CONTROLS ON PRECIOUS-METAL MINERALIZATION,
EASTON-PACIFIC VEIN,
VIRGINIA CITY MINING DISTRICT,
MADISON COUNTY, MONTANA

by

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ABSTRACT

The Virginia City mining district in southwestern Montana has produced economically significant amounts of placer and lode gold, with the Easton and Pacific mines being the largest lode producers in the district. Mining exploited composite quartz vein structures that are spatially related to the Brown's Gulch monzonite stock which intrudes Precambrian metamorphic rocks. Mineralization comprises pyrite, chalcopyrite, galena, sphalerite, acanthite, tellurides and native precious metals and can be characterized by two distinct mineralizing stages separated by periods of brecciation.

Argillic alteration in the area of the Pacific mine was produced by hydrothermal activity associated with mineralization. Illite:smectite ratio in the zone of argillic alteration varies inversely with respect to distance from the Pacific vein system. The results of this study are consistent with similar studies done on active geothermal systems and hydrothermal ore deposits. Systematic variations in illite/smectite ratios in zones of argillic alteration have been documented in deposits as diverse as Kuroko-type volcanogenic massive sulphide deposits (Inoue and Utada, 1983) to lower temperature
epithermal deposits (Horton, 1989) and modern geothermal systems (Eslinger and Savin, 1973).

Fluid inclusion data suggest ore-forming fluids evolved with time from moderate temperature (275°C), low salinity (3-6 eq wt% NaCl) solutions to lower temperature (175°C), higher salinity (10-12 eq wt% NaCl) solutions. This suggests that Virginia City mineralization involved the mixing of fluids from different sources.

When compared to other hydrothermal ore deposits, the Virginia City deposits appear most similar to the deposits of the Cheonan district in Korea. These deposits appear to bridge the gap between model epithermal and mesothermal deposits.
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INTRODUCTION

Lode gold deposits in the headwaters of Brown's and Alder Gulches have long been considered the source of placer gold in Alder Gulch, near Virginia City, Montana. Over 2.5 million ounces of placer gold were recovered from Alder Gulch in the late 1800's, making it one of the richest placer deposits in the U.S. The nature of the lode deposits in the Virginia City district have been discussed in many reconnaissance reports (Winchell, 1914; Tansley et al., 1933; Lorain, 1938) but no detailed studies have described this mineralization.

The Easton and Pacific mines were the largest lode producers in the Virginia City district. They were targeted by BHP/Utah International as a possible low-grade bulk tonnage deposit after reconnaissance sampling uncovered anomalous gold values within country rock. This project is the result of a follow up investigation of the property.

Purpose of Study

The primary goals of this research project are:

1. Document the occurrence of gold deposits in the Virginia City district with emphasis on
the Easton-Pacific vein system;
2. Interpret the structural controls on the mineralization in the district and the relationship to regional structural patterns;
3. Investigate the possibility of disseminated gold mineralization in the wall rocks in the area of the Easton and Pacific mines;
4. Define the conditions and timing of mineralization and alteration at the Easton and Pacific mines.

Since much of the high-grade ore has been exploited in the Virginia City district, this study will be useful in the search for hidden ore deposits in the district and elsewhere in the Tobacco Root Mountains and similar regions.

Methodology

The first step in fulfilling these goals was a complete literature search for any and all information that was available on the Virginia City district and the Tobacco Root Mountains in general. This information was then compiled with an emphasis placed on geologic and structural controls on mineralization along with the type and
abundance of mineralization throughout the Tobacco Root mining region.

The field methods used were surface and underground mapping, soil sampling, geophysics, trenching and drilling. Laboratory methods include thin section and polished section microscopy, fluid inclusion analysis, and X-ray diffraction.

Surface and underground mapping in the area of the Easton-Pacific mine was done at several scales (1"=1000', 1"=400', 1"=100', 1"=20'). Information collected on the Virginia City district was compiled at the scale of 1"=1000'. Enlarged USGS topo maps were used as base maps, along with airphotos at appropriate scales. Tape and brunton surveys were conducted in underground workings and in trenches. Emphasis in mapping was placed on wall rock alteration and geometry of vein/wallrock contacts. Samples were collected for thin section and polished section microscopy, fluid inclusion analysis, assay and X-ray diffraction identification.

Location, Access and Physiography

The Virginia City mining district is located in central
Madison County, southwestern Montana (fig. 1). The district, shown in figure 2, extends from Alder Gulch on the north and east, to the west of Brown's Gulch, and to the flanks of the Gravelly Range on the south (Cole, 1983).

The Easton and Pacific mines are located at the head of Brown's Gulch approximately 4.5 mi south of Virginia City. Virginia City is accessible via Montana Highway 287. The Easton and Pacific mines and the Virginia City district are accessible on numerous unimproved dirt roads, although winter access is difficult in the southern portion of the district. Many of the bedrock exposures occur in stream cuts, along ridgetops and in mine cuts. Several adits and crosscuts are still accessible but caution is advised in entering them. The majority of the Easton and Pacific mine workings are caved.

Elevations in the Virginia City district range from 5700 ft. above sea level in the north to 8561 ft. in the south. The low-lying northern half of the district is sparsely vegetated with sage brush and other low ground cover. This type of vegetation grades into thick conifer stands at higher elevations.
Figure 1. Location Map.
Figure 2. Map showing the location of mines and major vein trends in the Virginia City district.
The district is cut by numerous drainages, the main ones being Alder and Browns Gulches. These are medium to small size creeks whose level fluctuates with snow melt and rainfall.

**Property Ownership and Status**

The Easton and Pacific mines and approximately 8 mi² surrounding them are owned by the Easton, Pacific and Riverside Mining Company, Morrison, Colorado. The claim block consists of 34 patented mining claims and 284 unpatented mining claims. For a discussion of past ownership refer to section on district history.

**Previous Studies**

The Tobacco Root Mountains have been the subject of many petrographic, structural and regional studies, albeit detailed investigations of ore deposits in this region have not been performed. The following is a compilation of work done in the area dealing with regional geology and ore deposits.

The first record of the Easton-Pacific lode and the Virginia City mining district was published in Statistics
of Mines and Mining in the States and Territories West of the Rocky Mountains, for the calendar year 1869. Records of mining in the Virginia City district continued in this publication, but it was not until 1914 that any geologic investigations were conducted in the area. Winchell (1914) reported on the mining districts in the Dillon quadrangle and adjacent areas in southwestern Montana. Tansley, Schafer, and Hart (1933) conducted a reconnaissance survey of the general geology and ore deposits of the Tobacco Root Mountains. Lorain (1937) described the geologic settings of lode gold mines in the Tobacco Root Mountains along with mining and processing techniques used at that time. Levandowski (1956) investigated ore deposits in southern Sheridan mining district. Burger (1966) conducted a structural study of the Sheridan district and proposed structural controls on the mineralization present there. Hadley (1969) mapped the southern portion of the Virginia City district in the 15 minute Varney quadrangle. Vitaliano and Cordua (1979) mapped the southern Tobacco Root Mountains with an emphasis on the Precambrian geology. Weir (1982) published a preliminary map of the northern portion of the Virginia City district. Cole (1983) described the vein mineralogy and interpreted the alteration assemblage at the U.S. Grant mine in the Virginia City district. Ruppel (1985) studied the Middle
VIRGINIA CITY DISTRICT HISTORY

The 1863 discovery of gold in Alder Gulch, near Virginia City, caused an influx of miners and prospectors into the area. Within a few years lodes were discovered, and by the late 1860's a few stamp mills were in operation. Discoveries throughout the Tobacco Root Mountains made this region one of the most productive in the history of the early West (Young, 1970). By the early 1900's, 2.5 million ounces of placer gold were taken from Alder Gulch, and approximately 142,000 ounces of gold were taken from lode deposits. The most important mining areas in the Tobacco Root region were Virginia City, Pony, Norris, Renova and Sheridan districts.

Lode mining in Virginia City District began with the establishment of the Oro Cache and the Kearsarge mines in the mid-1860's at the head of Alder Gulch. Vigorous prospecting in the district resulted in the discovery of the Easton-Pacific, Prospect, U.S. Grant, Winnetka, and Marrietta mines, and numerous other smaller deposits. Figure 2 shows the location of mines in the Virginia City district. By 1890 stamp mills were installed at many of the mines. High-grade gold and silver ore was being exploited from the upper oxidized zones of these deposits (Lorain, 1937).
On May 3, 1869 the Easton lode was discovered by Joseph and D.J. Emery. The prospect was opened by two cross-tunnels, one 70 feet below the other, and a shaft. Most of the ore was treated at the mine, but select high-grade was sent to Swansea, Wales via San Francisco. Without a railroad, shipping the ore was prohibitively expensive. The Pacific lode was discovered by Joseph Emery in 1885. In 1889, a 10 stamp mill capable of processing 15 tons of ore a day was constructed on Brown's Gulch (Anon., 1889). As mining continued at Easton, the continuity and thickness of the vein was confirmed to be sufficient to warrant further upgrading of the processing facilities. By 1894, 100 men were employed at the Easton mine, and 2,200 feet of tunnels had been driven (Anon., 1894). Up to this point, very little stoping had been done as all of the ore was being extracted from the tunneling process. In late 1894, a mill capable of processing 28 tons a day was constructed at the Easton mine. Along with the mill came electric lights and power. The ore was being mined from several veins 3 to 5 feet thick with an average grade of 70 ounces silver and 1 ounce gold per ton. Some high-grade zones assayed as high as 700 oz. silver and 2 oz. gold per ton. Progress continued at Easton and development at the Pacific proved
it to be continuous and high-grade. By 1900, 1,400 feet of tunnel was complete at the Pacific mine as shown in figure 3 (Anon., 1900). Around this time smelter records show the first sulfide ores were being encountered at the Easton mine at a depth of about 400 feet. The early 1900's saw significant production from the Easton and Pacific mines, with shipping ore averaged 62 oz. silver and 2.7 oz. gold per ton. By the time WWI closed the gold mines, the Easton mine had been extended to 5 levels, 500 feet below the surface; the Pacific mine had been developed by two tunnels, 1,400 and 2,600 feet long.

After the war, production was mainly from the reworking of old tailings. Many operators tried to reopen the mines but none succeeded until the U.S. Grant Mining Co. took over in 1946. They had plans to drive a 3,600 foot tunnel that would intersect the veins at the 600 foot level and dewater the mine which had flooded (Anon., 1947). The tunnel was completed in 1948 and the first ore was shipped in 1949 (fig.4). This ore averaged 0.3 oz gold and 10.8 oz silver per ton. No more records of production from the Easton or Pacific mine are found after these shipments.

In the late 1970's, the late Ed Scheitlin operated an small open pit at the Easton and Pacific mines with some success.
Figure 3. Plan map of the Pacific mine.
Lower access portal 4,030 ft. from intersection with Main Vein.

Figure 4. Plan map of the Easton mine showing the location of major vein structures.
REGIONAL GEOLOGIC AND LITHOLOGIC SETTINGS

The Virginia City district is situated at the southern extent of the Tobacco Root Mountains and the northern extent of the Gravelly Range (Figure 5). The Tobacco Root Mountains are described by Mueller and Cordura (1976) as a large, northwest plunging domal uplift of multiply deformed and metamorphosed Archean rocks, which are concentrically surrounded by folded and thrusted Paleozoic and Mesozoic sediments. The uplift is cored by the Tobacco Root batholith, a Late Cretaceous (72-77 m.y.) quartz monzonite genetically related to the Boulder batholith (Vitaliano and others, 1980; Smith, 1970). Tertiary volcanic flows disconformably overlie Archean rocks in the area of Virginia City (Wier, 1983).

PRECAMBRIAN ROCKS

Metamorphic Rocks

Archean metamorphic rocks of the Tobacco Root Mountains belong to the Cherry Creek sequence. Pearle (1896) was the first to describe this sequence of rocks in the area of Three Forks, Montana, to the northeast of the Virginia City district. The Cherry Creek type section was later described
Figure 5. Regional Geology of Southwestern Montana.
(modified from Schmidt and Garihan, 1986)
by Runner and Thomas (1928) as a sequence of quartz-feldspar gneiss, quartz-mica schist, crystalline limestone, quartzite, and hornblende-biotite schist. Winchell (1914) and Tansley, et al. (1933) described the Pony Series, an older sequence of metamorphic rocks in the northern Tobacco Root Mountains. They reported the Pony Series as having similar mineralogy to the Cherry Creek sequence. Recent work by Gilette (1966), Mueller and Cordura (1976), and James and Hedge (1980) show that the Cherry Creek and Pony series rocks are similar in age; differing depositional environments possibly resulted in variations in lithology. The rocks of the Cherry Creek series have been subjected to two major deformational events. Cordura (1976) suggests the first event occurred at 2700-2900 m.y., which correlates with an event documented in the Beartooth Mountains to the east. He suggests that the second event occurred at 1600-1900 m.y., an event that is recorded throughout southwestern Montana.

Meta-ultramafic rocks are present in the Tobacco Root Mountains as small lenses, pods, and stocklike masses (Vitaliano and others, 1979). They consist mainly of serpentinized olivine, hornblende, orthopyroxene, and clinopyroxene. The origin of these bodies is controversial. Tendall (1978) suggests they may be tectonically emplaced
slices of the upper mantle or refractory residues from partially melted solid upper mantle. The presence of sharp contacts and the nonlinear distribution of the meta-ultramafic bodies, and the dominance of orthopyroxene over olivine favor an origin from a deep-seated magma (Vitaliano and others, 1979).

Pegmatites

Rocks of the Cherry Creek series have been intruded by numerous crosscutting and concordant pegmatite and mafic dikes. These pegmatites occur as lenses, streaks and tabular bodies. Vitaliano and others (1979) report that concordant pegmatites in the northern Tobacco Root Mountains occur as pods in the crests of subisoclinal folds and predate the latest metamorphic event. The discordant pegmatites as mapped by Vitaliano and others (1979) and Weir (1983) appear to be preferentially emplaced either along joints and faults or subparallel to the axial surfaces of open folds. In the northern portion of the Virginia City district discordant pegmatites occur as a swarm with as many as 5 dikes per 30 m which can be traced for several miles. These pegmatites are coarse grained and contain quartz, plagioclase, and microcline. Wier (1983) reports the pegmatite dikes to be approximately 1.9 billion
years old. Three sets of mafic dikes have been identified by Koehler (1972, 1976) and Wooden and others (1978). These mafic dikes range in age from 1.4 m.y. to 1.1 m.y. old. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of these dikes range from 0.702 to 0.703 which indicate probable derivation from mantle material (Vitaliano, 1979).

**POST PRECAMBRIAN ROCKS**

**Sedimentary Rocks**

Paleozoic sedimentary rocks unconformably overlie Precambrian rocks in the Tobacco Root Mountains. These sedimentary rocks comprise limestones with subordinate sandstone and mudstone (Samuelson and Schmidt, 1981). Paleozoic rocks are unconformably overlain by Mesozoic rocks (Tansley and others, 1933).

**Intrusive Rocks**

The late Cretaceous Tobacco Root Batholith and several smaller plutons form the central portion of the the Tobacco Root Mountains. Vitaliano and others (1979) reports the age of these plutons to be 74 to 71 m.y. These intrusions are granitic in composition and appear to zoned (Smith, 1970).
The Tobacco Root batholith crops out over a 120 mi² area. The composition of the batholith ranges from hornblende diorite to granite with intermediate facies of tonalitic, granodioritic, quartz monzonitic and monzonitic composition (Vitaliano and others, 1979). Smith (1970) documented a gradational concentric zoning from the periphery to the core of the batholith. Smith's study showed that the rocks become more silicic towards the core. Using this information, Vitaliano and others (1979) suggest that the batholith was emplaced by a single injection of magma and differentiated in place. This theory is also supported by the lack of primary flow structures preserved in the batholith except at the margins.

**Volcanic Rocks**

Tertiary volcanic rocks ranging in composition from basalt to rhyolite unconformably overlie Archean rocks (Wier, 1983; Chadwick, 1981). These rocks comprise a series of lava flows and pyroclastic and volcanoclastic sedimentary units. Weir (1983) reports the age of these volcanics in the area of Virginia City to be approximately 51 m.y.
Unconsolidated Deposits

Alluvium and colluvium derived from local outcrops have accumulated in valley floors and hillslopes (Vitaliano and others, 1979). Glacial debris in the form of terminal and lateral moraines are present in the valleys draining the highest peaks of the central Tobacco Root Mountains.
REGIONAL STRUCTURAL SETTING

Structures in the Tobacco Root Mountains show evidence of activity dating back to the Precambrian (Vitaliano and others, 1979) with intermittent activity along the same structures through the Eocene (Schmidt and Garihan, 1986). Two major thermal events (2.7 and 1.6 b.y.) folded the Archean rocks (Vitaliano and others, 1979) and brittle and semibrittle deformation has occurred along two sets of faults; northeast and northwest (Schmidt and Garihan, 1986).

FOLDS

Regional scale folding in the southern Tobacco Root Mountains is dominated by the Mill Gulch antiform, a north trending broad open fold that is flanked by a series of subisoclinal folds which are nearly parallel (Vitaliano and others, 1979). Drag folds are present along northwest trending fault zones that have experienced movement during the Laramide orogeny (Vitaliano and others, 1979).

Vitaliano and others (1979) interpret recumbent isoclinal folds as the result of a compressional event at approximately 2.7 b.y. Later in the Precambrian (1.6 b.y.)
this isoclinally folded strata was deformed into a set of northeast-trending open folds. Evidence for the refolding of Archean rocks along with overlying Phanerozoic rocks during the Laramide orogeny is recognized as drag folds along major transcurrent faults.

FAULTS

The major faults in southwestern Montana, shown in figure 6, can be classified into two sets: northwest-trending and northeast-trending (Vitaliano and others, 1979). The majority of these faults are steeply dipping, with dips varying between 50° and 80° to the north. These faults have been active since the Precambrian and show evidence for movement as recently as the Holocene (Schmidt and Garihan, 1986). In addition, these structures, especially those trending northwest, have been important in localizing mineralized quartz veins and igneous intrusions as well as sedimentary deposits and volcanic centers. Although ample conduits for fluid flow existed since the Archean mineralizing events appear to be related to the emplacement of the Tobacco Root batholith.

Vitaliano and others (1979) determined the earliest age of fault activity to be Precambrian through the fact that
Figure 6. Regional map showing major recurrent fault zones in southwestern Montana (after Schmidt and Garihan, 1986).
dikes and dikes swarms of late precambrian age are localized in northwest-trending fault and fracture zones. Schmidt and Garihan (1986) add other evidence to the theory of middle Proterozoic movement by noting that there are faults which offset Archean units but do not affect Paleozoic units. Emplacement of dikes indicate an extensional component to movement during this time. This extension also appears to have influenced the deposition of Middle Proterozoic Belt Supergroup rocks (fig. 7). Schmidt and Garihan (1986) have documented the occurrence of Late Cretaceous movement along the Precambrian faults in southwestern Montana. They conclude that the northwest-trending fault set is the principal Laramide fabric in the region. Vitaliano and others (1979) note more recent movement by the offset of the Cretaceous-age Tobacco Root batholith with relation with the surrounding Archean rocks. Reactivation of this Precambrian faulting is also responsible for the localization of Eocene volcanic centers (Chadwick, 1970).

The geometry of the northwest-trending faults is very similar. The longest of the northwest faults, the Bismark-Spanish Peaks-Gardiner fault, can be traced for 150 km (Schmidt and Garihan, 1986). The majority of these
Figure 7. Tectonic controls on the location of the Belt Basin (after Schmidt and Garihan, 1986).
faults are on the order of 10's of kilometers long. Most faults strike between N30°W and N70°W and dip 50° to 70° to the northeast. Schmidt and Garihan (1986) show that fault dips are usually 5° to 10° greater in Paleozoic rocks than in older Archean rocks. They also suggest a slightly listric geometry for the Precambrian faults through evidence in the southern Highland Mountains and the Ruby Range.

Figure 8 shows the development of structures in the Ruby Range as interpreted by Schmidt and Garihan (1986). They determined that middle Proterozoic activity was dominated by crustal extension which produced northwest-trending northeast dipping listric normal faults (fig. 8A). Crustal shortening during Late Crétaceous and Paleocene time was accomplished partly by left-reverse slip motion on the earlier normal faults and folding (fig. 8C). East-west extension during the Eocene resulted in the formation of major north to north-east trending basins and ranges (fig. 8D).

Schmidt and Garihan (1986) conclude that the Laramide movement along these faults was reverse left-lateral with equal reverse and sinistral components, but occurrence of dip-slip as opposed to strike-slip is correlated with fault
Figure 8. Schematic northeast-southwest sections showing the recurrent activity and intrusion associated with northwest-trending fault set in southwestern Montana (from Schmidt and Garihan, 1986). Refer to text for discussion of sequence.
strike. More northerly striking faults have greater components of dip-slip, whereas faults with a more east-west strike have greater components of strike-slip. These slip directions are compatible with compressive deformation suggested by Hamilton (1981).
REGIONAL MINERALIZATION PATTERNS

The Tobacco Root precious-metal mining region is comprised of the Virginia City, Pony, Norris, Sheridan and Renova districts (Figure 9). The precious-metal deposits of this region show many similarities (Lorian, 1937).

Winchell (1914) and Lorian (1937) report that the deposits in the Tobacco Root mining region are mainly quartz vein systems occurring in fractures in Precambrian metamorphic rocks or Laramide intrusions. The vein morphology varies from tabular bodies concordant with metamorphic foliation to quartz lens and stringers in crushed and sheared fracture zones which crosscut metamorphic foliation. The veins commonly contain gold, silver, pyrite, galena, sphalerite, and chalcopyrite. All deposits show variable depth and intensity of oxidation. Replacement deposits are also found where reactive host rocks are cut by these mineralized fracture systems. Orientation of the veins varies, but is controlled by either local foliation (northeast) or regional fracture pattern (northeast and northwest).

The following is a brief description of the host rocks and the mineralization in each of the districts in the Tobacco Root region.
Figure 9. Regional Map Showing Important Mining Districts.
Virginia City District

The Virginia City district was the largest producer in the region. The combined production from the Easton-Pacific, Oro Cache, Kearsarge, Marrietta, Prospect, U.S. Grant and many other smaller operations totalled approximately 142,000 oz. gold and 1.1 million oz. silver.

The Virginia City district is underlain by multiply deformed Precambrian gneiss with abundant crosscutting and concordant narrow pegmatite bodies. In the area of the Easton and Pacific mines the gneiss is intruded by a monzonite stock.

The deposits occur as quartz vein systems, localized by fractures in the gneiss. Veins show evidence of multiple stages of quartz emplacement, and comprise sulfides with native gold and silver. Supergene enrichment near the surface was significant and a large portion of the production was from oxidized ores (Lorain, 1937). Very little wall rock alteration is present in the district, except in the area of the Pacific mine where argillic alteration is pervasive over area approximately 75 m by 300 m with a minimum depth of 125 m.
Pony District

The Pony district has been one of the most important producers of lode gold in the Tobacco Root region. The major producers in the district were the Mammoth, Boss Tweed-Clipper, and the Strawberry-Keystone mines.

The district is underlain by Precambrian gneiss which has been intruded by the Cretaceous Tobacco Root quartz monzonite and pegmatite dikes. With exception of the Boss Tweed-Klipper, deposits in this district can be characterized as quartz veins in fracture zones which are parallel to the gneiss-quartz monzonite contact or the banding in the gneiss. Mineralization is confined to the veins and wall rock alteration is poorly developed (Hart, 1933). The Boss Tweed-Klipper system mineralization occurs in fractured and silicified gneiss (Lorian, 1937).

Hart (1933) proposed a district scale zoning pattern with respect to the intrusion. He noted that mineralization closest to the contact was typically gold-containing pyrite, chalcopyrite, and quartz (fig. 10). This pattern grades into a galena- and silver-dominant zone. Mineralization that occurs within the intrusion is characterized by the presence of fluorite and hubnerite.
Figure 10. Plan map showing the relationship of vein deposits in the Pony district to the Tobacco Root batholith.  
(after Lorain, 1937)
Norris District

Lode mining in the Norris district began shortly after the discovery of placer gold there in 1864 (Hart, 1933). The main producers of the Norris district were the Revenue, Boaz, Rosebud and Galena mines.

The geology of the Norris district can be grouped into two distinct units, Precambrian gneiss and the Tobacco Root quartz monzonite. The majority of the deposits occur in the gneiss (Hart, 1933). Gold mineralization is localized in quartz veins of various orientations. At the Galena mine quartz veins are present as narrow stringers occupying a zone up to 3 m wide. The greatest producer, the Revenue mine, is a quartz vein system within the quartz monzonite that has been cut by post mineralization shear zones. High-grade gold is present at the intersection of the veins and the shears (Hart, 1933). Secondary enrichment has been an important factor in the formation of economic concentrations of gold in the Norris district.

Sheridan District

Discovery of lode deposits in the Sheridan district occurred shortly after the discovery of gold in Alder Gulch in 1863.
The most important producers, although small, were the Red Pine, Smuggler, Belle, Sunnyside, and Tamarack-Broadguage mines. Lorian (1937) noted that although the deposits in this district were smaller, ore was being produced from five times as many mines as the other districts in the Tobacco Roots. He suggests that this represents the affects of a weakening mineralizing system related to the Tobacco Root batholith.

The principal rock types in the Sheridan district are Cherry Creek schists and gneisses. Limestones of the Cherry Creek series crop out throughout the district. Outcrops of the Tobacco Root batholith are limited to a few small areas in the eastern portion of the district.

The deposits are characterized as veins and replacements in limestones (fig. 11). The presence of limestone seems to be the most important factor in controlling the location of an ore deposit in the Sheridan district. Localization of mineralization is controlled by bedding plane faults and at contacts between the limestone and other members of the series. In the replacement type deposits disseminated gold is found in silicified limestone.

Lorian (1937) noted a district scale zoning pattern with
Figure 11. Plan map showing the relationship of vein deposits in the Sheridan district and the Tobacco Root batholith. Also shown, major ore minerals at various deposits.

(after Lorain, 1937)
respect to distance from the Tobacco Root batholith. Deposits close to the batholith contain pyrite-chalcopyrite, whereas pyrite-galena ore becomes more abundant with distance. Further to the west the deposits in Goodrich Gulch are primarily galena.

Renova District

The Renova District is in the northern end of the Tobacco Root Mountains. Important mines in the district include the Gold Hill, Surprise, Mary Ingabar, Colorado, Blue Bird and Mayflower (Lorain, 1937). Of these the Mayflower was the largest producer. Hart (1933) reports that the Mayflower Mine produced approximately 65,000 oz. of gold between 1896 and 1901. Ore at the Mayflower was very high-grade, averaging 7 oz/ton gold.

Geology at the Mayflower Mine is atypical of Tobacco Root deposits as they occur in Paleozoic rocks. Winchell (1914) reports the geology in the vicinity of the mine as slates of the Belt Series which are overlain by Cambrian conglomerates and sands and massive blue limestone. The ore is hosted in this limestone and along a fault that brecciated the limestone nearly parallel to bedding. Northwest of the fault the limestone is unaltered, but on
the southeast side it is brecciated, silicified and mineralized. The gold in the Mayflower ore was almost exclusively in the form of tellurides. Oxidation played an important role in concentrating gold and silver near the surface. At depth hypogene mineralization was encountered, but was to low grade to mined at a profit.

The other mines in the Renova district are located in Beltian arkosic sandstones which are crosscut by porphyritic dikes (Winchell, 1914). Mineralization occurs as fissure veins which crosscut bedding. The majority of ore mined was oxidized with free gold occurring in hematite and limonite and quartz.
VIRGINIA CITY DISTRICT GEOLOGY

The Virginia City district is underlain by multiply deformed Precambrian gneiss with abundant narrow pegmatite bodies both crosscutting and concordant with metamorphic foliation (fig.12; plate I). In the area of the Easton and Pacific mines the gneiss is intruded by a monzonite stock. The southern border of the district is formed by Mississippian Madison limestone in thrust contact with the gneisses. The eastern boundary of the district is formed by Tertiary volcanics which unconformably overlie the gneisses.

Precambrian Rocks

Gneiss

Quartzofeldspathic gneiss, as mapped by Weir (1983), is the dominant lithology in the district. It contains, in order of decreasing abundance: feldspar (orthoclase and plagioclase), quartz, biotite, amphibole, chlorite, pyroxene, garnet, and magnetite. The term quartzofeldspathic gneiss is used here in a general way denoting a variety of different combinations of the previously mentioned minerals.
Figure 12. Generalized geologic map of the area around the Easton and Pacific mines.
Three distinct units of quartzofeldspathic gneisses have been delineated for mapping purposes: quartz-feldspar -biotite (QFB) gneiss, amphibolite gneiss, and garnet bearing QFB gneiss.

The most mappable and abundant unit is the quartz-feldspar-biotite gneiss, recognized by its light tan color. This unit underlies approximately 90% of the Virginia City district. In outcrop it weathers brown/orange and exhibits coarse foliation in the form of cm- to m-thick banding. Figure 13 shows a typical exposure of QFB with intercalated amphibole-rich layers.

Amphibole-rich gneiss, which has a black to mottled appearance is the second most abundant gneissic rock type. It contains abundant (usually greater than 50% volume) mafic minerals and feldspar. In outcrop it appears massive but on close inspection foliation is obvious. The amphibole-rich gneiss occurs as lens in QFB which can be traced for several 100 meters. Thickness of the lens varies from about 1 meter up to several tens of meters.

Garnet-bearing gneiss is the least common and forms lenses in the other gneissic units. In outcrop it appears similar to QFB with a slight red tint from the garnets. Garnet
Figure 13. Photograph of quartzofeldspathic gneiss with amphibole-rich interlayers which is exposed in Brown's Gulch.
porphroblasts range in size from a maximum of 3 cm to 5 mm with an average of 50 mm. Garnets occur as distinct layers and disseminations within the gneiss.

**Pyroxenite**

Medium to coarse grained pyroxenites crop out throughout the district. These rocks are composed of pyroxene ± feldspar. They are massive with little or no foliation developed. Poor exposures make the geometry of this unit difficult to ascertain.

**Gabbro**

Gabbro, which has been serpentinized, was mapped at several localities in the district. In outcrop it weathers buff to white. A fresh surface reveals dark green very fine grained pyroxenes, feldspar, and magnetite. Faint foliation can be noted on the weathered surface. Serpentinite occurs as veins up to 1 cm thick. Outcroppings of gabbro coincide with large amplitude dipole anomalies generated by a total field magnetic survey of the map area. This magnetic data verifies the observation that the gabbro occur as elongated bodies, concordant with foliation (fig. 14).
Figure 14. Map showing gabbro outcrops and magnetic anomalies in the area of the Easton and Pacific mines. Anomalous areas are assumed to be underlain by gabbro.
Carbonates

Tan to brown meta-dolomites and marbles crops out discontinuously on the west side of Brown's Gulch and in upper Alder Gulch (Cole, 1983). Thickness varies from 1 meter to 20 meters, but is commonly less than 1.5 meters. These units are important marker units used to recognize structures in the relatively homogeneous quartzofeldspathic gneisses.

Pegmatites

Pegmatite dikes, which vary in thickness from a few centimeters to over 8 meters crosscut all of the forementioned rock units. They trend west-north-west and can be traced for several miles. These pegmatites are composed of quartz and feldspar with minor biotite and/or muscovite ± minor pyrite. They exhibit graphic texture or rough zonation of quartz-rich centers to feldspar-rich margins. In outcrop they are iron stained and weather to gruss. In many locations they are devoid of vegetation and therefore can be mapped on airphotos and on the ground easily (fig.15). Cole (1983) determined the age of one of these dikes in the area of the U.S. Grant mine as 1.6 billion years old using K-Ar dating. The density of diking
Figure 15. Aerial photograph of northwest-trending pegmatite dikes in the northern Virginia City district.
varies with a maximum of about 5 dikes per 30 meters. Figure 16 shows the density of dikes in the area of Marble Knob.

A small stock of pegmatitic rock composed of quartz and feldspar crops out on the ridge south of the Easton-Pacific mine. It is medium to coarse grained, with porphyritic texture. Feldspar phenocrysts range from several centimeters up to 0.3 meters in length. Many xenoliths of gneissic rock are present within this stock. The xenoliths are typically elongated along foliation with lengths up to 15 meters.

Post-Precambrian Rocks

Sedimentary Rocks

The district is bordered on the south by Paleozoic and Mesozoic sedimentary rocks in thrust-fault contact with underlying Precambrian metamorphic rocks.

Intrusive Rocks

The Brown's Gulch stock, a monzonite intrusion, crops out as an elongate mass in the vicinity of the Easton and
Figure 16. Geologic map of the Marble Knob area showing the density of pegmatite dikes.
Pacific mines. This stock was previously referred to as alaskite or aplite by earlier workers (Winchell, 1914; Tansley, 1933). The stock trends NW and crosscuts gneissic rocks. In outcrop it is difficult to distinguish from mafic-poor gneissic rocks because of their similar mineralogy and fine grained textures. The stock typically weathers orange-brown and forms blocky outcrops. Previous workers consider this stock to be coeval with the Tobacco Root batholith of Cretaceous age (72-77 m.y.; Vitaliano and others, 1980).
VIRGINIA CITY DISTRICT STRUCTURE

The major structures in the Virginia City district are northeast-trending isoclinal folds in Archean rocks and fault and fracture zones which crosscut (northwest-trending) and parallel these folds.

Folds

Cole (1983) and Weir (1982) documented the presence of two deformational events that produced folds in the northern portion of the Virginia City district. The first deformational event produced tight isoclinal folds. The second event refolded this strata into a northeast-trending southwest-vergent antiform. Fold limbs are easily traced by the location of resistant marble outcrops.

This structure was mapped in the area of the Easton-Pacific mine (fig.17). Garnet-rich layers within quartzofeldspathic gneisses adequately define the structure. Small scale isoclinal folds appear to be concentrated in rubble crop along the inferred axis of this structure.

The detailed geometry of folding is still poorly defined in the Virginia City district because of the limited extent of
Figure 17. Generalized map showing the location of folds in the area of the Easton and Pacific mines. Bold lines represent marker units.  

- garnet-rich
- amphibole-rich
outcrop in the southern portion and the homogeneous nature of the quartzofeldspathic gneiss which makes up a majority of the country rock. On a small scale, folding does not appear to be a major factor in the localization of mineralization.

Faulting and Fracturing

Brittle deformation in the district is best represented by a prominent northeast-northwest conjugate fracture set. Faults and fractures of the Virginia City district are important for localization of ascending fluids and can be broken down into 4 groups: northwest, northeast, north-south, east-west with the majority dipping to the north. Figure 18 is a rose diagram which shows the trend of veins in the Virginia City district. The northwest and northeast trending fractures have controlled the emplacement of Archean pegmatite dikes, the Brown's Gulch stock, and mineralized and unmineralized quartz veins. The other trends influenced the emplacement of mineralized quartz veins and drainage patterns throughout the district. These structures parallel or are segments of the regional scale structures discussed earlier.
Virginia City vein trends

Figure 18. Rose diagram showing trend of mineralized quartz veins in the Virginia City District.
Displacement along these faults is not well documented because of the homogeneity of the country rocks and the accelerated rate of weathering of the fault zones. Cole (1983) has documented the presence of right-lateral offset along the northeast-trending structure of the U.S. Grant mine. Weir (1981) mapped left-lateral offset of marble units in the northwest corner of the district. Slickensides in the area of the Pacific mine indicate a reverse component of slip. Judging from the age of the district scale structures, their displacement histories are probably complex.

In the area of the Pacific mine, low angle fault zones were detected. Drill core data indicates that low-angle fault zones crosscut mineralized veins. This is evidenced by the presence of mineralized clasts within the fault gouge. Flat lying pegmatites are also noted in the area of the Pacific mine. This might indicate that these flat lying structures are reactivated portions of listric faults developed during the Precambrian. Brecciation is abundant along the fault zone associated with the Pacific mine, and to a lesser extent along most veins of the district.

Dilatant zones developed along fault and fracture zones are important in localizing mineralizing fluids in the
Virginia City district. These zones of dilatancy are occur at bends and jogs along linear structures. The tectonic origin of these zones is evidenced by the tabular geometry of the brecciated zones, the abundance of fine grained cataclasites (gouge), and the presence of slickensides (Sillitoe, 1985).
DISTRICT MINERALIZATION PATTERNS

The precious metal deposits of the Virginia City district show many similarities in morphology and mineralization (Lorian, 1937). They are characterized by quartz vein systems which occupy shear zones and fractures in Archean gneisses. The veins average 1 meter in width and 100 meters several hundred feet in length. Vein morphology ranges from single-stage syntaxial quartz veins with sulphides filling open spaces to brecciated and rebrecciated quartz-carbonate veins with multiple stages of sulphide mineralization. The hypogene mineralogy of the veins consists of quartz and pyrite ± varying amounts of galena, sphalerite, acanthite, chalcopyrite, and gold. Appendix I lists the minerals historically reported from the Virginia City district. Hydrothermal alteration is limited to areas around the veins. Oxidation was an important factor in developing higher grade ores near the surface.

The Easton and Pacific mines are located the center of the Virginia City district and have been the greatest lode producers in the district. As with the other deposits in the district, they exhibit the characteristics previously mentioned.
LARGE SCALE MORPHOLOGY

The mineralized and unmineralized quartz veins of the Virginia City district are located within northeast, northwest, north-south and east-west trending structures. The majority of these structures are linear but many show the development of second order shear zones, jogs and bends (Hodgson, 1989) (fig 19). The veins are vertical to steeply dipping in various directions, mainly to the north. The average length of the mineralized veins is one hundred meters with the longest trend, the Kearsarge-Oro Cache, being approximately 1.5 km. Maximum depths of the veins are not known but depths of mining indicate that some veins are continuous to 220 meters. The veins vary in thickness from 0.25 meters to 7 meters with an average width around 1 meter. In the area of the Kearsarge mine the veins are sheeted, with several veins occupying a 12 meter wide zone.

The Easton-Pacific vein trend occupies a northwest trending curvilinear structure which crosscuts foliation and the Brown's Gulch stock. The structure is readily traceable using very-low-frequency electromagnetics (VLF). The results of a VLF survey over the area are shown in figure 20. The data shown has been modified by a Fraser filter which performs a phase shift so that the source of the data is
Figure 19. The nature of second-order structures responsible for localizing ore deposits in the Virginia City district.
Figure 20. Extent of VLF anomalies in the area of the Easton and Pacific mines. Heavy lines represent known vein locations. Positive values only.
located at a positive peak rather than at an inflection point. The Fraser filter also removes anomalies that are the result of topography. The survey succeeded in showing that the Easton and Pacific mines are located on the same structure. It also shows the horsetail geometry of the veins in the area of the Easton mine and the intersection of north-south, northwest, and east-west trending structures in the area of the Pacific mine. It should be noted that both the Easton and Pacific mines are located at the apex of the curves in the structure.

**SMALL SCALE MORPHOLOGY**

Morphology of individual mineralized veins throughout the district were investigated by drilling, trenching, and underground and surface mapping. The majority of the veins are hosted by gneisses with exception of the Easton-Pacific vein which cuts the Brown's Gulch stock. The veins occur as tabular bodies, lenses and pods in shear zones and fractures. Quartz is the dominant gange with subordinate calcite. Quartz occurs as euhedral to subhedral syntaxial crystals oriented perpendicular to the vein trend. In areas of brecciation, massive quartz and rock flour forms the matrix. Sheeted, 1 to 5 cm, quartz veinlets typically parallel major vein trends. Calcite occurs as a late fracture filling.
The nature of the contact between vein and wallrock is dependent on the amount of shearing within the structure. Veins in structures with little shearing have frozen contacts, that is the vein adheres closely to the wallrock. If high degrees of shearing were present in the structure, the contact is typically clay/gouge-rich where the vein can be easily separated from the wallrock. Figure 21 shows the smooth nature of the contact developed from a narrow selvage of clay in the Marble Knob adit.

Figure 22 shows a cross-sectional view of several quartz veins exposed in a trench #1 in the area of the Pacific mine. The veins strike approximately N10W and dip 55° to the east. At the surface the dip of the veins appears to be flattening out. Figure 23 shows an east-west cross-section through the Pacific mine. This cross-section is based on surface mapping and diamond drill-hole data. Drill-hole data suggests that the veins do flatten out, but this flattening is exaggerated by post-mineralizing low-angle faulting.

The veins and wallrock show textures which typify tectonic breccias (Sillitoe, 1985). Figure 24 shows various brecciated textures from the Pacific mine area. The variety
Figure 21. Photograph of stoping in the Marble Knob adit showing the smooth nature of the contact between the wall rock and the vein.
Figure 22. Photograph of Trench #1 in the Pacific Pit.
Figure 23. Generalized cross-section through the Pacific Pit.
Figure 24. Various breccia textures in the area of the Pacific mine: A) Angular quartz and pyrite in vein; B) Rounded pegmatite clasts in rock flour matrix; C) Subangular quartz cemented by later quartz in vein; D) Pegmatite breccia with zones of illite/smectite in matrix of rock flour.
of breccias present indicate multiple stages of brecciation (Hodgson, 1989). Early stage brecciation is best preserved in pyrite where angular clasts appear to be floating (matrix supported) in dark gray quartz. Later fault breccias are characterized by rounded clasts with abundant black gouge as matrix. Abundant slickensides are present along the vein contacts and in fault zones.

Two other types of quartz veins are present in the Virginia City district. Narrow, sheeted, gray to white bladed quartz veins occur as distinct zones in the gneisses. These veins characteristically have selvages of salmon-pink K-feldspar which are typically about the same width as the veins. The longitudinal extent of these veins seems to be limited. No sulphide minerals were noted in these veins. These veins show no evidence of brecciation or deformation, as do most of the mineralized veins, therefore they are consider to be younger than the mineralized veins of the district. Also present are bull-quartz veins which occupy northwest trending fractures. These bull-quartz veins can be traced for several hundred feet as they form blocky, very obvious outcrops. The width of these veins is about 1 meter. The genetic relationship of these bull quartz veins to the other veins of the district was not determined.
MINERALIZATION

Macro- and microscopic features of ore minerals can be used to unravel the sequence of mineralizing events responsible for ore deposition. Polished sections of ore were examined from the Easton and Pacific mines as well as other veins throughout the district. Location of these ore samples are shown on Plate 1.

Ore minerals occur as blebs, brecciated clasts, stringers and fracture fillings in quartz. Typically they constitute less than 10% of the vein material.

Pyrite occurs as an early sulphide phase in the veins. It is noted with quartz, brecciated and crosscut by later quartz and sulphide phases. Its texture is typically angular but in areas of intense brecciation it can appear quite rounded. In areas where veins are emplaced into pyroxenite, pyrite occurs as euhedral crystals forming a selvage around the vein. Pyrite also forms as the result of the sulphidization of biotite which occurs when mineralized quartz veins crosscut biotite-rich country rocks. Figure 25 shows biotite being replaced by pyrite.

Galena occurs as euhedral crystals, blebs and vein
Figure 25. Illustration showing biotite being replaced by pyrite.
fillings. Deformation has caused bending of individual crystals. Galena appears to be late in the paragenic sequence as it is seen filling voids and in crosscutting veinlets.

Sphalerite and tetrahedrite, in massive form, are present in the voids formed by early brecciation. Deformation has caused some bending of these minerals.

Acanthite, (Ag\textsubscript{2}S), is observed, associated with chalcopyrite, filling voids in brecciated quartz and in veins with galena and chalcopyrite.

The sequence in which these minerals were deposited was determined through the correlation of their textures and mode of occurrence. Figure 26 shows the paragenetic relationship of the individual ore and gangue minerals and deformational events. The sequence of mineralizing events can be broken into two main periods separated by a period of brecciation. Photomicrographs of polished sections showing the various textures and relationships are presented in Appendix II.
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**DEFORMATION**

| Brecciation   | X        | X        |
| Ductile       |          | X        |
| Fracturing     |          | X        |

**FIGURE 26.** Paragenetic sequence of mineralization for the Easton-Pacific Vein.
Period 1

Quartz and pyrite are the main minerals deposited during Period 1 mineralization. Quartz appears to be milkly to gray. Pyrite is euhedral to massive. Quartz and pyrite are brecciated and healed by more quartz before the onset of Period 2.

Period 2

Period 2 begins with brecciation which forms open space. This open-space is filled with galena, sphalerite, tetrahedrite, chalcopyrite and acanthite. These minerals occur as euhedral to anhedral grains which infill available space between breccia fragments. These early Period 2 minerals are then deformed and fractured. Fractures are filled with galena, acanthite and chalcopyrite veinlets. Late chalcopyrite and acanthite appear to fill any remaining voids. Quartz is ubiquitous through Period 2, seen filling fractures. Late calcite, in the form of veins up to 2.5 cm thick, crosscuts both period 1 and 2 mineralization.
ALTERATION

Three types of alteration were noted in the Virginia City district: potassic, argillic and supergene. The intensity of this alteration varies throughout the district. Alteration seems to be restricted to areas of veining but not all veins have alteration associated with them. Potassic alteration is the most pervasive on a district wide scale. Argillic alteration is restricted in its occurrence and appears to be best developed in the area of the Pacific mine. Supergene alteration is noted at most deposits.

Potassic Alteration

Potassic alteration is the most common alteration type in the Virginia City district. It occurs along vein structures as a selvage surrounding the vein. The selvage is typically wider than the vein it surrounds and appears to be laterally continuous. Close examination of the selvage shows that K-spar is selectively replacing existing feldspars in the wallrock whereas quartz remains unaffected. Figure 27 shows veins with the K-spar selvage characteristic of potassic alteration. This potassic alteration is associated mainly with narrow quartz veins and stringers.
Figure 27. Photograph of quartz vein with K-spar selvage.
Argillic Alteration

Pervasive argillic alteration is present around mineralized quartz veins in the area of the Pacific mine. It is characterized by pale green mixed-layer illite/smectite in the form of clots and wispy veinlets (fig 28). Clots appear to be replacing K-spar whereas veinlets crosscut all minerals present. Argillic alteration post dates brecciation since clasts and matrix appear to be altered. Veinlets average approximately 5-10 mm and can be traced for several feet where they pinch out. Clay minerals occur as platy masses within the veinlets.

Supergene

Supergene processes have affected a majority of the deposits in the Virginia City district. The extensive development of supergene enrichment of gold and silver has apparently been important in making many deposits profitable (Lorian, 1937). Oxidation is the dominant process in the conversion of primary sulphide phases to oxides. Goethite and limonite appear to be the dominant oxides. Malachite is in close association with chalcopryite. Oxides occur as blebs completely replacing
Figure 28. Photograph of argillically altered pegmatite in the Pacific pit.
sulphides, as replacement rims around sulphides, and as spongy masses. The depth at which primary ore is encountered varies from mine to mine. At the Easton mine unoxidized ores were encountered at 120 meters (Winchell, 1914). Unoxidized ores were encountered at 40 meters at the Kearsarge mine. This may reflect the difference in elevations of the two deposits.

LITHOGEOCHEMISTRY

Channel samples were collected across the major veins in the Easton-Pacific area. The host rock was also sampled, in many cases for up to 20 meters from the vein. Elemental analysis of these samples were conducted by Chemex Labs, in Butte, Montana.

Samples of mineralized veins are anomalous in Au-Ag-Cu-Pb-Zn-As-Sb-Bi. Figures 29 shows the distribution of Au, Ag, As, and Hg in Trench #1 which is located in the area of the Pacific mine. Also shown are background levels for Au and Ag, and detection limits for As and Hg. Anomalous precious-metal values appear to be restricted to the veins but a very low grade halo is also present surrounding the veins. Figure 30 shows the distribution of elements in Trench #10 above the Bear Adits. Again the
Figure 29. Distribution of elements in Trench #1.
Figure 30. Distribution of elements in Trench 10.
precious-metal values are restricted to the veins but the halo is more obvious because more samples were collected away from the vein. Arsenic varies sporadically throughout the trenches and is not preferentially localized by veins. Mercury appears to be elevated in most samples and does not appear to concentrated in the veins. Figure 31 shows the relationship of As, Hg and Ag to Au in all the trench samples. It can be seen that Au and Ag vary linearly with respect to each other with a ratio of approximately 1:10 (Au:Ag). Hg is elevated in most samples containing Au, with a consistent concentration of approximately 2 ppm. As is present in samples that contain Au and those that do not contain Au. The importance of these relationships is realized in developing a soil sampling program which targets hidden vein deposits. Hg which forms a widespread consistent halo would be more useful than As which occurs sporadically in and around the veins. Appendix III lists trench sample geochemical data.

**ILLITE/SHEETITE RATIOS**

To determine what the relationship is between the argillic alteration and the mineralized veins, a detailed study of the clay minerals present was conducted. Also, since the majority of the Pacific vein system is covered or
Figure 31. Graphs showing the relationship of gold to arsenic, mercury, and silver in trench samples.
inaccessible because of caved workings an exploration tool that would be able to determine the proximity to the high-grade veins in drillholes was needed. Illite/smectite ratios were examined to test for systematic variation with respect to the veins.

Background

The formation of illite/smectite as an alteration product, or newly precipitated phase under a variety of relatively low temperature (100°C-300°C) petrologic conditions has been well documented in the literature (Horton, 1985). It has also been shown that systematic variations in composition and structure of mixed-layer illite/smectite exist with changing temperature and depth in modern geothermal systems (Steiner, 1968; Eslinger and Savin, 1973; McDowell and Elders, 1980). Less work as been done in the area of illite/smectite systematics as related to ore deposits. Modern geothermal systems have been used as analogs for hydrothermal ore deposits (White, 1981). To better understand the correlation, Tooker (1963), Inoue and Utada (1983) and Horton (1985) have investigated the relationship of illite/smectite in modern geothermal systems to fossil geothermal systems.
Methods

Clay samples that were used in this study were collected from diamond drill core in the area of the Pacific mine. Sample locations are shown in Figure 32 and 33.

Samples were prepared for XRD analysis by soaking approximately 10 grams of sample in approximately 100ml of distilled water for several days. The samples were then gently dispersed into the water with a glass stirring rod. This clay and water slurry was then allowed to stand for 10 minutes to allow coarser grained particles to settle. An eyedropper was used to remove enough material from the surface to cover a glass slide. The upper most portion of the suspension should be 2µm fraction (equivalent spherical diameter) (Moore and Reynolds, 1989). The slides were air-dried, which allows the individual clay particles to become oriented parallel to the glass slide. This allows for measuring the c-axis thickness of the individual clay species. For a complete discussion of this methodology see Moore and Reynolds (1989).

X-ray diffractograms of air-dried, ethylene glycol-solvated and heated specimens were produced for each of the samples. First, the air-dried sample was run from 35° to
Figure 32. Plan map of the Pacific Pit showing the location of drill holes.
Figure 33. Cross-section showing the location of samples used for clay analysis.
2°2θ/minute. The same sample was then placed in an ethylene glycol atmosphere for 24 hours at ambient temperature. This allows for the expansion of smectites and mixed-layer clays. The slide is run from 15° to 2°2θ/minute. Expanded vs. the unexpanded thickness of the clay minerals are then compared. From this the amount of expandable clay species can be determined by analyzing the intensity of the shifted peak. The slide is then heated for 30 minutes at 375°C to collapse the expandable clays. The slide is then run from 9.5° to 7.5°2θ/minute while still hot and the from 15° to 2°2θ/minute. The comparison of this diffractogram with that of the glycol-treated clay was used to calculate the ratio of expandable to nonexpandable clays. The abundance of individual clay species, expressed in parts in 10, were calculated following the semiquantitative approach of Austin (Appendix III).

X-ray diffraction data were obtained with a Rigaku diffractometer using monochromatic Cu radiation, a scintillation counter, a 1° divergence silt, a 0.1mm scatter silt, a 0.3 mm receiving silt and a 0.3 mm detector silt. Samples were scanned at 2°2θ/minute and the data was recorded by a strip chart recorder at the rate of 20mm minute.
Results

A plan view of the extent of argillic alteration in the area of the Pacific mine is shown in Figure 34. Throughout the sampled interval light green, scaly illite/smectite occurs as veinlets and pods which crosscut foliation. Argillic alteration is restricted to the zone of brecciation which is outlined on the geologic map of the Pacific mine area (Fig. 35). The intensity of argillic alteration appears to be consistent throughout this zone.

A schematic representation of drill holes EPC-1 and EPC-2 is shown in Figure 36. Also shown are XRD patterns which illustrate the clay mineral peaks.

The proportion of illite and expandable clays (smectite and mixed-layer clays) shows a systematic change with respect to distance from the Pacific vein system. The amount of illite increases as the veins are approached. Expandable clays increase distally from the veins. This relationship is shown graphically in Figure 37. Kaolinite is also present in the zone of argillic alteration possibly as a weathering product but no definite patterns have been noted.
Figure 34. Plan map of the Pacific Pit showing the extent of argillic alteration.
Figure 35. Generalized geologic map of the Pacific Pit.
Figure 36. Schematic representation of drill hole geology and results of XRD.
Figure 37. Graph showing the relationship of illite and expandable clays to quartz veins.
Discussion

Horton (1985) compiled the results of several studies on illite/smectite relationships in modern geothermal fields and in burial metamorphosed shales (fig.38). The results of these studies showed that smectite is dominant at temperatures from $50^\circ$C to $120^\circ$C. As temperature increases mixed-layer illite/smectite where illite is most abundant is stable. Around $180^\circ$C minor smectite is present and all expandable clays are lost at $250^\circ$C to $270^\circ$C.

Horton also investigated the relationship of illite/smectite in the argillic alteration halo surrounding the Amethyst vein in the Creede district, Colorado. He found that the percentage of illite increased as the vein was approached. The random nature of illite/smectite interlayering (ordering) became more ordered (1 to 1) as the vein was approached. He was able to estimate thermal gradients which were consistent with those observed modern geothermal fields. Inoue and Utada (1983) studied a Kuroko-type deposit in northeast Japan. They found a zonal arrangement of increasing expandable clays distal to the center of hydrothermal activity.
<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Wairakei</th>
<th>Broadlands</th>
<th>Salton Sea</th>
<th>Shales</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>Illite</td>
<td>Illite</td>
<td>90-95% Illite</td>
<td></td>
</tr>
<tr>
<td>200</td>
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<td>90-95% Illite</td>
<td>80% Illite</td>
<td></td>
</tr>
<tr>
<td>150</td>
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<td></td>
<td>85% Illite</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Illite</td>
<td></td>
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<tr>
<td>50</td>
<td>Illite</td>
<td></td>
<td></td>
<td>0-66% Illite</td>
</tr>
</tbody>
</table>

**Figure 38. Temperature Dependence of the Smectite to Iillite/Smectite to Iillite to Muscovite Reaction Sequence at Three Modern Geothermal Areas and in Burial Metamorphosed Shales (Modified from Horton, 1985)**
The zoning of illite/smectite with respect to the Pacific vein system is consistent with the results of Horton (1985) and Inoue and Utada (1983). Comparison of the illite/smectite compositions present around the Pacific vein and those found in modern systems shows that the temperature of formation of clay adjacent to the Pacific vein can be estimated at $250^\circ\pm40^\circ$. This is based on the purity of illite in sample EPC-1-121.

Temperature is not the only controlling factor in the formation of various clay species. Solution chemistry could have also affected the zoning around the Pacific vein. Eberl (1978) found that the absence of available potassium retards the smectite to illite transformation. The lack of available potassium should not have been a limiting factor at the Pacific mine, since K-spar constitutes a major portion of the host rock. The abundance of $K^+$ is well documented with the presence of K-spar selvage around many veins in the district. With is available potassium it can be assumed that the I/S recorded the temperature at which the reaction took place.

Conclusions

Illite/smectite can be used in the area of the Pacific mine
to determine proximity to the Pacific vein system. It has been shown that illite increases as the vein is approached. This increase can be attributed to higher temperatures in proximity to the vein at the time of emplacement. From the purity of the illite temperatures can be estimated at approximately $250^\circ \pm 40^\circ \text{C}$. This range is consistent with the temperatures determined by fluid inclusion investigations.

**FLUID INCLUSIONS**

Fluid inclusions in quartz veins from the Easton-Pacific area were investigated. The samples analyzed represent different types of quartz veins with and without mineralization. Five samples were prepared and analyzed to determine the trapping temperature and salinity of the trapped fluids.

Samples were selected from several different quartz veins in hopes of determining a genetic relationship between the various types. Samples 001508 and 001514 are representative of narrow (up to 1 cm), unmineralized quartz veins with a K-spar selvage. The quartz occurs as syntaxial subhedral crystals oriented perpendicular to the vein trend. This type of quartz vein occurs randomly and is associated with
major producing veins throughout the district. Sample 001524 is similar in morphology and occurrence to 001508 and 001514 but has anomalous gold content (2.4 ppm). Sample 89 MSL 010 represents mineralized quartz from the Easton-Pacific vein. It is gray, fine-grained quartz that has been brecciated, silicified, and cross cut by later quartz veinlets. Sulphides occur as disseminations, blebs and fracture fillings. ML-G1 is from a highly mineralized vein at the Little Lode mine in Alder Gulch. Open space in subhedral quartz is filled with native gold and telluride minerals.

Microthermometric measurements were performed, by Kurt Panter at New Mexico Tech. The temperature of homogenization ($T_h$) was determined for 65 inclusions. Salinities of the fluids were calculated from the temperature at which the frozen fluid melted ($T_m$). Determination of the primary versus secondary nature of the inclusions were made following criteria outlined by Roedder (1984).

Temperatures of homogenization for both primary and secondary inclusions range from $143^\circ$ to $312^\circ$. Calculated salinities vary from 1.0 to 13.3 eq. wt.% NaCl. The size of the individual inclusions used for the
measurements ranged from 2 to 9 micrometers. The majority of inclusions are liquid-rich, two phase (NaCl eq. + H₂O liquid + H₂O vapor). Subordinate to these are liquid-rich two phase inclusions that contain variable amounts of CO₂. Although a separate, visible CO₂ phase was not observed, the presence of CO₂ was determined by presence of clathrate and positive Tₘ values. CO₂ content of the inclusions varies with no perceivable pattern but is present in some yet not others. This indicates that the CO₂ content of the solutions was low.

Figures 39 thru 43 show plots of salinity vs. Tₘ for the individual samples. In general gold bearing veins appear to have high Tₘ's and low to moderate salinities. The unmineralized veins tend to have higher salinities and lower Tₘ's. This trend is shown in figure 44 with a combined plot of all the samples. It should be noted that secondary inclusion in sample ML-Gl are similar to primary inclusions in 001508. Based on paragenetic relationships of the quartz veins this could indicate that ore-forming fluids evolved from a higher temperature, low salinity solution to a low temperature, high salinity solution with time. A mechanism for this change could involve mixing of water from various sources. The present limited data base makes impossible to define the sources of these waters.
"001508"

Figure 39. Salinity vs. $T_h$ - sample #001508
"001514"

Figure 40. Salinity vs. $T_h$ - sample #001514
Figure 41. Salinity vs. $T_h$ - sample #001524.
Figure 42. Salinity vs. $T_h$ - sample # 89 MSL 010.
"mlg1"

Figure 43. Salinity vs. $T_h$ - sample # ML-G1.
Figure 44. Combined plot of salinity vs. homogenization temperature for all fluid inclusion samples.
DISCUSSION

The precious metal deposits of the Tobacco Root mining region show many similarities in their host rocks, structural controls, and mineralization patterns. The lithology of the host rocks appears to have influenced the style of mineralization (i.e. vein vs. replacement), regional scale fracture patterns have controlled the location of deposits in most cases, and the association with the Tobacco Root batholith and its satellite intrusions has developed vein deposits typical of a near-plutonic environment.

Lithology

Host rock lithology appears to have influenced the style of mineralization in the Tobacco Root mining district. Quartzofeldspathic gneiss and quartz monzonite are the most common host rocks and appear to restrict the development of disseminated type deposits because of their low permeability. As result deposits are typically located in zones where secondary permeability was increased through fracturing.

Reactive host rocks such as limestone appear to favor the
development of replacement type deposits like the Bear Gulch deposits in the Sheridan district (Winchell, 1914). Since limestone is subordinate to the typical quartzofeldspathic gneisses, these replacement type deposits are limited.

The host rock lithology in the area of the Easton-Pacific vein system is of the relatively "unreactive" variety therefore the majority of the mineralization is restricted to the veins.

**Structure**

In the Tobacco Root mining region, long-lived Precambrian fracture zones that have periodically been reactivated have served as conduits for ascending solutions through time. These structures and structural zones have localized the emplacement of plutons, dikes and veins systems. Second-order structures are important sites for mineral deposition on a deposit scale.

Precious metal deposits of the Tobacco Root mining district occur over a large area but all exhibit strong structural control. NW and NE trending fracture zones were important in localizing ore-forming fluids. Reactivation of these
fracture zones developed dilatant zones in which vein material could form. Why then are the length of veins on the order of hundreds of feet and the length of the fractures on the order of miles? The location of these dilatant zones within main fracture appear to control the location of veins and the location of dilatant zones can best be explained by the mechanism of bulk, inhomogeneous shortening proposed by Hodgson (1989). On a smaller scale brecciation and opening along jogs and bends in the structure appear to be important mechanisms for developing dilantancy.

In the Virginia City district the presence of many relatively short veins (compared to the length of regional scale structures) can be explained using Hodgson's mechanism. Hodgson suggests that dilation can occur along individual segments of a conjugate fracture set. Figure 45 shows a diagrammatic representation of the results of bulk, inhomogeneous shortening. The dilatant zones developed in this model could represent the quartz veins of the Virginia City district (fig. 46). Evidence for the throughgoing nature of the veins but the limited extent of wide mineralized zones can be seen in the area of the Pacific mine. Geophysics was able to trace the veins away from the Pacific mine but only narrow veins were encountered in trenching and drilling away from the main structure.
Figure 45. Diagrammatic representation of the development of dilatant zones along individual segments of a conjugate fracture set (after Hodgson, 1989).
Figure 46. Plan view of mineralized segments of fracture zones in the Virginia City district for comparison with Hodgson's model of homogeneous shortening.
From the available data it appears that some of these fracture zones penetrated through the crust of the Earth. This is evidenced by the presence of NW-trending mafic dikes with isotopic signatures indicative of mantle derivation. The emplacement of the Tobacco Root batholith also indicates that the fracture system must be extensive, not only in a lateral sense but in the vertical direction as well.

The Easton-Pacific vein trend exhibits strong structural controls. Mineralization is restricted to fracture zones or immediately adjacent to them. Second order structures within these fractures appear to have facilitated the deposition ore minerals (fig. 47). Intersections, bends and jogs are the locus for high-grade mineralization. Dilatancy caused by episodes of brecciation and brittle fracturing during and after Period 1 mineralization provided continued access for mineralizing fluids into the main fracture zone. This continued access was important in developing ore-grade mineralization. The large area of brecciation at the Pacific mine appears to be the result of strain accumulated during periods of left-lateral displacement along the Easton-Pacific structure. Brecciation is localized by right-stepping strike variations in the structure (fig. 48).
Figure 47. The nature of jogs, bends, and zones of transpression and transtension (after Hodgson, 1989).
Figure 48. Schematic representation of structures in the area of the Easton and Pacific mines showing the development of transpressional breccia at the Pacific mine.
Fracturing of the wall rocks in some areas has led to very limited disseminated mineralization. Brecciation in the area of the Pacific mine has facilitated the development of argillic alteration over a large area.

Kelly and Goddard (1969) documented the structural controls on telluride mineralization in Boulder, Colorado. They reported that economic concentrations of ore minerals occur at intersections of veins, and irregularities along the vein related to movement along the veins. They also noted the importance of brecciation and shearing in the veins for the development of secondary open-space.

**Plutonic Association**

Precious metal deposits of the Tobacco Root mining region appear to be genetically associated with the Cretaceous-aged Tobacco Root batholith (Kinley, 1987; Cole, 1983; Vitaliano, 1979; Lorain, 1937). Deposits of this type, throughout the world, show similar characteristics (Newberry et al., in press).

Following is summary of data on plutonic-related gold deposits of the vein and replacement type compiled by Newberry et al. (in press):
Intrusive type - reduced, mid to late Cretaceous, granitic.

Ore mineralogy - arsenopyrite, pyrite, + pyrhotite, stibnite, tellurides, molybdenite and Bi and W minerals.

Geochemical expression - Au-As-Bi-Sb-Te (Zn, Cu, Ag, B, Sn, Be).

Morphology - vein and breccia bodies; replacement bodies occur where carbonate-bearing rocks are present.

Attempts have been made to explain gold-enrichment in plutons through various mechanisms. Tectonic setting of gold-enriched plutons was investigated by Kesler (1973), his data suggests that porphyry copper deposits in island arc settings are more gold-enriched. Keith and Swan (1987) used the oxidation state of the plutons to show that reduced plutons favored gold-enrichment. A review of the geochemistry of plutons with associated gold deposits was compiled by Mutschler et al. (1985) showing that a variety of gold deposits are associated with alkaline intrusives. The combination of the alkalinity and oxidation state of plutons appears to be a valid empirical method of determining the "gold favorability " of plutonic rocks which was proposed by Leveille et al. (1988). In their
Figure 49. Distribution of reduced/alkaline plutons and gold deposits in western Montana (from Leveille, Newberry, and Bull, 1988)
compilation the alkalinity/oxidation state of the plutons in western Montana was investigated. They determined that the Tobacco Root batholith was of the "gold-favorable", reduced variety (fig 49).

Ore minerals present in the Tobacco Root mining region are indicative of plutonic related deposits. Kinley (1987) reported the association of gold and bismuthinite at the Red Pine mine in the Sheridan district. Winchell (1914) reported the occurrence of huebnerite (MnWO₄) and molybdenite at the Bismark mine in the Pony district. In the Virginia City district, arsenopyrite and stibnite are reported to occur at the Easton-Pacific mines and at the Marietta mine (Winchell, 1914).

General Deposit Type

The comparison of the precious-metal veins of the Virginia City district with other well-documented precious-metal vein deposits throughout the world is a useful way of determining the genetic implications of the observed characteristics. Although these deposits occur in a variety of geologic environments, their chemical characteristics are similar enough to indicate a commonality (Barnes, 1979). Research in the area of vein deposits has uncovered a wide
range of conditions at which ore minerals are deposited. The variety of conditions possible is expressed in the wide variety of deposit types observed. The goal of this discussion is not to pigeon-hole the Virginia City deposits into a rigid category but to contrast them with the continuum of hydrothermal deposits.

Table 1 shows the generalized characteristics of epithermal deposits after Eimon (1988), mesothermal deposits after Nesbitt et al. (1986), Korean-type deposits after So and Shelton (1987) and the Virginia City deposits. From this comparison it can be seen that the Virginia City deposits do not fit perfectly into any one category but rather they span the gap between several deposit types.

The host rocks in the Virginia City district are Precambrian gneisses and Cretaceous monzonite. In contrast host rocks of epithermal deposits are typically Tertiary volcanic and sedimentary rocks (Eimon, 1988). Mesothermal deposits are typically hosted in metamorphosed greenstone belts (Nesbitt, 1988). The Precambrian gneissic and Cretaceous intrusive host rocks of the Korean deposits most closely resemble those of the Virginia City district.

The strong structural control of the deposits of the
TABLE 1. Comparison of Virginia City deposits with other hydrothermal deposits.

<table>
<thead>
<tr>
<th></th>
<th>EPITHERMAL</th>
<th>VIRGINIA CITY</th>
<th>KOREAN-TYPE</th>
<th>MESOTHERMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>Tertiary; late Jurassic</td>
<td>late Cretaceous</td>
<td>early Cretaceous</td>
<td>Jurassic to Tertiary</td>
</tr>
<tr>
<td><strong>Host Rocks</strong></td>
<td>Inter. to felsic volcanics, seds; unmetamorphosed</td>
<td>Archean gneiss, Cret. monzonite</td>
<td>pЄ gneiss, Jur.-Cret. granites</td>
<td>greenschist metamorphosed volcs.&amp; seds.</td>
</tr>
<tr>
<td><strong>Structural Setting</strong></td>
<td>Fractures and faults assoc. with volcanic centers</td>
<td>Second order structures along regional scale structures</td>
<td>Major fault zones</td>
<td>Major trans-current fault zones</td>
</tr>
<tr>
<td><strong>Morphology</strong></td>
<td>Stockworks, vein fillings, comb structures, crustiform</td>
<td>Composite veins, breccia zones</td>
<td>Composite veins</td>
<td>Massive or ribbioned veins</td>
</tr>
<tr>
<td><strong>Ore Minerals</strong></td>
<td>Sulphides, tellurides, sulfosalts</td>
<td>py, cp, gl, sph Au^n,Au^m, tellurides</td>
<td>py, asp, sph, gl</td>
<td>py, cp, gl</td>
</tr>
<tr>
<td><strong>Alteration</strong></td>
<td>Adv. argillic, silicification, potassic, propylitic</td>
<td>Argillic, potassic, late calcite</td>
<td>Argillic, potassic, pyritization, late calcite</td>
<td>Carbonatization, silicification, seritization</td>
</tr>
<tr>
<td><strong>Fluid Chemistry</strong></td>
<td>Temp. 250°C 10w CO₂ 3-4 eq wt% NaCl</td>
<td>Temp. 275°C 10w CO₂ 1-13 eq wt% NaCl</td>
<td>Temp. 225-285°C moderate CO₂ 3-9 eq wt% NaCl</td>
<td>Temp. 300°C high CO₂ 3-6 eq wt% NaCl</td>
</tr>
</tbody>
</table>
Virginia City district is common in all the deposits, however the structural styles vary greatly. Epithermal deposits are localized in shallow structures associated with volcanic centers (Eimon, 1988). Mesothermal deposits are typically located along regional scale strike-slip faults, and many show brittle and ductile textures on a local scale (Bursnall, 1989). The Korean-type deposits are localized in brecciated regional-scale fault zones similar to those of the Virginia City district.

The morphology and mineralization of the precious-metal deposits of the Virginia City district are characterized by composite quartz veins restricted to fracture zones with a relatively simple assemblage of sulphides, tellurides native precious-metals. Textures of the quartz vary from subhedral syntaxial crystals with poorly developed open-space to silicified breccias. Sulphides occur as blebs and stringers within the quartz. Minor late calcite crosscuts earlier quartz. In contrast mineralization in epithermal deposits occurs as stockworks, disseminations, breccia pipes and irregular pods. On a small scale, ore textures include open-space fillings, drusy cavities, crustification, comb structure and colloform banding (Eimon, 1988). Epithermal mineral assemblages include sulphides, tellurides, selenides, sulfosalts with gangue
minerals of quartz, barite, fluorite, rhodochrosite and
adularia (Eimon, 1988). Mesothermal deposits are
characterized by a simple assemblage of sulphides contained
in a gangue of quartz and carbonate with tourmaline, and
muscovite. Mineralization of the Korean-type deposits show
the greatest similarity to that of the Virginia City
district. They are characterized by a simple assemblage of
sulphides in composite quartz veins with minor open-space
texture.

The geochemical and physical conditions that prevailed at
the time of ore deposition can be estimated using a variety
of techniques such as fluid inclusion and isotopic
investigations (Skinner, 1979). Fluids responsible for the
deposition of precious-metals in epithermal deposits appear
to consist mainly of shallowly circulated meteoric waters
which range in temperature from 50 to 250°C, contain low
concentrations of CO₂ and NaCl (3-4 eq wt%). Mesothermal
fluids contain high concentration of CO₂ (4-30 wt%),
moderate amounts of NaCl (3-6 eq wt%) and range in
temperature from 250 to 370°C. Isotopic values indicate
that mesothermal fluids evolved from deeply circulated
meteoric waters (Nesbitt, 1986). The Korean-type deposits
appear to bridge the gap between the two end-member deposit
types (Shelton, 1988). The fluids which formed the
Korean-type deposits appear to have evolved from high temperature (400°C) to low temperature (200°C). Salinities of the fluids also evolved from moderate salinity (3-9 eq wt% NaCl) to a more dilute solution (3-4 eq wt% NaCl). Characteristics of the fluids which deposited ore minerals in the Virginia City deposits evolved from a high temperature (275°C), low salinity fluid (3-6 eq wt% NaCl) to a lower temperature (175°C), higher salinity fluid (10-12 eq wt% NaCl).

Alteration patterns appear to reflect the physical and chemical conditions under which ores were deposited (Rose and Burt, 1979). Alteration assemblages of epithermal deposits typically contain minerals indicative of argillization, silicification and propylization (Eimon, 1988). This alteration is usually pervasive. Alteration associated with mesothermal deposits is dominated by carbonization, sericitization, chloritization and pyritization. At Virginia City as well as the Korean-type deposits alteration is restrict to narrow selvages around the veins and zones of intense brecciation. The alteration assemblage is characterized by argillic and potassic alteration.

The Easton-Pacific vein trend was the largest lode producer
in the Virginia City district. Characterization of the mineralizing events at the Pacific mine indicate that the deposit formed in the deep portion of an epithermal system (approximately 350 meters) as evidenced by mineralogical, textural, geochemical and fluid inclusion data. The correspondence of temperatures determined by illite:smectite ratios and fluid inclusions indicates a pressure correction for the fluid inclusion data is not needed, confirming this shallow depth of formation. Ore deposition was spatially associated with the Brown's Gulch stock and appears to post date its emplacement.

Crosscutting relationships at the El Fleeda mine indicate that the mineralization in the Virginia City district predates the emplacement of a 51 m.y. old andesite plug (Cole, 1983). Mineralizing fluids appear to have evolved with time from a high temperature, low salinity fluid to a lower temperature, higher salinity fluid. Structural controls on ore deposition range from large scale regional fracture zones to small scale dilatant zones within these regional structures. Alteration is restricted to narrow selvages because of the lack of permeability in the host rock.
CONCLUSIONS

1. The host rock lithology of the Virginia City mining district in southwestern Montana does not favor the development of bulk-tonnage low-grade precious-metal deposits. The low primary permeability of the gneisses and intrusive rocks limits the occurrence of deposits to areas of increased secondary permeability such as fractures and brecciated zones.

2. The mineralization of the Virginia City district is localized along throughgoing regional-scale fractures that have been reactivated through time. Second order structures within these large scale structure are important sites of ore deposition. The limited extent of these mineralized zones does not favor bulk-mining.

3. Morphological evidence indicates that the Virginia City deposits are spacially and possibly genetically related to the Brown's Gulch stock, a satellite of the larger Cretaceous-aged Tobacco Root batholith.

4. Fluid inclusion data suggests that ore-forming fluids evolved from a high temperature (275°C), low salinity (3-6 eq wt% NaCl) solution to a lower temperature
(175°C), high salinity (10-12 eq wt% NaCl) solution possibly indicating a mixing of fluids from different sources.

5. Temperatures estimated by illite/smectite ratios are consistent with those estimated by fluid inclusions. Illite/smectite ratios indicate that a zoning of high illite proximal to the vein with increasing smectite distal to the vein is present at the Pacific mine.

6. Comparison of the Virginia City deposits to other hydrothermal deposits worldwide reveals a continuum of deposit types. The Virginia City deposits most closely resemble the deposits of the Cheonan area in Korea studied by So and Shelton (1987). The deposits of both of these districts appear to bridge the gap between epithermal and mesothermal deposits.
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Appendix I.

Ore and gangue minerals historically reported in the districts of the Tobacco Root mining region.
## Appendix I.

<table>
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<th>VIR.CITY</th>
<th>PONY</th>
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<th>NORRIS</th>
<th>RENOVA</th>
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<td>X</td>
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<td>X</td>
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<td></td>
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<tr>
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<td>X</td>
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(from Cole, 1983)
Appendix II.

Photomicrographs of polished sections with location, hand-sample description, and sequence of mineralizing events.
f.o.v. = 0.6mm

89 ms1 018A- High Up mine dump; light gray, brecciated quartz with rounded to subangular clasts with quartz matrix and minor sulphide blebs (1%).

quartz + pyrite ➞ brecciation ➞ chalcopyrite.
89 msl 026- Northern Pacific vein; brecciated quartz with dark sulphide matrix (30%), clasts are angular to subangular.

quartz + pyrite $\rightarrow$ brecciation $\rightarrow$ chalcopyrite + tetrahedrite
89 ms1 028- Surface sample of the "South Vein" at the Easton mine; massive, milky quartz with fractures filled by sulphides (2%).

quartz + pyrite → brecciation → chalcopyrite + acanthite.
f.o.v. = 0.6mm

89 ms1 052- Eastern most vein in the Pacific Pit; light gray brecciated and massive quartz with minor sulphides (3%).

quartz + pyrite → brecciation → sphalerite → quartz + acanthite + galena + chalcopyrite veinlets.
89 ms1 070- Lower Easton dump, position on dump suggests sample represents lowest level in Easton mine; light gray, brecciated quartz with minor sulphides (3%).

quartz + pyrite → brecciation → galena → deformation (bending) → chalcopyrite → quartz veinlets.
89 ml 071- Section 16 prospect dump; massive milky quartz with sulphide blebs (5%) and abundant malachite staining on fractures.

quartz + chalcopyrite — chalcocite —
goethite — malachite.
ML-G1- Little Lode mine; light gray to milky massive quartz with blebs of native gold and sulphides (3%).

quartz + gold + acanthite.
Appendix III.

Trench sample geochemistry.
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Appendix IV: Equations for quantitative determination of clay mineral species.

The calculations are as follows and reported in parts in 10:

\[ \text{Illite} = \frac{I(10)}{T} \times 10 \]

\[ \text{Smectite} = \frac{S(1)}{4} \times \frac{1}{T} \times 10 \]

\[ \text{Chlorite} = \frac{C(3)}{I(2)} \times \frac{I(1G)}{T} \times 10 \]

\[ \text{Mixed-layer I/S} = \frac{I_{1H} - I(1G)}{T} - \frac{S(1)}{4} \times 10 \]

\[ \text{Kaolinite} = \frac{K(1)}{T} \times 10 \]

or, if chlorite is present

\[ = \frac{K(2)}{2C(4)} \times \frac{C(3)}{I(2)} \times \frac{I(1G)}{T} \times 10 \]

where \( T \) is equal to "total counts"

If chlorite is not present

\[ T = I(1H) + K(1) \]

or, if chlorite present

\[ = I(1H) + \frac{C(3)}{I(2)} \frac{I(1G)}{I(2)} + \frac{K(2)}{2C(4)} \frac{C(3)}{I(2)} \frac{I(1G)}{I(2)} \]
References for clay mineral identification:


This thesis is accepted on behalf of the faculty of the Institute by the following committee:

William X. Adams, J.H.  5 December, 1990

Adviser

Andrew Campbell

Paul E. Emerson

Dec 5 1990

Date