CHAPTER 8

OTHER SIGNIFICANT GOLD-QUARTZ VEIN DEPOSITS, NORTH AMERICAN CORDILLERA

INTRODUCTION

Gold-quartz vein deposits of the famous Grass Valley, Mother Lode and Alleghany districts in northeastern California and the Alaska-Juneau deposit of the Juneau gold belt in southwestern Alaska (Figure 1.1) are discussed briefly to aid in the comparison with those in British Columbia. These U.S. deposits appear to have a similar origin and occur within a similar orogenic setting. They are also the most significant Cordilleran gold producers (Figure 8.1) and are commonly used and referred to as type examples for this class of Paleozoic gold-quartz vein deposit (Boyle, 1979; Kerrich and Wyman, 1990; Schroeter and Lane 1991; Goldfarb et al., 1998). More importantly, these include mines for which there is ample detailed description of the geological setting and character of the veins, published during active mining periods (Figure 1.3). This chapter emphasizes the lithotectonic setting and relevant geological history of the host terranes relative to the timing of gold-quartz vein mineralization. A more detailed examination of the character of the veins is given in Appendix III.

CALIFORNIA GOLD-QUARTZ VEINS

Total gold recovered from California gold deposits is estimated in excess of 100 million ounces\(^1\), with sixty percent recovered from placers and the remainder from lodes (Clark, 1970). Peak annual production was almost 4 million troy ounces in 1852, less than five years after the initial discovery of placer gold at the edge of the South Fork of the American River at Sutter’s Mill, Coloma, by John Marshall in 1848. In 1849, the year of the ‘49ers’, more than 90 000 people made the journey to California’s gold fields.

Significant lode-gold production from the belt was from three main regions that included the Grass Valley and Alleghany districts, and the Mother Lode belt (Figures 8.1 and 8.2). Although the Mother Lode gained the most notoriety and is often used to characterize these gold deposits, the Grass Valley district was the most productive gold-quartz vein mining district in both California and the North American Cordillera as a whole.

PREVIOUS WORK

Early descriptive works on the individual gold camps include those of Knopf (1929) for deposits along the Mother Lode belt; Lindgren (1896) and Johnston (1940) for Grass Valley; and Ferguson and Gannett (1932) for Alleghany deposits. Clark (1970) and Albers (1981) presented summaries of the production and setting of the California gold quartz vein deposits. Recent, detailed studies have focused in large part on the Alleghany District and emphasize hydrothermal fluid and alteration characteristics of the vein systems (Coveney, 1981; Wittkopp, 1983; Böhlke and McKee, 1984; Böhlke, 1988, 1989; Böhlke and Irwin, 1992). Landefeld and Silberman (1987) and Landefeld (1988) described the lithotectonic setting of gold veins along the Mother Lode Belt relative to the ages of magmatism and mineralization. Böhlke and Kistler (1986) and Weir and Kerrick (1987) summarize fluid characteristics and mineralization ages for most of the significant gold camps. A recent overview of California gold vein deposits is presented by Böhlke (1999).

The Sierra Nevada metamorphic belt is one of the most intensely studied areas of oceanic terrane rocks within the North America Cordillera. The ophiolitic character and tectonic history of these rocks has been recognized for some time (Moores, 1970; Irwin, 1977; Saleeby, 1982) and has become relatively well established (Edelman and Sharp, 1989; Dilek, et al., 1990; Edelman, 1990; Saleeby, 1990, 1992; Saleeby and Busby Spera, 1992). Interpretations regarding overall plate tectonic construction, however, remain a matter of debate (Dickson et al., 1996; Saleeby, 1999).

REGIONAL GEOLOGICAL SETTING

Gold-quartz vein deposits of California are mainly within the Sierra segment of the Western Sierra-Klamath belt (Saleeby and Busby-Spera, 1992) (Figure 8.2 and inset map). The belt consists of highly disrupted late Paleozoic marine sedimentary and ophiolitic rocks interleaved with early and late Mesozoic submarine volcanic-arc and basinal terranes (Saleeby, 1990, 1992; Saleeby and Busby-Spera, 1992). The eastern faulted margin of the belt is referred to as the Foothills Suture (Saleeby, 1982), which separates rocks of oceanic origin to the west from those of continental margin affinity to the east (Figure 8.2).

Continental margin rocks are assigned to the Northern Sierra Terrane and consist of the latest Proterozoic to Silurian Shoo Fly Complex which is unconformably overlain by a near-continuous, Late Devonian to Middle Jurassic succession of predominantly volcanogenic strata (Edelman and Sharp, 1989). The Shoo Fly Complex is an internally deformed and imbricated, southwest-verging thrust sequence of mainly Ordovician to Silurian metamorphosed sandstone, siltstone and shale. It is considered as continental

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\(^1\) Böhlke (1999) indicates total estimated gold production for California to 1995 is on the order of 115 million ounces.
slope-and-rise strata built outboard of the ancient North American miogeocline. The Sierra City mélange forms the structurally highest thrust sheet of the complex and includes blocks of serpentinized peridotite, gabbro, massive and pillowcd basalt, chert, limestone and sandstone within a sheared sedimentary matrix (Saleeby, 1992). Plagiogranite from the mélange with a Late Precambrian age (U-Pb, 600±10 Ma), suggests that it is part of a disrupted vestige of an ophiolite sequence. It is interpreted as basement for continental rise strata deposited off the ancient passive margin (Saleeby, 1990). Three major unconformity-bounded sequences of Late Devonian-Pennsylvanian, Permian, and Late Triassic to Middle Jurassic ages are recognized within the overlying volcanic strata (Edelman and Sharp, 1989).

In the predominantly oceanic Western Sierra belt three distinctive lithotectonic elements are recognized (Saleeby, 1990), each hosting significant gold vein deposits. These include from oldest to youngest (Figure 8.3):

1. A highly disrupted basement framework consisting of:
   a) late Paleozoic abyssal ophiolitic fragments; b) chaotic late Paleozoic to early Mesozoic chert-argillite deposits;
   c) subordinate late Paleozoic Tethyan-affinity limestone with associated blocks of mafic alkali basalt and;
   d) sporadic Triassic blueschist slabs and blocks.

Within this lithotectonic framework gold-quartz vein deposits appear to be preferentially associated with ophiolitic rocks, for example; in the Alleghany district along the Feather River belt, as well as those in the central Mother Lode along the Tuolumne belt.

Chaotic chert-argillite deposits, termed the Calaveras Complex form a fairly continuous belt along the length of the Sierra Nevada. Similar rocks are also found intercalated within ophiolitic rocks in the Tuolumne River belt. Similar to Cache Creek and Bridge River complexes in British Columbia, the chert-argillite units are typically devoid of gold-quartz vein deposits except near their contacts with ophiolitic rocks.

2. Late Triassic to Early Jurassic submarine lava flow and pyroclastic sequences with overlying cherty, tuffaceous and epilastic strata, or hypabyssal-plutonic complexes

Figure 8.1. Significant gold-quartz vein producing mines of California compared to other significant North America Cordilleran gold producers. Data sources for the areas indicated are: California deposits (Clark, 1970), Bralorne-Pioneer mine (Leitch, 1990), Alaska-Juneau (Fredericksen and Miller, 1989), Barkerville and Rossland (Schroeter and Lane, 1991). Production figures for California converts the dollar value to ounces using a value of $20.67 US per ounce. Production figures given in all cases are estimates. In many instances complete production records do not exist. Individual mines are indicated for California deposits, whereas gold production for all other camps includes all mines and are therefore not directly comparable.
Figure 8.2. Geology and distribution of significant gold-quartz vein camps in the Western Sierra Nevada metamorphic belt, California. Compiled after Edelman and Sharp (1989).
Figure 8.3. Relative age and tectonostratigraphic relationships for lithologies in the Western Sierra Nevada metamorphic belt. Age constraints for lithostratigraphic elements indicated are from Edelman and Sharp (1989), Edelman (1990) and Saleeby (1990, 1992). Isotopic age data for hydrothermal alteration are from Böhlke and Kistler (1986).
which intrude late Paleozoic ophiolitic basement rocks (Figure 8.3). These complexes are common in the Toulumne River belt and also act as basement for younger strata of the western belt. The bulk of the Grass Valley gold-quartz veins (Lake Combie complex), as well as some of those along the central and southern portions of the Mother Lode Belt in the Sullivan Creek and Penon Blanco Formations, are hosted by these tectono-stratigraphic elements.

(3) Middle-Late Jurassic (Callovian to Kimmeridgian) submarine mafic volcanic and slaty flysch sequences dominate the western margin of the belt (Western belt) where they are associated with coeval sheeted dike swarms and shallow-level intrusions, such as the Smartville ophiolite complex. Related sequences unconformably overlie all older elements of the western Sierra and are interpreted to be depositionally linked, as a volcano-sedimentary apron sequence and give the overall assemblage an ophiolitic character (Saleeby, 1990). Many of the significant producing lode gold deposits along the Mother lode belt are hosted by this tectono-stratigraphic element (i.e., Logtown Ridge and Mariposa Formations).

Early plate-tectonic interpretations of the origin of the Sierra belt postulate a number of discrete, exotic island-arcs which were accreted to the North American continental margin during the Late Jurassic Nevadian orogeny. These views have been supplanted (Edelman, 1990; Saleeby, 1990; 1992) by a scenario of tectonically disrupted, predominantly late Paleozoic ophiolitic rocks and chaotic chert-argillite deposits that formed an oceanic basement along the continental margin. This oceanic basement was disrupted by extensional fore-arc and possibly interarc basin development during the Late Triassic-Early Jurassic and again in the latest Middle Jurassic to early Late Jurassic. Both periods of constructional fore-arc basinal magmatism were followed by intervals of tectonism and related deformation during the Middle Jurassic Siskiyou orogeny and again during the latest Jurassic Nevadan orogeny. The main structural expression of the Nevadan orogeny was the eastward thrusting of the Smartville complex onto the Central belt, followed by high-angle reverse faulting, folding and cleavage development in the Mariposa flysch (Edelman and Sharp., 1989; Saleeby, 1982, 1990).

The post-Nevadian, Sierra Nevada batholith intrudes the Sierra Nevada metamorphic belt along its eastern margin. It is interpreted to be the roots of a Late Jurassic and Cretaceous magmatic arc related to eastward subduction of oceanic lithosphere, which generated the Franciscan subduction complex on the west. The timing of Sierran plutonism appears to have been episodic. An interval of post-Nevadan magmatism in the Late Jurassic, between 150 and 140 Ma, was followed by a lull in magmatic activity from 140 and 120 Ma, with renewed activity in the Cretaceous between 120 and 80 Ma. The earlier 150 to 140 Ma event is characterized by small intrusive bodies and high level dikes and sills throughout much of the Sierra Nevada Metamorphic belt. The younger intrusive activity produced the bulk of the batholith.

**GRASS VALLEY**

Grass Valley was the most prolific lode-mining district in California, producing close to 300 000 kilograms (10 million ounces) of gold from roughly 20 square kilometres (Figures 8.4 and 8.5). Gold was discovered in 1850 and apart from a shutdown during World War II, the district operated almost continuously until 1956, ending close to 106 years of mining (Clark, 1970).

Gold veins of the Grass Valley are hosted primarily within fissures cutting both the Lake Combie igneous complex and a younger (?) quartz monzodiorite to granodioritic intrusive body, the La Barr Meadows pluton (Tuminas, 1983). The Lake Combie complex is a fault-bounded, pseudostratigraphic sequence of serpentinized, foliated harzburgite, dunite and pyroxenite that is intruded and structurally overlain by a mafic igneous sequence of plutonic, hypabyssal and volcanic rocks (Tuminas, 1983; Day et al., 1985). Plutonic rocks range from gabbro to quartz diorite and grade upward through a sheeted zone into massive diabase. It is overlain in turn by a thick (>5km) sequence of mafic to intermediate volcanic rocks, followed by volcaniclastic and finally epiclastic sediments. The age of the complex has not been determined but a comparable pseudostratigraphic sequence with similar structural relationships occurs within the well dated latest Triassic to earliest Jurassic (210-200 Ma) Slate Creek complex to the north (Figure 8.1) and suggests a correlative age for the Lake Combie complex (Dilek et al., 1990; Edelman and Sharp, 1989; Edelman, 1990).

These volcano-plutonic igneous sequences are considered as suprasubduction zone ophiolite-transitional arc complexes developed during a period of incipient fore-arc rifting during the Late Triassic. This produced narrow oceanic basins in the Paleozoic basement rocks (Dilek et al., 1990; Saleeby, 1990). Subsequent Middle Jurassic orogenic activity (Siskiyou orogeny) resulted in west-vergent imbrication of these extensional fore-arc sequences and their ophiolitic mélangé basement rocks. A 168 Ma pluton cuts the basal thrust fault of the Slate Creek complex and places an upper limit on the timing of tectonic emplacement of the igneous complex onto deformed Paleozoic oceanic basement (Saleeby, 1990).

The La Barr Meadows pluton (Tuminas, 1983) is a granodiorite to quartz monzodiorite intrusion, which underlies and extends south from the town of Grass Valley and also in part hosts many of the significant gold-quartz veins (Figures 8.4 and 8.5). This intrusion has been consistently interpreted to be a post-orogenic stock of the Sierra Nevada Batholith (Lingdren, 1896; Johnston, 1940; Clark, 1970; Boyle, 1979; Hutchinson and Albers, 1992).

Such an association in which post-orogenic intrusions are host to gold quartz veins is clearly inconsistent with the setting of gold veins in all other camps described previously. In all other cases the main plutonic rocks hosting gold-quartz veins are older accreted tectonic blocks or slivers of oceanic-transitional arc crust. Association of gold quartz veins with coeval, late syn-orogenic, high-level intrusions is not uncommon, but in such cases veins are proxi-
Figure 8.5 Geology of the Grass Valley - Colfax area depicting regional setting of the Grass Valley district (after Day et al., 1985 with updates to legend from Dilek et al., 1990 and Edelman, 1990).
Figure 8.5. Geology of the Grass Valley district after Johnston (1940) with revised legend using data from Day et al. (1985), Edelman and Sharp (1989) and Edelman (1990).
mal to or co-structural with the intrusions and are not prominent host rocks.

Gold-quartz vein-bearing fissures cross-cut the intrusive contact of the La Barr Meadows Pluton with little, or no apparent offset (Johnston, 1940) suggesting that the mineralization is younger than the pluton.

The currently implied vein host rock relationship for Grass Valley implies that either the most productive gold quartz vein camp in the North American Cordillera is somehow lithotectonically distinct from all other similar deposit, or alternatively, as suggested following, the intrusion is not a post-orogenic stock of the Sierra Nevada Batholith.

The only existing isotopic age constraint for the La Barr Meadows pluton is a hornblende K-Ar date of 126.7 ± 3 Ma on a sample collected from the Empire mine (Böhlke and Kistler, 1986). Visual examination of a similar sample collected for U-Pb dating from the general area of the previously dated sample indicates that the rock is altered with both epidote and chlorite replacing plagioclase and hornblende respectively (J. Böhlke and J. Dilles, personal communication, 2000). This observation is consistent with that of Johnston (1940) who found that all samples of the pluton showed some degree of alteration of both the hornblende and plagioclase. The alteration affecting the dated sample suggests that the calculated K-Ar age might not reflect the magmatic cooling age of the pluton but may be more an artifact of subsequent thermal events.

If this is the case it eliminates the ambiguity of the isotopic K-Ar date of 143.7 ± 4 Ma for hydrothermal mica (mariposite) from the Brunswick vein (Böhlke and Kistler, 1986), the only constraint for the timing of vein mineralization in the camp. This latest Jurassic apparent mineralization age is older than the previously inferred age of the pluton. Notably, the Brunswick vein is hosted entirely within diabase in the northeastern part of the Grass Valley camp roughly two kilometres from the pluton (Figure 8.3). The isotopic data suggests that either: a) there are two distinct ages of vein mineralization in the Grass Valley camp or, b) the interpreted age of 127 Ma for the La Barr Meadows pluton does not accurately reflect its cooling age. The general consistency of coeval ages of mineralization in the general region of mineralization for previously described camps argues against such a relationship.

Although an absolute age for the La Barr Meadows pluton is not available, detailed as well as regional geological considerations provide relative age constraints. Johnston (1940, page 15) identified detailed contact relationships between granodiorite and host hypabyssal rocks which suggested to him that the two were co-magmatic due to multiple intrusive relationship in which host diabase was seen to also intrude as dikes, the younger intrusion. He discounted this possibility in view of prevailing geological concepts at that time. In describing the contact relationship between the granodioritic rocks and the porphyritic diabase (his ‘porphyrite’) he states;

“...The contact is remarkable for its sharpness and for lack of fine grained borders indicating chill or other contact phenomena. ... Dikes of intermediate composition cut the granodiorite, many of these dikes closely resemble the older diabase and porphyrites in texture and mineral composition.”

He concludes (page 16);

“The similarity in mineral composition and texture between the porphyrite dikes that cut the granodiorite and the earlier pre-granodiorite porphyrite immediately suggests the existence of a single magmatic source for both rocks. It is very difficult, however, to postulate the independent existence of such a magmatic reservoir during the intrusion of the granodiorite.”

Clearly his difficulty in accepting the observed relationships are a moot point in view of current plate tectonic concepts in which multiple intrusive contact relationships are a characteristic feature in the igneous genesis of volcano-plutonic arc/ophiolitic complexes.

From a regional geological standpoint there are several lines of evidence to support Johnston’s (1940) initial contention that the intrusive-hypabyssal units are co-magmatic. The limits of the pluton are conspicuously constrained to within the Lake Combie complex and are for the most part within the massive diabasic portion (Day et al., 1985). Where not intrusive into the diabase or volcanic rocks of the Lake Combie complex, the pluton is cut by the bounding faults of the complex. This appears to be the case where in contact with Fiddle Creek Complex rocks (Dilek et al., 1990) along the northern edge of the Grass Valley town site (Johnston, 1940). It is also apparent along the western margin of the complex, where bordered by the Wolf Creek-Bear Mountain fault zone (Day et al., 1985). Further south this fault zone is cut by the by the Folsom-Aubrun dike swarm which is dated at 160 Ma (E.M. Moores, personal communication, 2000), suggesting significant movement along the fault was complete by that time. However, these dikes are foliated and have been affected by later deformation. This general relationship of bounding faults of the complex also cutting the pluton suggests both units were likely emplaced as a single tectonic entity onto the late Paleozoic basement.

It cannot be ruled out that the La Barr Meadows pluton could be coeval with the larger, north-trending Yuba Rivers pluton (158 ± 2 Ma; Saleeby et al., 1989) located several kilometres north of Grass Valley District (Figure 8.4). It would seem that the most productive gold-quartz vein deposit in the North American Cordillera is worthy of modern day isotopic analysis to clarify existing age relationships between the plutonic host and mineralization. Such an exercise would be necessary to definitively compare this deposit to others discussed in this report.

MINERALIZATION

Gold from Grass Valley was obtained primarily from two vein systems, the Empire-Star and Idaho-Maryland groups (Figure 8.4 and 8.1). Gold-quartz veins at the Empire and North Star mines are hosted mainly by the La Barr Meadows pluton and its country rock, massive diabase. Most of the veins have a north to northwesterly strike with shallow to moderate dips (average 35°); those on the west side of the pluton have prevailing dips to the east, while those on the east side have prominent dips to the west. Veins pass from diabase into granodiorite with little if any dis-
placement at the contact. Most of these veins were observed to have remarkable persistence. The Empire vein, for example, extended over a strike length of 1.5 kilometres with a down dip extent of 2.1 kilometres and had an average gold content of 19.2 g/t (0.56 ounces/ton).

In contrast, the Eureka-Idaho-Maryland group of veins, northeast of the Grass Valley townsite, have a more easterly strike with steep southerly dips (average 70°) although several veins dip at steep to moderate angles in the opposite direction. Veins in this group are better characterized as contact veins, as they occur primarily along highly ankerite altered faults that separate diabase and/or gabbro from serpentinite. The Idaho-Maryland vein contained one of the most famous ore shoots in which most of the gold was free and from which significant numbers of gold ore specimens were recovered (Johnston, 1940). The width of the ore shoot was on average 0.8 metres but in places was up to 2.5 metres wide. The ore shoot had a pitch length of 1.6 kilometres and a width of 150 to 300 metres with an average gold content of 34.3 g/t (1 ounce/ton).

**MOTHER LODGE GOLD BELT**

The Mother Lode (from the Spanish ‘veta madre’) is a narrow, 1 to 1.5 kilometre wide, semi-continuous belt of gold deposits that extends over 190 kilometres from Georgetown in the north to Mariposa at its southern terminus (Knopf, 1929; Landefeld, 1988; Figure 8.2). Host rocks for gold-veins along the belt are varied. In the northern portion they are dominated by mafic volcanic rocks and black slate, whereas in the central portion they are predominantly green schists and serpentinite, and in the southern segment are again dominated by mafic volcanic rocks and slate.

The majority of significant, producing gold-quartz vein deposits in the Mother Lode are in the north-central portion of the belt along a 16 kilometre stretch between Jackson and Plymouth (Figures 8.1, 8.2 and 8.6). Both the Central Eureka and Kennedy mines produced in excess of 46 500 kilograms (1.5 million ounces) gold with the Argonaut and Keystone each producing over a million ounces. Veins along this portion of the belt are hosted in a moderate to steeply east-dipping shear zone considered a splay of the Melones fault. The vein-hosting fissure zone cuts at an acute angle across a sequence of steep, easterly dipping, alternating 60 to 200 metre thick intervals of mafic volcanics and black slate. These units are part of relatively intact Callovian to Kimmeridgian (late-Middle and to middle-Late Jurassic) submarine mafic volcanic and slaty flysch sequences referred to as the Mother Lode Terrane by Graymer and Jones (1994). This Terrane consists of a lower strigraphic succession with Callovian basaltic sandstone and argillites, overlain by Callovian to Oxfordian basaltic to andesitic clinopyroxene phryic breccias and tuffs of the Logtown Ridge Formation. These are overlain, in turn, by Oxfordian to Kimmeridgian slates and conglomerates of the Mariposa Formation. This Jurassic volcano-sedimentary succession was deposited on a composite basement of previously accreted and deformed late Paleozoic oceanic rocks and early Mesozoic fore-arc basinal sequences (Saleeby, 1990).

Gold-quartz veins within these various units occur most commonly at the stratigraphic and interfingering contact between the volcanic-dominated Logtown Ridge Formation and the overlying sediment dominated-Mariposa Formation.

The Carson Hill mine situated roughly 30 kilometres south of Jackson is the only other mine along the Mother Lode to produce in excess of one million ounces gold that is not along the gold rich portion of the belt between Jackson and Plymouth (Clark, 1970, Figure 8.1). The mine was noted for its high-grade pockets of gold ore and is hosted by highly disrupted late Paleozoic ophiolitic basement and younger basinal rocks. Carson Hill had a very rich, near surface deposit, which produced close to 4.5 tonnes (145 000 ounces; reported as $3 000 000), in its first two years of mining around 1850. In 1854 the mine produced the largest piece of gold ever found in California weighing 72.8 kilograms (2340 troy ounces, Knopf, 1929). High-grade gold ore was obtained largely from the steeply-dipping Bull vein where it intersected a number of flat-lying shear veins. The geology of Carson Hill is described as the most complex of the entire Mother Lode belt. Rock types include black phyllite, augite tuffs and breccias, chlorite and amphibolite schists, serpentinite (talc and mariposite schists) and gabbro. Vein hostrocks vary from massive ankerite rock to well-banded sericite-ankerite schist with mariposite-ankerite rock occurring in considerable quantity in the footwall schists of the Bull vein. Knopf (1929) reported that the combined underground workings of the Morgan and Melones mines on Carson Hill, which extended to a depth of nearly 1.5 kilometres, total more than 25 kilometres.

**MINERALIZATION**

Knopf (1929) characterized the ores of the Mother Lode belt as being of low to moderate grade with an average grade of 10.3g/t gold (0.3 ounces/ton; reported as $7.00 US). In addition to the typical quartz vein ore containing free gold (see Appendix III), a considerable amount of gold was recovered from disseminated sulphides in hydrothermally altered mafic igneous host rocks. Knopf (1929) applied the term ‘grey ore’ to the ankeritized greenstone with minor sericite and sulphides, which carried sufficient gold to warrant mining. This type of mineralization constituted the bulk of the gold resources in some of the more famous mines. ‘Grey ore’ was the mainstay at the Keystone mine, which is renowned for its longevity, operating almost continuously from 1852 to 1920. The prevalence of sulphide replacement ore along the Mother Lode belt, compared to most other gold vein deposits described from the Cordillera, may be due to enhanced permeability resulting from the primary brecciated character of the mafic volcanic host rocks.

Knopf (1929) described many of the ‘grey ore’ shoots as large, valuable bodies. The largest at the Fredmont mine, for example, formed at the wedge end of a mass of greenstone that lay between two converging fissures. The orebody was 90 metres long by 5 to 20 metres wide (average 12 metres) and up to 100 metres down dip. The localization of such orebodies at the wedge end of greenstone between converging veins was noted as a common controlling feature. Grey ore contains from 3 to 6% sulphides consisting of
Figure 8.6. Geology of the Mother Lode belt between Jackson and Plymouth after Knopf (1929, Figure 3) with revised legend using data from Graymer and Jones (1994).
pyrite and arsenopyrite within carbonate and sericite-altered host rocks commonly traversed by veinlets of quartz containing ankerite and albite. The gold content of the grey ore is reported to be spotty but is as much 35 g/t, with some large bodies containing an average 10.3 to 13.7 g/t (0.3 to 0.4 ounces/ton) or more. The gold value of such ore could not be estimated on inspection, even by the most experienced miners. In some instances, quartz veins adjacent to the grey-ore were devoid of gold.

**ALLEGHANY DISTRICT**

The Alleghany camp in the northeastern Sierra Nevada (Figure 8.2 and 8.7) is the most famous gold-mining district of California. It differs from other gold vein districts in that nearly all production was from small shoots with very rich ore; little was obtained from lower grade ore characteristic of most other camps (Ferguson and Gannett, 1932). As a rule, the high-grade shoots carried from 3 kilograms per tonne (~100 oz/ton) in free gold and often exceeded many times that amount. The largest ore shoot in the Sixteen to One mine, for example yielded nearly 1370 kilograms (44,000 ounces) from an area less than 12 metres-square from 60 centimetres of quartz next to the hanging wall.

Lode mining started in 1852 but continuous production did not begin until 1904. The most productive vein system, the Sixteen to One (Figure 8.1 and 8.7) was mined for a total of 60 years prior to its closure in 1965 (Clark, 1970). This was the last lode mine to close that had been operated in the state of California on a sustained basis. Ironically it was in that same year that gold was designated as the official state mineral. Alleghany is recognized as the only town in California in which gold mining was the principal sector of the economy following World War II.

**GEOLOGICAL SETTING**

Gold-quartz veins of the Alleghany district occur west of the terrane-bounding Foothills suture within the ophiolitic Feather River Belt (Figure 8.2). This is a fault-bounded linear zone from 2 to 10 kilometres wide that extends southward for close to 150 kilometres from the northern end of the Sierra Nevada metamorphic belt (Saleeby, 1990). The Feather River belt contains harzburgite and lherzolite tectonite, dunite and pyroxenite, layered and massive gabbro and amphibolite that range from middle to late Paleozoic (Edelman, 1989; Edelman, 1990; Saleeby et al., 1989; Saleeby, 1990; 1992). A relatively coherent Carboniferous ophiolite crustal sequence of massive gabbro, sheeted dikes, MORB pillow basalts and overlying metachert referred to as the Devils Gate ophiolite occurs along the west-central portion of the belt (Figure 8.2). The concurrence of mantle and crustal components suggests the remnants of a polygenetic ophiolite.

The geology of the Alleghany district comprises a number of panels of predominantly mafic igneous rocks separated by north-trending fault zones marked by tabular bodies or lenses of serpentinite (Ferguson and Gannett, 1932; Böhlke and McKee, 1984). The amphibolite and metagabbro protoliths consist mainly of a mafic to interme-

**AGE OF MINERALIZATION**

Most of the existing isotopic data for the California gold-quartz vein deposits described above include K-Ar ages mainly on mariposite, and Rb-Sr age determinations on quartz or carbonate. This data is summarized by Böhlke and Kistler (1986) and in Figure 8.3. A single K-Ar age of 143.7±4 Ma on mariposite with a corresponding Rb-Sr age of 140.9±3 Ma on quartz from the Brunswick Mine are the only constraints for hydrothermal activity related to gold vein mineralization at Grass Valley. Along the southern por-
Figure 8.7. Geology of the Alleghany District after Ferguson and Gannett (1932) with revised legend using data from Böhlke and McKee (1984), Edelman and Sharp (1989) and Saleeby (1990).
tion of the Mother Lode, six K-Ar ages from hydrothermal vein micas reveal a near continuous range over 25 million years between 130 and 105. In the Alleghany camp K-Ar mica data from three different deposits including the Ireland (112.9±3 Ma), Plumbago (112.5±3 Ma) and Rainbow extension (part of the 16 to 1 vein) (111.6±3 Ma) indicate a fairly restricted age range which is coeval with a more recent 40Ar/39Ar age of 111 Ma on mariposite from the Oriental vein (Böhlke, 1989). Rb-Sr ages from this camp show considerable variability, ranging from 109.6±3 to 124.5±3 Ma.

The overall variation in mineralization ages for California vein gold deposits has been interpreted in several ways. Böhlke and Kistler (1986) and Weir and Kerrick (1987) suggest the range of hydrothermal ages results from mineralizing fluids generated by deep magmatic activity in response to resumption of east-dipping subduction along the western margin of North America following the Nevadan orogeny. This implies that the mineralizing episode occurred over a protracted period of about 30 million years following orogenesis. Another interpretation, preferred here, was provided by Landefeld (1988) who proposed that the oldest ages (141-144 Ma) are closer to the true age of formation of the Mother Lode gold-quartz veins. She considers the spread of younger isotopic ages to be an effect of later thermal overprinting related to intrusion of the large, Cretaceous Sierra Nevada batholith (Figure 8.2). Notably, the oldest alteration ages are also most distant from the batholith. Support for Landefeld’s (1988) interpretation that thermal resetting has taken place is provided by recent examination of mariposites from the Mother Lode belt (Y. Jia, personal communication, 2000) which indicate that they are altered to some degree to varieties of Cr-bearing clay minerals (illite, smectite, etc.).

Additional age data (Elder and Cashman, 1992) for gold veins from Quartz Hill in the Klamath Mountains, Northern California (inset map, Figure 8.2), add additional support for resetting as a cause for the span of younger ages. Deposits at Quartz Hill occur in a series of gold-quartz veins, in footwall basaltic greenstones along the Soap Creek Ridge fault zone. K-Ar data for two samples of hydrothermal vein micas give conventional K-Ar ages of 145.8±3 and 147±2.8 Ma and are considered the age of mineralization. This deposit is far removed from the influence of thermal overprinting related to Sierra Nevada magmatism. The data indicate a gold-mineralizing event within the latter stages of the Nevadan orogeny and is consistent with the age of Grass Valley mineralization.

**RELATIONSHIP TO MAGMATISM**

For the California deposits discussed there is a common spatial association with high level intrusive rocks. However, temporal relationships between the gold quartz veins and intrusions are not well constrained for most areas. In the Alleghany district, Ferguson and Gannett (1932) indicate that granite and aplite masses lie within a narrow zone that trends across the area in a northerly direction (Figure 8.5). The dikes in the host gabbro lack the penetrative fabric and postdate the regional greenschist metamorphism. Locally dikes are also hydrothermally altered with secondary carbonate-sericite-pyrite. Two distinct ages of granitic intrusion are known. In the western and southwest part of the camp (Figure 8.7) quartz dioritic intrusions of the Indian Valley suite are dated by K-Ar on hornblende at 143±5 Ma (Bohlke and McKee, 1984) consistent with a late syn-orogenic episode of magmatism following the Nevadan orogenic event. A peraluminous granitoid stock of Devonian age (Saleeby, 1990) intrudes the amphibolite/metagabbro in the Oriental Mine and forms the footwall to the Oriental vein (Coveney, 1981). This stock is coeval with the larger Bowman Lake pluton intruding Shoo Fly complex rocks to the east (Figure 8.6). Marginal to the vein, the Oriental Mine stock is pervasively albitized and contains fine gold in disseminated pyrite with an average grade of 7 g/t (0.2 ounces/ton).

Along the Mother Lode belt, Landefeld and Silberman (1987) indicate that late orogenic dikes intrude margins of the Melones fault zone and its adjacent rocks and that in the Coulerville region such dikes are hydrothermally altered. In a similar manner, south of Jackson along the central portion of the Mother Lode, Knopf (1929) described several localities of albite porphyry dikes, which are in places auriferous. In the northern part of the belt, the Coloma stock, an elongate 2 to 4 kilometre wide intrusion extending over 16 kilometres north of Placerville, has been dated at 143 Ma by U-Pb (Graymer and Jones, 1994). It provides an example of late syn-orogenic plutonism that is coeval with the age of vein mineralization suggested for the Mother Lode belt (Landefeld, 1988), indicating a magmatic event which immediately postdates the Nevadan orogeny.

At Grass Valley, Johnston (1940) describes leucocratic aphanitic to quartz-albite porphyritic granitic dikes as a conspicuous feature throughout the mine workings. Relationships between vein mineralization and these high level intrusive rocks are not evident and there are no age constraints on the dike rocks.

**SUMMARY**

- Significant production from gold-quartz vein deposits in California was obtained from three main areas, the Grass Valley and Alleghany districts, and the Mother Lode belt which represent classic examples of gold-quartz vein deposits within accreted Phanerozoic terranes.
- There is a clear diversity of host rock associations for these gold-quartz vein deposits. Veins in the Alleghany are hosted by Paleozoic ophiolitic rocks, Early Paleozoic amphibolite and Devonian granite at Grass Valley, metamorphic ultramafic and mafic igneous rocks of the Late Triassic-Early Jurassic Lake Combie suprasubduction zone ophiolite/arc complex and a younger (?) enigmatic granodiorite-quartz monzodiorite intrusion, the La Barr Meadows pluton are host to veins. Along the Mother Lode belt veins are hosted primarily in a Late Jurassic sequence of alternating mafic volcanic breccia and slate but are also associated with Late Triassic granitic rocks and older Paleozoic ophiolitic rocks.
The enigmatic La Barr Meadows pluton, which is host to significant gold quartz veins at Grass Valley is of unknown age and correlation. Traditional views that the pluton is a younger satellite stock of the Sierra Nevada Batholith have been considered but it is more likely an older and possibly a co-genetic with the Lake Combie complex for the following reasons:

1. The limits of the pluton are conspicuously constrained to within the Lake Combie complex and mostly within the massive diabasic portion.
2. Where not intrusive into the diabase or volcanic rocks of the Lake Combie complex, the pluton is cut by the bounding faults of the complex.
3. Multiple intrusive contact relationships between the pluton and the host diabase suggest that the two are co-magmatic, i.e. dikes that are texturally and mineralogically similar to the host diabase also intrude the pluton.
4. A reported Early Cretaceous hornblende K-Ar age for the pluton cannot be considered a reliable indication of the age of the intrusion as all primary hornblende appears to be, at least in part, altered to chlorite.

California quartz-vein deposits discussed are some of the most significant gold producers in the North American Cordillera. They represent most of the better-documented deposits and occur in a region for which the geological setting is possibly best constrained. However, modern Ar-Ar dating to adequately constrain ages of mineralization (see discussion, chapter 9) combined with information for the age of host rocks, particularly for the Grass Valley district, are required to make definitive correlations with camps elsewhere in the Cordillera.

Within the significant producing gold vein deposits of Western Sierra belt, high-grade, native gold is often found in close spatial association with carbonate-altered ultramafic rocks. This is entirely the case for the Alleghany camp, similarly for the Idaho-Maryland vein in the Grass Valley camp and is also characteristic of high grade gold for the central portion of the Mother Lode belt.
ALASKA-JUNEAU DEPOSIT

Alaska-Juneau is the largest among a number of gold quartz vein deposits in the Juneau Gold Belt of southeastern Alaska (Spencer, 1906; Figure 8.8). This belt contains a northwest-trending linear array of gold-quartz vein deposits that extend 200 kilometres from Windham Bay in the south, to Berners Bay in the north. Gold was discovered in 1880 by Joe Juneau and Richard Harris and the town of Juneau being named after the elder of the two discovers (Spencer, 1906). During its 40-year productive history from 1885 to 1944 close to 110 tonnes (3.5 million ounces) of gold were recovered from 90 million tonnes (99 million tons) of ore which makes it one of the largest and lowest grade underground operations in the world (Figure 8.1; Fredericksen and Miller, 1989).

PREVIOUS WORK

Geological mapping in the area was done first by Spencer (1906) and more recently by Brew and Ford (1985) and Gehrels (2000). Earliest descriptive works of the deposit include those of Spencer (1906) and Wernecke (1932). Recent work has focused on establishing the nature and age of mineralizing fluids (Leach et al., 1986; Goldfarb et al., 1988a, b; Goldfarb et al., 1991; Miller et al., 1995). Summary descriptions of the deposit have been published by Newberry and Brew (1987) and Fredericksen and Miller (1989).

GEOLOGICAL SETTING

The Juneau gold belt (Figure 8.8 and 8.9) consists of a number of northwest trending belts of oceanic rocks that comprise several distinct lithotectonic terranes (Miller et al., 1995; Gehrels, 2000). These consist largely of deformed and recrystallized marine clastic sediments and intermediate to mafic volcanics which are bordered to the east by the Eocene (54-48 Ma) granites and granodiorites of the Coast plutonic complex. Individual terranes are interpreted to be juxtaposed against one another along a series of southwest-verging, moderately to steeply northeast dipping, mid-Cretaceous thrust faults (Miller et al., 1995).

The oldest, most easterly belt of rocks, termed the ‘schist band’ by Spencer (1906) consists mainly of metamorphosed calcareous and argillaceous sandstone that occur as a garnet-mica-hornblende schist with intervals of quartzite and marble. These are currently correlated with the Yukon Tanana Terrane and are considered displaced near-shore remnants of the Early Paleozoic North American continental margin (Miller et al., 1995).

West of this belt, are intercalated slate- greenstone and greenstone schists, which are remnants of Permian and Middle to Late Triassic interbedded clastic sediments and mafic volcanic rocks, correlated with the Taku Terrane (Gehrels, 2000).

MINE GEOLOGY

Gold-quartz veins of the Alaska-Juneau deposit are hosted in the Taku Terrane, a sequence of deformed and metamorphosed Late Triassic intercalated black slates intruded by Mesozoic metagabbro (Figure 8.9). The slates are metamorphosed carbonaceous shales which are typically graphic and contain occasional thin, dark limestone intervals.

Recrystallized gabbro and pyroxenite intrusions are prominent lithologies in the Juneau area (Spencer, 1906). They intrude all rock units in the mine region including the greenstone, greenstone schists and slate, from Gastineau Channel to the intrusive contact of the main Coast plutonic complex. The position of these dikes, however, is only shown on Figure 8.10 where they occur in the area of black slates hosting gold veins. A detailed geology map by Wernecke (1932) showing the distribution of ore bodies in the area of Gold Creek (North ore body), indicates that the gabbro bodies comprise nearly 50% of the slate belt in that area. These intrusions are from 3 to 60 metres in width and form irregular fingered laccolithic bodies or chonoliths and sills. They are dark-green to black in colour and commonly
schistose, but where less deformed, they display a moderately coarse-grained, granular texture. They are described as being hornblende-rich (secondary hornblende after pyroxene) but no quantities of the mineral are reported. Wernecke (1932) interpreted the gabbro, which intrudes the older tuffs and slates, to be sills and laccoliths feeding Early Jurassic mafic volcanic rocks. Recent interpretations (Newberry and Brew 1987, Goldfarb, et al., 1988a, 1990, 1991) are consistent with a Mesozoic age for these intrusions, although they are undated.

**MINERALIZATION**

Gold-quartz vein mineralization at the Alaska-Juneau deposit occurs in metagabbro and amphibolite bodies and in black slates immediately adjacent to metagabbro. Relatively continuous tabular quartz veins occur occasionally within the metagabbro. Many of the deposits, however, consist of broad irregular zones of numerous dispersed quartz stringers that fill irregular fractures in the slate.

Mine workings extend along the hillside over a strike length of almost half a kilometre and over a roughly 230 metre-wide zone. The ore occurs as irregular and discontinuous concentrations of quartz veins and veinlets that constitute typical ‘stringer leads’ (Spencer, 1906) or ‘stringer lodes’ (Wernecke, 1932). Although sparsely distributed along the zone these quartz veins are locally numerous and constitute ore where closely spaced, which in the early days permitted mining by open pit.
Bodies of quartz stringers in these broad mineralized zones occur in irregular, elliptical, isolated or discontinuous pipe-like groups along fracture ridges or tongues of carbonate-sericite-pyrite altered metagabbro (Wernecke, 1932). Vein filling is relatively uniform, consisting of either quartz or calcite, with negligible to several percent sulphide minerals that are locally abundant within some of the ore shoots. Where individual veins are well-developed they can be followed for several kilometres along strike. More commonly they are discontinuous and less than 100 metres in length.

Sulphide minerals include pyrite and arsenopyrite with lesser sphalerite, galena and chalcopyrite (Spencer, 1906; Wernecke, 1932). Pyrite is the most common sulphide mineral in the majority of the veins and is also common in altered mafic igneous wall rocks. Arsenopyrite occurs in many modes in the veins and in some it carries high gold values. Well-developed crystals and crystal aggregates are common. Sphalerite and galena occur in variable amounts, and only in the quartz veins. They are generally associated, with the former being more abundant. Chalcopyrite is minor but ubiquitous in the quartz veins.

Similar to the Mother Lode, gold was also recovered from replacement ore, which Spencer (1906) referred to as ‘impregnated ore’. He reported that fracture fillings are well-developed at least locally in all rock types. Replacement is inconsequential in slate and is confined mainly to igneous rocks, in particular greenstone and diorite.

**AGE OF MINERALIZATION AND RELATIONSHIP TO TECTONISM**

Ar-Ar hydrothermal mica ages reported from five of the largest deposits developed along the 200 kilometre belt suggest that the veins were emplaced during a tightly bracketed time interval in the Early Eocene (ca. 53 to 56 Ma) (Figure 8.8.). This coincides with the late stages of orogenic deformation and is broadly coeval with intrusion of batholiths in the Coast Belt (Goldfarb, 1988a, b; Goldfarb et al., 1991; Miller et al., 1995). These data confirm the interpretations of Spencer (1906) and Wernecke (1932) that at least in part the ‘Coast Plutonic Complex’ is genetically related to gold vein mineralization at the Alaska Juneau deposits.

**SUMMARY**

- Alaska-Juneau is one of a number of gold-quartz vein deposits in the Juneau Gold Belt of southeastern Alaska. During its 40-year productive history close to 109 000 kilograms (3.5 million ounces) of gold were recovered from ores with a remarkably low average grade of 1.37 g/t (0.04 ounces/ton) gold.

- Gold-quartz veins of the Alaska-Juneau deposit are hosted entirely within a sequence of deformed and metamorphosed steeply-dipping intercalations of black slates and metagabbro, part of the Taku Terrane that lies immediately east of a terrane bounding suture, the Sundum thrust fault.

- Gold-quartz vein mineralization within the Alaska-Juneau deposit occurs in metagabbro and amphibolite bodies and black slates immediately adjacent to the metagabbro bodies. Relatively continuous tabular quartz veins occur in the metagabbro bodies. However, many of the deposits consist of broad irregular zones with numerous quartz stringers filling irregular fractures in the slate. Bodies of quartz stringers are arranged in these broad mineralized zones as irregular, elliptical, isolated or discontinuous pipe-like groups along ridges or tongues of carbonate, sericite, pyrite altered metagabbro.