Controls of gold mineralization in the southern portion of the Hodson Mining District west Mother Lode gold belt California

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CONTROLS OF GOLD MINERALIZATION
IN THE SOUTHERN PORTION OF THE HODSON MINING DISTRICT,
WEST MOTHER LODE GOLD BELT,
CALIFORNIA

By
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B. A., Montana State University, 1980

Presented in partial fulfillment of the requirements
for the degree of
Master of Science in Geology
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1986

Approved by
Chairman, Board of Examiners

Dean, Graduate School

Date
CONTROLS OF GOLD MINERALIZATION
IN THE SOUTHERN PORTION OF THE HODSON MINING DISTRICT,
WEST MOTHER LODE GOLD BELT,
CALIFORNIA

Director: Ian M. Lange

Gold mineralization in the Hodson Mining district, located in the West Belt of the Mother Lode, is similar in character to the deposits of the Central Mother Lode. Gold mineralization is hosted in a major, penetrative, oblique, dextral shear zone, localized along stratigraphic discontinuities between Late Jurassic island arc sequences of metasedimentary and metavolcanic rocks. Lensoidal bodies of fault-bounded serpentinitized ultramafic rocks also occur along this zone.

Three stages of deformation and at least two stages of metamorphism have affected the rock packages, producing slaty cleavage (D1), penetrative, plastic deformation (D2), and brittle thrusting (D3). Regional greenschist facies metamorphism accompanied D1 deformation while more isolated shear zone alteration and metamorphism occurred during D2 deformation. Two types of gold mineralization occur: high-grade, quartz stringer and breccia zones and low-grade, stratiform horizons of carbonate-rich metavolcanic rock. The quartz stringer zones are oriented along D2 fabric, predominantly in the metasedimentary rocks, within a major shear zone, along the contact between metasedimentary and metavolcanic rocks. Carbonate-rich, gold-bearing horizons parallel stratigraphy and represent altered mafic to ultramafic(?) flows, pyroclastics and tuffaceous sediments. They contain quartz, ankerite, mariposite (chromiferous mica), pyrite and gold. Carbonate alteration preceded the development of the quartz stringer zone but is apparently not syngenetic. The gold mineralization in the Hodson Mining district is probably a result of shear zone secretion and consists of an early carbonate-gold enrichment, followed by a later redistribution and gold concentration in quartz-stringer zones during D2 deformation.

Multi-element soil and rock geochemistry indicates arsenic is the best pathfinder element for gold mineralization. Arsenic shows a broader, stronger response over both the quartz-stringer zone and the stratiform, carbonate zone gold mineralization.
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Introduction

Gold mineralization in the Mother Lode region of California has long been considered to be related to the development of the Sierra Nevada batholith. More recent theories propose a shear zone or metamorphogenic origin. The mineralization also contains attributes which suggest an earlier, possibly syngeneric origin. To test these hypotheses, I conducted a detailed examination of the Hodson mining district and a reconnaissance investigation of the entire Mother Lode region.

The Mother Lode region lies in the Sierra Nevada metamorphic belt consisting of several allochthonous terranes of Paleozoic and Mesozoic eugeoclinal, ocean floor and island arc related sediments (Saleeby, 1981). The terranes are separated by major shear zones which subparallel the north-trending, steeply-dipping stratigraphy. Within and adjacent to these shear zones are ophiolite complexes, melange zones and linear belts of serpentinized ultramafic rocks. Gold mineralization occurs in and adjacent to these shears, often associated with ultramafic bodies (Figure 1).

Three parallel belts of gold mineralization together with smaller, less continuous belts form the Mother Lode system. Gold mineralization occurs as quartz fissure veins and as large bodies of carbonate-altered greenstone known as “gray ore”. A belt of exhalative massive sulfide deposits (Kemp, 1982), known as the Foothills Copper-zinc belt, overlaps and lies west of the gold belts in more
felsic volcanic rocks. The Hodson mining district lies in the west gold belt of the Mother Lode, 5 kilometers northwest of Copperopolis, California, and contains both gold and copper–zinc mineralization (Figure 2).
WE^TTERN SIERRA NEVADA METAMORPHIC BELT, CALIFORNIA

EXPLANATION

Cenozoic sedimentary and volcanic rocks

Granitic rocks of the Sierra Nevada batholith, chiefly of Mesozoic age

Mesozoic sedimentary and volcanic rocks, in places strongly metamorphosed

Ultramafic rocks, chiefly of Mesozoic age

Paleozoic sedimentary and volcanic rocks, in places strongly metamorphosed

Contact

Fault
Dotted where concealed

Figure 1 Generalized geologic map of the western Sierra Nevada metamorphic belt, showing location of study area. Modified from Clark (1976).
Figure 2 Map of the Mother Lode gold belts and the Foothills copper-zinc belt.
Southern half of the western Sierra Nevada metamorphic belt, California. From Clark (1970).
Geology

The Hodson mining district lies along the Hodson fault zone, part of the major northwest-trending Bear Mountain fault zone. The trace of the fault zone is marked by lensoidal bodies of serpentine (Figure 3). Shearing is localized along structural discontinuities between upper Jurassic slate and metavolcanic rocks. Gold mineralization occurs within the shear zone as quartz stringer zones and as bodies of carbonate-rich metasedimentary and metavolcanic rocks. Horizons of copper-zinc mineralization also occur in this zone. The rock packages strike northwest and dip steeply to the east, and have been altered to greenschist facies by regional metamorphism. Shear zone alteration overprints regional metamorphism and is localized along the slate-volcanic contact. The southern Hodson mining district is divided into three regions: (1) a western slate belt; (2) an eastern greenstone belt; and (3) a central zone of shearing, which includes altered protoliths from the other two belts (Figure 4).

Stratigraphy

The slate sequence is upper Jurassic in age and known regionally as the Salt Spring Slate. It is 3 kilometers thick and consists of black and brown fissile slate, with interfingering lenses and tongues of pyroclastic rocks and associated coarse greywacke, tuff and pebble conglomerate (Figure 5).

The volcanic sequence, regionally known as the Copper Hill Volcanics, is
Copperopolis fault zone

EXPLANATION

- Copper Hill Volcanics
- mafic metavolcanics.
- sl. cherty slate.
- Salt Spring Slate.
- Quartz diorite(?)
- Serpentine.

Fault zone
with thrust faults

Gold mine
Copper mine

Figure 3. Generalized geologic map of the Hodson mining district, showing gold mines and nearby copper mines. (WW) Wilbur Womble mine, (GK) Gold Knoll mine, (MK) Mountain King mine, (R) Royal mine, (K) Keystone, (U) Union, (E) Empire. Modified after Clark (1970) and; Taliaferro and Solari (1944).
Figure 4. Geology map of the southern Hodson Mining district. See Figure 5, lithologic descriptions. WW = Wilbur Womble Mine, GK = Gold Knoll Mine.
upper Jurassic in age and conformably overlies the slate sequence. It consists primarily of subaqueous mafic to intermediate (with minor felsic) pyroclastic rocks with subordinate massive, amygdaloidal flows, aggregating a combined thickness of 1500 meters (Clark, L., 1970). The volcanic rocks are predominantly tholeiitic in composition, with local calc-alkaline volcanic centers containing associated massive sulfide deposits (Kemp, 1982). In the Hodson mining district, the volcanic package thickens and coarsens to the northwest, indicating probable derivation from that direction.

Shear zone lithologies are altered, heavily sheared sedimentary and volcanic rocks. The type of alteration and degree of shearing is partially dependent on the original composition and competency of the rock type. Thus, shear zone lithologies, while discriminated primarily by alteration assemblages, also reflect primary stratigraphy. These associations are discussed under the alteration section of this paper. The width of shearing varies from 30 meters to greater than 200 meters across the slate-volcanic contact. It is wider in the less competent mafic pyroclastic rocks.

Structure

Three deformational events are recorded in the rocks of the study area; isoclinal folding $D_1$, shearing $D_2$ and thrusting $D_3$ (Figure 6). Isoclinal folding accompanied greenschist facies metamorphism and is expressed by bedding plane and axial planar cleavage ($S_0$ and $S_1$, figure 7) (Eric et al., 1955; Clark, 1960).

Folding was followed by shearing producing the Hodson fault zone. Shearing
Figure 5 Stratigraphic section of the southern Hodson mining district. Mapped from trenches and stream gullies, located approximately along section B-B', Figure 4.
is most evident in the slates and sericite schists producing penetrative cleavage, pencil structures, chevron folds and quartz stringer zones. Multiple generations of folded, brecciated and ribbed quartz veins, indicate ductile and brittle conditions existed within the shear zone (Chace, 1949; McKinstry and Ohle, 1949). The direction of shear displacement (determined by rotated crystals, oriented crenulation cleavage, sigmoidal surfaces, rotated blocks and en echelon tension gashes) is right lateral (Simpson and Smith, 1983). Shear zone cleavage ($S_2$) contains two orientations: compressional shear or slip cleavage; and tensional shear cleavage (Figure 7).

The third deformational event is represented by thrust faulting ($D_3$). Relative motion, indicated by drag folds and striated, graphitic shears, suggests that over-thrusting is directed to the southwest. The total amount of displacement is not known; however, stratigraphic offset (Figure 11) indicates at least 37 meters of low-angle thrusting has occurred. The orientation of the thrust planes correlates well with expected orientations developed within a shear couple. The thrusting event probably represents a culmination of $D_2$ forces, but with brittle dislocation rather than ductile deformation.

In addition, east-west cross faulting is suggested by the anomalous curvature in the thrust plane, abrupt termination of the southern ultramafic body, and termination of certain stratigraphic horizons (Figures 4, 9 and 21). Cross faulting is probably related to thrusting, though its orientation, style and displacement are not known. Major serpentine bodies appear structurally controlled; they are fault-bounded, cross-cut stratigraphy and boudin in areas of dilatancy, controlled mainly by warped surfaces along the shear zone.
Alteration and Metamorphism

Two episodes of metamorphism affected the rocks in the Hodson mining district. The first, accompanied isoclinal folding (D₁) as regional greenschist facies metamorphism. The intensity is uniform throughout the study area and is characterized by chloritization of original mafic minerals. The second episode of metamorphism accompanied shear zone deformation (D₂), producing localized alteration within the shear zone characterized by carbonate alteration.

Alteration assemblages reflect the chemistry of the host rock and the proximity and intensity of shearing. Shearing and alteration intensity is greatest along the sediment–volcanic contact, decreasing outward, forming cylindrical alteration shells surrounding dilatant zones. Dilatancy occurs within the shear zone due to wrench faulting and ductile shear. Alteration in slate horizons is minimal, consisting of a slight bleaching (potassic alteration) and development of disseminated pyrite. Alteration intensity increases in mafic volcanic rocks, often forming multiple zones with distinct mineral suites. Central quartz veins are surrounded by a zone of ankerite, mariposite and pyrite, followed by a zone of chlorite plus or minus pyrite and talc, and typically flanked (on the east) by serpentine (Figure 8). Similar alteration patterns occur in Timmins, Ontario, Canada (Colvine, et al., 1984), the southcentral Mother Lode (Evans and Bowen, 1977), and in South Africa (Pearton, 1978). Delineation of the serpentine bodies was facilitated using a magnetometer survey (Figure 7). The anomalously high magnetic response is due to disseminated magnetite which formed during serpentinization of the ultramafic rocks (Figure 9).
Figure 6 Tectonic development in the Hodson mining district.
(a) Isoclinal folding, axial planar cleavage development (D₁); (b) shear zone, dextral strike-slip displacement with the development of gash veins (D₂); and (c) west-verging thrust faulting (D₃).
Bedding or axial planar cleavage ($S_0$ and $S_1$).

Shear zone penetrative cleavage. Compressional ($S_{2c}$).

Shear zone penetrative cleavage. Tensional ($S_{2t}$).

Thrust plane orientation.

Figure 7 Stereonet plot of cleavage development in the Hodson mining district.
The generalized paragenetic sequence of alteration and gold mineralization is depicted in Table 1. Most of the alteration occurred during shear zone deformation ($D_2$), with complex, overlapping and repeated phases. Crosscutting relationships indicate that the sequence of alteration began with widespread carbonate development, followed by mariposite and sericite formation. Pyrite followed, with development along mariposite lineation bands. Quartz and quartz-carbonate veining occurred during and after mica development and was accompanied by sulfidation and contemporaneous or later gold mineralization. Brecciation of the quartz veins, with additional(? ) gold mineralization, may have occurred during the $D_3$ thrusting event.

Geochemistry

In order to determine trace metal associations and possible pathfinder elements for the gold mineralization, I conducted a soil and rock geochemical investigation. An experimental “soil-line” (located along section A–A’, Figures 12 and 13) containing 17 sample locations was analysed for 11 elements (As, Hg, Te, Mn, Pb, Zn, Sb, B, F, W and Au, Table 2 and Figure 10). Analytical procedures are listed in Appendix 2). The results indicate that:

1. in addition to gold, arsenic is the best pathfinder element for gold mineralization, followed by tungsten;

2. arsenic also outlines mariposite schist horizons, which are not always mineralized;

3. arsenic anomalies form a stronger, broader response, extending out and beyond gold mineralization;
Figure 8 Diagrammatic illustration showing alteration zones surrounding gold quartz veins in greenstone lithologies. (after Colvive et al., 1984).
Ground magnetic map, showing total intensity magnetic field of the earth in gammas, relative to an arbitrary datum. Contour interval 1000 gammas. Data controlled by bore hole measurements every two hours and surveyed to datum. Survey completed May 6 to April 2, 1976. Measurements made every 50 feet, along lines spaced at 500 foot intervals.

Figure 9 Magnetic map of the southern Hodson mining district.
### Table 1: Interpreted mineral paragenetic sequence.

<table>
<thead>
<tr>
<th>D&lt;sub&gt;1&lt;/sub&gt;</th>
<th>D&lt;sub&gt;2&lt;/sub&gt;</th>
<th>D&lt;sub&gt;3&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>isoclinal folding</td>
<td>shearing</td>
<td>thrusting</td>
</tr>
<tr>
<td>griscenst facies metamorphism</td>
<td>penetrative cleavage</td>
<td>shear zone metamorphism</td>
</tr>
</tbody>
</table>

- Chlorite
- Carbonate
- Sericite
- Mariposite
- Pyrite
- Quartz
- Gold
- Serpentinization

---

*Note: The table depicts the sequence of mineral paragenesis during different stages of metamorphism.*
4. mercury delineates areas of soil contamination by mill tailings (because amalgamation plates were used to extract gold in the old mills);

5. soil geochemistry correlates well with rock geochemistry (Figures 10 and 11);

6. the strongest gold mineralization is in the quartz stringer zone and central portion of the mariposite schist horizons.

Geochemistry maps of gold and arsenic distributions in soil outline two major linear bands of anomalously high metal concentration, which correspond to the mineralized quartz stringer zone and mariposite schist horizons (compare Figures 12 and 13 with Figure 4).

A comparison of elemental distributions in soils shown in Figure 10 with bedrock lithologies, indicates four geochemical zones with unique metal enrichments (Figure 14):

1. A copper-zinc zone, with enrichment of Cu, Pb, Hg, Te and Mn with minor Au and Ag. The copper-zinc zone exhibits a much stronger response in drill hole samples (underlined element indicates it is unique to that zone.) (Figure 13).

2. An eastern mariposite schist stratiform horizon, with massive, white quartz veins, enriched in As, Sb, B, W, Au, Hg and minor Zn and F.

3. A western, chlorite-rich, mariposite schist stratiform horizon with minor, irregular quartz pods. This zone is proximal to the quartz breccia zone, but shows enrichment in Ba, Te, As, F, B, W and Au.

4. A quartz stringer zone consisting of quartz veining, brecciation and replacement at the volcanic-sediment contact. It is enriched in Au, As, W, B, F and Te.

The variability of metal suites in the separate zones is in part related to the host rock lithologies. Tellurium and manganese concentrations increase in the volcanic rocks, while barium, boron, fluorine and zinc background concentrations are greater
Figure 10 Multi-element soil geochemistry in relation to geology.
Location, grid-line 6400N, section A-A' on soil geochemistry maps. 50 foot, spot-sample spacing. * = Detection limit. See Figure 5 for stratigraphic descriptions.
Table 2: Pathfinder elements for gold mineralization (see figure 10).

<table>
<thead>
<tr>
<th>Element</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>Excellent pathfinder element. Very strong response over a broader area than gold. Arsenic also delineates carbonate altered zones which are not enriched in gold.</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>Fair correlation, not very consistent but also picks up hydrothermally altered areas. Mercury is best used to delineate contamination from mill tailings.</td>
</tr>
<tr>
<td>Tellurium (Te)</td>
<td>Fair correlation with quartz veining and carbonate altered zones. Shows strong, broad response in volcanics over the copper–zinc horizon.</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>Poor pathfinder element. Very little to no response. Slight anomaly over copper–zinc zone.</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Poor pathfinder element. Shows highest response over slate. Picks up eastern mariposite schist horizon and hydrothermally altered zone, but fails to resolve western quartz breccia zone. Good lithology indicator for slate.</td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>Inconsistent. Strong response over carbonate altered gold mineralization, but no response over quartz breccia gold mineralization.</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>Fair correlation with gold, but also shows anomalous high response in slates. Strong response over carbonate altered rock, similar to arsenic. Good lithology indicator for slates.</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>Fair correlation with gold. High values over slate and the western carbonate altered zone, but fails to outline quartz breccia mineralization. Small, broad response over copper–zinc mineralizations.</td>
</tr>
<tr>
<td>Fluorine (F)</td>
<td>Fair to good correlation with gold. Picks up both gold zones with a stronger response over the quartz breccia zone. Anomaly is broader, but peaks are not well resolved.</td>
</tr>
<tr>
<td>Tungsten (W)</td>
<td>Good correlation with gold but weak response.</td>
</tr>
<tr>
<td>Gold (Au)</td>
<td>Soil geochemical response shows excellent correlation with rock geochemistry. Strong response over quartz stringer zone and western carbonate altered zone.</td>
</tr>
</tbody>
</table>
in the slates. Other metal variation, such as the high concentration of As, Sb, and B in the eastern mariposite schist horizon, could be the result of fluid temperature variations between shear zones.

Mineralization

Gold mineralization in the study area is controlled by both structure and stratigraphy; structure dominates. The two main types of gold mineralization are quartz stringer zones and stratiform horizons of gold-bearing, mariposite schist. Copper-zinc mineralization forms stratabound horizons stratigraphically above the gold mineralization in the mafic volcanic rocks, and forms within chlorite shear zones, adjacent to fault-bounded serpentine bodies (see Map 1).

Structurally controlled gold mineralization, located within the Hodson fault zone, forms high-grade (averaging 0.08 ounces of gold per ton), quartz stringer zones. These zones consist of elongate, irregular, discontinuous clots and boudined quartz stringer veins. The stringer zones form strikingly chaotic, ribboned patterns with approximately equal amounts of quartz and country rock. They occur primarily in the slate sequence adjacent to the volcanic contact, and to a lesser degree, in the mariposite schists and tuffaceous (sericitic) slate sequences (Figures 15, 16 and 17). The zones, typically 6 to 10 meters wide, attain widths of over 40 meters at the Gold Knoll mine.

The quartz stringers are orientated along $S_2$ major and minor cleavage directions, as well as along $S_2$ axial plane cleavage and folded in $S_2$ microfolds, indicating that they developed during the $D_2$ oblique shearing event. The folded
Figure 11 Rock geochemistry in relation to geology.
Located along grid line 6400N, trench E. Samples are 10 foot average, continuous rock chips. See Figure 5 for stratigraphic descriptions.
Figure 12 Map of gold distribution in soil.
Figure 13 Map of arsenic distribution in soil.

Contours drawn at: 100, 200, 400 and 500 ppm arsenic. Samples taken every 50 feet along lines spaced at 500 foot intervals.
Figure 14 Map showing separate metal zones.
and unfolded quartz stringers appear identical, with no consistent cross-cutting relationships. Folded, brecciated and ribbed gold-bearing quartz veins indicate quartz influx occurred repeatedly at temperatures and pressures near the boundary between brittle and ductile conditions.

Stratigraphically controlled gold mineralization occurs in carbonate-altered, mariposite schist horizons. The horizons are low grade (averaging 0.02 ounces of gold per ton), stratiform, and appear stratabound, interfingering with slate and sericite schist horizons (Figures 15, 16, 17 and 18). They subparallel and are cut by the quartz stringer zone. The horizons are lithologically and chemically distinct, containing a unique suite of enriched elements (see Figure 10). It is unclear whether these horizons represent original sedimentary accumulations or are the result of an epigenetic mineralization process.

In thin-section a typical mariposite schist contains 40% quartz, 30% ankerite or ferroan dolomite, 15% tuffaceous material, 10% mariposite or sericite and 1 to 2% pyrite. Mariposite is a distinctive, bright-green, chromium-rich variety of muscovite (or phengite), similar to fuchsite. The matrix of the schist is composed of subangular, fine quartz sand and silt with lesser interstitial, carbonate. Quartz is strained, recrystallized and locally shows sedimentary sorting and grading. Tuffaceous material consists of minor, euhedral (commonly zoned) pyroxene (augite?) and clasts containing unoriented, felted mats of plagioclase laths. Crystals are thoroughly altered to fine-grained assemblages of carbonate, sericite and chlorite. The rock is sheared, commonly mylonitized, with mariposite and pyrite development along lineation bands producing a marked schistosity. The
bands are subparallel to compositional layering and form a penetrative cleavage. Pyrite occurs preferentially along mariposite lineation bands (Figure 19) as sharply euhedral, 2 to 3mm cubes and pyritahedrons. Pyrite cubes are often rotated and surrounded by pressure shadows of feathery quartz (Figure 20). Coarse cubic pyrite is the dominant gold carrier with enclosed gold particles from one micron to one millimeter (Meridian Company report).

The orientation and distribution of mineralized quartz veins within the shear zone appears to be controlled by dilatancy. Movement along the shear zone is right-lateral with a lesser thrusting component, therefore, dilatant zones form as a result of strike-slip displacement and dip-slip movement (Figure 22). The result is an anastromosing network of gash veins developed by tensional dilation within the shear zone. District-wide and throughout the Mother Lode region, ore bodies (and serpentine bodies) form at spaced intervals along the shear zone. This periodicity could result from rotation of blocks within a shear couple, producing alternating regions of compression and extension (Figure 23). The spacing between zones of dilatancy would be determined by the size of the rotational blocks, which is dependent on the width of the shear zone, the intensity and depth of shearing, and the competency of the rock package.

Horizons of copper-zinc mineralization form statigraphically above the gold mineralization in the mafic volcanic rocks. They consist of finely disseminated pyrite and minor chalcopyrite and form within silicified zones, in sericite schists, beneath slate horizons and in chlorite shears adjacent to fault bounded serpentine bodies (Figure 18 and Map 1).
Figure 15. Cross section B-B', along grid line 5600N, showing geology and geochemistry. Note: gold mineralization in shear zone along metasediment-metavolcanic contact and in highly fractured and sheared upper-plate rocks. Zinc mineralization in slate horizons and in pyritic interbeds within the undifferentiated greenstone package. See Figure 5 for lithologic descriptions.
Figure 15. Cross section C-C', along grid line 7200N, showing geology and geochemistry. Note: gold mineralization in mariposite schist horizons and in shear zone, along the metasediment-metavolcanic contact. Arsenic anomalies show excellent correlation with gold anomalies. See Figure 5 for lithologic descriptions.
Figure 17. Cross section D-D', along grid line 8000N, showing geology and geochemistry. Note: gold mineralization in mariposite schist horizons and in shear zone, along the metasediment–metavolcanic contact. See Figure 5 for lithologic descriptions.
Figure 18. Longitudinal section, showing geology and geochemistry. Section E-E'. See Figure 5 for lithologic descriptions, and Figure 4 for location.
Figure 19  Photomicrograph of mariposite schist, showing pyrite preferentially located along mariposite lineation bands. Field of view = 2 mm.

Figure 20  Photomicrograph of rotated pyrite cube in mariposite schist, showing pressure shadows of feathery quartz. Arrows indicate direction of rotation. Field of view = 2 mm.
Figure 21. Structure contour map of the Hodson fault (volcanic-slate contact), showing distribution of major gold mineralization by dot pattern.
Figure 22 Dilatant zone development as a result of fault displacement. (a) Dip slip, high angle reverse motion; (b) shear zone, strike slip motion; and (c) combination of shearing and overthrusting.
Figure 23  Dilatant zone development as a result of shearing, block rotation and wrench faulting.
Discussion

Gold mineralization in the southern portion of the Hodson mining district contains both syngenetic and epigenetic attributes. Gold mineralization in secondary structures suggests an epigenetic genesis, while gold mineralization in stratigraphically-related, mariposite schist horizons, indicates possible primary, syngenetic gold mineralization with subsequent secondary concentration during deformational events. Any model or models that attempt to explain the genesis of the gold mineralization must effectively address the relationships between stratigraphically and structurally controlled gold mineralization. Ore genesis models which are applicable include exhalative-hydrothermal and shear zone secretion.

Syngenetic Model

An exhalative-hydrothermal model was proposed by Kemp (1982) for the formation of the Foothills copper-zinc belt, which parallels the Mother Lode gold belts. A syngenetic, exhalative model has also been suggested by other workers for the formation of the Mother Lode gold belts. In the syngenetic model gold is deposited by volcanic-related, hot spring activity on the sea floor (Rye and Rye, 1974; Karvinen, 1980). The resulting deposits are stratiform and consist of chemical, sedimentary exhalites. The deposits form in association with mafic and/or ultramafic volcanic rocks and are overlain by a sedimentary sequence.
Exhalative mineralization in the form of massive sulfide deposits are well documented in the Mother Lode region (Kemp, 1982) and occur in rocks of practically all ages (Franklin et al., 1981). Known examples of exhalative gold deposits are less common, occurring principally in Archean terranes (Karvinen, 1980; Hutchinson, 1976).

Exhalative gold deposits may be present in the Sierra Nevada Metamorphic belt because the rock sequences are remarkably similar to the greenstone belts of Archean age. Support for exhalative gold mineralization in the Hodson mining district and throughout the Mother Lode gold belts includes:

1. the parallel nature of the belt of syngenetic, exhalative, volcanigenetic copper-zinc deposits
2. the formation of the gold deposits at volcanic-sedimentary rock contacts
3. the deposits contain a distinct suite of trace metals often associated with exhalative gold mineralization (gold, silver, arsenic, tungsten, boron, barium and antimony)
4. the deposits contain diagnostic alteration minerals associated with exhalative gold mineralization (ankerite, mariposite or chromiferous mica, sericite and quartz)
5. the deposits are stratiform and are often delineated by diffuse, gradational contacts (ore body contacts are typically grade cutoffs (Knopf, 1929))
6. the deposits are often associated with conglomerate horizons, indicating proximity to faulting (hydrothermal feeder pipes are located along faults)
7. the deposits occur at spaced intervals similar to exhalative, massive sulfide deposits, possibly representing the size of hydrothermal convection cell
8. the deposits occur primarily along major sedimentological transitions, but also to a lesser degree as smaller deposits between major belts (indicating the continuation of hydrothermal, exhalative activity but with more sediment dilution)

While these characteristics are permissive evidence for syngenetic, exhalative mineralization, there are certain aspects of the deposits which do not support the model. They include:

1. no apparent exhalative, chemical facies transition or variation along strike (i.e. absence or paucity of chert horizons)

2. the lack of (identified) crosscutting hydrothermal feeder pipes (necessary for venting hydrothermal solutions onto the sea floor)

3. stratigraphy in the study area is reversed: volcanic rocks are stratigraphically above sedimentary rocks (exhalative deposits typically form at the base of a sedimentary sequence)

4. strong spatial association of mineralization with post-depositional, fault zones (characteristic of epigenetic, not syngenetic mineralization)

5. strong spatial association of mineralization with serpentinized ultramafic bodies (most of the ultramafic bodies are structurally emplaced along the fault zones, compatible with structurally controlled gold mineralization)

6. carbonate alteration overprints regional metamorphic fabric (gold mineralization is spatially related to carbonate alteration and therefore, may also be post-regional metamorphism)

Many of the above discrepancies in the exhalative model can be summarily explained. Mineralization associated with post-depositional fault zones may be coincidental, related only because tectonic forces and exhalative gold mineralization are both often localized along structural discontinuities represented by volcanic-sedimentary rock contacts. The gold deposits may be related to the ultramafic bodies because erosion and concentration of metals from these bodies
could form the gold-bearing, mariposite schist horizons (Schreyer, 1982; Hinse, et al., 1986). The gold may have already been present in the rock units prior to shearing, and was merely remobilized during carbonate alteration. Furthermore, hydrothermal feeder pipes are often hard to distinguish and may only be indicated by footwall alteration assemblages. Finally, volcanically-induced hydrothermal, alteration-mineralization may have preceded volcanic outpourings.

Epigenetic Model

The close spatial relationship between gold mineralization and major shear zones suggests an epigenetic origin for the formation of the Mother Lode gold deposits. A shear zone secretion model, proposed by Zimmerman (1981) and Nesbitt et al., (1986), and largely adapted from Boyle (1959 and 1979) may have operated. In the model, Mother Lode-type gold deposits form by secretion of metamorphic or deep meteoric fluids along shear zones. Movement along these zones produces heat, causing circulation of fluids which leach metals from the surrounding rocks. The fluids then migrate to low pressure, dilatant zones produced by fault displacement. Gold and other constituents precipitate in these zones, possibly due to decreased pressure and/or chemical reduction.

Shear zones are common structural characteristics of accreted continental margins. They often develop due to oblique convergence or transpression, resulting in wrench faulting with accompanied strike-slip and minor reverse motion. The shear zones subparallel stratigraphy, and are characteristically delineated by lensoidal bodies of serpentinized ultramafic rocks. The ultramafic
rocks are believed to be structurally emplaced along the shear zones (Misra and Keller, 1978; Snoke, et al, 1982).

The shear zone secretion theory, therefore can explain many attributes of the gold mineralization in the study area, throughout the Mother Lode region, and in similar greenstone terranes. Permissive evidence includes:

1. the gold mineralization is associated with faults and major shear zones

2. primary controls of gold mineralization are along secondary structures

3. existence of active faulting during mineralization (successive periods of folded, brecciated and ribboned, gold quartz veins)

4. paucity of vertical mineral zoning (possibly resulting from deep-seated mineralization)

5. spatial association of serpentinized, ultramafic bodies to many of the deposits (because both are probably controlled by zones of dilatancy)

6. mineralization contains a distinct suite of trace metals: gold, silver, arsenic, tungsten, boron, barium and antimony (compatible with mesothermal, hydrothermal conditions)

7. mineralization contains diagnostic alteration minerals: ankerite, mariposite or chromiferous mica, sericite and quartz (which developed during shear zone activation)

8. deposits are lensoidal-shaped with diffuse mineralized contacts (compatible with deep-seated mineralization)

9. deposits occur at spaced intervals along the shear zones (possibly indicating local zones of dilatancy developed by shearing)

10. carbonate alteration clearly overprints regional metamorphic fabric (carbonate alteration accompanied gold mineralization)

11. mineralization and shearing occur primarily along major sedimentological transitions (which also represent structural discontinuities)
The shear zone secretion theory fails, however, to sufficiently explain the common, parallel occurrence of exhalative, massive sulfide mineralization, and the existence of interfingering, low grade, stratiform horizons of mariposite schist.

A major question concerning the genesis of the gold mineralization is its relationship to the shear zone. Is the gold mineralization related to the shear zone or is the shear zone developed at the stratigraphic transition where earlier gold mineralization occurred? The key to the problem may lie in the genesis of the gold-bearing, mariposite schist.

**Genesis of mariposite**

Throughout the Mother Lode and in other, similar greenstone terranes, gold mineralization is often closely related to, and hosted in mariposite schist, or rocks containing abundant iron carbonate and green, chromiferous mica (mariposite and fuchsite). This rock-type has been variously described as:

1. a metamorphosed alunite deposit (Schreyer, 1982)
2. chemical sediment, classified as a mixed carbonate-sulfide iron formation (Karvinen, 1980)
3. carbonate altered serpentine (Knopf, 1929; Evans and Bowen, 1977; Pearton, 1978)
4. carbonate altered mafic pyroclastic or tuffaceous sediments (this investigation)
5. carbonate altered komatiite (Fyon and Crocket, 1980; Schreyer, 1982)
6. carbonate altered, differentiated tholeiitic sill (Phillips, 1986)
The large number of suggested protoliths for chrome mica-bearing rock, indicates that it can probably form from alteration of many different rock types, controlled principally by the chemistry of the enclosing rock and environment of alteration.

Chromiferous mica occurs in two environments: in detrital, metasedimentary rocks, and more commonly, in greenstone, metavolcanic rocks (Leo, et al, 1965). In the metasedimentary rocks the mica is associated with detrital chromium, concentrated in heavy metal accumulations (Leo, et al, 1965; Sinha-roy and Kumar, 1984; Ramiengar et al, 1978). In metavolcanic rocks, as in the Hodson mining district, the mica is associated with carbonate alteration and gold mineralization. In the metavolcanic rocks three elements are always present: (1) mafic to ultramafic igneous rocks; (2) greenschist facies (or higher) metamorphism; and (3) major shear zones. The chromiferous mica occurs in or adjacent to the ultramafic rocks, suggesting that they provide the source for the chromium, either by hydrothermal alteration and leaching (Whitmore, et al., 1946), or by erosion and concentration in heavy metal accumulations. Metamorphism supplies the correct combination of temperature, pressure and fluid chemistry for development of the mica; and the major shear zones provide the necessary fluid pathways and dilatant zones for the collection and precipitation of the mineral.

An important spatial relationship is that many of the altered ultramafic bodies hosting chromiferous mica and gold mineralization are believed to be structurally emplaced along the shear zone. The alteration post dates emplacement, which strongly discounts the possibility that the chrome mica and the gold are of an exhalative source. The chrome mica-bearing rock is therefore, not diagnostic of
exhalative gold mineralization, rather, it indicates alteration of mafic and ultramafic igneous rocks related to shearing in greenschist facies metamorphic terranes.

Not all carbonate-rich, greenstone gold deposits are associated with chromite-bearing rock. In California, gold mineralization occurs in other rock types along the major shear zones, indicating gold mineralization is more directly related to the shear zone and not a particular host rock. These relationships lead me to believe that the gold mineralization in the Hodson mining district formed epigenetically due to the circulation of mineralizing fluids in a shear zone. In addition, in the shear zone secretion model, mineralization occurs at great depth along the shear zone (Nesbitt et al, 1986; Kerrich and Fyfe, 1981), thus necessitating large vertical uplift and erosion to expose them at the surface. In the syngenetic, exhalative gold model, however, mineralization should be readily detectably on the sea floor. No examples of active exhalative gold systems have yet been documented.

While the above reasoning strongly supports shear-zone genesis for the formation of greenstone-type gold deposits, certain characteristics remain enigmatic, such as: (1) the common association of parallel belts of exhalative massive sulfide mineralization; (2) the occurrence of gold deposits only along certain shear zones and not others; and (3) the common, regional, spatial, plutonic association of many of the deposits. These relationships can be explained by their common association with accretionary tectonics which is the requisite environment for the formation of greenstone-type gold deposits.

The entire length of the western margin of North American, from southern
California north through Alaska is composed of accreted terranes (Jones, et al., 1977; Monger and Price, 1982). Carbonate-rich, greenstone-type gold deposits occur intermittently along its entire length: from those of the Mother Lode of California; north to the Klamath Mountains in northern California and Oregon; the Seven Devils Complex of Idaho; the Caribou, Cassiar and other districts in British Columbia; to deposits of the Juneau Gold Field in Alaska (Nesbitt, et al, 1986). These occurrences indicate that shear zone-related gold deposits are not unique to the Mother Lode region and can occur throughout accreted volcanic, greenstone terranes. Greenstone-type gold deposits are very common in rocks of Archean age. The litho-tectonic characteristics of the Archean deposits are similar to those of the Mother Lode, probably indicating the past existence of accretionary plate margins.

Speculation

Additional studies which may be useful in shedding further light on the genesis of greenstone-type gold deposits would be to identify the tops and bottoms of these systems, in order to define vertical alteration and chemical zoning. The higher portion of these systems may be enriched in antimony and mercury while at deeper levels tungsten concentration may increase. Stable isotope studies may be useful to "see through" metamorphic chemical changes to determine the extent of shear zone related alteration. It would also be interesting to compare the location, periodicity and structural relationships between greenstone gold deposits and spatially associated copper-zinc deposits.
Conclusion

Structural data from cleavage and fault plane orientations indicate three periods of deformation affected the rocks of the Hodson mining district: $D_1$-isoclinal folding; $D_2$-strike slip displacement; and $D_3$-reverse motion. Regional greenschist facies metamorphism accompanied $D_1$ folding while shear zone metamorphism and alteration accompanied $D_2$ strike slip motion. Gold mineralization is controlled primarily along $D_2$ structures with minor stratigraphic control. Relationships strongly suggest that the epigenetic gold mineralization formed due to shear zone secretion, in a brittle-ductile shear zone. Successive periods of gold mineralization progressed from widespread carbonate alteration, to the development of quartz stringer zones, ending with brittle fracture and breccia zone development.
References


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Chace, F. M. 1949, Origin of the Bendigo saddle reefs, with comments on the formation of ribbon quartz: Econ. Geol., v.44, p.561-597.


Zimmerman, J. E., 1983, The geology and structural evolution of a portion of the
Appendix A

Petrographic Descriptions

Many of the thin section from the Hodson mining district are clouded by alteration and weathering products. Carbonate alteration is particularly prevalent, obscuring primary textures with recrystallized carbonate. In most instances the carbonate is an iron-rich dolomite, presumably ankerite. The discrimination between mariposite and fine sericite is not possible in thin section. Therefore, the presence and percent of mariposite in the rock was determined by hand sample identification.

---

**Rock Name:** Pebble conglomerate, No. W-65.

**Important Properties**

<table>
<thead>
<tr>
<th>Mineral %</th>
<th>Important Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% Quartz</td>
<td>Angular to subrounded, &lt;0.1mm. to &gt;2mm. (in thin section). In o/c, up to 5 cm. Strained, rotated, often w/ inclusions.</td>
</tr>
<tr>
<td>25% Plagioclase</td>
<td>As &gt;2mm. clots of interlocking, subhedral crystals, and as subhedral crystals in matrix. Fairly fresh, equidimensional and lath-shaped.</td>
</tr>
<tr>
<td>4% Carbonate</td>
<td>Tan rhombs. in slate clasts.</td>
</tr>
<tr>
<td>1% Sericite</td>
<td>Fine needles disseminated throughout.</td>
</tr>
<tr>
<td>&lt;1% Actinolite?</td>
<td>Lt. brn., fibrous. Acicular habit.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments:***

Conglomeratic: Variable clast size.

*Sheared:* Smeared-out, elongated 5:1. Rotated and strained quartz.

Carbonate rhombs. growing in slate.
<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Meta siltstone, No. 44.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>90% Quartz</td>
<td>Fine, equigranular qtz. in matrix of slate, and 30% recrystalized, coarse qtz. in veinlets and clots.</td>
</tr>
<tr>
<td>3% Carbonate</td>
<td>Along fluid influx lineation bands; 2 directions. Also as diss. rhombs.</td>
</tr>
<tr>
<td>3% FeOx</td>
<td>As lt. brn. alteration of rhombic carb. blebs-diss., and as alt. boarders of recrystalized qtz. vnlets.</td>
</tr>
<tr>
<td>Tr. Sericite</td>
<td>Diss. fine kneedles w/ carbonate.</td>
</tr>
<tr>
<td>Chert(?)</td>
<td>Gray, isotropic blebs, diss. in matrix and as gash vns. w/ carbonate.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

Rock is sheared, with carbonate and sericite influx along "C" surfaces, semi-parallel to bedding. Qtz.-filled, gash veins orientated at 45° from "C" surfaces.

<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Coarse, polymict conglomerate, No. 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>60% Chert clasts</td>
<td>Elongate clasts of chert or fine slate. Subangular.</td>
</tr>
<tr>
<td>20% Quartz</td>
<td>Recrystalized, interlocking qtz., often rolled along zones of shearing.</td>
</tr>
<tr>
<td>10% Volc. clasts</td>
<td>Predominantly clots of unoriented plag. laths, w/ some blocky crystals.</td>
</tr>
<tr>
<td>3% Carbonate</td>
<td>Growth along interclast, fluid migration lineation (&quot;C&quot; surface).</td>
</tr>
<tr>
<td>Tr. Sericite</td>
<td>W/carbonate, along foliation (and fluid migration) parallel to clast elongation.</td>
</tr>
<tr>
<td>2% FeOx</td>
<td>Lt. brn., w/carb.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

Conglomeratic. Sheared and elongated 1:5. Carb. alt. only inter-clast. Clast supported matrix. Slight imbrickation. Clast size: 2 to 8 mm. length.
<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Greywacke, No. W-64.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral % of rock</td>
<td>Important Properties</td>
</tr>
<tr>
<td>50% Slate clasts</td>
<td>Composed of variable, fine to coarse qtz. grains. Stretched, similar to ripup clasts.</td>
</tr>
<tr>
<td>25% Quartz</td>
<td>Strained, recrystallized frags. and oblate clasts.</td>
</tr>
<tr>
<td>20% Orthoclase</td>
<td>Lt. grey to white, biaxial (-), large 2V. Subangular frags., some square, equidimensional, others oblate, anhedral.</td>
</tr>
<tr>
<td>Tr. Carbonate</td>
<td>lineation bands</td>
</tr>
<tr>
<td>Tr. Sericite</td>
<td>W/carbonate.</td>
</tr>
</tbody>
</table>

Textures, Alteration and Comments
Subangular grains, rotated, elongated, sheared. Bimodal.

<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Contorted slate, No. W-52.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>60% Quartz</td>
<td>Lt. grey, euhedral. Occurs in hing of axial plane, in crenulationss. Also as strained blebs throughout.</td>
</tr>
<tr>
<td>30% Sericite</td>
<td>Fibrous, lt. brn. to colorless. Throughout rock.</td>
</tr>
<tr>
<td>Tr. Opaques</td>
<td>Blk. flakes, possibly graphite.</td>
</tr>
<tr>
<td>2% FeOx</td>
<td>Lt. brn.</td>
</tr>
</tbody>
</table>

Textures, Alteration and Comments
Crenulation cleavage. Could also be named a Sericite, quartz schist.
<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Mariposit, carbonate, quartz schist, No. W-53.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>85% Quartz</td>
<td>Granular throughout entire rock. Sed. clastic. Also as euhedral, recrystallized open spaces.</td>
</tr>
<tr>
<td>10% Carbonate</td>
<td>Secondary, as smears and surficial coatings. Cuts groundmass.</td>
</tr>
<tr>
<td>8% Muscovite</td>
<td>Probably mariposite and sericite. With carb.</td>
</tr>
<tr>
<td>Tr. Actinolite(?)</td>
<td>Acicular, radiating kneedles on qtz.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**
Granular qtz. Interlocking grains, equigranular, w/ clots of larger qtz.
Protolith: greywacke.

<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Mariposit schist, No. W-54.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>50% Quartz</td>
<td>Granular, fine silt sediment. Difficult to estimate.</td>
</tr>
<tr>
<td>30% Carbonate</td>
<td>dolomite. Pervasively alt. rock. Granular text.</td>
</tr>
<tr>
<td>17% Muscovite</td>
<td>Mariposite. In lineated streaks throughout rock.</td>
</tr>
<tr>
<td>&lt;1% Pyrite</td>
<td>Anhedral blebs, ass. w/ mariposite lineation bands.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**
Protolith: Crystal tuff, or tuffwacke.
**Rock Name:** Mariposit schist, cut by veining. No. W-55.

**Mineral %**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Important Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% Carbonate</td>
<td>In vein, 85%, as euhedral dolomite (polysynthetic twinning). In matrix, as fine grained (clastic ?) assemblage of carb. and plag. (albite ?), carb.= 70%, plag.=30%.</td>
</tr>
<tr>
<td>10% Quartz</td>
<td>In groundmass as fine banding. 15% of vein. Later than carbonate.</td>
</tr>
<tr>
<td>&lt;1% Pyrite</td>
<td>Blebs, cubes, boudins, elongated, sheared, smeared and rotated.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**


Name: Sheared, carbonate altered, pyrite, mariposite, quartz schist.

Protolith: Tuffwacke.

---

**Rock Name:** Mariposit schist, No. W-61.

**Mineral %**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Important Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% Quartz</td>
<td>Spherical and oblate blebs, possibly qtz. eyes. Strained, granular, in groundmass as sed.</td>
</tr>
<tr>
<td>45% Carbonate</td>
<td>As blebs, similar to qtz. Also pervasive throughout entire rock, as alt. Obscurs text.</td>
</tr>
<tr>
<td>2% Muscovite</td>
<td>Diss. throughtout. Alined, schistousity.</td>
</tr>
<tr>
<td>&lt;1% Pyrite</td>
<td>Cubes and aggregates in secondary qtz. clots. Occurs along fluid migration lineations, and with carb.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

### Rock Name: Mylonitized, cherty slate. No. 44a.

<table>
<thead>
<tr>
<th>Mineral %</th>
<th>Important Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>35% Quartz</td>
<td>Recrystallized along low pressure, &quot;C&quot; and &quot;S&quot; surfaces. Strained.</td>
</tr>
<tr>
<td>30% Matrix</td>
<td>Slaty rx. w/ alt., blk., grungy, isotropic matrix; chert (?).</td>
</tr>
<tr>
<td>10% Chert</td>
<td>As above.</td>
</tr>
<tr>
<td>5% Carbonate</td>
<td>Predominantly along &quot;S&quot; surfaces.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

Heavily sheared, mylonitized. Fluid influx along "C" surfaces, carb. alt. Devel. of gash vns. (ladder struct.) in more competent hor.

### Rock Name: Vein quartz. No. W-50.

<table>
<thead>
<tr>
<th>Mineral %</th>
<th>Important Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>65% Quartz</td>
<td>Strained, euhedral, interlocking crystals. Carb. before qtz.</td>
</tr>
<tr>
<td>30% Carbonate</td>
<td>As above, elongate.</td>
</tr>
<tr>
<td>Tr. Muscovite</td>
<td>Mariposite, along small shear.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

Coarsly crystaline, carb. before qtz. and minor carb. on qtz., euhedral, interlocking. Vein assayed 0.3 opt. Au. Name: Compound qtz–carb. vein.
<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Carbonate alt. volcanic rock, No. W-59.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>70% Carbonate</td>
<td>Rock is completely carbonate altered. Equicrystaline to slightly elongate rombs and plates.</td>
</tr>
<tr>
<td>20% Quartz</td>
<td>In groundmass w/ carb., and fibrous in pressure shadows surrounding pyrite cubes.</td>
</tr>
<tr>
<td>&lt;1% Pyrite</td>
<td>Cubes and blebs. Rotatated. Appears to have grown in the matrix, post carb., or contemporaneous.</td>
</tr>
<tr>
<td>Tr. Sericite</td>
<td>Also chlorite.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**
Relict plag. and pyroxene (?) crystals. Porphyritic text. Heavily carb. alt.  
Name: Carbonate alt. plagioclase porphyry.

<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Carbonate alt. chlorite schist, No. W-51.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>50% Carbonate</td>
<td>Forms matrix, obsquers text. Ragged, splotchy, w/ FeOx patches.</td>
</tr>
<tr>
<td>10% FeOx</td>
<td>Lt. redish-brn., cloudy patches on iron-carb. (ankerite ?).</td>
</tr>
<tr>
<td>15% Feldspar</td>
<td>Ortho(?), as mosaic of stuby and alt. laths, in groundmass.</td>
</tr>
<tr>
<td>&lt;1% Sericite</td>
<td>Scaly aggregates, in shadow struct. of rotated pyrite cubes.</td>
</tr>
<tr>
<td>&lt;1% Pyrite</td>
<td>Cubies. Rotated.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**
Name: Carbonate alt., sheared, sericite, quartz, chlorite schist.
<table>
<thead>
<tr>
<th>Rock Name:</th>
<th>Mafic pyroclastic, No. 87b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>40% Plagioclase</td>
<td>Unorientated phenos. Cloudy, saussaritized, corroded edges.</td>
</tr>
<tr>
<td>35% Relict Px.</td>
<td>Brn., totally alt. pyroxene crystal. Now carbonate. Large, euhedral.</td>
</tr>
<tr>
<td>10% Slate</td>
<td>Lithic clasts.</td>
</tr>
<tr>
<td>10% Chlorite</td>
<td>Chloritized matrix.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

Name: Carbonate alt. augite(?), plag. porphyry.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral %</td>
<td>Important Properties</td>
</tr>
<tr>
<td>40% Glass</td>
<td>Isotropic groundmass, Chloritized.</td>
</tr>
<tr>
<td>15% Amygdules</td>
<td>Filled w/ lt. blue-green, fibrous, pleochroic (yellow-green to clear) zeolites or chlorite.</td>
</tr>
<tr>
<td>10% Pyroxene</td>
<td>Euhedral, porphyritic.</td>
</tr>
<tr>
<td>15% Plagioclase</td>
<td>Saussuritized, cloudy, glomer-al-porphyritic.</td>
</tr>
<tr>
<td>10% Feldspar</td>
<td>Orthoclase(?). Stubby and lath-shaped crystals in groundmass.</td>
</tr>
</tbody>
</table>

**Textures, Alteration and Comments**

Glassy, porphyritic, abund. spherilites. No apparent shearing.

Name: Chloritized, amygdaloidal, pyroxene, plag. pyroclastic. augite(?), plag. porphyry.
Appendix B

Geochemical sampling and analytical techniques

Rock sampling

Rock chip samples from backhoe trenches and underground workings were taken in 5 to 10 pound sample bags, as "continuous chips". Most of the trench samples and many of the underground samples were of oxidized rock.

Drill holes 1 to 25 were drilled using a pneumatic, conventional rotary drill. Drill holes 26 to 51 were drilled using a reverse circulation, rotary drilling method. Holes were drilled using compressed air when possible, however, water was used in many of the holes below 100 feet, because of the high water table. Most samples were taken as average splits from 5 foot intervals.

Soil sampling

Standard soil sampling techniques were employed. Soil samples were taken in half pound samples, from the "B" horizon. Thick profiles of terra rosa soil form over serpentine and silicate-carbonate bodies, whereas thin soil forms over slaty rocks.
Analytical techniques

The majority of the geochemical samples were analyzed by Skyling Labs in Tucson, Arizona. Standard sample preparation methods and analytical techniques were employed. Internal standards, duplicate samples, repeat runs and cross-checking samples with other laboratories were used to confirm accuracy.

Most samples were analyzed using graphite furnace, atomic absorption methods. Exceptions include: mercury- mercury detector; boron- semi-quantitative, emission spectroscopy; and fluorine- specific ion electrode. Samples with values greater than 6 ppm (parts per million) gold were re-analysised using a fire assay method. Overall accuracy for sample preparation and analysis is ± 10% (personal communications, Jack Allen, geochemist, Skyline Labs).
### Whole rock chemistry (wt. %)

<table>
<thead>
<tr>
<th>No.</th>
<th>Rock description</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Massive, dk. green metavolc.</td>
<td>54.3</td>
<td>0.55</td>
<td>15.4</td>
<td>8.1</td>
<td>0.11</td>
<td>5.3</td>
<td>10.9</td>
<td>0.26</td>
</tr>
<tr>
<td>1</td>
<td>Chl. Sch., sl. carb. alt.</td>
<td>40.8</td>
<td>1.10</td>
<td>16.4</td>
<td>10.0</td>
<td>0.14</td>
<td>3.8</td>
<td>11.2</td>
<td>1.40</td>
</tr>
<tr>
<td>11</td>
<td>Talcose, chl. sch.</td>
<td>38.1</td>
<td>0.06</td>
<td>7.5</td>
<td>8.9</td>
<td>0.23</td>
<td>19.8</td>
<td>8.2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>10</td>
<td>Carb. alt., chl. sch., tr. mar.</td>
<td>39.1</td>
<td>0.12</td>
<td>9.6</td>
<td>8.2</td>
<td>0.15</td>
<td>18.6</td>
<td>4.7</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>Blk. mafic sch., ultra mafic ?</td>
<td>40.0</td>
<td>0.17</td>
<td>5.0</td>
<td>10.5</td>
<td>0.13</td>
<td>28.1</td>
<td>4.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>3</td>
<td>Ank. mar. sch., no vis. qtz.</td>
<td>40.3</td>
<td>0.07</td>
<td>9.8</td>
<td>8.4</td>
<td>0.12</td>
<td>9.0</td>
<td>7.7</td>
<td>0.70</td>
</tr>
<tr>
<td>7</td>
<td>Ank. mar. sch., O₂, G. Knoll pit</td>
<td>62.2</td>
<td>0.15</td>
<td>13.6</td>
<td>14.3</td>
<td>0.04</td>
<td>1.1</td>
<td>0.08</td>
<td>3.50</td>
</tr>
<tr>
<td>5</td>
<td>Diabase sill?, carb. alt.</td>
<td>55.2</td>
<td>0.08</td>
<td>16.10</td>
<td>5.1</td>
<td>0.06</td>
<td>3.3</td>
<td>4.8</td>
<td>3.30</td>
</tr>
<tr>
<td>6</td>
<td>Peridotite, sl. serp.</td>
<td>44.4</td>
<td>0.23</td>
<td>15.40</td>
<td>7.6</td>
<td>0.15</td>
<td>9.0</td>
<td>17.8</td>
<td>0.03</td>
</tr>
<tr>
<td>8</td>
<td>Partially serp. ultramafic</td>
<td>41.3</td>
<td>0.007</td>
<td>0.29</td>
<td>7.9</td>
<td>0.09</td>
<td>38.2</td>
<td>0.24</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>9</td>
<td>Serpentine</td>
<td>41.4</td>
<td>0.340</td>
<td>10.60</td>
<td>11.1</td>
<td>0.17</td>
<td>23.8</td>
<td>3.5</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Appendix C.** Whole rock chemistry from the southern Hodson mining district. Samples taken along section D-D', near the Gold Knoll Mine.