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GEOLOGIC SETTING, CHARACTERISTICS, AND GEOCHEMISTRY OF GOLD-BEARING QUARTZ VEINS IN THE KLAMATH MOUNTAINS IN THE REDDING 1 x 2 DEGREE QUADRANGLE, NORTHERN CALIFORNIA

by

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Geologic Setting, Characteristics and Geochemistry of Gold-Bearing Quartz Veins in the Klamath Mountains in the Redding 1 x 2 Degree Quadrangle, Northern California

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ABSTRACT

More than three million ounces of gold have been produced from several geological terranes of the Eastern Klamath Mountains in the Redding, California 1 x 2 degree quadrangle. The most common lode-gold deposits are mesothermal-type quartz or quartz-carbonate veins which are hosted by a variety of rock types including meta-sedimentary, meta-volcanic and granitic rocks. There is a spatial association between significant gold deposits and granitic plutons or hypabyssal intrusions that are related to the plutons. The gold-bearing quartz veins have similar physical characteristics and mineralogy, but they occur in at least seven different geologic settings. Distinct trace element compositions occur in veins hosted by different rock types.

REGIONAL GEOLOGY

The southern Klamath Mountains in the Redding 1 x 2 degree quadrangle consist of a series of lithotectonic units or belts of rock that form thrust plates in a generally eastward-dipping sequence (Irwin, 1981). These "terranes," as they are now referred to, and their structural and tectonic evolution, have been described by Irwin (1981; 1985). They consist of island-arc volcanic and sedimentary rocks and oceanic crust and upper mantle rocks (now ophiolites) that formed during Ordovician through Jurassic time. The Eastern Klamath Terrane (fig. 1), the nucleus of the Klamath Mountains to which the other terranes were joined, was formed during long standing volcanic-arc activity that extended from the Devonian through the Jurassic (Irwin, 1981). This Eastern Klamath Terrane (EKT) was built on Ordovician oceanic crust and upper mantle, now represented by the Trinity Terrane (TT). Along the western edge of the EKT, the Central Metamorphic Terrane (CMT; fig. 1) developed during Devonian subduction beneath the TT. Subsequently, during middle to late Jurassic time, the Northfork (NFT), Hayfork (EHT and WHT), Rattlesnake Creek (RCT), and Western Jurassic Terranes (WJT) were then amalgamated and (or) accreted to the combined EKT and CMT by successive subduction events (Irwin, 1981; 1985).

The terrane boundaries are thrust faults, many of which commonly contain serpentinized ultramafic bodies. Most of the serpentinites are parts of ophiolites which were deformed during terrane amalgamation and (or) accretion. Deformation led to dismemberment, remobilization, and emplacement of the serpentinites along the regional terrane boundaries and other thrust faults. The serpentinites are strongly magnetic and their subsurface extent, which in many areas is much larger than their outcrop areas, is well delineated on aeromagnetic maps (Griscom, 1991, in press).

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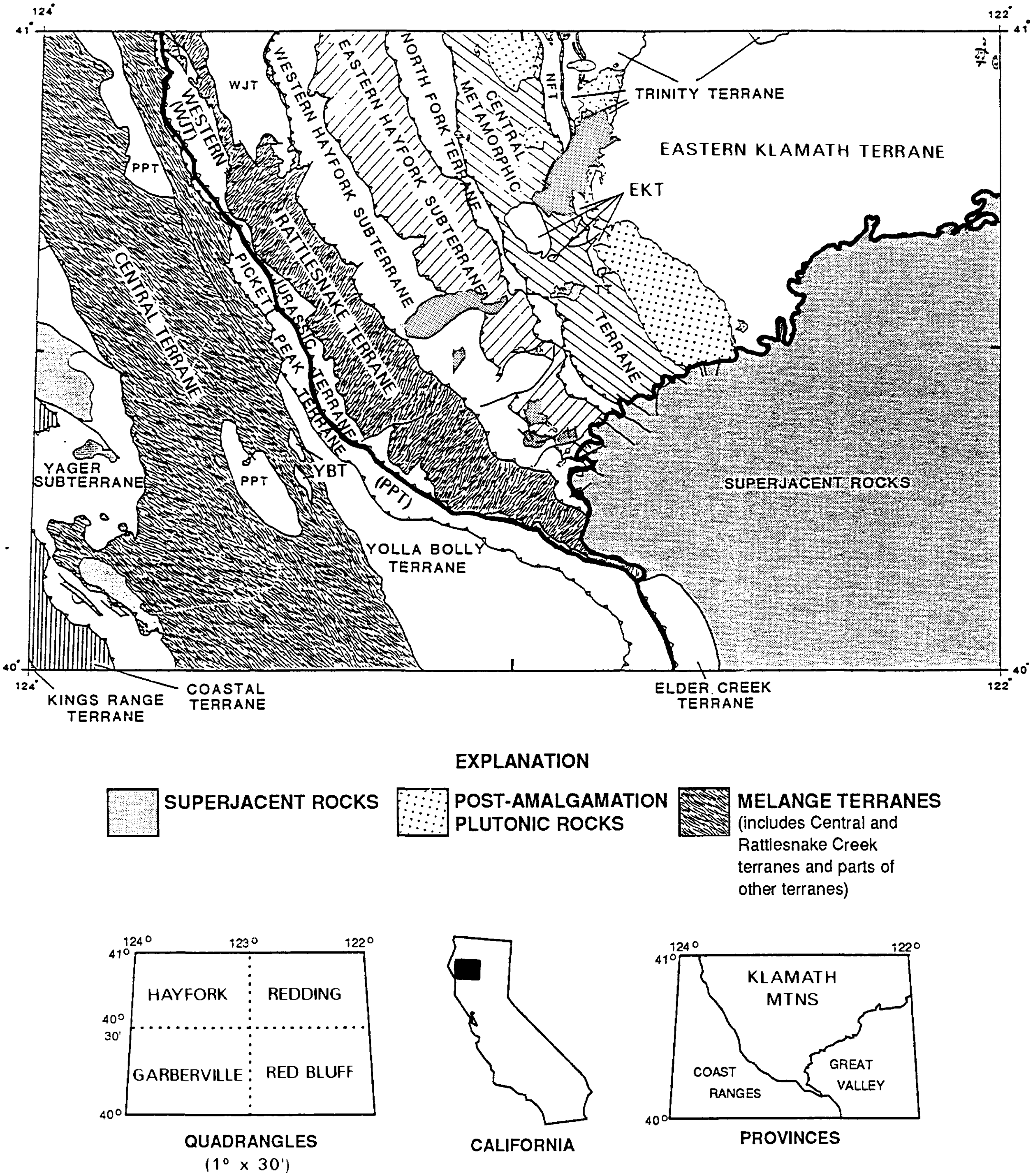

Figure 1. Generalized geologic map of the Redding 1 x 2 degree quadrangle showing physiographic provinces and geologic terranes. Modified from Fraticelli and others, 1987.

Granitic plutons and associated hypabyssal rocks of Devonian through Cretaceous age intrude the rocks of all of the terranes. They occur in belts of equivalent age that generally follow the overall trends of the amalgamated terranes (Irwin, 1985; fig. 2). Some plutons and plutonic belts were emplaced before the host terrane was attached to an adjacent terrane and are hence, "pre-amalgamation." Most of these are parts of ophiolites or are co-magmatic with volcanic rock sequences that formed in the same island arc. An example of this is the Ironside Mountain batholith belt (fig. 2) in the WHT which is co-magmatic with the Hayfork Bally meta-andesite, which underlies a large part of the terrane (Irwin, 1985).

There are plutons and plutonic belts that are clearly post-amalgamation, as they are significantly younger than their wall rocks in their host terranes, based on isotopic ages, or they cut across terrane boundaries (Irwin, 1985). The Shasta Bally batholith, and the belt of plutons in which it occurs are post-amalgamation (Irwin, 1985; fig. 2).

Regional metamorphic grade of the volcanic and sedimentary rocks of the terranes ranges from unmetamorphosed, through greenschist facies to almandine-amphibolite facies (Davis, 1966). Metamorphosed rocks of variable grade are present in all of the terranes. Contact metamorphism has affected rocks adjacent to plutons, particularly post-amalgamation intrusions, as exemplified by the banded gneiss zones along the contacts of the Shasta Bally batholith with its wall rocks (Albers, 1964).

Superjacent rocks that overlie the amalgamated terranes include the Great Valley Sequence sedimentary rocks of Cretaceous age, and other sedimentary and volcanic rocks of Cretaceous and Tertiary age. Most of these occur in the Great Valley Physiographic Province (fig. 1).

Most of the terranes of the Klamath Mountains Province contain similar lithologies, including sandstone, mudstone, shale, greenstone, minor limestone, and their metamorphosed equivalents. A few, such as the RCT and the CMT are unique. The former is largely dismembered ophiolite, the latter is a complex of mafic and felsic gneisses and schists. Some terranes such as the NFT and EHT are melanges or contain a significant melange component. The melanges are chaotic mixtures of varied oceanic or island-arc lithologies in a shaley matrix. Fraticelli and others (1987) describe individual formations, including plutons, in the terranes. Their geologic map was the basis for figure 1.

LODE GOLD DEPOSITS

Geologic setting, relationship to plutonic belts, plutons and hypabyssal intrusions:

Gold in the Klamath Mountains has been produced from a variety of deposit types including placer deposits, gold-bearing quartz veins, Cu-Zn massive sulfide deposits, and sulfide disseminations and sulfide-rich veins in ultramafic rocks. More than half of the

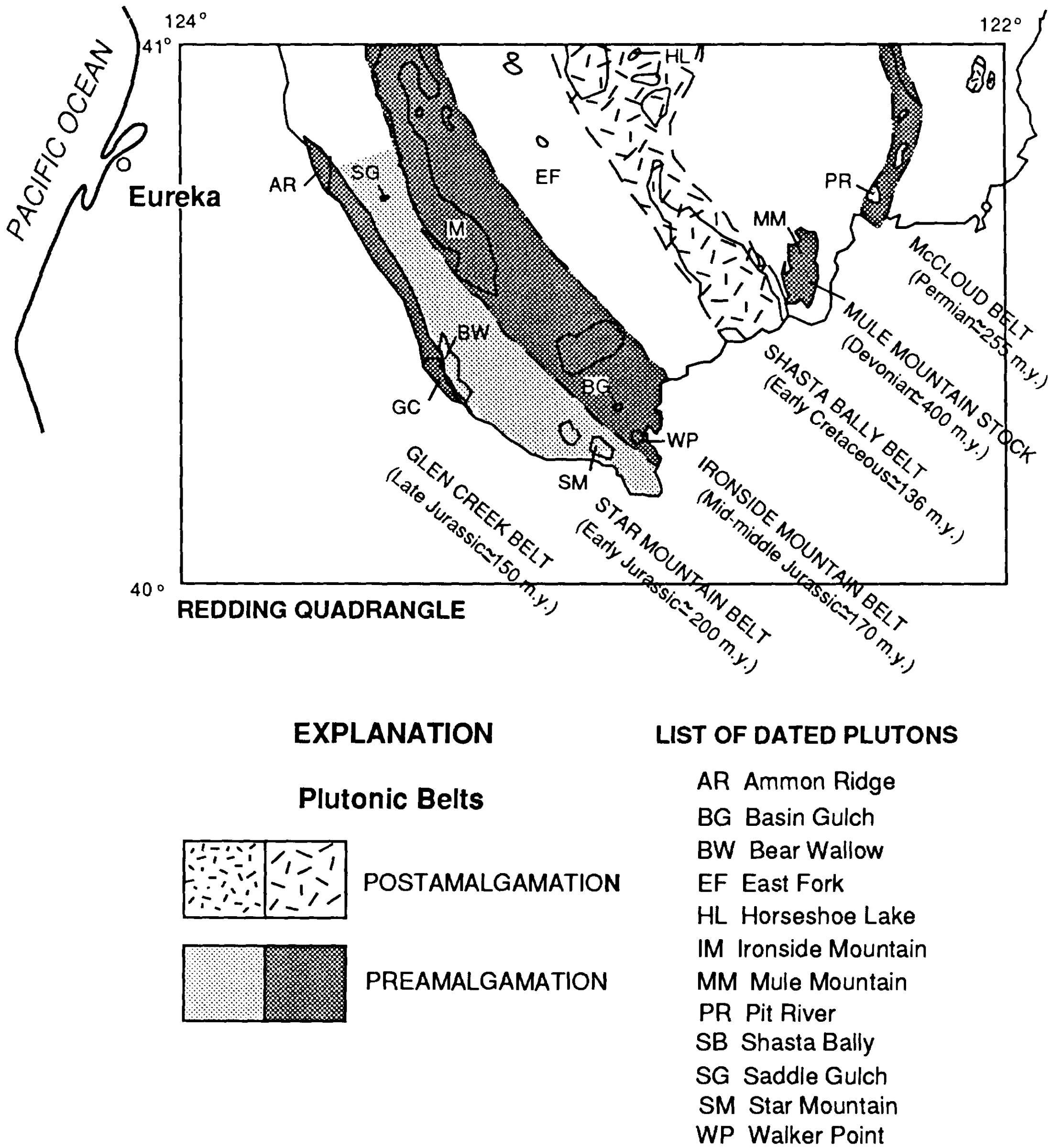

Figure 2. Map of the Klamath Mountains in the Redding 1 x 2 degree quadrangle province showing outlines of major plutons and trends of plutonic belts. Modified from Irwin, 1985.

gold (64%) was produced from placers. Gold rich quartz veins produced about 27 percent and the remainder, about 9 percent, was produced as a by-product of Cu- and Zn-rich massive-sulfide deposits. There are no reliable figures for gold production from ultramafic rocks (Irwin, 1960; Albers, 1964). The most common lode deposits are Au and Au/Ag-rich quartz and quartz-carbonate veins similar to those found along the Mother Lode Belt in central California (Landefield and Silberman, 1987; Danielson and Silberman, 1988; Elder and Cashman, 1991).

Danielson and Silberman (1988) suggested that most of the productive gold-bearing quartz vein districts are situated between pre- and post-amalgamation pluton belts, and are within a few kilometers, at most, of the contact between their host rocks and one or more granitic plutons of either association (figs. 2 and 3). The observation appears to work best in the EKT where many of the districts are located between the Cretaceous Shasta Bally belt and either the Devonian Mule Mountain Stock or plutons belonging to the Permian McCloud belt (figs. 2 and 3). In the CMB, the districts occur within the Shasta Bally belt; in the Hayfork Terrane, the districts occur within the Ironside Mountain belt.

Lanphere and others (1968) plotted the distribution of lode gold deposits which produced greater than $100,000 (approximately 5,000 oz) in the California part of the Klamath Mountains. They concluded that there was a strong association between gold mineralization and the youngest (now called post-amalgamation) plutons (fig. 4). Both of these interpretations could be correct, although some deposits such as those in the Hayfork and Harrison Gulch districts are clearly in the Ironside Mountain belt, which is pre-amalgamation.

Most of the gold-mining districts have two or more petrographically distinct sets of intermediate to felsic hypabyssal intrusions that are spatially associated with the gold-bearing quartz veins. These dikes and sills are believed to be offshoots of the larger plutonic bodies (Hotz, 1971; Danielson and Silberman, 1988). The French Gulch-Deadwood district, which was the largest gold producer in the Klamath Mountains, and nearby Whiskeytown district (table 1) are good examples of the relationships between plutonic belts, plutons and hypabyssal intrusions. The most productive mines in these districts are situated between the pre-amalgamation, Devonian Mule Mountain stock and the post-amalgamation, Early Cretaceous Shasta Bally batholith. The gold-bearing quartz veins are closely associated with dikes and sills of quartz porphyry, dacite, quartz diorite and diorite (Albers, 1965; Danielson and Silberman, 1988). The "Birdseye" porphyry described by Albers (1961; 1965) that is so frequently associated with gold-bearing quartz veins at French Gulch-Deadwood and other districts in the EKT ranges in composition from dacite to diorite, and may be of several different ages (Danielson, 1988).

Districts such as South Fork, Canyon Creek-East Fork, Hayfork, and Harrison Gulch appear to occur within individual plutonic belts rather than between them. However, in the more productive districts, there is an association with at least two petrographically distinct hypabyssal intrusions. At Canyon Creek-East Fork, for

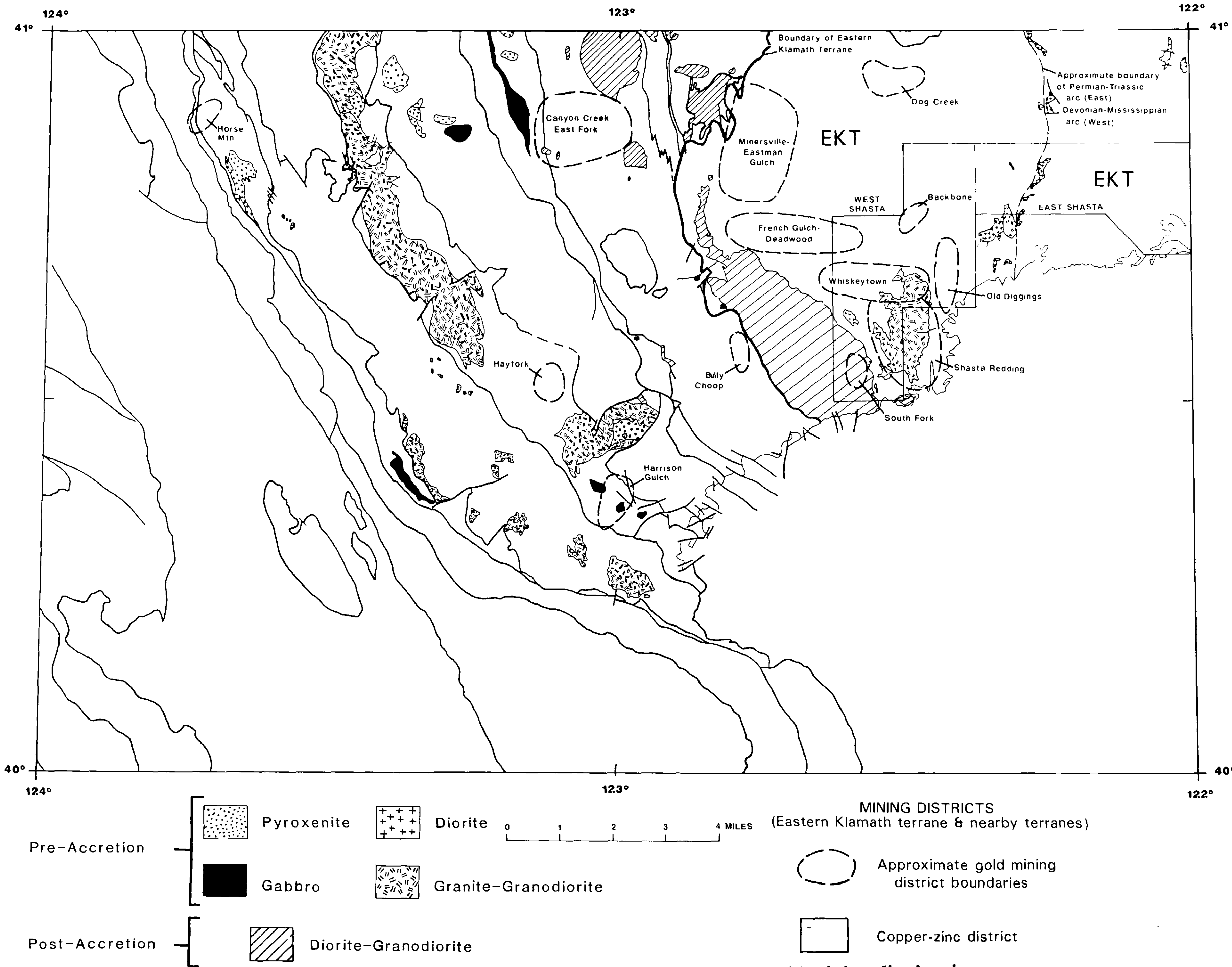

Figure 3. Map showing pre- and post-accretion plutons and lode gold mining districts in the Redding 1 x 2 degree quadrangle. Modified from Fraticelli and others, 1987. **EKT = Eastern Klamath Terrane**

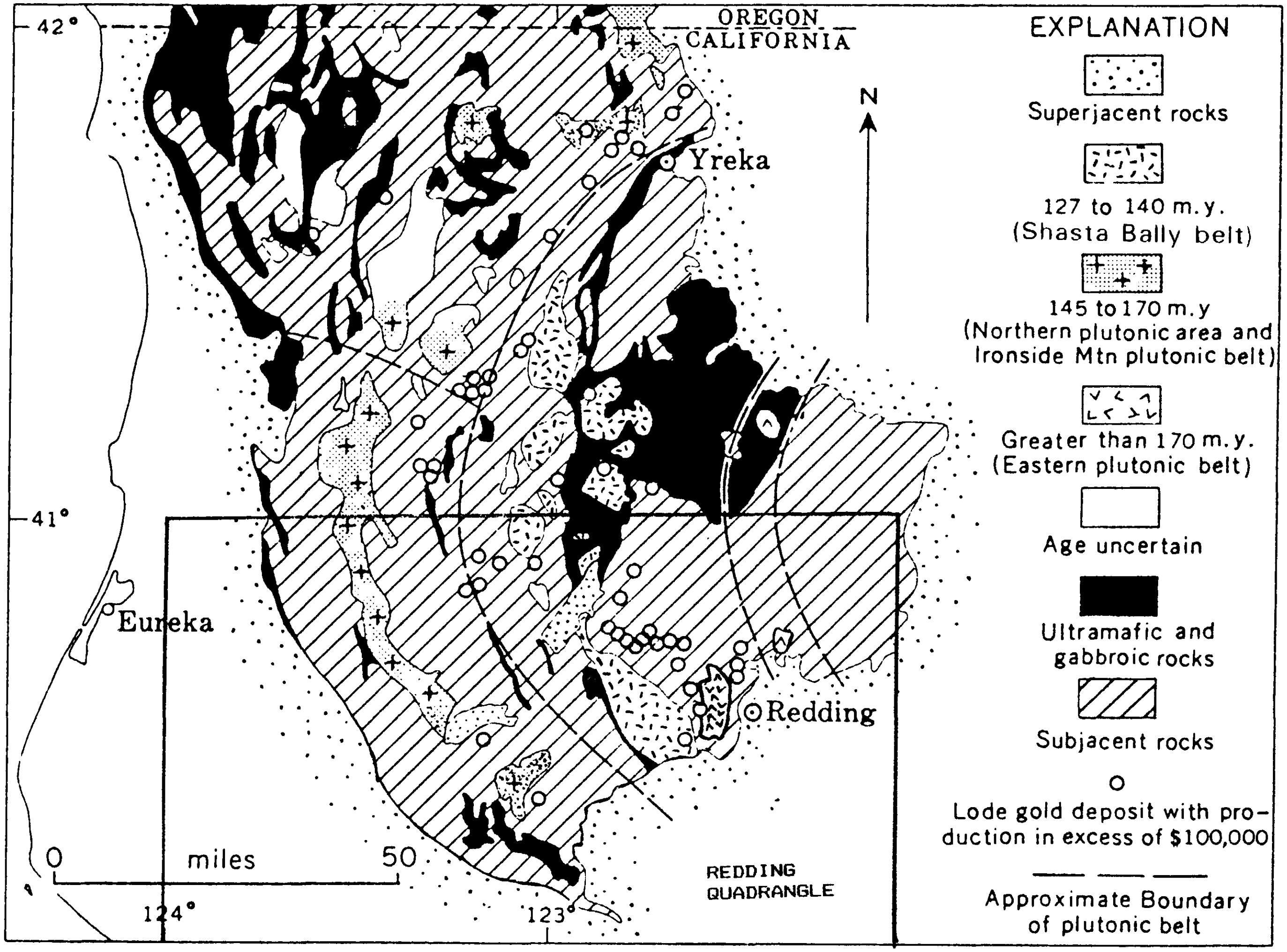

Figure 4. Map showing distribution of granitic plutons and lode gold deposits with greater than $100,000 (5,000 oz) production in the Klamath Mountains. Modified from Lanphere and others, 1968.

Table 1. Lode gold production from mining districts and terranes of the Klamath Mountains

[EKT = Eastern Klamath Terrane, CMB = Central Metamorphic Terrane, HT = Hayfork Terrane. Harrison Gulch and Hayfork are at or near boundary of Eastern and Western Hayfork subterranes. 1. Hotz, 1971; 2. Clark, 1970; 3. Albers, 1965; 4. Hotz and others, 1972. [1]Mostly by-product from massive sulfide deposits, East and West Shasta districts.]

District	Terrane	Au (oz)	Reference
French Gulch-Deadwood	EKT	800,000	1.
		1,500,000	2.
Minersville	EKT	39,000	1.
Whiskeytown	EKT	54,000	1.
		70,000	3.
Backbone	EKT	50,000	1.
Shasta-Redding	EKT	25,000	1., 2.
Old Diggings	EKT	200,000	1.
Shasta Cu-Zn belt[1]	EKT	560,000	2.
Canyon Creek-East Fork	CMB	192,000	1., 4.
Harrison Gulch	HT	200,000	1.
Hayfork	HT	5,000	1.

example, quartz porphyry, pegmatite, aplite, and diorite are associated with many of the quartz veins (Hotz, 1971; Hotz and others, 1972).

The Old Diggings district which is located between the Devonian Mule Mountain Stock and the Permian McCloud belt plutons, including the Pit River stock (figs. 2 and 3), appears to corroborate the suggestion of important districts being located between plutonic belts. However, a recent K-Ar age determination on sericitic alteration adjacent to one of the large veins at the Reid mine in the district shows that the mineralization was Devonian in age, and approximately the same age as the Mule Mountain stock (Danielson and Silberman, 1990).

Production

More than 7 million ounces of gold have been produced from lode and placer deposits in the Klamath Mountains (Hotz, 1971). The most common lode deposits are mesothermal-type, quartz veins similar to those along the Mother Lode belt. A variety of host rocks and three geologic terranes of the eastern Klamath Mountains contain the veins (Danielson and Silberman, 1988). Significant gold has also been produced, mostly as a by-product, from Cu-Zn massive sulfide deposits, particularly in the Shasta Copper-Zinc belt (Clark, 1970). During the 1860's Au and Ag were originally mined from gossans in these districts (Clark, 1970). Elsewhere in the Klamath Mountains, auriferous massive sulfide deposits have also produced Au. For example, the Siskon mine in the Happy Camp district, near Yreka produced more than 180,000 oz of Au from ferruginous gossan ore, which resulted from the weathering of a massive sulfide body (Hotz, 1971).

French Gulch-Deadwood, with an estimated production of 800,000 oz Au (Hotz, 1971) or 1.5 million ounces Au (Clark, 1970), was the most productive district in the Klamath Mountains. Based on Au production figures given by Clark (1970), Hotz (1971), and Albers (1965), we estimate that the total lode gold produced from mining districts of the Klamath Mountains in the Redding quadrangle exceeds 2 million ounces (table 1).

Because we lack adequate data for smaller, but still productive mines, and from many of the smaller districts, such as Dog Creek and Bully Choop, and the fact that much of the data from Hotz (1971) are minimum estimates, the summary figure for Au production can be considered a lower limit. Table 1 gives an estimate of 1.6 million ounces of Au production from quartz veins, with another 560,000 oz from by-product of massive sulfide deposits. The minimum lode production of the Redding quadrangle is thus 2.1 million ounces of Au (using the lower estimate for French Gulch-Deadwood).

Placer Au production from the entire Klamath Mountains and the Redding quadrangle is much more difficult to estimate. There are few good production summaries in the literature, and much of the Au was produced early in the mining history, before good records were kept. Placer gold mining was the principal industry in Trinity County, which occupies a good part of the Redding quadrangle, from 1849 until World War II (O'Brien, 1965). The La Grange mine, in the CMT, was one of the largest placer mines in the U.S. and was active from 1851 through the 1940's. It produced approximately 390,000 oz of Au (Clark 1970). No adequate data exist from most of the rest of the placer mines, but we suggest that their aggregate production was at least the equivalent of the La Grange.

Adding these estimates, results in a suggested minimum figure of Au production for the Redding quadrangle of about 3 million ounces accounting for nearly one-half the production of the Klamath Mountains. The great preponderance of the Au came from the EKT, followed by the Hayfork Terrane, and the CMT. Although significant lode gold deposits have not been found in other terranes of the Klamath Mountains and Coast Ranges in the Redding quadrangle, geochemical anomalies, of Au and other elements associated with gold-bearing deposits in this region are present in rocks and stream-sediment samples throughout the quadrangle (Silberman and others, 1991; Smith and others, 1990; 1991).

Geologic settings of gold-bearing quartz veins and gold-mining districts in the Klamath Mountains in the Redding Quadrangle:

Gold-bearing quartz veins occur in a variety of host rocks and geologic settings throughout the Klamath Mountains, but the largest deposits and the most productive districts are located in the EKT, CMT, and the Hayfork Terranes (fig. 3). We define seven common geologic settings in which gold-bearing quartz veins occur. The distinctions are based on our observations and on published descriptions. It is likely that additional work, particularly detailed work, will revise this classification.

1. Steeply dipping veins in greenstone with or without meta-rhyolite of Devonian age. The host rocks are within the greenschist facies. Examples are the Old Diggings and Dog Creek districts (Hotz, 1971), in the EKT.

2. Steeply dipping veins in graywacke and argillite of late Devonian to Early Carboniferous age, and moderately dipping quartz veins along the thrust contact of the graywacke-argillite rocks and underlying Devonian greenstone. Both sets of veins are associated with dikes and sills of quartz-porphyry, and "Birdseye" porphyry of diorite to dacite composition (Albers, 1965; Hotz, 1971). Examples are French Gulch-Deadwood, Eastman Gulch, Minersville, and parts of the Whiskeytown district, in the EKT.

3. Steeply dipping quartz veins in the Devonian Mule Mountain stock and co-magmatic meta-rhyolite and greenstone near the contacts of these rocks with the stock. Examples are the Shasta-Redding, and parts of the Whiskeytown districts (Albers, 1965; Hotz, 1971; Lydon and O'Brien, 1967). The Backbone district has quartz veins hosted in a Devonian meta-rhyolite intrusion some distance from the contact of the Mule Mountain stock (Lydon and O'Brien, 1967), but we include it in this category.

4. Steeply dipping Ag-rich quartz veins in the Early Cretaceous Shasta Bally batholith. The South Fork district is an example, the only precious metal, quartz-vein

district in the Klamath Mountains that was Ag rich, with little Au production (Tucker, 1926; Albers, 1965; Hotz, 1971).

5. Low and moderate to steeply dipping quartz veins in amphibolite facies grade schists and gneisses. The steeper veins appear to be associated with pegmatite, aplite, and quartz porphyry dikes. Examples are the Canyon Creek-East Fork and Bully Choop districts in the CMB (Ferguson, 1914; Hotz, 1971; Averill, 1941; O'Brein, 1965).

6. Steeply dipping quartz veins in argillites and cherts of late Paleozoic or Jurassic age near the contact with Hayfork Bally Meta-andesite of Jurassic age. Examples are Hayfork and Harrison Gulch districts (Hotz, 1971), in the Hayfork Terrane.

7. Gold-bearing quartz veins which contain copper sulfides, and (or) disseminated copper sulfides and carbonates in serpentinite, diorite, and gabbro in ultramafic rock complexes (Eric, 1948). These deposits have not been described in the recent literature. They are common in many of the terranes of the Redding quadrangle, including the Franciscan terranes, Josephine Ophiolite at the WJT, TT of the EKT, north of the Redding Quadrangle, and in other terranes that contain serpentinites and dismembered ophiolites such as the RCT. The only significant example of this deposit type in the Redding Quadrangle is in the Horse Mountain district (fig. 3).

Horse Mountain produced between 100,000 and 1,000,000 pounds of Cu (Eric, 1948). The district is underlain by serpentinite which is cut by dikes of diorite, gabbro and felsite (Laizure, 1925) which we found to be plagiogranite. Lowell (1916) and Laizure (1925) report the occurrence of chalcopyrite, bornite, chalcocite, native copper, cuprite and copper carbonates. Gold is reported to be present (Lowell, 1916; Laizure, 1925) but the few samples collected during the course of our work did not contain detectable Au, although one sample had 5 ppm Ag, along with greater than 2 percent Cu. No quartz veining is present at Horse Mountain, but small veins of chalcocite were seen in serpentinite. Descriptions of other "Horse Mountain" type deposits indicate the presence of quartz veining in some of them (Hotz, 1971; Eric, 1948).

Descriptions of the quartz veins, alteration and mineralogy are taken mostly from Hotz (1971), modified by our own observations. Quartz veins in all of these settings are medium to coarse grained and contain variable amounts of wall rock fragments and subordinate calcite. Ribbon texture is common in the veins. The sulfide mineral content is generally low, from less than 3 percent to approximately 5 percent. Sulfides are usually concentrated in wall rock inclusions and the wall rocks immediately adjacent to the veins. Pyrite is the most abundant sulfide mineral. Others are arsenopyrite (particularly common in argillite-graywacke-hosted veins), galena, sphalerite, chalcopyrite, pyrrhotite, and molybdenite (Hotz, 1971). Gold tellurides are present in veins hosted in greenstones (MacDonald, 1986). Elemental gold occurs in quartz and within sulfides, mainly pyrite (Hotz, 1971). The Au/Ag, based on analyses of quartz-vein samples collected during this study is usually 1 or more, except for the Ag-rich South Fork District.

Wall rock alteration adjacent to the quartz veins depends on host rock lithology. In greenstone, meta-rhyolite and granitic rock, including dikes and sills, sericitic alteration is most common. Chloritic alteration and carbonate enrichment may also occur. Dikes and sills adjacent to veins generally are silicified and have sericitic alteration assemblages slightly further from the veins. Albitic alteration and carbonatization are also common and some paragonite is reported adjacent to some veins (Ferguson, 1914; Albers, 1965; Hotz, 1971). Wall-rock alteration in argillite and graywacke is not obvious, although local silicification occurs immediately adjacent to veins. Petrographic study of wall rocks at the Summit Mine in French Gulch however, shows that sericite and chlorite alteration minerals and thin calcite or ankerite veins are commonly developed within a few meters of the larger Au-bearing quartz veins in those host rocks (H. Folger, written commun., 1986). Hornblende schist is usually chloritized adjacent to veins.

Trace element content of mineralized quartz veins does not show a consistent relationship to host rock chemistry. However, quartz veins hosted in different lithologies do tend to have different overall trace element compositions. Ag content of mineralized quartz veins is generally less than 10 ppm, with Au/Ag usually greater than 1. The South Fork district is an exception, with Ag content of samples from the base metal-silver veins ranging from 50 to 5,000 ppm and Au/Ag less than .01. Arsenic content is highest (>1,000 ppm) in veins hosted by argillite and graywacke. Te (2-20 ppm) and B (50-300 ppm) are highest in veins hosted by greenstone. Cu (10-100 ppm), and Pb and Zn (both 10-1,000 ppm) contents are highest outside of the South Fork district in veins hosted by hornblende schist in the Canyon Creek-East Fork mining district. These veins also contain an average of 1.2 ppm Hg, much higher than gold-rich veins from other lithologies, and other mining districts. At Horse Mountain mineralized rocks contain greater than 2 percent Cu and high amounts of Ni and Cr (1,500-2,000 ppm). Ag (5 ppm) is anomalous.

An appendix follows the main text of this report. It summarizes the geological and geochemical characteristics of many of the mining districts discussed above and shown on figure 3.

Origin of the gold-bearing quartz veins:

The petrography, textures and associated alteration of their wall rocks suggests that these veins are typical mesothermal gold-bearing veins similar to those found along the Mother Lode belt of California to the southeast of the Klamath Mountains. We lack the fluid inclusion and light-stable isotope data that would enable us to specify the conditions of formation of the veins, although a few stable isotope analyses are currently in progress. Stable isotope studies of the mother lode veins suggest that they were formed from two different fluids, an early, isotopically heavy, CO_2-bearing fluid of deep origin followed by an isotopically light fluid of permiable meteoric origin (Böhlke and Kistler, 1986).

Elder and Cashman (1991) suggest, on the basis of fluid inclusion data, that mineralized quartz-carbonate veins at Quartz Hill, Oro Fino district, central Klamath Mountains, north of Redding, were formed by partial mixing of two fluids, one of metamorphic origin, and the other possibly of meteoric origin. They have submitted a detailed study of this area for publication (Elder and Cashman, in press). The veins at Quartz Hill are associated with a major transcurrent fault (Elder and Cashman, 1991) and are not spatially associated with granitic plutons or hypabyssal intrusions, as are many of the mineralized Redding Quadrangle examples. We need isotopic-age data on the veins, their spatially associated hypabyssal igneous rocks, and fluid inclusion and stable isotope data before we can launch into a discussion of genesis. We are hopeful of obtaining those data in the future.

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APPENDIX A

SUMMARY OF CHARACTERISTICS AND GEOCHEMISTRY OF GOLD-BEARING QUARTZ VEINS IN SOME OF THE LODE GOLD MINING DISTRICTS IN THE KLAMATH MOUNTAINS IN THE REDDING 1 x 2 DEGREE QUADRANGLE

Old Diggings district

- Terrane: Eastern Klamath

- Host rock lithology: Meta-andesite and -dacite of Copley Greenstone and meta-rhyolite of Balaklala Rhyolite

- Vein characteristics: Parallel to subparallel massive quartz veins from a few inches to 25 ft wide, which strike north to northeast, and dip vertical to steep east. The average width of veins is 10 ft at the Reid mine, the largest in the district (Averill, 1933). Quartz is very clean and was used as smelter fluxing ore (Hotz, 1971).

- Igneous rocks: District occurs between Mule Mountain stock (Devonian), and Pit River stock (Permian), however, K-Ar age of quartz-paragonite adjacent to quartz vein is 396 ± 9 Ma, which is the age of the Mule Mountain stock (Danielson and others, 1990).

- Geochemical characteristics: Mineralized veins have moderate Ag content, high B content (geometric mean of 56), and elevated Te (6-21 ppm) in samples with greater than 1 ppm Au. Base metal content is very low, with Cu being highest on average, reflecting greenstone host rocks. Cu and Zn contents are both lower than wall and host rocks. Hg is relatively high, but not as high as Canyon Creek-East Fork. In the veins, gold correlates well with Ag and Te, less well with B, not at all with Cu, Pb, or Zn (table 3).

- Production: Approximately 200,000 oz Au (Hotz, 1971).

- Mineralogy: Pyrite, chalcopyrite, Au- and Ag-bearing tellurides, free gold (Hotz, 1971; MacDonald, 1986).

- Au/Ag = 1.0 (9 samples).

French Gulch-Deadwood (includes Minersville and Eastman Gulch) district

- Terrane: Eastern Klamath

- Host Rock Lithology: Argillite and graywacke of Mississippian Bragdon Fm., metavolcanic rocks of the Copley Greenstone and Balaklala Rhyolite, Dikes and sills of feldspar porphyry, quartz porphyry and "Birdseye" porphyry (Albers, 1965).

- Vein Characteristics: Quartz and quartz-calcite veins several inches to tens of feet in width. Moderate dip along thrust contact of Bragdon and Copley or steeply dipping within Bragdon. Latter type are most productive. Major zone of production is along an E-W fracture system which contains dikes and sills of felsic to intermediate composition (Albers, 1961; 1965).

- Igneous Rocks: Gold-bearing veins are closely associated with dikes and sills of a variety of compositions, and frequently cut them. Among the most common dikes are "Birdseye" porphyry, which vary in composition from dacite to quartz dacite and diorite. All compositional varieties are characterized by large plagioclase feldspar phenocrysts--the "Birdseyes" (Albers, 1965). Quartz porphyry dikes are also associated with quartz veins (Albers, 1965). Preliminary K-Ar ages suggest at least some quartz porphyry dikes are about 135 Ma, and that some varieties of Birdseye porphyry are about 160 Ma. Several other petrographic varieties of dikes are present in the area (Albers, 1964; 1965; Danielson, 1988) but their relationship to gold mineralization is uncertain. Dikes represent hypabyssal equivalents of the Shasta Bally and probably Permian and (or) Devonian plutons.

- Geochemical Characteristics: Most productive veins have very high As content. Wall rocks, particularly dikes, have strongly elevated As and anomalous Au relative to background. Cu, Pb, and Zn contents are low, generally below those of host rocks, except for greenstone-hosted veins. B is moderate, Ba relatively high, but both are below host rock levels. Hg is very low, and below host rock content. Proximal host rocks (wall rocks) have lower Cu, Pb, Zn, Hg, and B than distal host rocks (tables 4 and 5). Sb is below detection in nearly all rocks.

- Production: Between 800,000 oz Au (Hotz, 1971) and 1,500,000 oz Au (Clark, 1963).

- Mineralogy: Pyrite, galena, sphalerite, arsenopyrite, and rare chalcopyrite. Free gold in quartz and in sulfides (Hotz, 1971; Albers, 1961; 1965).

- Au/Ag = 8.9 (10 samples)

Canyon Creek-East Fork mining district

- Terrane: Central Metamorphic

- Host Rock Lithology: Hornblende gneiss and schist and interbedded argillite of the Salmon Formation.

- Vein Characteristics: Quartz veins, a few inches to 6 ft in width at low to moderate dips in much of the district. Some veins, particularly in the north, are considerably wider and steeper (Ferguson, 1914; O'Brien, 1965).

- Igneous Rocks: Canyon Creek trondjhemite pluton is just north of the district. Quartz porphyry, pegmatite, and aplite dikes are associated with some of the deposits, particularly those in the northern and eastern parts (Ferguson, 1914; Averill, 1941; Hotz, 1971).

- Geochemical characteristics: Geochemically complex. Very high grade gold. Moderately high As, but lower than French Gulch. Hg is high, at 1.2 ppm (geom. mean), higher than most other gold districts. Moderately high Ag, but Au/Ag = 2.4. Pb and Zn are elevated, up to 2,000 and 1,500 ppm, although geometric means are much lower (table 6). Pb content of veins higher than host rocks, Cu and Zn lower (on average). Au correlates well with As, Ag, Pb, and Zn in the veins, somewhat the same in wall rocks. Au, Ag, and As averages drop off from veins through wall rocks to host rocks. Low level Au anomaly present in host and district igneous rocks, well above crustal average.

- Production: 192,000 oz Au (Hotz, 1971; Hotz and others, 1972).

- Mineralogy: Pyrite, galena, sphalerite, free gold in quartz, and also associated with sulfides (Ferguson, 1914; O'Brien, 1965).

- Au/Ag = 2.4 (11 samples).

Harrison Gulch mining district

- Terrane: Hayfork

- Host Rock Lithology: Cherts and slaty argillites of the middle unit of the Hayfork Terrane of probable Permian age (Irwin, 1981), at or near contact with Hayfork Bally meta-andesite which underlies the sedimentary rocks. Fraticelli and others (1987) now consider these rocks to be Jurassic.

- Vein Characteristics: Two or more parallel quartz veins, which strike NW and dip moderately to steeply SW. Approximately 1- to 3-ft wide. The two main productive veins are along the contact between meta-andesite and sedimentary rocks, and within the sedimentary rocks respectively. Irregular, though nonproductive veinlets occur in the andesite (Kramm, 1913; Brown, 1916).

- Igneous Rocks: District occurs near Wildwood pluton, a quartz diorite-syenodiorite mass. Small bodies of intrusive granite and serpentinite are exposed near the Midas mine. Other prospects in the district are reportedly adjacent to diabase and quartz porphyry dikes (Hotz, 1971).

- Geochemical Characteristics: High As (250-400 ppm), low base metals, moderate to low Ag (2-7 ppm). Generally similar to French Gulch, except lower As and higher Ag (table 2).

- Production: Approximately 200,000 oz Au (Hotz, 1971).

- Mineralogy: Pyrite, tetrahedrite, free gold alloyed with some silver, minor chalcopyrite (Kramm, 1913).

- Au/Ag = 3.1 (very limited data; 2 samples).

Hayfork mining district

- Terrane: Hayfork

- Host Rock Lithology: Argillite, siliceous argillite, and chert of the middle unit of the Hayfork Terrane of probable Permian age (Irwin, 1981). Veins occur near the contact with underlying Hayfork Bally meta-andesite. These rocks are now considered to be Jurassic (Fraticelli and others, 1987).

- Vein Characteristics: Stringers of quartz in slate. Gold occurs in the quartz associated with pyrite, arsenopyrite, and galena (Averill, 1941).

- Igneous Rocks: None reported (limited data), but district occurs near the Wildwood pluton, a diorite-syenodiorite body.

- Geochemical Characteristics: Generally similar to French Gulch, high As (200-600 ppm), low base metals, very low Ag. Very high grade gold (table 2).

- Production: Approximately 5,000 oz Au (Hotz, 1971).

- Mineralogy: Pyrite, galena, arsenopyrite. Free gold in quartz, some in pyrite (Hotz, 1971; Averill, 1941).

- Au/Ag = >20 (very limited data; 2 samples, very low Ag).

South Fork mining district

- Terrane: Eastern Klamath

- Host Rock Lithology: Granitic rock of the Shasta Bally batholith where it intrudes Copley Greenstone.

- Vein Characteristics: Roughly parallel series of quartz veins striking NE and dipping steeply SE to vertical, 1- to 8-ft wide (Tucker, 1926).

- Geochemical Characteristics: Base metal-silver association. Very high Ag, up to 5,000 ppm. High Pb and Zn (1,000-10,000 ppm, and 800 to >10,000 ppm, respectively). High Cu (up to 1,500 ppm) and Mo (up to 1,000 ppm). Hg content highest found in the Klamath districts, many at >10 ppm level. Relatively low Au, although one high grade Ag sample had 4.3 ppm (table 2).

- Production: Approximately $1,000,000, mostly from Ag. Low Au production.

- Mineralogy: Tetrahedrite, galena, small amounts of pyrite, sphalerite, some chalcopyrite, with small amounts of Au (Hotz, 1971; Tucker, 1926).

- Au/Ag = 0.005 (6 samples).

APPENDIX B

GEOCHEMICAL DATA FOR QUARTZ VEINS AND HOST ROCKS FROM SOME LODE GOLD DISTRICTS IN THE KLAMATH MOUNTAINS IN THE REDDING 1 x 2 DEGREE QUADRANGLE*

Table 2. Geochemistry of selected high grade quartz-vein samples from lode gold districts of the Klamath Mountains, California

[-- indicates not analyzed]

Mine	Au ppm	Ag ppm	As ppm	Hg ppm	Te ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Old Diggings district									
Reid	70	50	<5	0.7	21	200	<5	<5	300
French Gulch-Deadwood district									
Summit	75	70	1,100	<0.02	2.1	5	20	10	50
Brown Bear	50	5	>10,000	<0.02	0.7	5	20	<5	20
Canyon Creek-East Fork district									
Enterprise	86	23	658	1.8	--	21	267	165	20
Ozark	76	27	3,126	1.0	--	12	60	56	<10
Harrison Gulch district									
Midas	34	7	400	0.1	1.0	20	15	<5	10
Hayfork district									
Kelly	22	0.5	190	0.06	1.0	<5	30	5	10
South Fork district									
Crystal	4.3	300	10	>10	<0.05	700	1,000	10,000	10
Crystal	0.4	5,000	10	0.2	<0.05	70	2,000	>10,000	30

Table 3. Geochemical summary, Old Diggings district

[Values are geometric means. Number in paranetheses is number of samples used to calculate mean. [1]Samples of unaltered greenstone were collected in the French Gulch and Shell Mountain quadrangles, west of the Old Diggings district.]

Rock type	Au ppm	Ag ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Quartz vein (11)	0.9	1.5	<5	0.14	12	<10	<5	56
Wall rock greenstone (13)	0.07	0.4	<5	0.02	67	<10	45	47
Host rock greenstone[1] (23)	<0.05	<0.5	2	0.02	58	<10	49	15

Table 4. Geochemical summary, French Gulch district--quartz veins

[Values are geometric means. West (Br.B.) is the Brown Bear mine, the largest in the Klamath Mountains, with approximate production of 500,000 oz Au. Number in parentheses represents number of samples analyzed from each area. MNVL = Minersville, Gy = Graywacke, Arg = Argillite, Grnst = Greenstone, Dk = Dike]

Area	Au ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm	Host rock
Center (21)	0.2	225	0.02	11	10	12	28	Arg/Gy/Dk
East (4)	0.5	478	0.02	6	7	5	14	Arg/Gy/Dk
West (Br.B.) (3)	2.1	8,772	0.02	11	27	2	37	Arg/Gy/Dk
Eastman Gulch (2)	10	30	0.06	39	77	58	12	Grnst/Dk
Mnvl (10)	0.04	4	<0.02	7	6	6	17	Arg/Gy/Grnst

Table 5. Geochemical summary, French Gulch mining district wall rocks and host rocks

[Values are geometric means. Number in parentheses is number of smaples used to calculate mean. Background refers to samples collected away from areas of quartz veins. Wall rock includes samples adjacent to and within a few meters to tens of meters from quartz veins.]

Rock type	Au ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Argillite (49) (Background)	<0.05	4.5	0.09	41	21	82	99
Argillite (23) (Wall rock)	<0.05	56	0.04	32	17	68	77
Graywacke (26) (Background)	<0.05	2.6	0.05	28	13	54	58
Graywacke (9) (Wall rock)	<0.05	16	0.03	28	13	36	50
Greenstone (23) (Background)	<0.05	2	0.02	58	6	49	15
Greenstone (8) (Wall rock)	<0.05	8	0.01	50	6	44	13
Dike-Fspr (9) (Background)	<0.05	10	0.03	15	15	42	54
Dike-Fspr (4) (Wall rock)	0.05	98	0.03	10	13	31	34
Dike-qtz (1) (Background)	<0.05	10	0.02	15	30	30	150
Dike-qtz (9) (Wall rock)	0.21	512	0.02	6	13	17	73

Table 6. Geochemical summary, Canyon Creek-East Fork district

[Values are geometric means. Number in parentheses is number of samples used to calculate mean. Host rock is background, as in table 5. Igneous rock refers to samples of dikes collected within district.]

Rock type	Au ppm	Ag ppm	As ppm	Hg ppm	Cu ppm	Pb ppm	Zn ppm	B ppm
Quartz vein (12)	2.5	1.5	45	1.2	12	17	30	13
Wall rock gneiss (12)	0.03	0.09	6.1	0.9	34	2.6	55	14
Host rock gneiss (9)	0.02	0.04	2.4	<0.5	33	1.5	27	22
Igneous rock (7)	0.01	0.06	2.3	<0.5	17	1.7	14	16

*Analytical data and methods of analyses reported in Hassemer and others (in press).