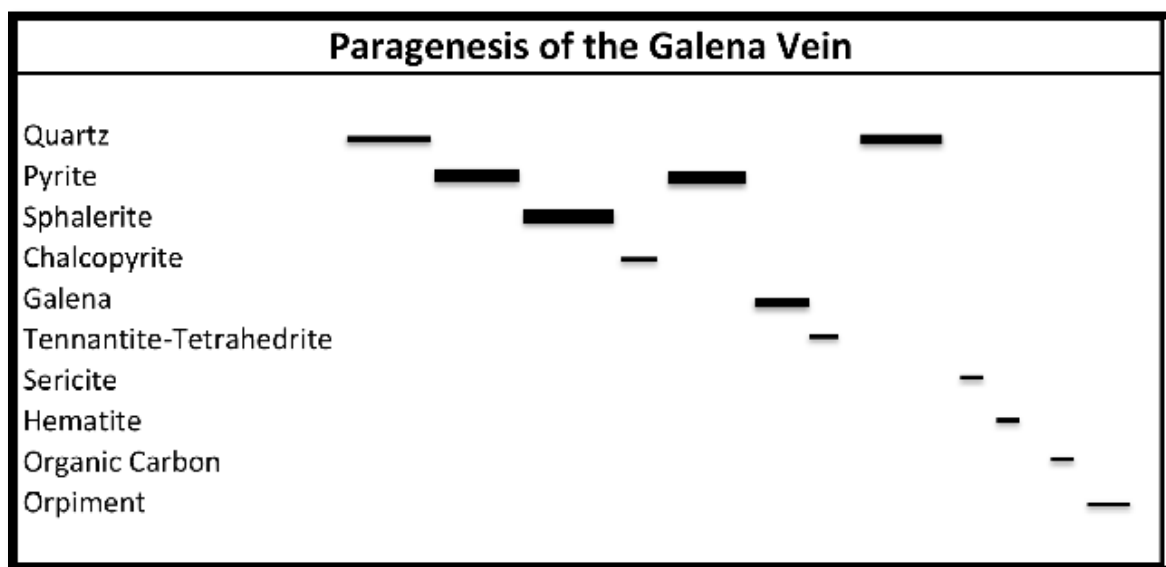


Figure 32. Paragenetic diagram of the Galena Vein.

## Chapter 7: Alteration

### *Methods*

Alteration was studied through logging multiple core drill holes during the summer field season, looking at numerous core photographs, and taking select samples for polished sections and detailed petrographic analysis. Alteration mineralogy was documented through examination of 60 polished sections that were collected during the field season of the summer of 2013. The 60 rock samples were sent to Spectrum Petrographics, based in Vancouver, WA for polished thin section preparation.

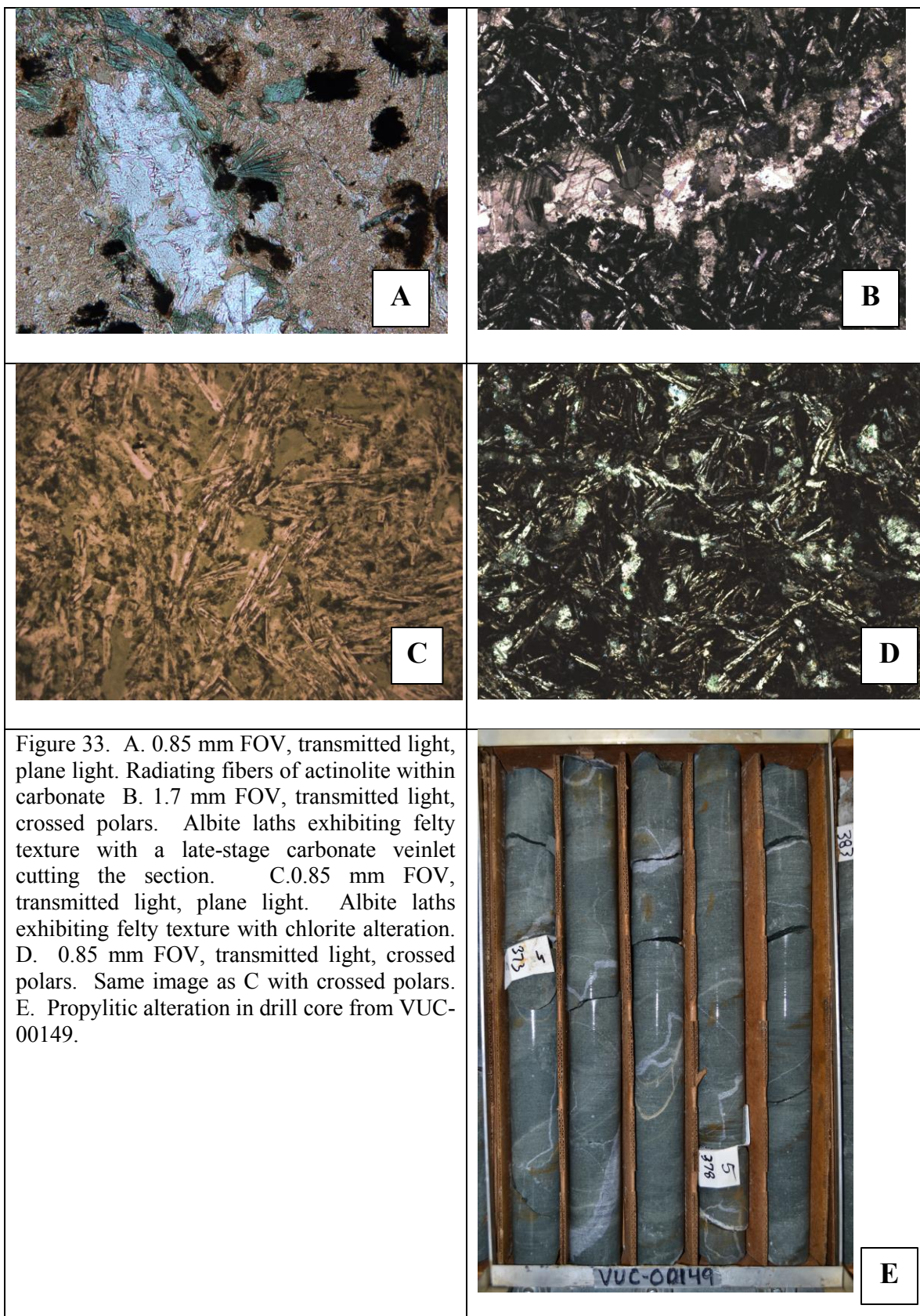
### *Alteration Assemblages*

Hydrothermal alteration is both pre-ore and ore-stage. There are six main alteration mineral assemblages associated with the VVSZ deposit (listed from early to late): propylitic, biotitic, phyllic, silicic, decarbonatized, and argillic assemblages. The upper unit of the Valmy Formation has been completely altered propylitically prior to ore fluids introduction. All other alteration is very localized along fractures, minor faults, or within the actual shear zone. Phyllic alteration (quartz-sericite-pyrite or QSP) tends to be concentrated in the porphyritic dacite intrusives and in the shear zone.

### *Propylitic Alteration*

The propylitic alteration event is a regional event that propylitized the Valmy basalts and is the most distal alteration suite in relationship to the VVSZ. Propylitic is the first alteration event to take place in this deposit. The upper unit of the Valmy Formation was regionally propylitically altered (Fig. 33). The propylitic mineral

assemblage consists of: calcite  $\pm$  chlorite  $\pm$  epidote  $\pm$  actinolite. The package of basalt rocks that has endured propylitic alteration range in color from light to dark green as seen in drill core. The entire upper unit of the Valmy Formation was propylitically altered. All other alteration that has taken place is post-propylitic alteration and is either related to an intrusive event or the hydrothermal fluids of this deposit. In thin section, the massive propylitically altered basalt is characterized by microlites of plagioclase (Fig. 33D) that exhibit a felty texture (randomly oriented plagioclase laths). XRD results from McComb (2011) indicate that the plagioclase is albite. Albite laths are subhedral-euhedral in crystal shape and have albite twinning. Albite can also occur in radiating sheaves indicating that devitrification took place (McComb, 2011). The ferromagnesian minerals have been replaced by chlorite (Fig.33C), epidote, and actinolite (Fig. 33A). Amygdules are mostly filled with calcite and locally some are filled with quartz. These amygdules range in size but are typically  $<0.4$ mm in diameter. Veinlets of calcite and locally quartz that cut the propylitically altered basalt occur in drill core and thin sections. Opaques in propylitically-altered rocks include: pyrite, chalcopyrite, and pyrrhotite. The pyrite is fine-grained, disseminated and anhedral. Pyrite also occurs in calcite veinlets and on the margins of amygdules.



### *Biotitic Alteration*

Biotitic alteration is pervasive, with the groundmass and propylitic minerals replaced by shreddy biotite. Biotite alteration (Fig.34), displays a range in color from faint to dark brown.



Figure 34. Biotite alteration in drill core from VUC-00150.

The biotite alteration is a hornfels event associated with the intrusive represented by the porphyritic dacite dikes. In thin section, the wallrock that has experienced biotitic alteration is typically pervasively altered (Fig. 35), where the ferromagnesian minerals have been altered to biotite. There are plagioclase microlites exhibiting felty texture. Plagioclase laths, that are anhedral-subhedral in crystal shape, have albite twinning, are deteriorated, and have been altered. Groundmass is typically composed of carbonate and biotite. Small vesicles that are <2 mm in diameter filled with carbonate are abundant

throughout section. Carbonate veinlets cut the biotitic altered basalt. These veinlets are <3mm in width. Opaques in biotitic altered rock include: marcasite in veinlets, disseminated pyrite and chalcopyrite.

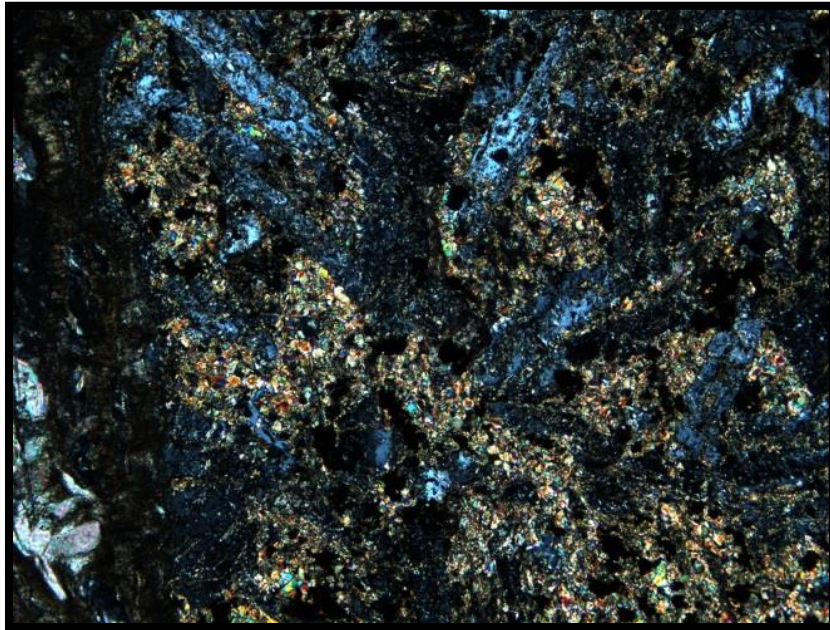


Figure 35. 0.85 mm FOV, transmitted light, crossed polars. Biotite alteration within plagioclase microlites.

#### *Phyllic (Quartz-Sericite-Pyrite) Alteration*

Phyllic alteration occurs in the porphyritic dacite dike that is cut by the VVSZ. The dike has completely been replaced by quartz, sericite, and pyrite. Phyllic (quartz-sericite-pyrite) alteration tends to be concentrated within the porphyritic dacite dikes, localized along fractures, and within the shear zone. Wallrock clasts within the shear zone are also composed of quartz, sericite, and pyrite (Fig. 36).



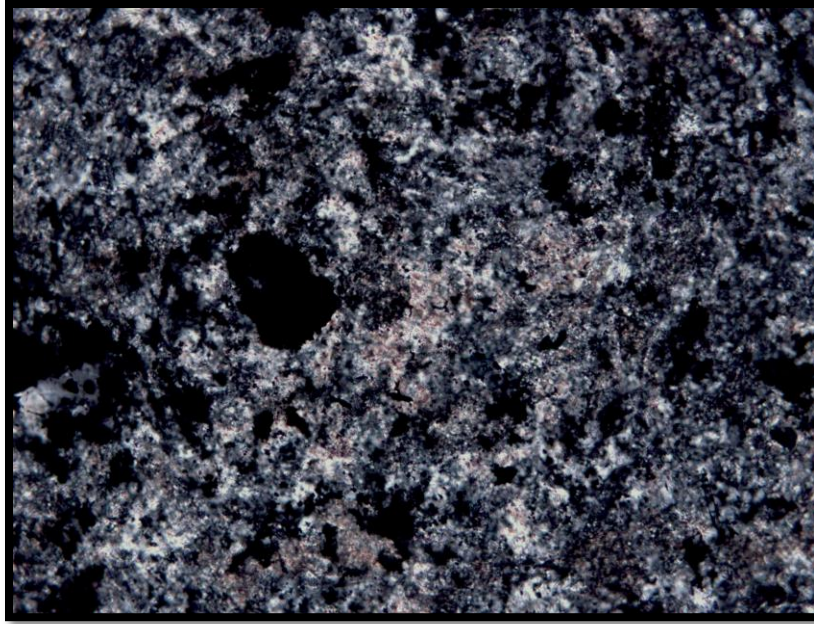


Figure 36. 0.18mm FOV, transmitted light, crossed-polars. Phyllic alteration in the Vista Vein shear zone.

A leapfrog model of rubidium (Rb) values were used as a proxy for potassium (K) (Melker, 2014) to model the sericitic alteration zonation. In Figures 37 and 38, Rb values greater than 50 ppm are controlled by a sub-parallel structure to the dike in the northern part of the deposit. This structure separates high Rb values to the north from low Rb values to the south.

Five cross-sections were created using Melker (2014) rubidium leapfrog models. In Figures 39-44, rubidium zonation changes from the northern part of the deposit to the southern part of the deposit. In the north, rubidium is enriched, but to the south, rubidium is depleted.

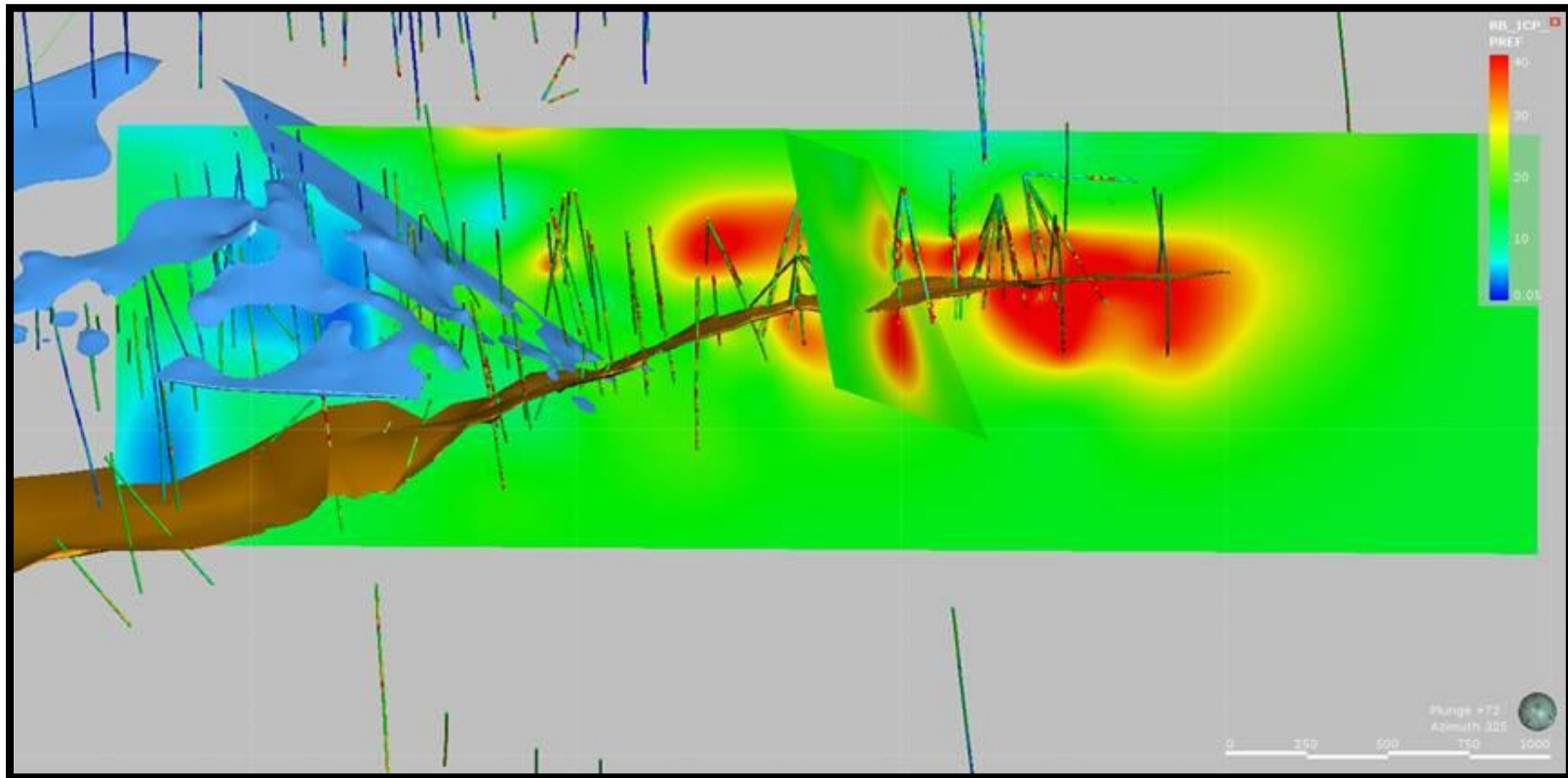


Figure 37. Plan View of the VVSZ. Plunge = 72, Azimuth = 325. Screenshot of the Vista Vein leapfrog model showing rubidium (Rb) enrichment in the northern part of the deposit. Orange and red color indicates Rb values greater than 30 ppm. Brown shape = Vista Vein shear zone (VVSZ shape). Blue shape = porphyritic dacite dikes. Green shape = sub-parallel structure to the dike. Leapfrog models created by Melker (2014).

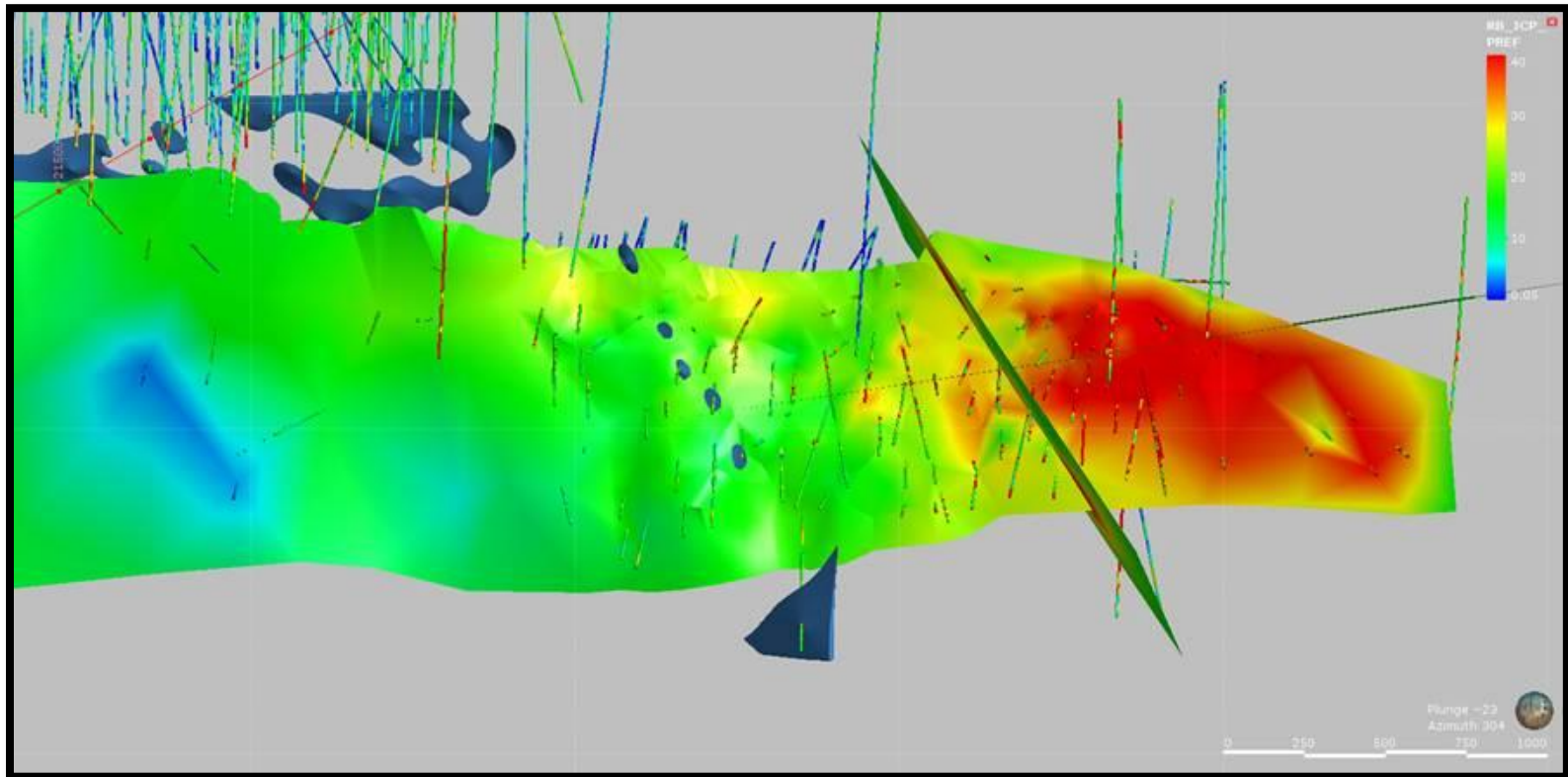


Figure 38. Looking at the footwall of the Vista Vein shear zone shape. Plunge = 22, Azimuth = 304. Sub-parallel structure to the north controls Rb and confines it to north of the structure. Orange and red colors indicate Rb values greater than 30 ppm. Blue shape = porphyritic dacite dikes. Leapfrog models created by Melker (2014).

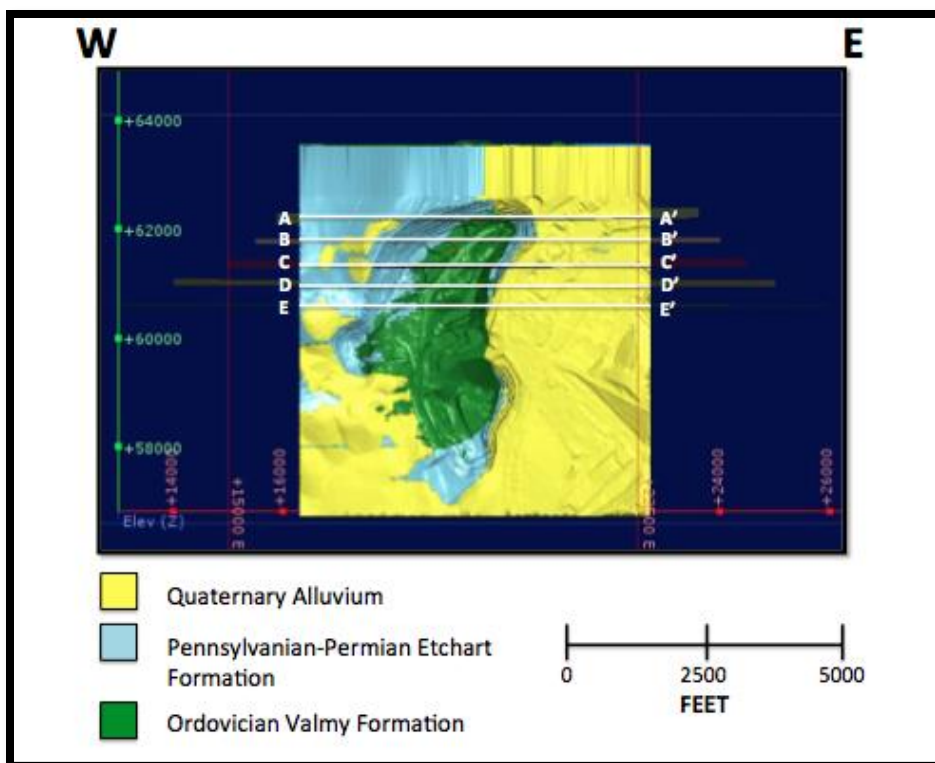


Figure 39. Plan View showing creation of rubidium (Rb) cross-sections.

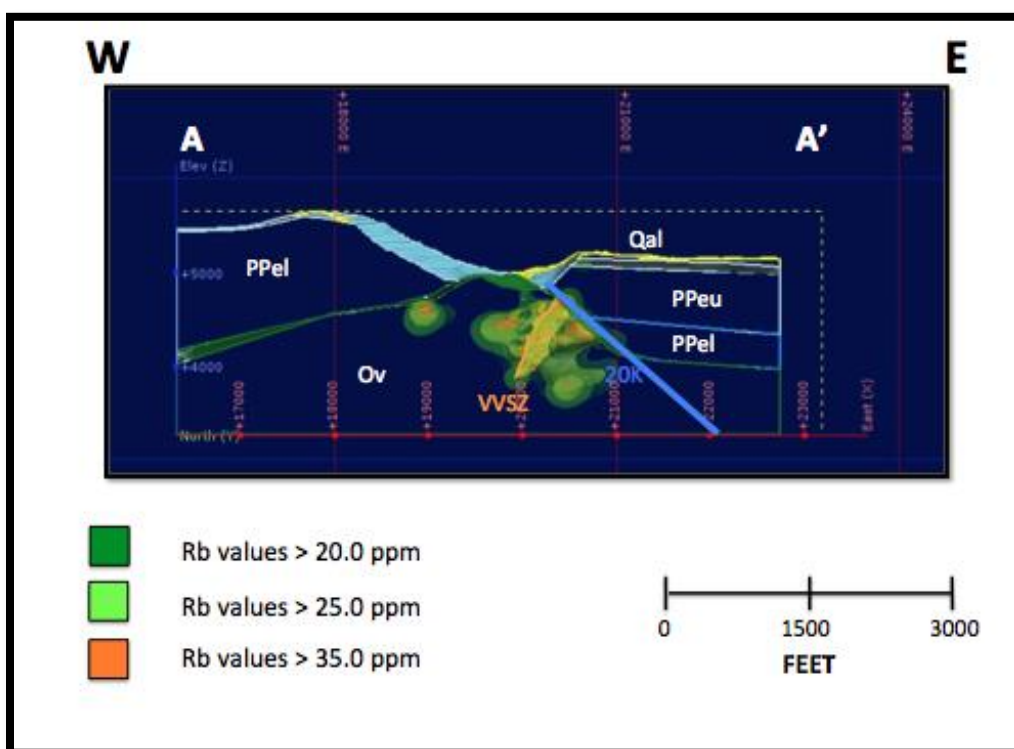


Figure 40. A-A' cross-section showing the zonation of Rb.

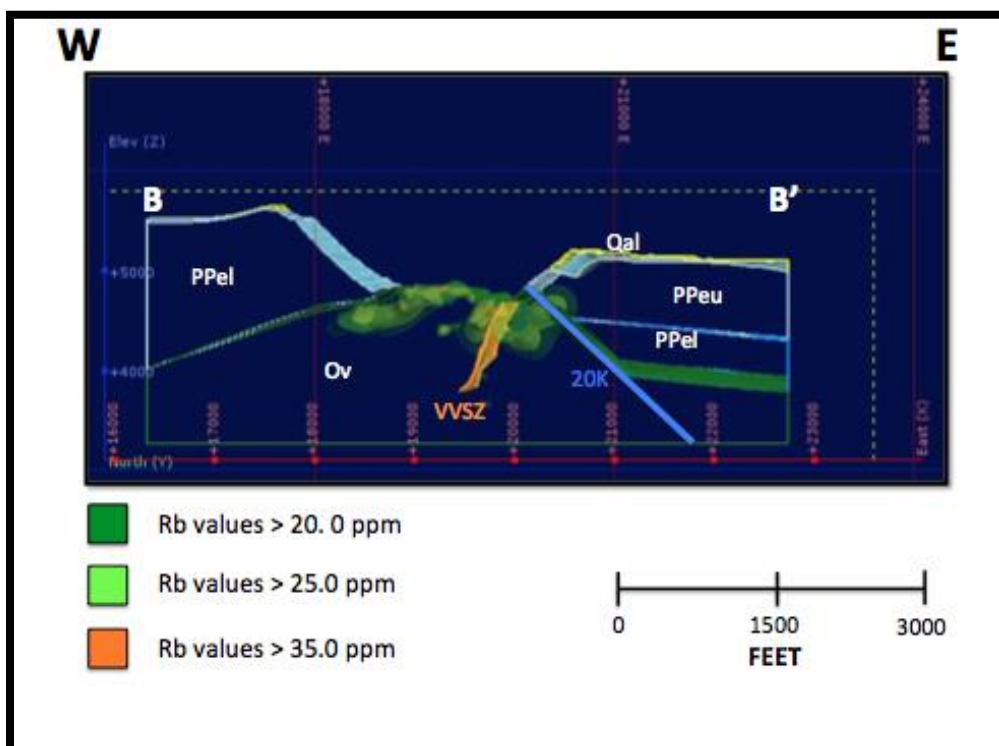


Figure 41. B-B' cross-section showing the zonation of Rb.

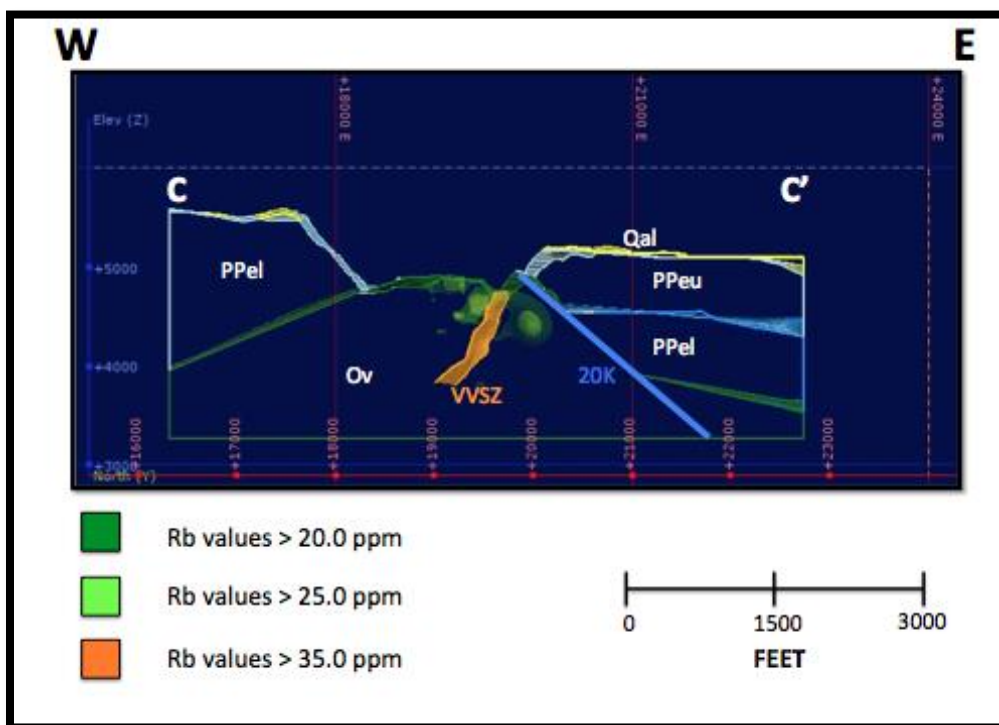


Figure 42. C-C' cross-section showing the zonation of Rb.

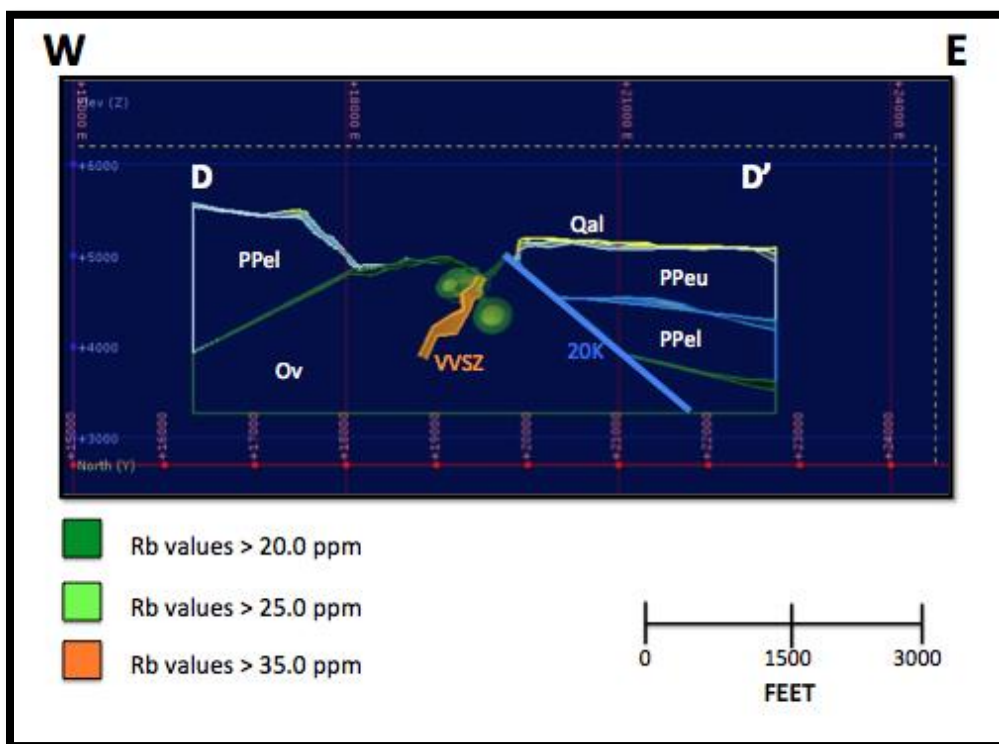


Figure 43. D-D' cross-section showing zonation of Rb.

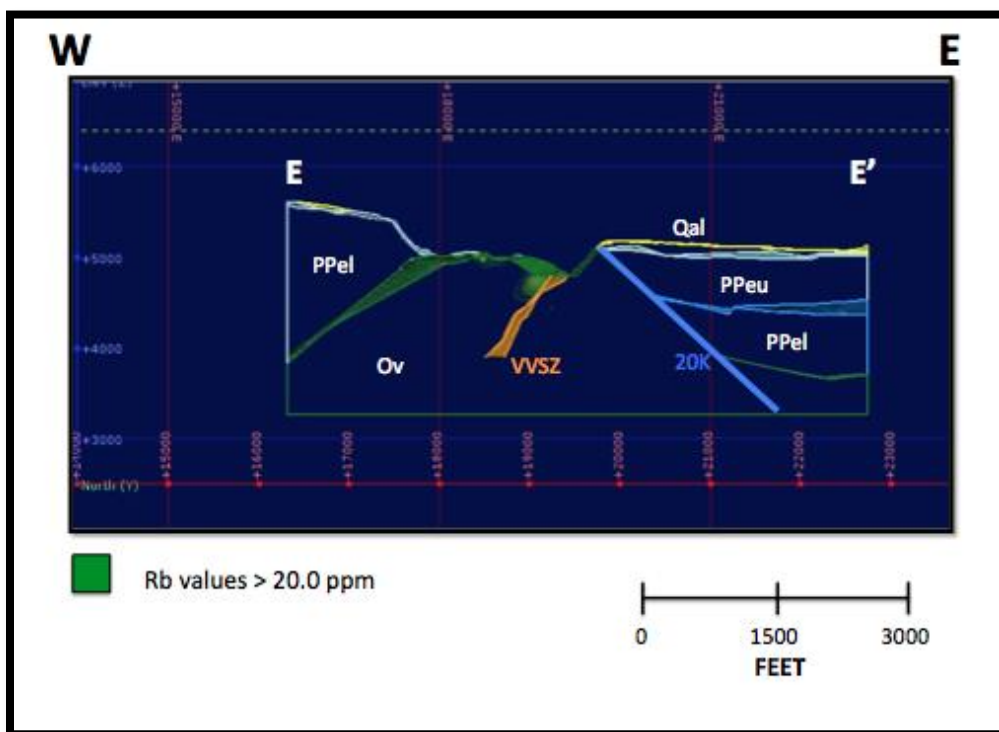


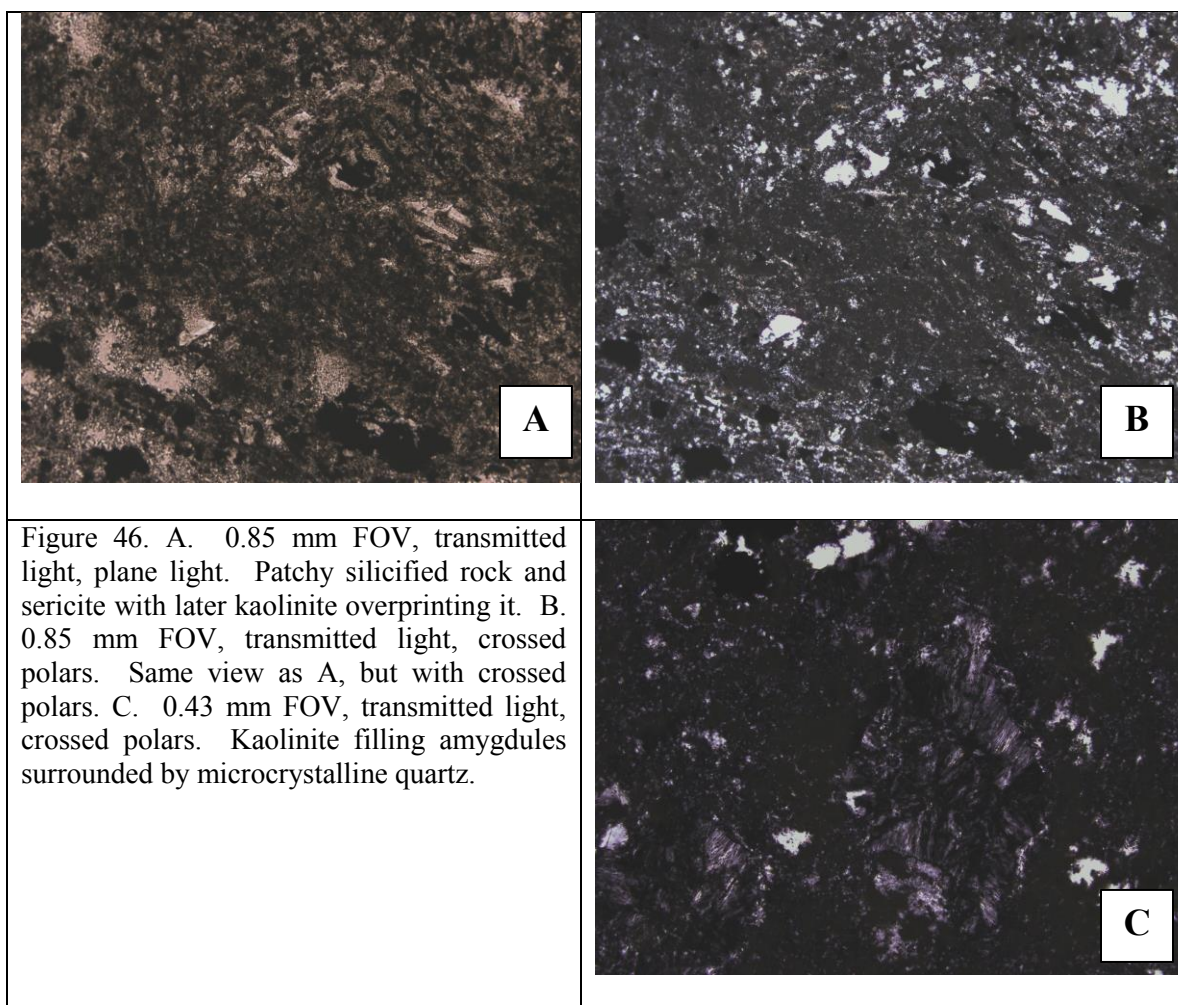
Figure 44. E-E' cross-section showing zonation of Rb.

*Argillic Alteration*

Figure 45. Core box photograph from VUC-00152 of argillic altered basalt.

Argillic alteration (Fig. 45) is located along the Trench fault and fractures of the shear zone. Petrography (Fig. 46A-C) indicates that the argillic alteration assemblage consists of: clays, quartz, chlorite, sericite, pyrite, ankerite, and rutile. Within the shear zone, kaolinite is the dominant high-temperature clay mineral. Outboard of the shear zone, are low-temperature clay minerals such as illite and smectite. Smectite overprints the propylitic-altered rock. In pervasive clay altered zones, the original textures of the basalt have been destroyed and the original mineralogy has been completely altered. Typical argillic altered core has been bleached due to the removal of Fe-Mg minerals during the hydrothermal alteration process from the acidic, low pH fluids and the alteration of sericite into kaolinite. Sericite replaces kaolinite, which was confirmed by

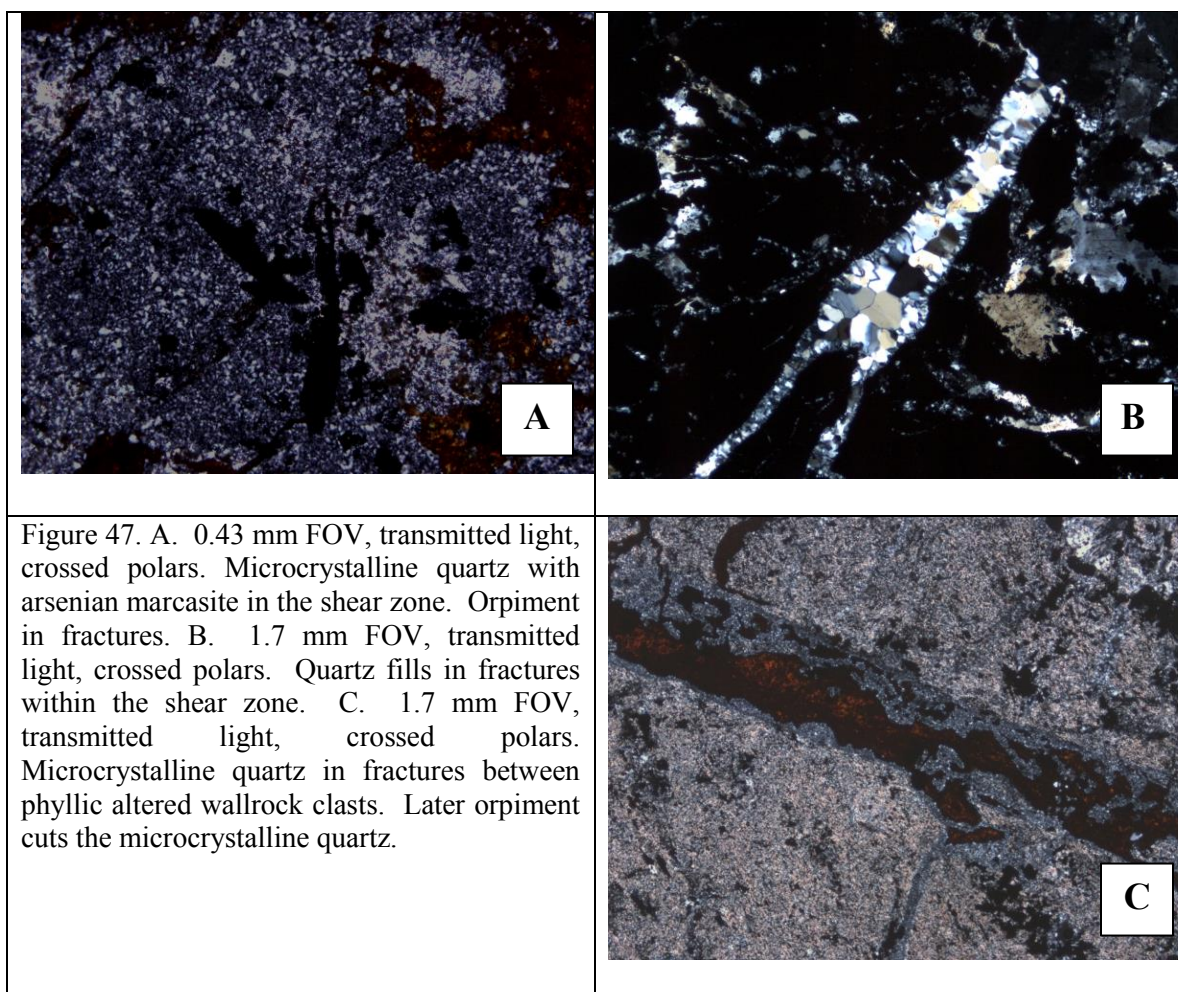
XRD and Raman analysis (McComb, 2010). The carbonate in the clay-altered rocks was identified by Raman analysis to be ankerite (McComb, 2010). Parallel tension gashes can also be present in argillic-altered basalt, and are filled with marcasite and pyrite. These gashes are basically tensional fractures that are due to extensional movement. Within these tension gashes, pyrite is replaced by subhedral feathery tabular laths of marcasite.





### *Silicification*

Silicification (Fig. 47) occurs along fractures and within the shear zone. Silicification occurs in the ore zone and replaces the groundmass of the altered wallrock, possibly acting as significant rock preparation for brittle fracturing and mineralized fluid flow (Gray, 2011). Silicification is localized in fault zones, fractures, and breccias. The Vista Vein shear zone has experienced silica flooding. Silicified breccias occur throughout the upper unit of the Valmy Formation either in very localized fault planes, flow margins, or within the actual Vista Vein shear zone.



### *Decarbonatization*

Decarbonatization is pervasive and is localized within and immediately adjacent to the Vista Vein shear zone. Decarbonatization is only present within areas through which hydrothermal fluids flowed (faults, fractures, etc). Decarbonatization probably occurred during the sulfidation event. Strontium (Sr) was used as a proxy for calcium (Ca) in Leapfrog models by Melker (2014) to show decarbonatization outboard of the shear zone (Figs. 48-54). In Figure 48, Sr depletion in the shear zone is clearly indicated by the light blue color (Sr values < 50 ppm). Peripheral to the shear zone Sr values increase to greater than 100 ppm. This indicates that decarbonatization was a primary alteration in this ore deposit. It would appear that carbonate flooding occurred west of the 20K fault. There are no textures that can be documented or seen in thin sections to show decarbonatization; it is represented by the absence of carbonate and the lack of reaction to HCl that implies that the alteration has occurred.

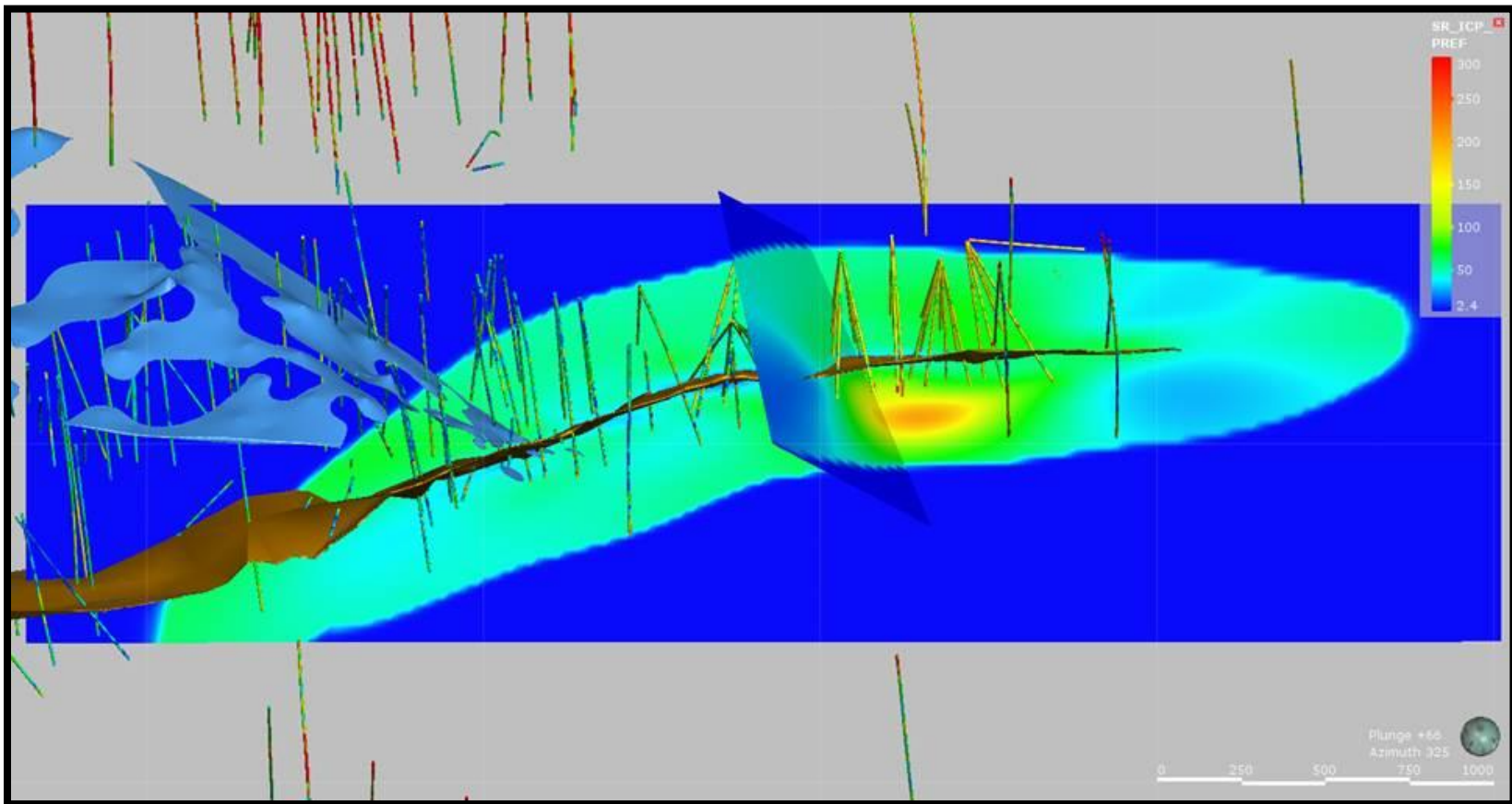


Figure 48. Oblique View. Plunge = 60, Azimuth = 325. Screenshot of the Vista Vein leapfrog model showing strontium (Sr) depletion along the shear zone. Brown shape = Vista Vein shear zone (VV1 shape) Blue shapes = porphyritic dacite dikes. Modeling efforts by Marc Melker.

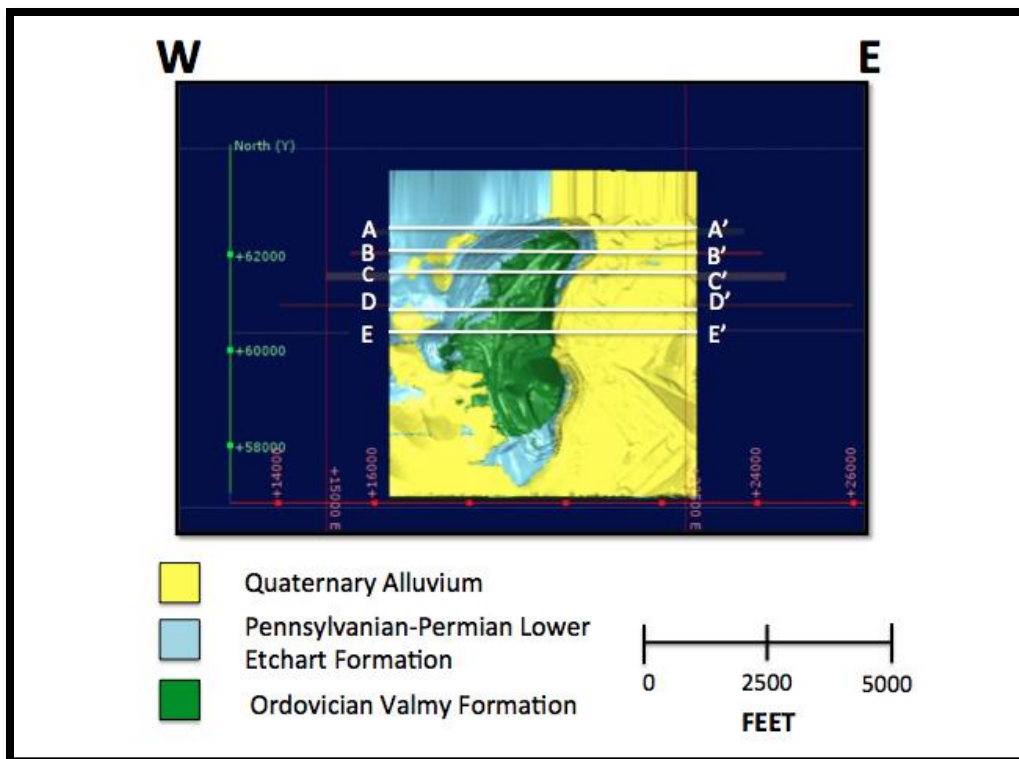


Figure 49. Plan view showing locations of strontium cross-sections.

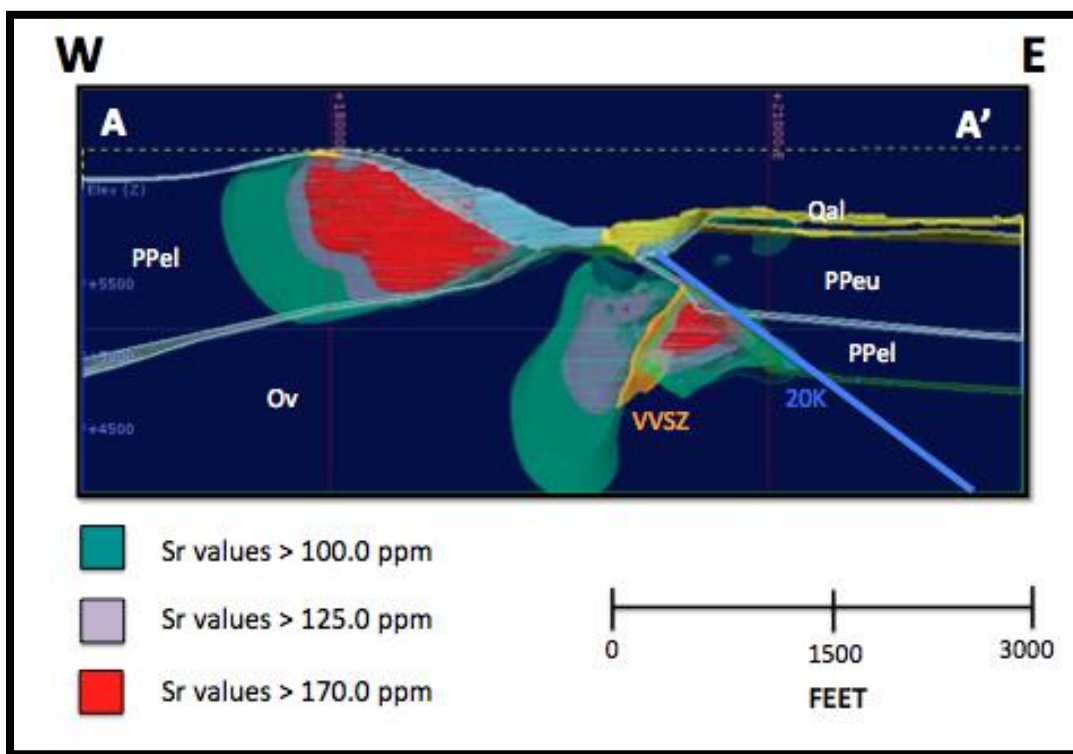


Figure 50. A-A' cross-section showing Sr zonation.

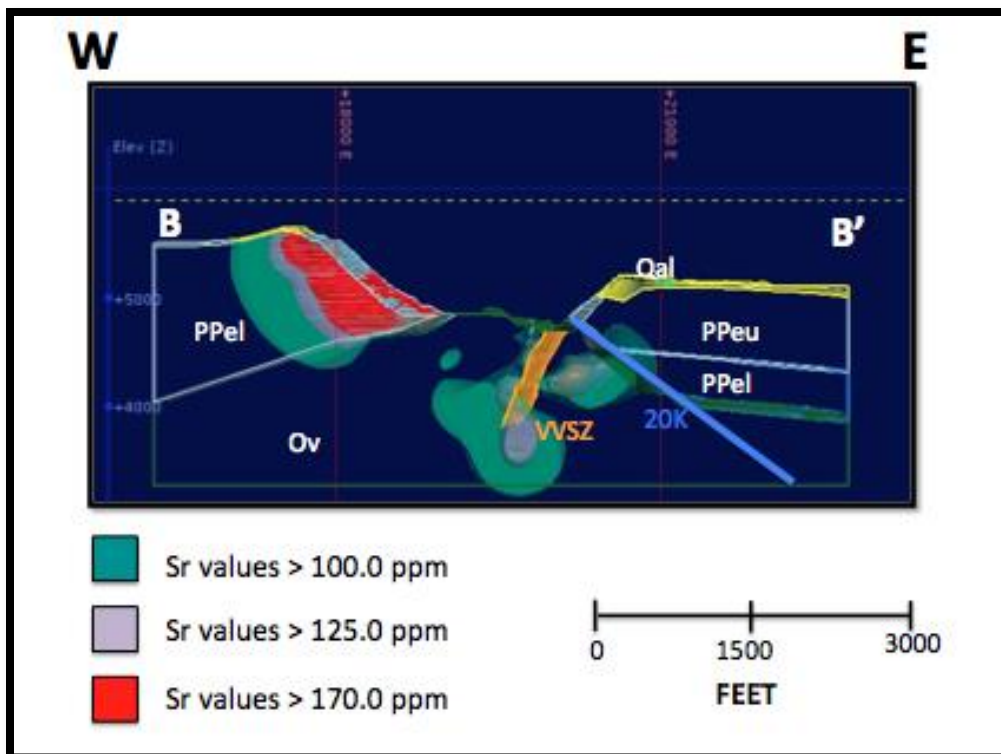


Figure 51. B-B' cross-section showing Sr zonation.

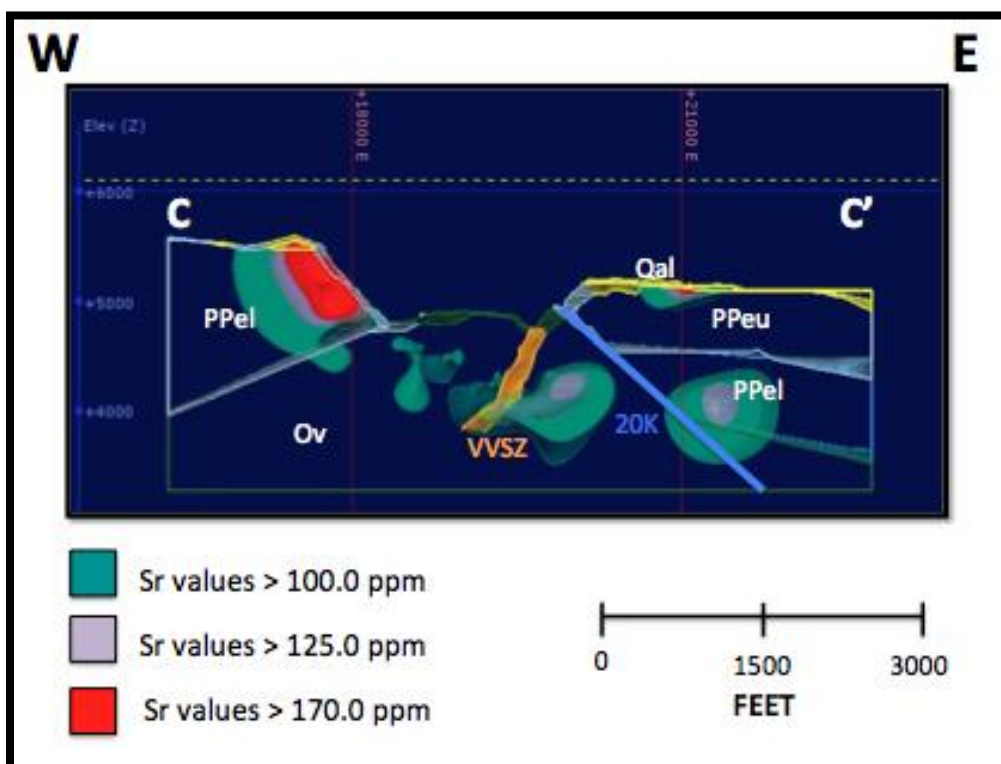


Figure 52. C-C' cross-section showing Sr zonation.

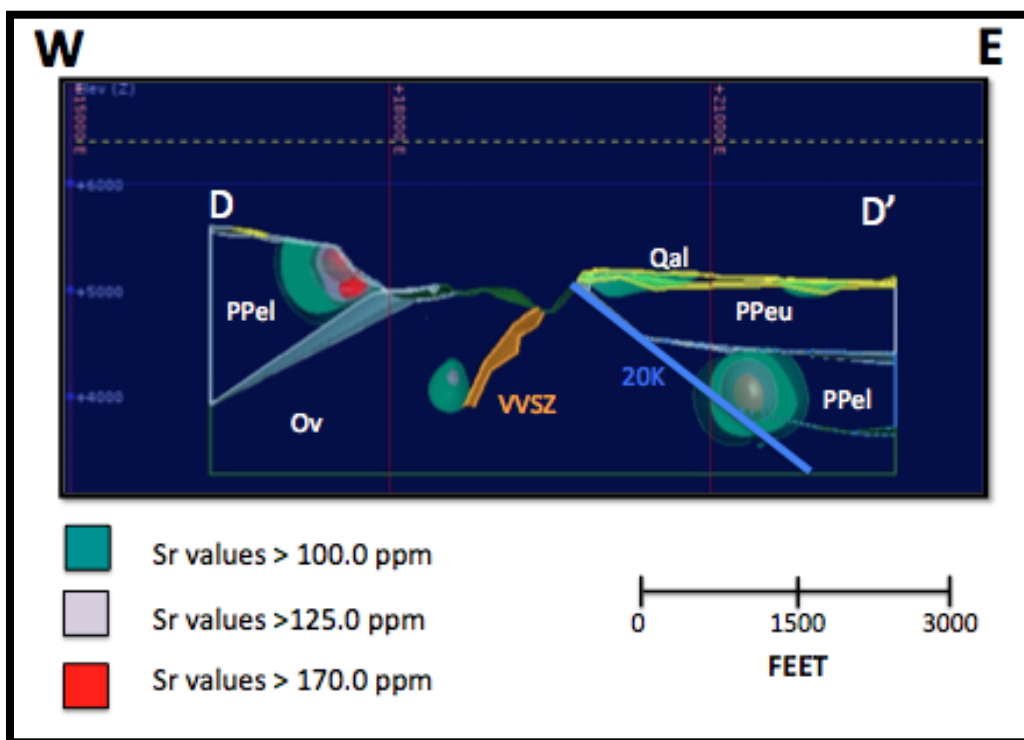


Figure 53. D-D' cross-section showing Sr zonation.

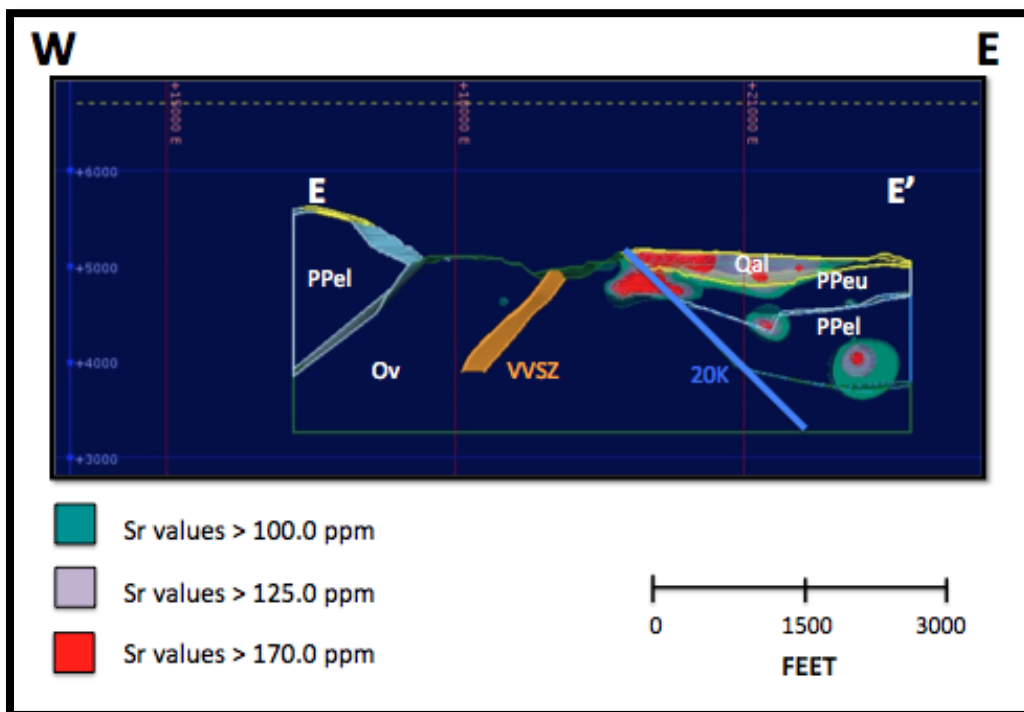


Figure 54. E-E' cross-section showing Sr zonation.

## Chapter 8: Paragenesis

The paragenetic diagram of the entire VVSZ deposit (Fig. 55) shows seven stages. Six of these stages are pre-ore alteration. The first stage of alteration was a regional propylitic alteration event that altered the Valmy basalts. Primary rock forming minerals of albite, olivine, and pyroxenes were altered to actinolite, chlorite, epidote, and calcite. The second stage of alteration was biotite hornfels alteration that replaced the ferromagnesian minerals in the propylitic-altered rock. Biotite alteration can be pervasive and is the result of the intrusive event that is related to the porphyritic dacite dikes in the Vista pit area. Heat and fluids from the intrusive event flowed through the surrounding rocks altering the ferromagnesian minerals to biotite. The third stage of alteration and paragenetic event was a phyllic alteration event (quartz-sericite-pyrite) that is also related to the intrusive event. Porphyritic dacite dikes in the Vista Pit area are phyllicly altered as well as rock within the VVSZ. Heat and fluids from the intrusive caused the geochemical-mineralogical changes within the basalt.

Silicification, decarbonatization, and argillic alteration all acted as rock preparation for the Carlin-type fluids. The Vista Vein shear zone is brecciated and is cemented with silica. The acidity of the fluid flowing through the shear zone caused dissolution of carbonate resulting in decarbonatization of wall rocks. The argillic alteration event, represented by smectite and kaolinite overprints all other minerals in the shear zone. The kaolinite is found occurs in the shear zone, whereas smectite is found distal to the shear zone. Carlin-type Au mineralization veinlets of arsenian pyrite and marcasite are within argillized rocks and are spatially coincident.

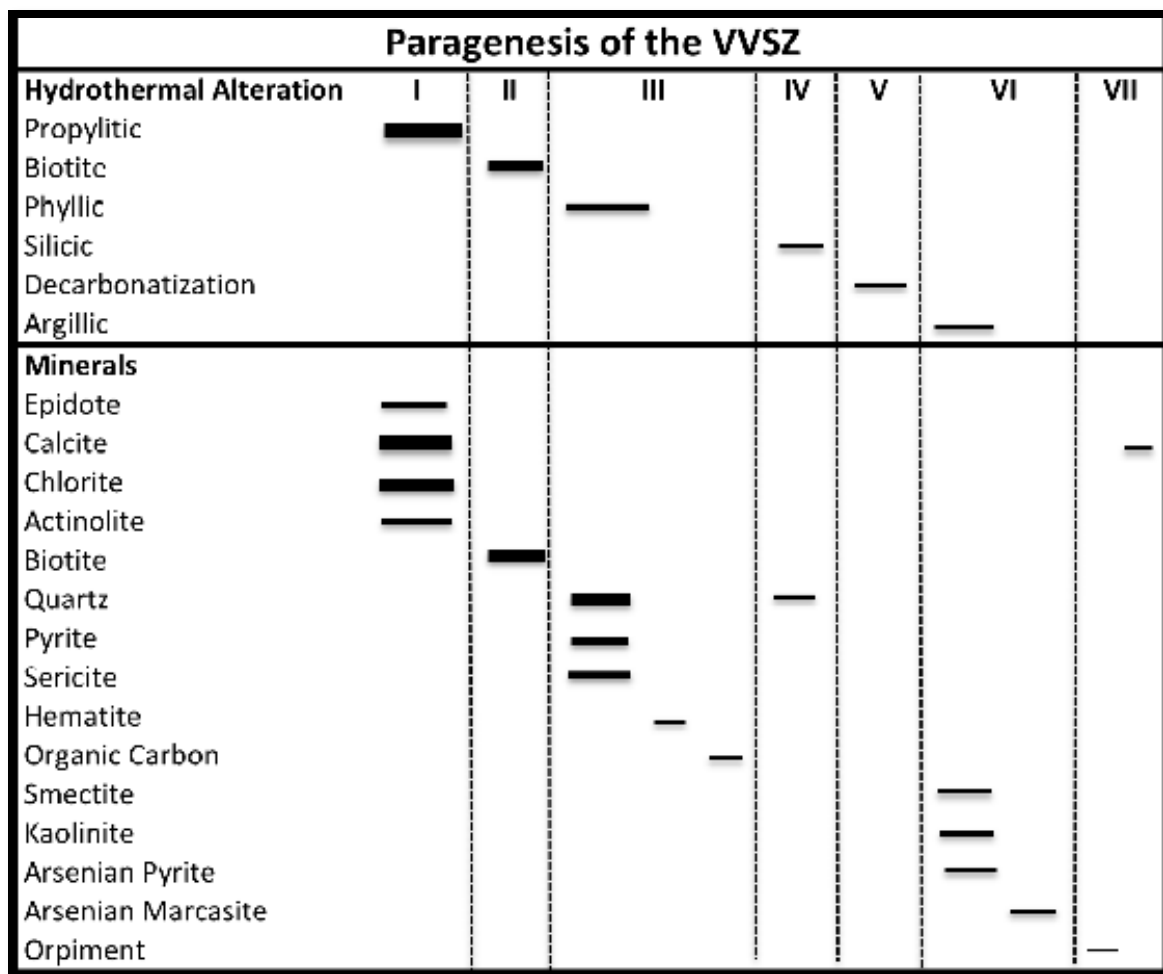


Figure 55. Paragenetic diagram of the Vista Vein shear zone deposit. The thicker the line the more abundant the mineral.

## Chapter 9: Geochemistry

### *Trace Element Zoning*

#### *Methods*

Analysis of trace element geochemistry by ICP-MS was used in order to derive two correlation matrices that were used to develop trace element zonation longitudinal sections in the plane of the VVSZ deposit. These correlation matrices were constrained to intercepts of gold mineralization above 0.1 oz/ton. Twenty-one trace elements were



analyzed by the ALS Chemex Laboratory (ALS) including: Au, Ag, As, Sb, Hg, Tl, Cu, Pb, Zn, Mo, Bi, Ni, Se, Te, W, Fe, U, Ca, K, Li, and Sn.

The Spearman correlation method was used because it does not constrain the variables to linear relationships, in contrast, for example, with the Pearson correlation method. The Spearman method allows for variables to show nonparametric statistics, meaning that the data being analyzed will not be constrained to follow a normal distribution. Basically, the Spearman method focuses on monotonic functions between two variables. The perfect Spearman correlation matrix between two variables that have monotonic functions have values of +1 or -1. Strong positive correlations are highlighted in blue in the following matrices (Figs. 56-58) and are considered to be strongly positive above 0.5. Strong negative correlations are highlighted in red and are considered to be strongly negative below -0.5. Values that were below detection limit were replaced with half of the detection limit value.

The two Spearman correlation matrices that were created using ioGAS software include: (1) Vista Vein shear zone intercepts only and (2) Galena Vein intercepts only.

#### *Vista Vein shear zone Intercepts*

This correlation is restricted to VVSZ intercepts (Fig. 56). A total of 251 intercepts from 46 different drill holes were used in the correlation matrix. Strong positive correlations with Au include: Ag (0.54), As (0.58), Sb (0.67), Hg (0.68), Tl (0.71), Se (0.72), Te (0.76), and Sn (0.54). Ca has a strong negative correlation with Au at (-0.57).

Vista Vein shear zone Intercepts (ppm)																							
Spearman	Au	Ag	As	Sb	Hg	Tl	Cu	Pb	Zn	Mo	Bi	Ni	Se	Te	W	Fe	U	Ca	K	Li	Sn		
Au	1	0.54	0.58	0.67	0.68	0.71	0.047	0.18	0.17	0.39	0.0095	-0.025	0.72	0.76	-0.16	-0.11	0.064	-0.57	-0.18	-0.3	0.54		
Ag	0.54	1	0.42	0.62	0.65	0.57	-0.013	0.58	0.38	0.37	0.066	0.0098	0.72	0.71	-0.32	-0.039	0.31	-0.29	-0.38	-0.54	0.34		
As	0.58	0.42	1	0.7	0.48	0.53	0.018	0.19	0.21	0.24	0.12	0.06	0.59	0.55	-0.2	-0.049	-0.1	-0.34	-0.3	-0.38	0.28		
Sb	0.67	0.62	0.7	1	0.74	0.72	0.046	0.32	0.28	0.54	0.066	-0.016	0.84	0.75	-0.26	-0.036	0.18	-0.52	-0.34	-0.52	0.48		
Hg	0.68	0.65	0.48	0.74	1	0.64	-0.053	0.44	0.25	0.46	-0.033	0.01	0.74	0.72	-0.2	0.074	0.3	-0.49	-0.23	-0.4	0.44		
Tl	0.71	0.57	0.53	0.72	0.64	1	-0.053	0.15	0.18	0.41	-0.072	0.025	0.87	0.85	-0.31	-0.15	0.19	-0.43	-0.31	-0.3	0.56		
Cu	0.047	-0.013	0.018	0.046	-0.053	-0.053	1	0.18	0.4	0.2	0.74	0.043	-0.083	-0.018	0.2	0.43	-0.28	-0.23	0.33	0.034	0.32		
Pb	0.18	0.58	0.19	0.32	0.44	0.15	0.18	1	0.63	0.24	0.32	0.18	0.32	0.28	-0.26	0.26	0.25	-0.097	-0.15	-0.31	0.17		
Zn	0.17	0.38	0.21	0.28	0.25	0.18	0.4	0.63	1	0.23	0.58	0.15	0.23	0.21	-0.012	0.27	0.02	-0.14	-0.035	-0.2	0.23		
Mo	0.39	0.37	0.24	0.54	0.46	0.41	0.2	0.24	0.23	1	0.19	-0.13	0.48	0.42	0.0079	0.018	0.4	-0.5	-0.13	-0.27	0.33		
Bi	0.0095	0.066	0.12	0.066	-0.033	-0.072	0.74	0.32	0.58	0.19	1	0.077	-0.078	-0.0058	0.17	0.29	-0.24	-0.13	0.19	-0.061	0.18		
Ni	-0.025	0.0098	0.06	-0.016	0.01	0.025	0.043	0.18	0.15	-0.13	0.077	1	0.032	-3.20E-04	-0.17	0.23	-0.054	-0.11	0.13	0.12	0.044		
Se	0.72	0.72	0.59	0.84	0.74	0.87	-0.083	0.32	0.23	0.48	-0.078	0.032	1	0.92	-0.35	-0.1	0.27	-0.47	-0.41	-0.47	0.56		
Te	0.76	0.71	0.55	0.75	0.72	0.85	-0.018	0.28	0.21	0.42	-0.0058	-3.20E-04	0.92	1	-0.38	-0.11	0.2	-0.44	-0.34	-0.41	0.53		
W	-0.16	-0.32	-0.2	-0.26	-0.2	-0.31	0.2	-0.26	-0.012	0.0079	0.17	-0.17	-0.35	-0.38	1	0.31	-0.14	-0.066	0.093	0.19	-0.13		
Fe	-0.11	-0.039	-0.049	-0.036	0.074	-0.15	0.43	0.26	0.27	0.018	0.29	0.23	-0.1	-0.11	0.31	1	-0.055	-0.089	0.23	0.14	0.14		
U	0.064	0.31	-0.1	0.18	0.3	0.19	-0.28	0.25	0.02	0.4	-0.24	-0.054	0.27	0.2	-0.14	-0.055	1	-0.069	-0.16	-0.14	-0.023		
Ca	-0.57	-0.29	-0.34	-0.52	-0.49	-0.43	-0.23	-0.097	-0.14	-0.5	-0.13	-0.11	-0.47	-0.44	-0.066	-0.089	-0.069	1	-0.0028	0.16	-0.44		
K	-0.18	-0.38	-0.3	-0.34	-0.23	-0.31	0.33	-0.15	-0.035	-0.13	0.19	0.13	-0.41	-0.34	0.093	0.23	-0.16	-0.0028	1	0.5	-0.056		
Li	-0.3	-0.54	-0.38	-0.52	-0.4	-0.3	0.034	-0.31	-0.2	-0.27	-0.061	0.12	-0.47	-0.41	0.19	0.14	-0.14	0.16	0.5	1	-0.18		
Sn	0.54	0.34	0.28	0.48	0.44	0.56	0.32	0.17	0.23	0.33	0.18	0.044	0.56	0.53	-0.13	0.14	-0.023	-0.44	-0.056	-0.18	1		
							Strong Positive Correlation					Strong Negative Correlation											

Figure 56. Spearman correlation matrix of Vista Vein shear zone intercepts. Strong positive correlations are highlighted in blue. Strong negative correlations are highlighted in red.

*Galena Vein Intercepts*

The second correlation matrix is strictly focused on intercepts of the Galena Vein (Fig. 57). A total of 29 Galena Vein intercepts from 18 different drill holes were used. Strong positive correlations with Au include: Hg (0.58), Tl (0.52), and Sn (0.51). Strong positive correlations with Ag include: Sb (0.52), Pb (0.87). There was a strong negative correlation of Ag with Tl (-0.62). Strong positive correlations with Cu include: Zn (0.53), Bi (0.53), and Fe (0.84). Strong negative correlations with Cu include: Ni (-0.69), Ca (-0.69), and K (-0.66). Strong positive correlations with Pb include: Ag (0.87) and Sb (0.61). Strong negative correlations with Pb include Tl (-0.53).



### *Element Zonation*

The zonation of the Carlin-type pathfinder elements and the base metal elements were determined by loading ICP data from 105 core drill holes into ioGAS software, flagged only as “VV1”; meaning intercepts were determined by geology and Au grade for Newmont’s Vulcan model. The intercepts used were strictly confined to the flagged VVSZ. Samples that were averaged over 20 foot composites were resent for ME-MS41 analysis to ALS Chemex Laboratory. This allowed the exact footages to be analyzed. Multiple longitudinal sections oriented along the strike of the VVSZ projected onto the footwall were created using ioGAS. Trace elements that correlate strongly with Au (Carlin-type pathfinder elements) based on the results generated from the VVSZ + Galena Vein intercepts correlation matrix in ioGAS were then contoured using the Display Gridded data option. The grids were modified using the settings shown below (Fig. 58).

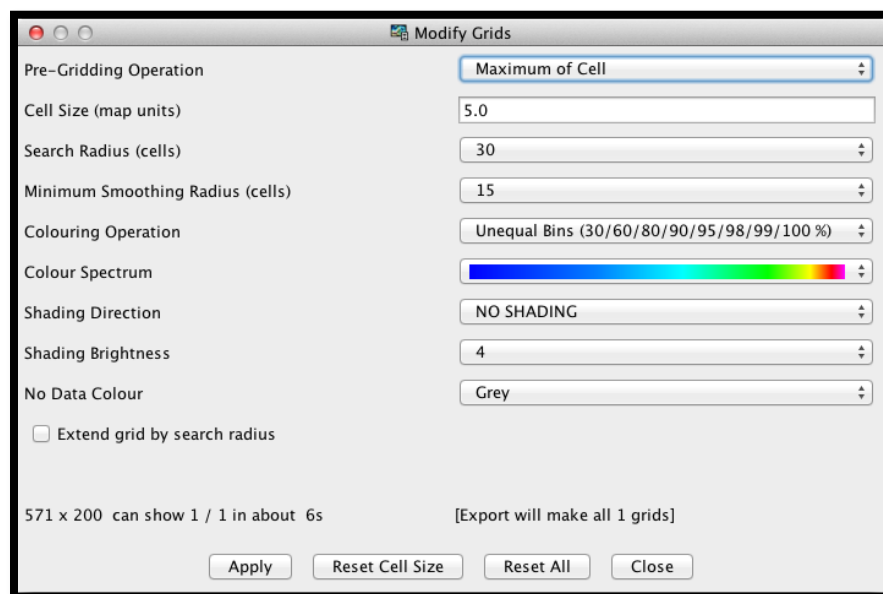


Figure 58. The parameters used to create trace element longitudinal sections.

### *Carlin-type Pathfinder Elements*

The Carlin-type pathfinder elements that have strong positive correlations with Au (Fig. 59-65) include: As (0.5), Sb (0.65), Hg (0.69), Se (0.69), Te (0.72), Tl (0.7) and Sn (0.53). The longitudinal sections show contoured values of a single trace element in parts per million (ppm).

As, Tl, Hg, Se, and Te all increase at depth to the northeast. This is a promising target for expansion of this deposit because the ore deposit remains “open” at depth for further exploration. Hg, Se, Te, Tl, and Sn all have very similar spatial distributions with elevated ppm concentrations at depth to the north. As and Sb also show spatial distributions, but with a less pronounced spatial distribution than the other Carlin-type pathfinder trace elements. It is likely that As, Sb, Hg, Se, Te, Tl, and Sn were deposited in the Eocene during the Carlin-type gold mineralization event.

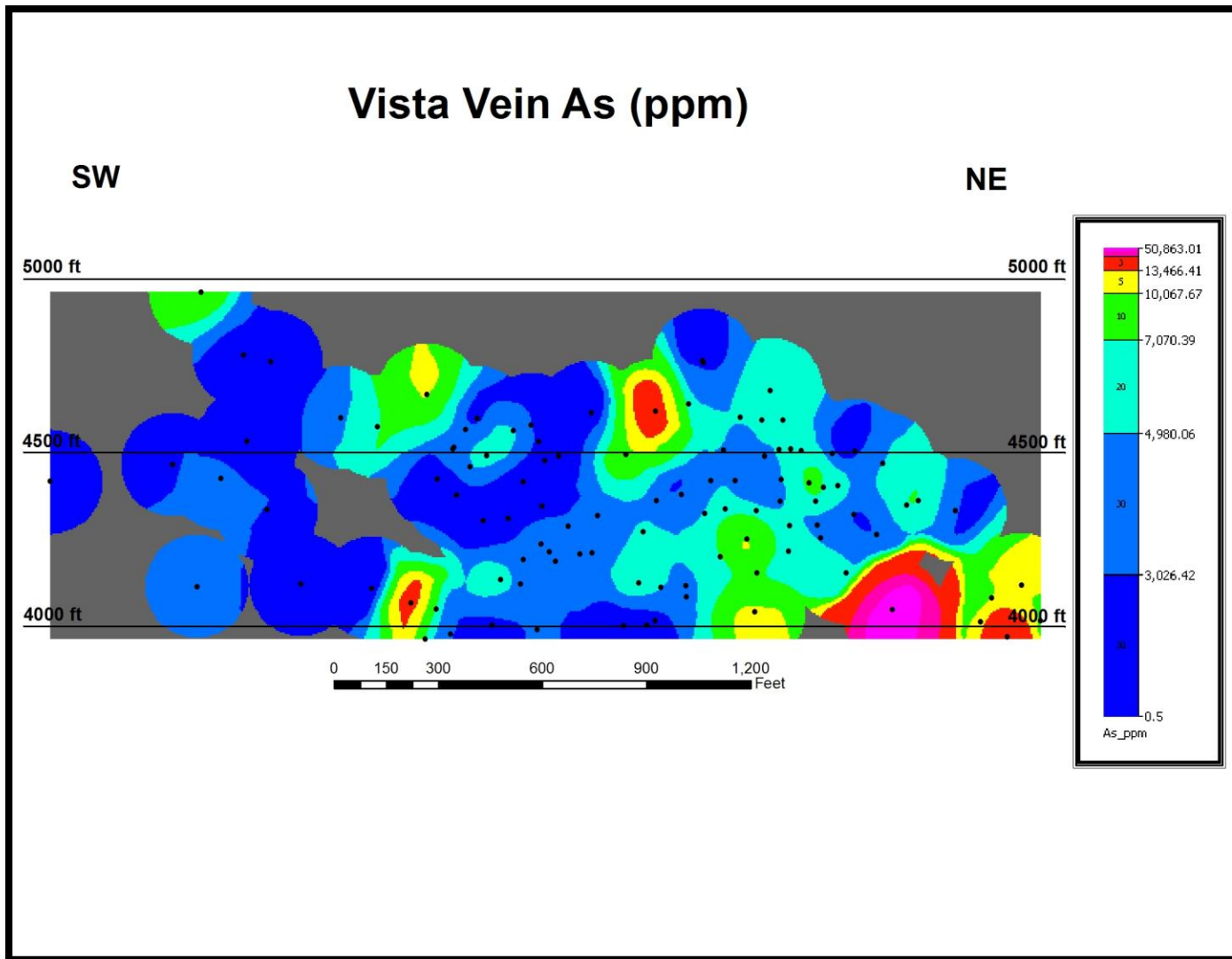


Figure 59. Arsenic (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.

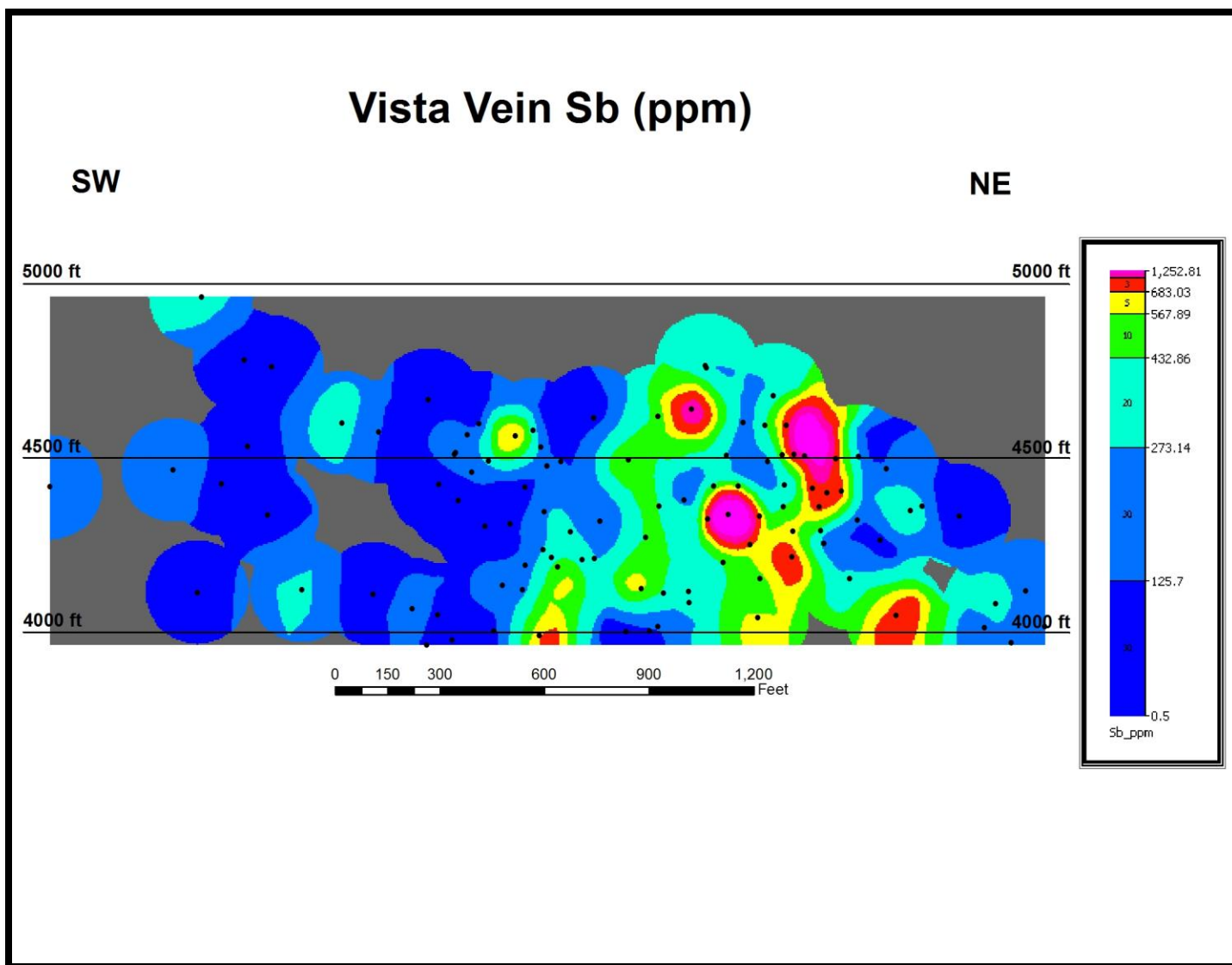


Figure 60. Antimony (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.



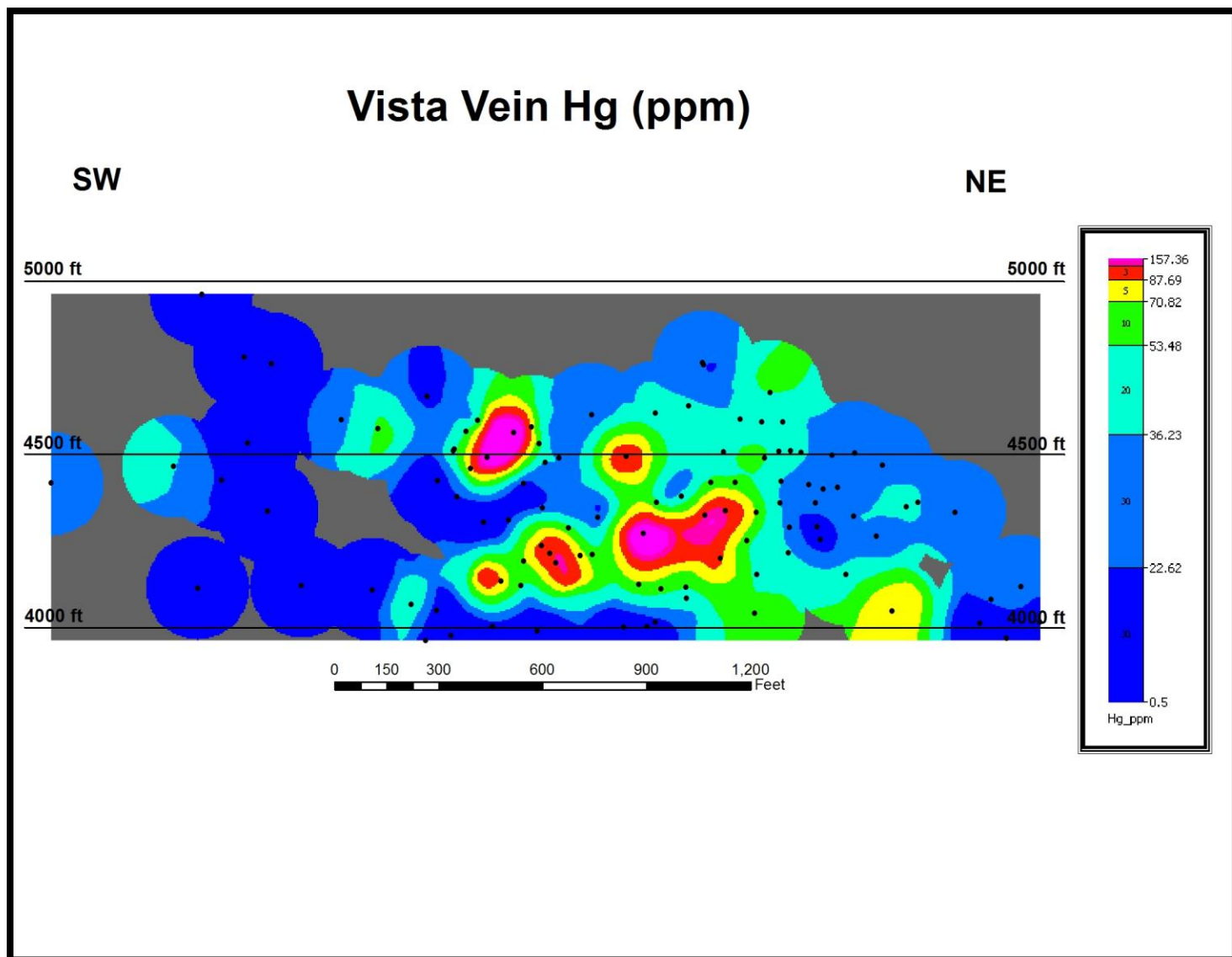


Figure 61. Mercury (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.

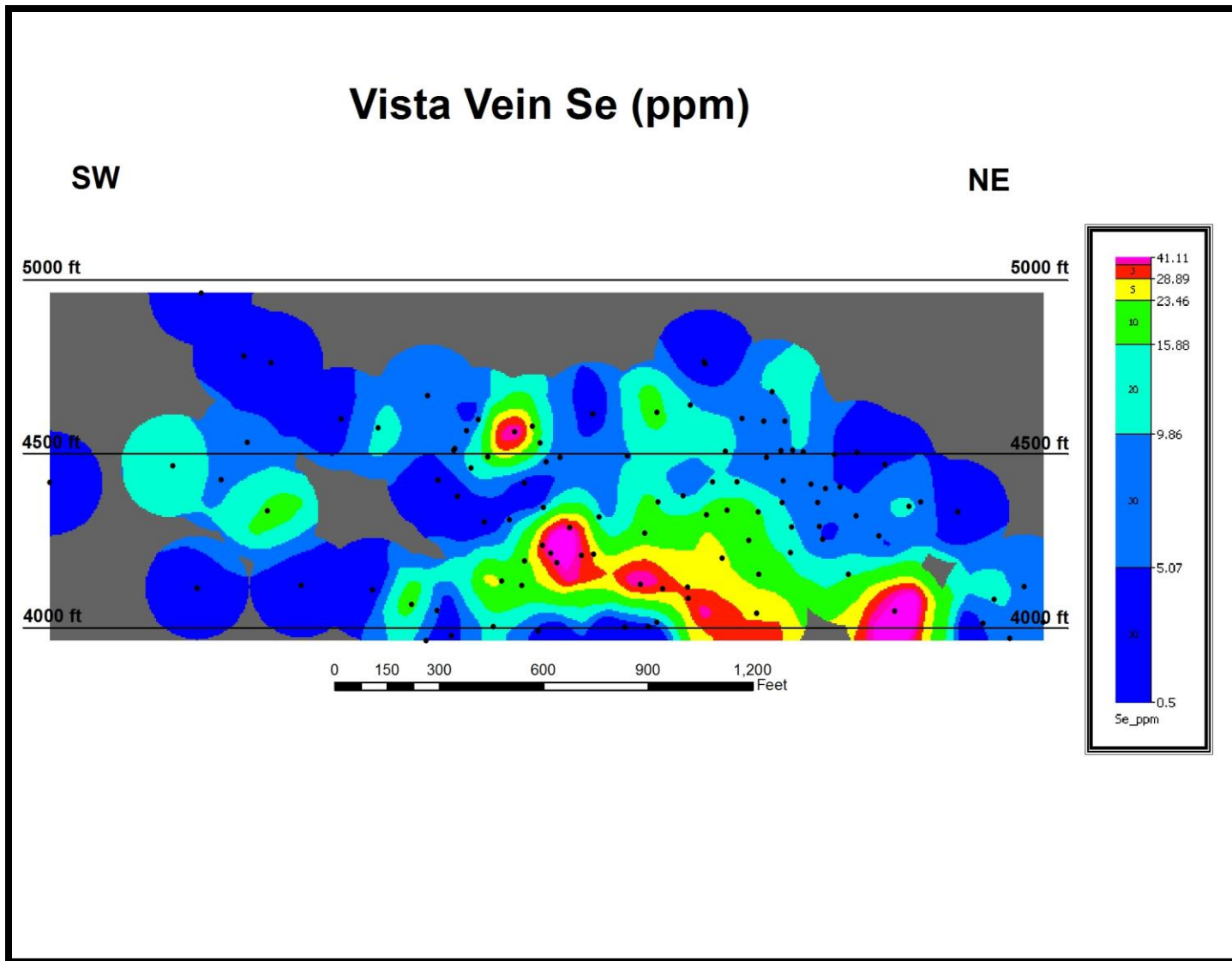


Figure 62. Selenium (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.

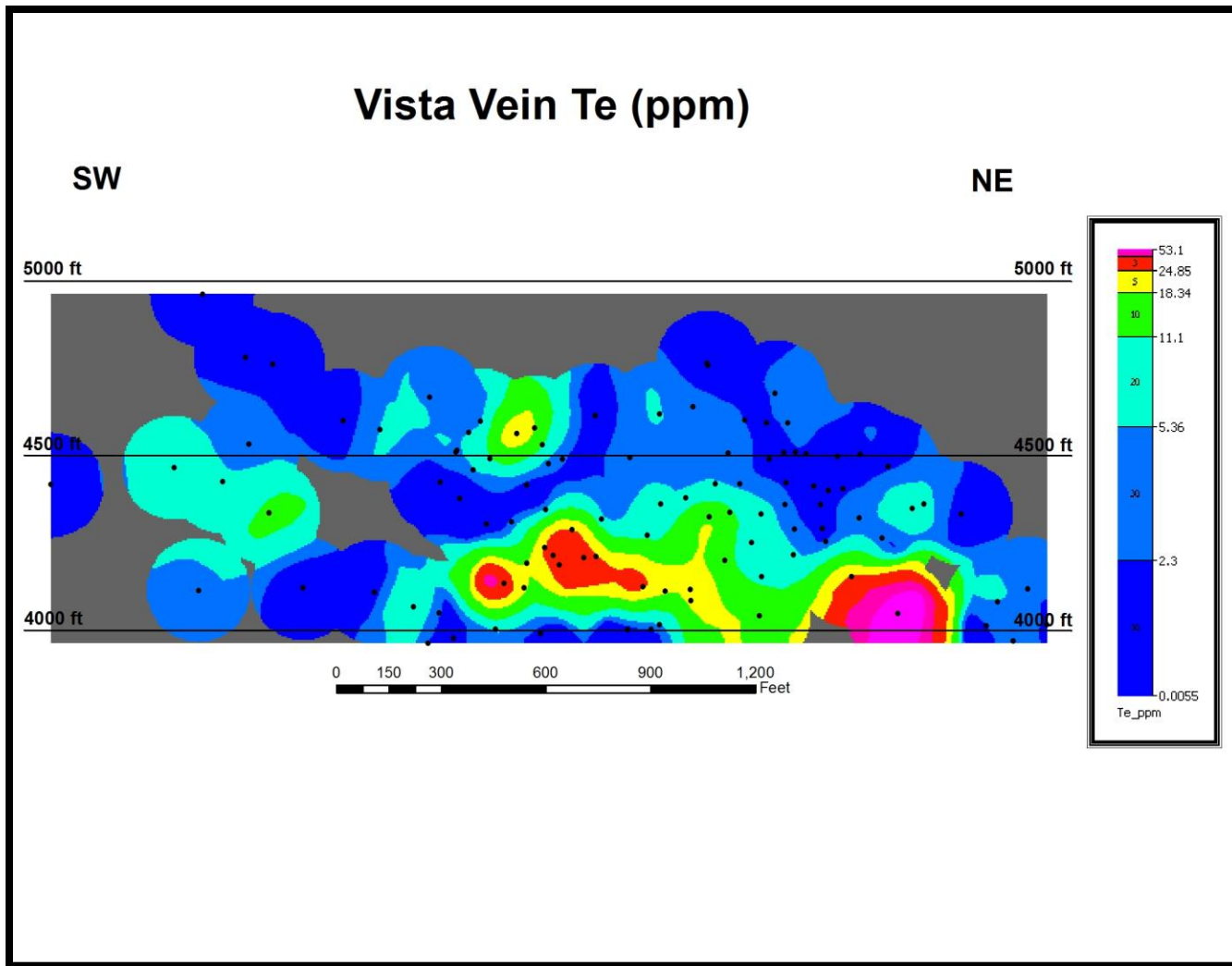


Figure 63. Tellurium (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.

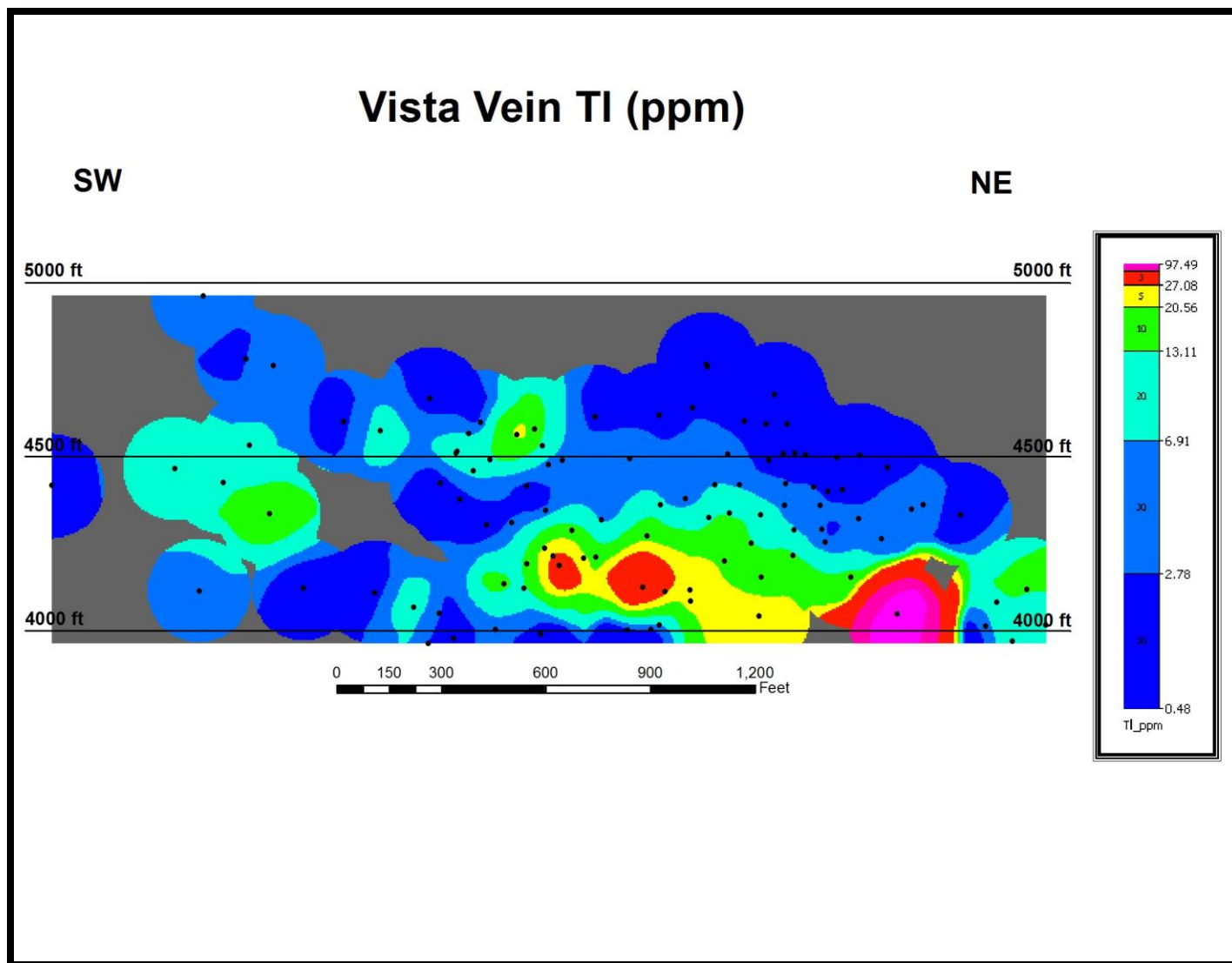


Figure 64. Thallium (ppm) contours in the Vista Vein shear zone deposit. This is a longitudinal section looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.

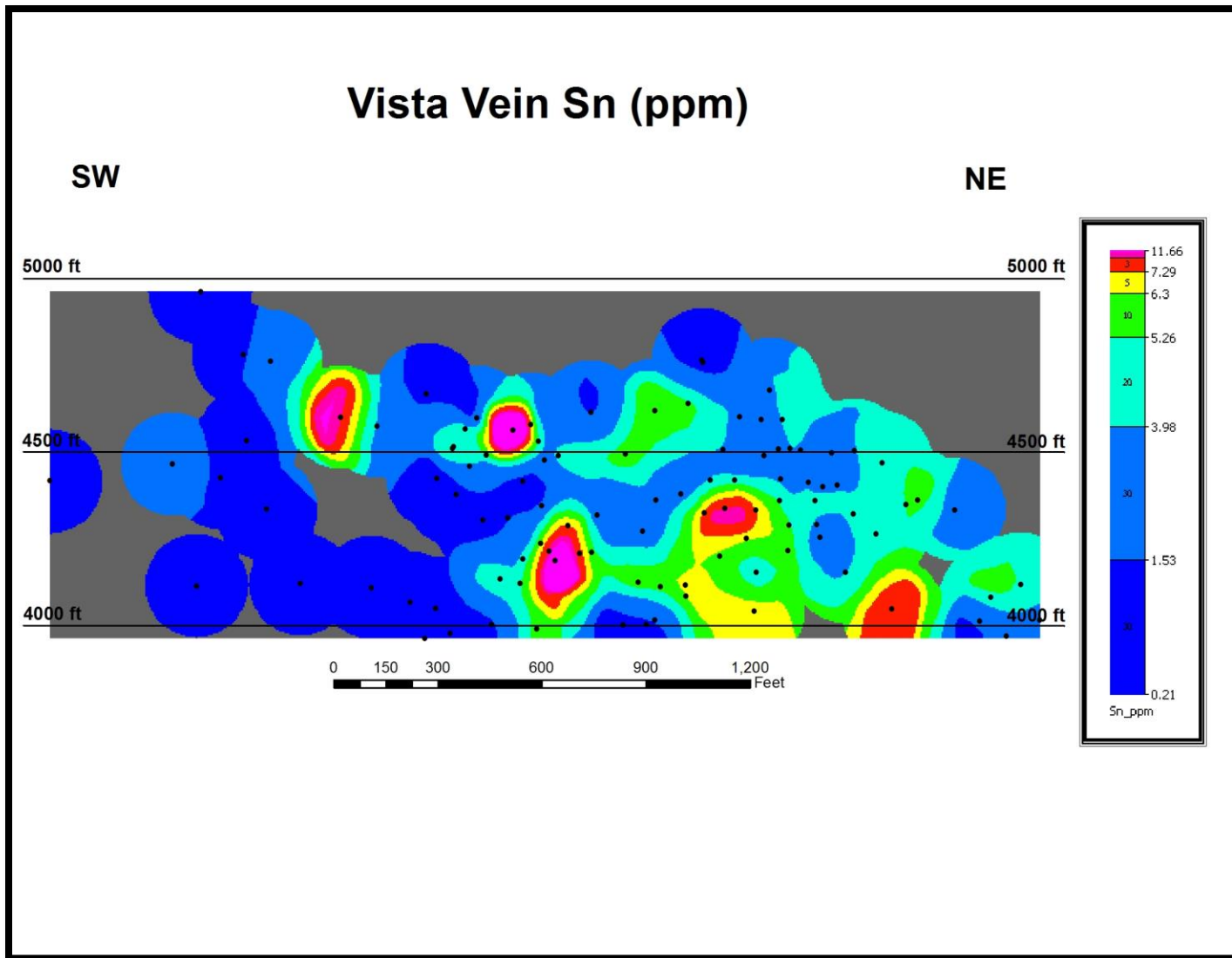


Figure 65. Tin (ppm) contours in the Vista Vein shear zone deposit. This is a longitudinal section looking to the northwest at the footwall. Drill hole pierce points are shown as black dots.

*Silver and Base Metal Elements*

Ag (Fig. 66), Pb (Fig. 67), Zn (Fig. 68), and Cu (Fig. 69) concentrations on longitudinal sections show different distributions relative to the Carlin-type pathfinder elements. These elements have elevated values that increase to the northeast at higher elevations in the deposit. Silver, lead, and zinc longitudinal sections show similar spatial distribution of elevated ppm concentrations with copper elevated at upper and lower positions. It is possible that silver, lead, zinc, and copper were deposited at the same time during the formation of the Galena Vein. The presence of elevated Ag, Pb, Zn, and Cu concentrations higher in elevation indicates that these elements were deposited separately from the Carlin-type pathfinder elements. This is a strong indicator of two separate events. It should be noted that copper is present and may have been concentrated during both events.

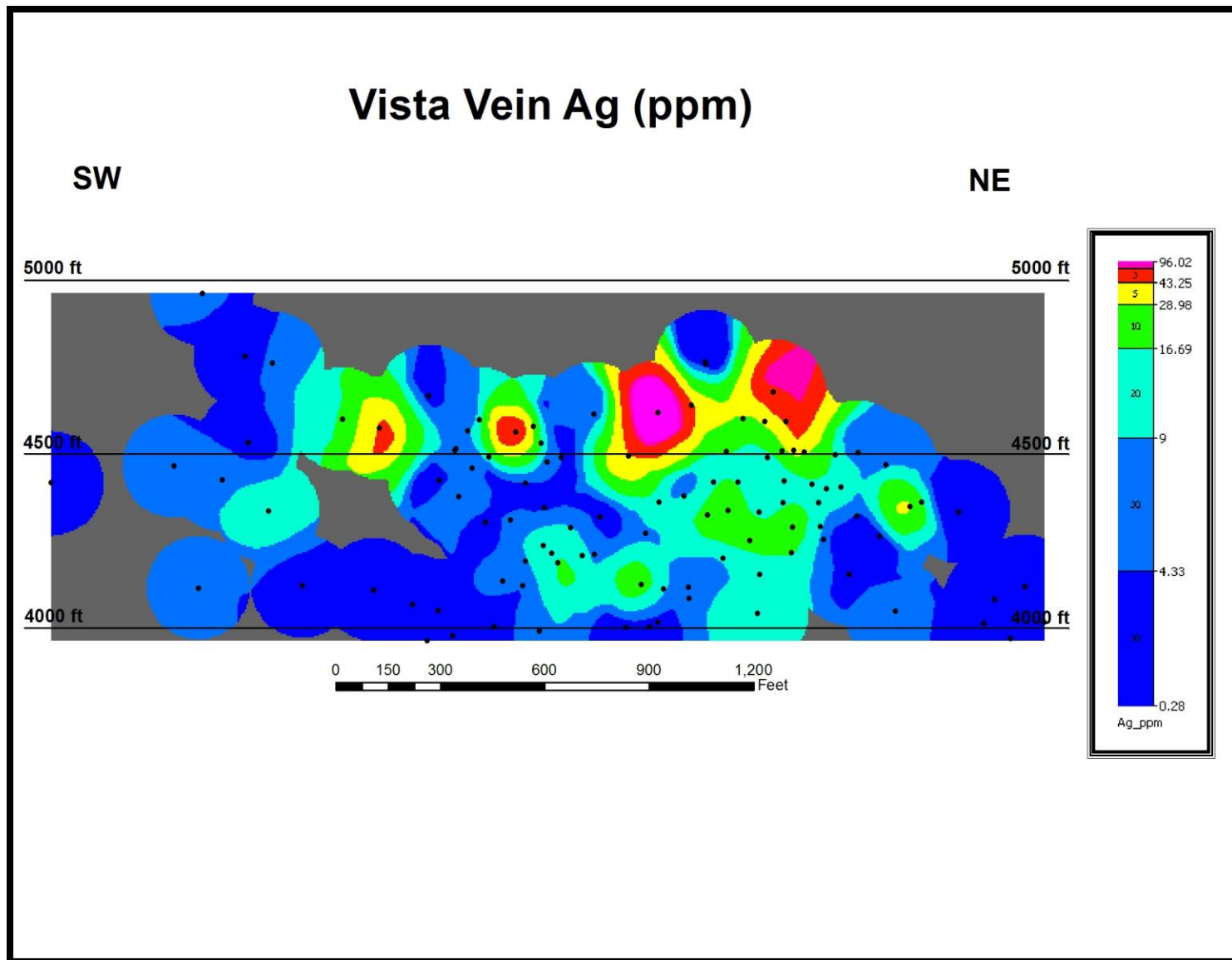


Figure 66. Silver (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are black dots.

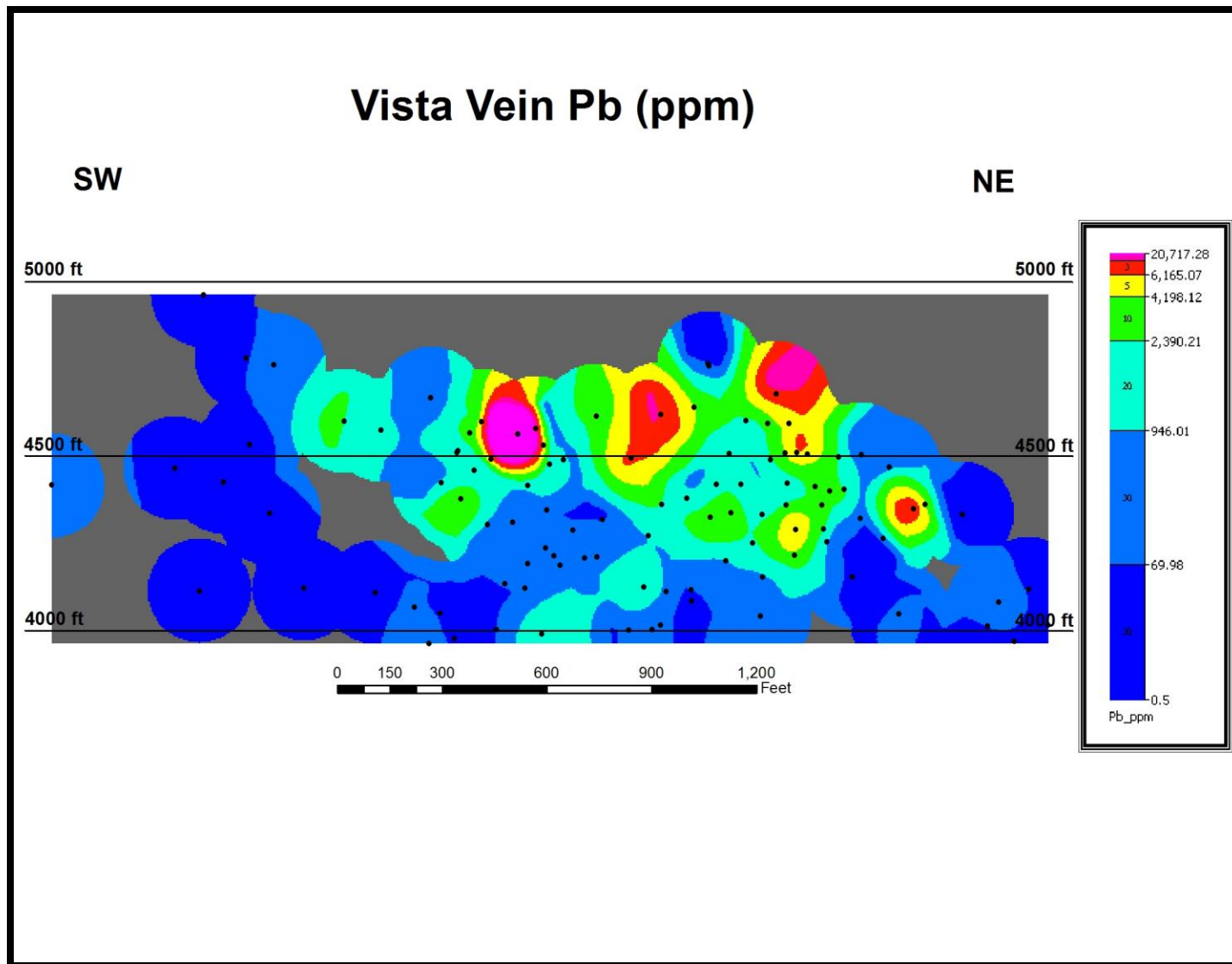


Figure 67. Lead (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are black dots.



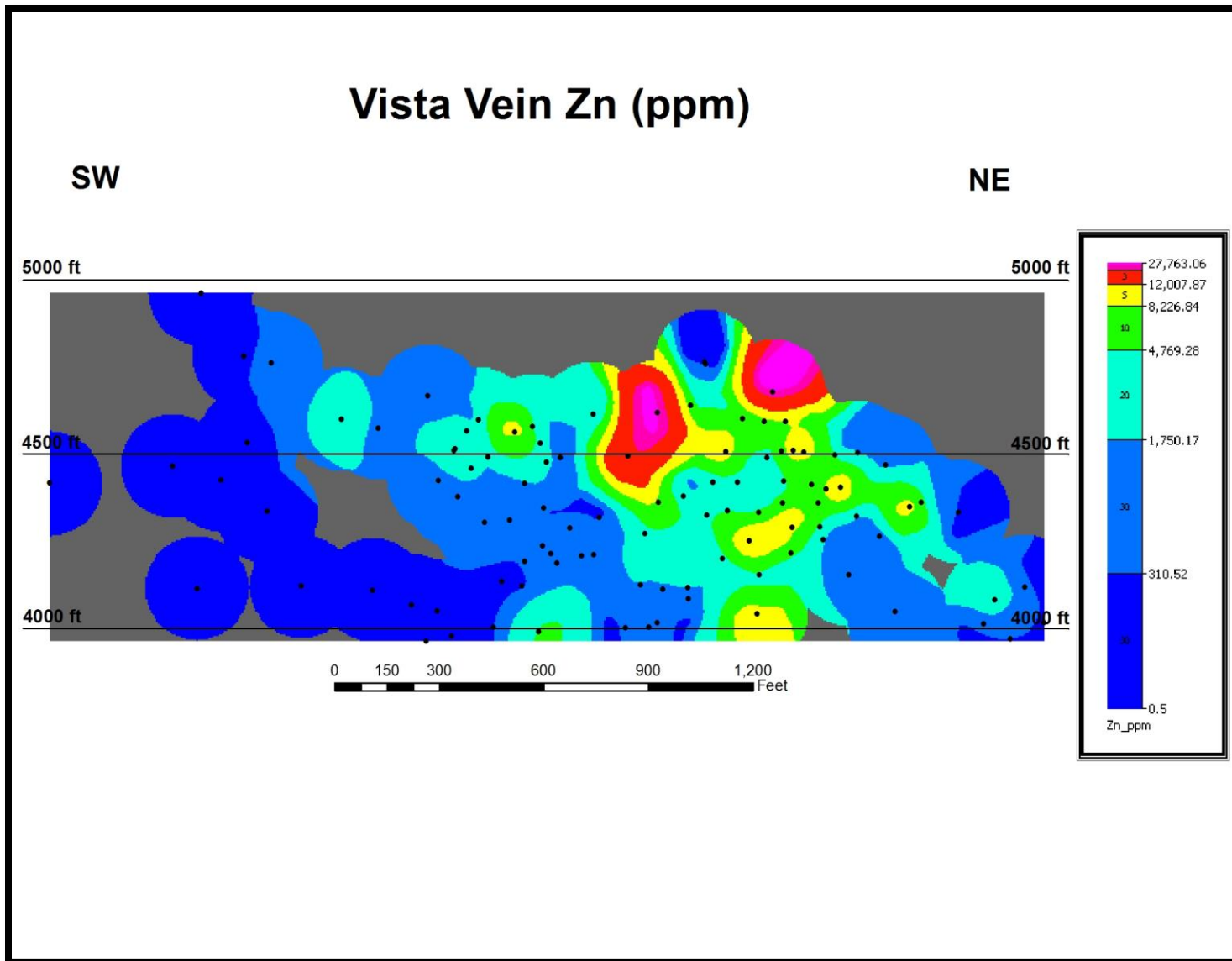


Figure 68. Zinc (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are black dots.

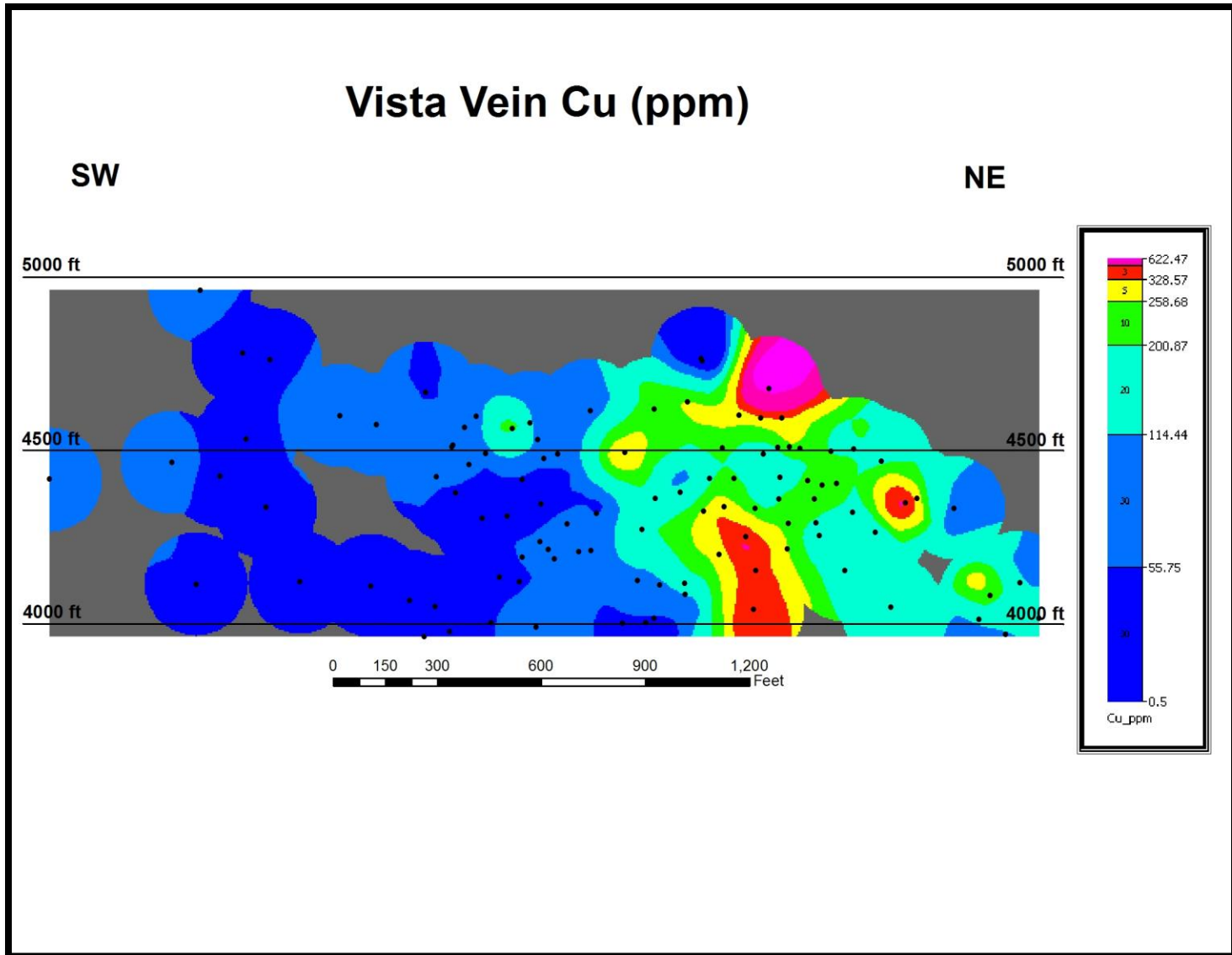


Figure 69. Copper (ppm) contours in the Vista Vein shear zone deposit. This longitudinal section is looking to the northwest at the footwall. Drill hole pierce points are black dots.

## Chapter 10: Discussion and Future Work

### *Controls on Mineralization*

There are two main controls of mineralization in the VVSZ deposit. These two controls are alteration and structure.

Four alteration assemblages are associated with the ore zone and therefore act as controls on gold mineralization. Alteration types are: phyllic, argillic, decarbonatized, and silicified rock. Carlin-type Au deposits typically have decarbonatization, silicification, and argillization associated with gold deposition. These three alteration processes are localized along the shear zone and in other fractures, but outside of the shear zone they are uncommon. The removal of carbonate within the shear zone acted as rock preparation for gold deposition.

The VVSZ deposit is hosted in tectonic breccias within the shear zone. Due to shearing the rock was fractured, cracked, and fragments were rotated. Shearing provided the ore fluids with open spaces and permeable fractures within the breccia. Another structural control is the change in strikes and dips, which controlled dilational openings that channeled the ore fluids.

The most important secondary structural control within this deposit is a porphyritic dacite dike that is offset by the shear zone and appears to have acted as a barrier to Au mineralization. Gold mineralization is constrained to north of the dike. This intrusive shape is newly modeled and has opened interesting questions regarding secondary structural controls with the VVSZ deposit. If the mineralizing fluid were rising up from what now is the northeastern end of the shear zone and then moving

laterally to the southwest, the dike would seem to have been an impermeable barrier to expansion of the mineralization plume.

### *Geochemistry*

Trace elements that are typically associated with Carlin-type Au mineralization include: Hg, As, Tl, and Sb. Pathfinder elements will locally exhibit zonation and could help vector in on the ore bodies both vertically or laterally (Patterson and Muntean, 2011). There have been a handful of published geochemical signatures for Carlin-type Au deposits across the state of Nevada. Some of the deposits that have had geochemical statistical analyses include: Goldstrike, Jerritt Canyon, Turquoise Ridge, Northumberland, and Deep Star (Patterson and Muntean, 2011). At Barrick's Goldstrike property on the Carlin Trend, Bettles (2002) found an elemental signature of Au, As, Sb, Hg, Tl, S, Te, and Ag. Jerritt Canyon (Patterson and Muntean, 2011) established a geochemical signature of Au, Tl, Hg, and As. At Barrick's Turquoise Ridge mine on the Getchell trend, Cassinerio and Muntean (2010) used factor analysis and correlation matrices from downhole trace element data to show that Au strongly correlates with S, W, Tl, Sb, Te, As, and Hg. Lanier et al. (1993) at Northumberland discovered that ore grade gold mineralization was enriched in As, Ag, Cu, Hg, Mo, Sb, Se, W, and Zn. Heitt et al. (2003) at Deep Star showed that Au is strongly associated with As, Hg, Tl, Ag, Zn, and Sb.

The Vista Vein elemental signature is Au, Ag, As, Hg, Te, Tl, Sn, and Se. It should be noted that the Vista Vein is characterized by alteration, mineralogy, and trace-element signatures that mimic other Carlin-type Au deposits. The two elements that are

most unusual at Vista Vein are Se and Sn, which are only sparingly described for Carlin-type Au deposits. The highest values of Sn and Se in the sampled suite at Vista Vein are 11.6 ppm and 41 ppm, respectively, in both cases in association with high-grade Au. The mean value for Se within the VVSZ is 21.15 ppm and the mean value for Sn within the VVSZ is 5.7 ppm. Concentrations of Se and Sn in Vista Vein are thus relatively low, especially compared to the  $10^3$  ppm Se concentrations in most mid-Miocene epithermal Au-Ag deposits in north-central Nevada such as Midas, Buckskin-National, and Sleeper. For Carlin-type deposits, Se is commonly noted as anomalous (Hofstra et al., 1995 and Harris and Radtke, 1976). In contrast, Sn is rarely reported, although, Johnston (2003) reported Sn  $\pm$  Au at the Cove distal disseminated gold deposit. Interestingly, Se and Sn are anomalous in both Miocene epithermal deposits and some Carlin-type or Carlin-like (e.g., Cove) gold deposits. Therefore, Se and Sn are not diagnostic signatures of Miocene epithermal deposits in Nevada, although extremely high values of Se characterize Miocene epithermal deposits and not Carlin-type systems.

#### *The role of sulfidation in the VVSZ deposit*

If the Galena Vein was deposited prior to Carlin-type mineralization then the iron in the Galena Vein most likely reacted with sulfur to deposit the ore-stage pyrite. The Carlin-type fluids were “iron starved” and needed to react with iron in the Galena Vein to precipitate the pyrite and gold. This concept of sulfidation for gold deposition was first introduced by Stenger et al. (1998) at the Twin Creeks mine. The higher grade Au of the VVSZ compared to the bulk tonnage deposit maybe attributed to (1) the localization of the fluids within a concentrated area and (2) the Galena Vein had abundant reactive iron

in pre-ore pyrite and sphalerite so more gold was deposited there. Future research to test this hypothesis might include stable isotopes values of sulfur in minerals and rocks.

#### *Relationship of the VVSZ to the Bulk Tonnage Deposit*

The bulk tonnage deposit located within the upper Valmy Formation is referred to as the Vista Sulfide deposit by Newmont geologists. The Vista Sulfide zone is a series of anastomosing thin fractures/veinlets filled with arsenian pyrite and marcasite. Argillic alteration is typically associated with the Vista Sulfide ore. These thin fractures are not laterally extensive enough to form continuous mineable structures, so the Vista Sulfide deposit has to be mined by open pit. These veinlets and fractures are interconnected and the favored hypothesis is that the Vista Sulfide deposit is the same age as the VVSZ. Breit et al. (2005) proposed that the VVSZ acted as a feeder to the overlying bulk tonnage deposit. A recent leapfrog model by Melker (2014) shows Hg shells with values > 5.0 ppm and another shell with values >15.0 ppm (Fig. 70) relative to the modeled formations. The distribution of Hg in the cross-section suggests that fluids flowed up and out along the contact of the Ordovician Valmy Formation and the Pennsylvanian-Permian Etchart Formation. This model supports the concept that the VVSZ was a feeder to the overlying bulk tonnage mineralization.

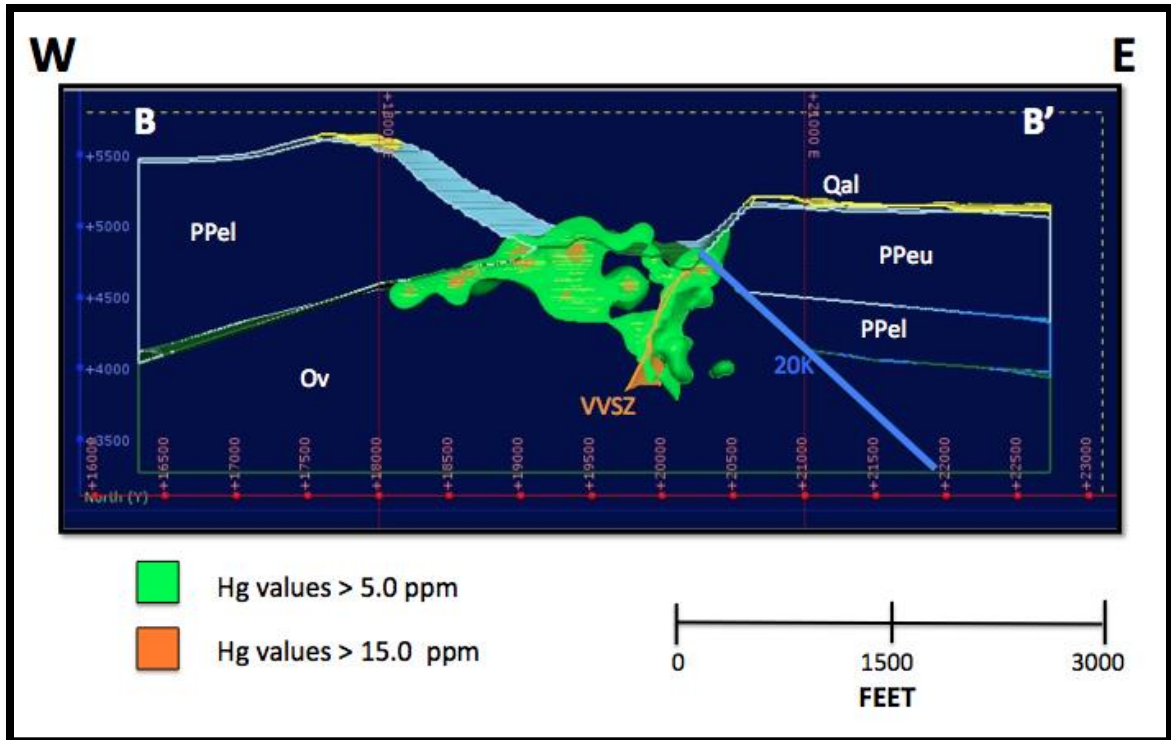


Figure 70. Cross-Section showing formations and the VVSZ in orange. Green shell is Hg values >5.0 ppm. Orange shell is Hg values > 15.0 ppm. Blue line = 20K fault. PPel = Pennsylvanian-Permian lower Etchart formation. PPeu = Pennsylvanian-Permian upper Etchart formation. Ov = Ordovician Valmy Formation. Qal = Quaternary Alluvium.

### *Future Work*

A recommendation for future work includes creating a correlation matrix of downhole geochemistry from Vista Sulfide drill holes in order to determine the trace element signature of the bulk tonnage Vista sulfide deposit. A similar trace element signature to the Vista Vein trace element signature could support the hypothesis that the VVSZ acted as a feeder to the Au ore zones in the overlying Valmy and Etchart formations.

Establishing absolute ages of the gold mineralization and the Galena Vein at the VVSZ deposit would be an important addition to the understanding of this Carlin-type

gold deposit. Without having definitive ages it is unknown whether the Galena Vein was deposited pre- or post- Carlin type Au mineralization. Molybdenite has not been identified petrographically, but that does not rule out its absence. If molybdenite was discovered in future petrographic work, a radiometric date could be obtained to help define the age of base metal mineralization.

The structural understanding of the VVSZ deposit is incomplete due to the lack of underground exposure and limited access to the workings now that the project has been shut down. If and when the project starts up, Vista underground geologists would no doubt continue the tradition of detailed structural mapping. The deposit poses a complex structural problem, but I believe unraveling this problem will lead to identification of further Au reserves, and a unique insight into the roots of Carlin-type Au deposits.

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