DETAILED DEPOSIT FEATURES

Determining the detailed geological character of host rocks for most of the significant gold producing deposits in California and Alaska required the use of older classic works for the individual camps (Figure 1.2). In addition to providing detailed lithological descriptions and contact relationships, these works also provided an overwhelming amount of data of the detailed vein relationships. From these early descriptive works, the salient features consistent throughout are summarized herein. Such an exercise is considered both necessary and timely. Necessary, as it is a wealth of descriptive data that is often not adequately considered in generating recent deposit models. And timely, as many of these dated classic works are becoming increasingly difficult to obtain and impossible to replicate.

Knopf (1929) used the term ‘gold-quartz veins’ because this deposit type contains economic concentrations of gold either in quartz veins or in bodies of mineralized country rock marginal to the quartz veins. He stated that;

“the only systematic relations that appear unmistakably with reference to gold mineralization in the MotherLode is that unless it is a substantial body of quartz there is no ore; and where the vein enters a stringer lode it becomes barren. Only in places adjacent to a quartz shoot does a stringer zone constitute ore”.

The tenor of the vein material in these deposits is always dominated by quartz, with usually subordinate carbonate and less abundant albite. Sulphides are almost everywhere dominated by pyrite, usually with subordinate arsenopyrite, lesser sphalerite, tetsahedrite and minor chalcopyrite and galena. Total sulphides vary from trace to several percent and may locally be dominant within the limited extent of ore shoots. A generalized summary for some of these vein features and terminology applied to them is illustrated in (Figure A.2).

These veins display remarkable similarities in gangue mineralogy and metal signature, irrespective of location, but the geometry or style of the veins and types of alteration associated with them shows considerable variation. These variations primarily reflect differences in both the composition and physical character, or competency, of the original host rocks.

Variations in alteration (Figure A.2) result from two factors. Primarily, differences in original host lithology result in the greatest variability and produce distinctly different alteration also decreasing intensity of hydrothermal alteration of the individual units away from mineralized fissures results in a lateral, gradational zoning. In general igneous units are susceptible to hydrothermal alteration, with the more mafic-rich lithologies being the more intensely carbonatized whereas metasediments such as phyllites and slates are much less altered. Altered metasedimentary rocks typically contain several percent euhedral, disseminated pyrite grains adjacent to quartz veins and in selvages along the veins.

It has been long recognized that the persistence of the vein bearing fissures is a function of the competency of the host rock. At the Alaska-Juneau deposit vein geometry varies from discrete tabular bodies of quartz, commonly hosted by competent metagabbro and diabase, to zones of pervasive micro-veining in the slates. There Spencer (1906, p.23) found it necessary to qualify his use of the term vein to account for this variability. He wrote;

“The word vein is here applied to mineral aggregates of whatever form or extent, deposited from solution in fractures in the rocks.”

Even where hosted by competent bodies vein character has considerable variation. As pointed out by Lindgren (1896) the character of the fissure determines to a great extent the character of the vein. The zone of schistosity can vary from less than a metre up to 6 metres in width containing one or several quartz veins. Compound vein fissures with fractures formed over several feet, are usually separated by highly altered crushed and brecciated rock. Persistent veins are characterized by frequent pinches and swells along their length. Describing the character of the Empire vein at Grass Valley, Johnston (1940, page 88) wrote;

“The Empire fissure is not a simple break that can be followed continuously on the dip and strike; rather it is a zone of variable width and degree of shattering, within which the vein, as defined by the quartz filling, is confined”

VEIN EVOLUTION

Studies of vein paragenesis for most of the significant deposits e.g., Grass Valley (Johnston, 1940), Bralorne (Cairns, 1937), Alleghany (Ferguson and Gannett, 1934; Coveney, 1981), Cassiar (Hopper, 1984) and Quartz Hill (Elder and Cashman, 1992), indicate that there are progressive stages of vein development and that gold deposition is consistently late in their development. All investigators define at least three and sometimes more stages of vein development. There is an older quartz-dominant stage, and a younger stage dominated by carbonate, with free gold associated with the latter. Some authors identify a very early stage which Ferguson and Gannett, (1932) referred to as the chlorite stage and related to initial development of the host shear zone or vein fissure.

The early quartz stage is the principle stage of vein formation, during which massive bull quartz is the primary gangue mineral. The earliest sulphides which include pyrite and arsenopyrite are deposited at this stage and are at least in part earlier than some of the early quartz.

A younger carbonate-bearing stage with associated gold mineralization is marked by the deposition of carbonates together with quartz and the associated sulphide minerals sphalerite, chalcopyrite, galena with or without
tetahedrite. These sulphides, unlike the pyrite and arsenopyrite which also occur in the host rocks, are consistently only found within the quartz veins. Gold is the latest metallic phase to be deposited and is often associated with galena, which are both later than sphalerite and chalcopyrite. The timing of sericite formation within the sequence of vein-forming is interpreted to take place at various stages according to the individual authors.

A significant observation is that in all the deposits described gold deposition is late and is most often concentrated in deformed parts of veins. Following an investigation of Alaska Juneau deposit, Wernecke (1932, page 405) states: "A remarkable fact is that in the quartz veins of the Alaska Juneau, Bendigo, the Mother Lode of California, and Nova Scotia the gold is younger than the quartz, and is deposited on the outside of the quartz or in fractures in the veins, associated with muscovite ankerite and some pyrite. Like effects should have like causes, even though different eminent geologists have formulated different theories for the different deposits."

Studies of gold-quartz vein deposits in France by Bonnemaison and Marcoux (1990) suggest that successive stages of vein evolution result in the progressive concentration of gold. These authors define three major evolutionary stages: an early stage with invisible gold, an intermediate stage of fine-grained gold and a late stage accompanied by coarse nugget gold. Their early stage, synonymous with the early chlorite stage of Ferguson and Gannett (1932) relates to the development of the host structure in which the rock is converted to schists and mylonites along restricted zones. This provides the fluid conduit and sites of subsequent dilation and vein development. In these early formed structures invisible gold is broadly disseminated in pyrrhotite and within the structure concentrated in pyrite. The second stage involves the deposition of quartz as lenses and veins in dilational zones with fine gold deposited in both quartz and altered hostrocks. The third stage is characterized by brittle

---

Figure A.2. Schematic representation of alteration products for different ophiolitic host rocks marginal to gold sulphide bearing quartz veins.
deformation of quartz with associated deposition of coarse gold in fractures.

These observations on the paragenesis of gold-quartz vein deposits suggests that they develop in a dynamic environment in which fluid source regions change over time.

**SULPHIDE MINERALS**

North American Cordillera gold-quartz vein deposits display a relatively limited, though consistent ore mineralogy. Although there is a range in overall abundance of sulphides between individual deposits, they all display a similar paragenesis. Sulphide assemblages typically include a combination of pyrite, arsenopyrite, sphalerite, chalcopyrite and galena with or without tetrahedrite and pyrrhotite.

The data are in large part constrained by visual observation. In limited instances where modern day analytical techniques have been applied like scanning electron microprobe (SEM) analysis, it shows that an extended range of sulphides is present. Veined quartz in listwanite-altered ultramafic rocks examined at both Alleghany (Wittkopp, 1983) and Atlin (Chapter 2) reveals that the nickel arsenide gersdorffite (NiAsS) is common where associated with ultramafic rocks. Bonnemaison and Marcoux (1990) found that both ulmmanite (NiSbS) and gersdorffite (NiAsS) are present in all listwanites studied from France, China and Arabia with millerite (NiS) being common but less consistent.

**Pyrite** is the most abundant sulphide mineral in all vein deposits. It is everywhere the most abundant sulphide in altered and mineralized wallrocks and is the most abundant mineral recovered by gravity on concentrating tables during the milling of ores. The bulk of its deposition is earlier than, or contemporaneous with the earliest vein quartz in association with arsenopyrite.

**Arsenopyrite** paragenesis throughout the deposits is similar to that of pyrite but its relative abundance is highly varied. The bulk of the mineral is formed early during the initial quartz stage and is characterized by well-developed pyramidal crystals and crystal aggregates. At many of deposits such as Bralorne-Pioneer (Carriens, 1937), Alleghany (Ferguson and Gannett, 1932), Alaska-Juneau (Spencer, 1906) and in the central Mother Lode (Knopf, 1929), coarse arsenopyrite consistently coincides with extraordinarily high gold content. This was the general nature of most gold ore at Alleghany, which is renowned for this style of gold-rich pockets with coarse arsenopyrite. Though generally less abundant, arsenopyrite is also found as a minute acicular crystals in late veins. In contrast to most other deposits it is rarely reported at Grass Valley (Lindgren, 1896; Johnston, 1940).

**Sphalerite** is more abundant than galena and the two generally occur together. They are present in variable amounts and can locally be abundant. In most cases galena and to a lesser degree sphalerite are contemporaneous with gold. At Grass Valley sphalerite is abundant and widely distributed and occurs in quartz within almost every vein. Throughout California galena has been consistently considered as the most favorable indicator of gold (Lindgren, 1896; Ferguson and Gannett, 1932; Johnston, 1940). Knopf (1929) indicated that among all the sulphide minerals galena is the only reliable indicator of gold mineralization.

**Chalcopyrite** is comparatively rare, but generally is widely distributed in small quantities throughout most veins but in some mines it can be locally conspicuous. Johnston (1940) suggested that it belongs to the same age group as the sphalerite and galena, being later than the pyrite. At Cassiar, however, Hopper (1984) found that chalcopyrite forms isolated blebs and rims on sphalerite and tetrahedrite, indicating that it is at least in part later, likely formed by exsolution.

**Tetrahedrite** is one of the most varied in abundance of the sulphide minerals between these deposits. In a number of camps it is relatively common sulphide, for example Grass Valley and Cassiar. At most other deposits it was either not recognized or extremely rare.

**Bismuth** sulphides have been described from the Barkerville deposits, where they are associated with native gold in the quartz veins (Skerl, 1948; Sutherland Brown, 1957). Scanning electron microprobe investigation of sulphide grains in quartz veins from the Atlin camp (Chapter 2) reveal that both bismuthinite and tetradymite are present at several gold occurrences.

**Stibnite** has been rarely described from these gold deposits in any of the significant gold-producing mines. In the underground workings of one of the mines at the southern end of the Mother Lode stibnite occurs along a distinct fracture zone that was clearly later than the gold-quartz veins (Knopf, 1929). At the Snowbird deposit, a past producer of the mineral in central British Columbia (Chapter 3) it is the predominant sulphide mineral. The paragenetic relationship between the gold and stibnite at this deposit has not been determined.

**Gold** is invariably late in the history of vein paragenesis and it is generally present in the deformed, sheared and ribboned parts of the early-formed quartz veins. Free, native gold is found only in the quartz veins, and is contained within or closely associated with sulphide minerals, often filling fractures or as inclusions in association with galena. In hydrothermally altered wall rock gold is microscopic and usually within pyrite and less often arsenopyrite.

The association between gold and sulphide minerals is a consistent one, increased sulphide content reflect increased gold values. Knopf (1929) referred to this relationship as being:

“the only visible feature that distinguishes some but not all ore shoots from the remainder of the vein.”

Significantly, this consistent increase is not a dramatic one, with amounts of sulphide minerals increasing from trace to a few percent (1-4%).

**DISTRIBUTION OF GOLD ORE**

An early-recognized and often reiterated feature of these vein systems is that the distribution of gold ore within them is extremely erratic. Economic concentrations are referred to as ‘ore shoots’ or ‘pay shoots’ with smaller areas of limited extent (roughly a metre or less) and irregular form
termed pockets. As a rule, pay shoots are long-drawn bodies with maximum extension in the direction of dip (Lindgren, 1896). Ore shoots with a regular long-drawn form were referred too as 'chimneys'.

In the Mother Lode, Knopf (1929, p. 27) described ore shoots as short, generally a small fraction of the vein with shoots up to 300 metres in length being exceptional and 60 to 90 meters being closer to the average stope length. Ore shoots generally occur where there are abrupt bulges in the vein and commonly fray out into stringer lodes that eventually become unproductive. Knopf (1929) uses the Empire shoot at the Plymouth Mine as an example from which over 300,000 ounces of gold was recovered from a shoot that was only 140 meters of the greater than two kilometre strike length of the vein. An important feature of the Mother Lode belt is that most of the ore shoots did not crop out on surface. Gold ore on the Central Eureka vein, for example, was not encountered until a depth below surface of 335 metres.

Consistent relationships documented for all the developed mines regarding the localization of pay shoots within these vein systems can provide camp-scale exploration guidelines. These features relate specifically to the late stages of gold deposition within the brittle and deformed parts of the veins and are related to localized structural conditions that promote brittle fracture. The most prevalent observation relates to the localization of many shoots to the intersection or junction of veins. Knopf (1929, page 29) stated:

"The earliest generalization that has stood the test of time is that point and junction and intersection of veins are favorable to the occurrence of ore."

Ferguson and Gannett (1932) studied the peculiar concentration of gold in high-grade shoots of the Allegheny district. They found that areas in which physical conditions favored the fracture of the vein prior to the introduction of the gold were seen as most promising. Such fracturing is largely dependent on changes in strike or dip of the vein with such changes commonly found when domains are near serpentinite and at junctions of veins, or where veins have been faulted prior to the introduction of gold.

Although for most deposits ribbon quartz is a good indicator of ore, ribbon quartz is not always mineralized. In the same manner, vein intersections, although common loci for gold ore shoots, do not always contain gold.

**EXPLORATION CRITERIA**

Deep crustal faults with extensive carbonate alteration are clearly indicated by the presence of listwanite-altered ultramafic rocks. Although gold-quartz veins are not generally hosted by listwanite, the richest gold veins are almost always found in shoots close to the ultramafic rocks, usually within competent tectonic blocks of plutonic to hypabyssal crust that are in faulted contact with the listwanite-altered ultramafic rocks. A definitive spatial and temporal relationship to high-level felsic intrusive rocks is either defined (Bralorne, Atlin, Snowbird, Alaska-Juneau) or suggested (Alleghany, Grass Valley).

Undoubtedly it appears that ultramafic rocks, particularly where carbonatized, are important as indicators and perhaps vectors to gold-quartz vein mineralization. Ultramafic rocks in British Columbia have received considerable attention for potential economic concentrations of asbestos, jade, magnesite, chrome-ite and talc. Occurrences of these commodities have been summarized, notably: jade (Leaming, 1978), chromite (Hancock, 1990), magnesite (Grant, 1987), talc (MacLean, 1988) and asbestos (Harvey-Kelly, 1995). These works provide information about the distribution of such rocks throughout the province. The report on magnesite (Grant, 1987) is particularly relevant for isolating specific occurrences of carbonate-altered ultramafic rocks.

Significant gold-quartz vein deposits are characterized by silicification, sulphidation and potassic metasomatism in alteration envelopes within broader carbonate-alteration haloes. Systematic surface mapping that focuses on the distribution and intensity of the listwanite alteration suite is critical in identifying potential fracture-controlled veins. This alteration zonation can therefore be used to provide a vector for locating the zones of dilation and fluid flow, now marked by quartz veining.

Alteration envelopes surrounding productive gold-quartz veins in ophiolitic mafic to intermediate plutonic rocks (gabbros, diorites and trondjemites) are typically more subdued than those associated with mafic volcanic or ultramafic rocks. Altered wallrock margins are relatively narrower (<1 to 3 metres) and the lower primary Mg-Fe content of these mafic plutonic rocks compared to that of associated more mafic rocks results in much less visibly conspicuous weathered exposures. Both these features suggest that gold-quartz veins and their related alteration envelopes in the most prospective host rocks will be more elusive than the commonly associated listwanite-altered ultramafic rocks, particularly in areas of significant overburden.

Collisional suture zones containing relatively coherent blocks of oceanic plutonic crust that are intruded by late syn-orogenic plutonic rocks are prime targets. Detailed exploration of a prospective fault zone should focus on segments with alteration characteristics indicative of carbonate, potassium and sulfur metasomatism.