Chapter D

Gold Deposits in Metamorphic Rocks—Part I

Gold in the United Verde Massive Sulfide Deposit, Jerome, Arizona

By ED DEWITT and JEROME WAEGLI

The Alaska-Juneau and Treadwell Lode Gold Systems, Southeastern Alaska

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The Alaska-Juneau and Treadwell Lode Gold Systems, Southeastern Alaska

By Thomas D. Light, David A. Brew, *and* Roger P. Ashley

Abstract

The Alaska-Juneau and Treadwell lode-gold systems (or deposits) in southeastern Alaska produced more than 6.7 million ounces of gold, about 75 percent of the total lode gold production from Alaska. Each system consists of four separate contiguous ore bodies aligned in a northwesterly direction along the regional structural trend. The composition and competence of the stratigraphic units as well as the structural setting were major factors in localizing the individual ore bodies. At the Alaska-Juneau deposit, gold, silver, and lead occur in quartz veins in hydrothermally altered amphibolite, phyllite, and schist. Albite diorite sills at the Treadwell deposit host gold-bearing calcite and quartz veins and stringers as well as disseminated gold. Both lode-gold systems were emplaced, probably between 50 and 60 million years ago, at or near the end of a major regional compressive stress event and before or during the uplift of the Coast Mountains. Fluid inclusion and isotopic compositions suggest that the ore-forming fluids were derived from the metamorphism of deeper rocks rather than from circulating meteoric waters. These physical, chemical, and temporal conditions coincide with the transition from strongly compressive subduction to transpressive collision along the western margin of North America, and indicate an environment of formation similar to that of the California Mother Lode deposits.

INTRODUCTION

The Alaska-Juneau (A-J) and Treadwell systems represent the two largest lode gold deposits in Alaska, and together produced more than 6.7 million oz of gold. These deposits are located about 6 km apart on opposite sides of Gastineau Channel near Juneau, along the western flank of the Coast Mountains in southeastern Alaska (fig. D11). The deposits lie in the western metamorphic zone of the northern Coast plutonic-metamorphic complex (Brew and Ford, 1984a).

The A-J system comprises four separate ore bodies in Silverbow Basin in upper Gold Creek: the Ebner mine on the northwest end of the system, the North and South ore bodies of the Alaska-Juneau mine, and the Perseverance mine to the southeast (fig. D12). The Treadwell system on Douglas Island includes, from northwest to southeast, the Treadwell, the 700-Foot, the Mexican, and the Ready Bullion mines, located contiguously along 1,200 m of a mineralized albite diorite sill.

HISTORY, PRODUCTION, AND RESERVES

Gold was first discovered in Gold Creek, at the present site of Juneau, Alaska, during the summer of 1880 by Richard T. Harris and Joseph Juneau. Subsequently, placer deposits in Gold Creek and other nearby streams were worked for several years. The Alaska-Juneau Gold Mining Company was organized in 1897, and it mined open pits on both the North and South ore bodies in Silverbow Basin east of Juneau. Underground operations began in 1903 and continued until 1944 (Twenhofel, 1952).

The Ebner mine was worked intermittently until 1912, when U.S. Smelting and Refining Co. acquired the property. The property was idle from 1917 to 1925, when arrangements were made with the Alaska-Juneau Gold Mining Co. to mine and mill ore from the Ebner (Twenhofel, 1952). Spencer (1906) listed total production from the Ebner mine at about 29,000 oz gold. No figures are available for production after 1905.

The Perseverance mine began production in 1895, and was worked intermittently until it was acquired by the Alaska-Gastineau Mining Co. in 1912. From 1895 to 1921, approximately 500,000 oz gold was recovered from the Perseverance mine. The property was idle from 1921 until 1933, when it was purchased by the Alaska-Juneau Gold Mining Co. and was integrated into the Alaska-Juneau mine (Twenhofel, 1952).

Total lode production from the A-J system was approximately 3.5 million oz gold, 1.9 million oz silver, and 40.2 million lb lead (Berg, 1984). In addition, more than 120,000 oz gold was recovered from placer deposits in Gold Creek and Silverbow Basin (Spencer, 1906).

The A-J deposit was mined predominantly by modified block-caving, and hand-sorting was used to eliminate much of the waste. This hand-cobbing of the sulfide-bearing quartz veins eliminated approximately 45 percent of the rock mined, and raised the tenor of the ore from 0.045 to 0.086 oz Au/ton (Wayland, 1939;

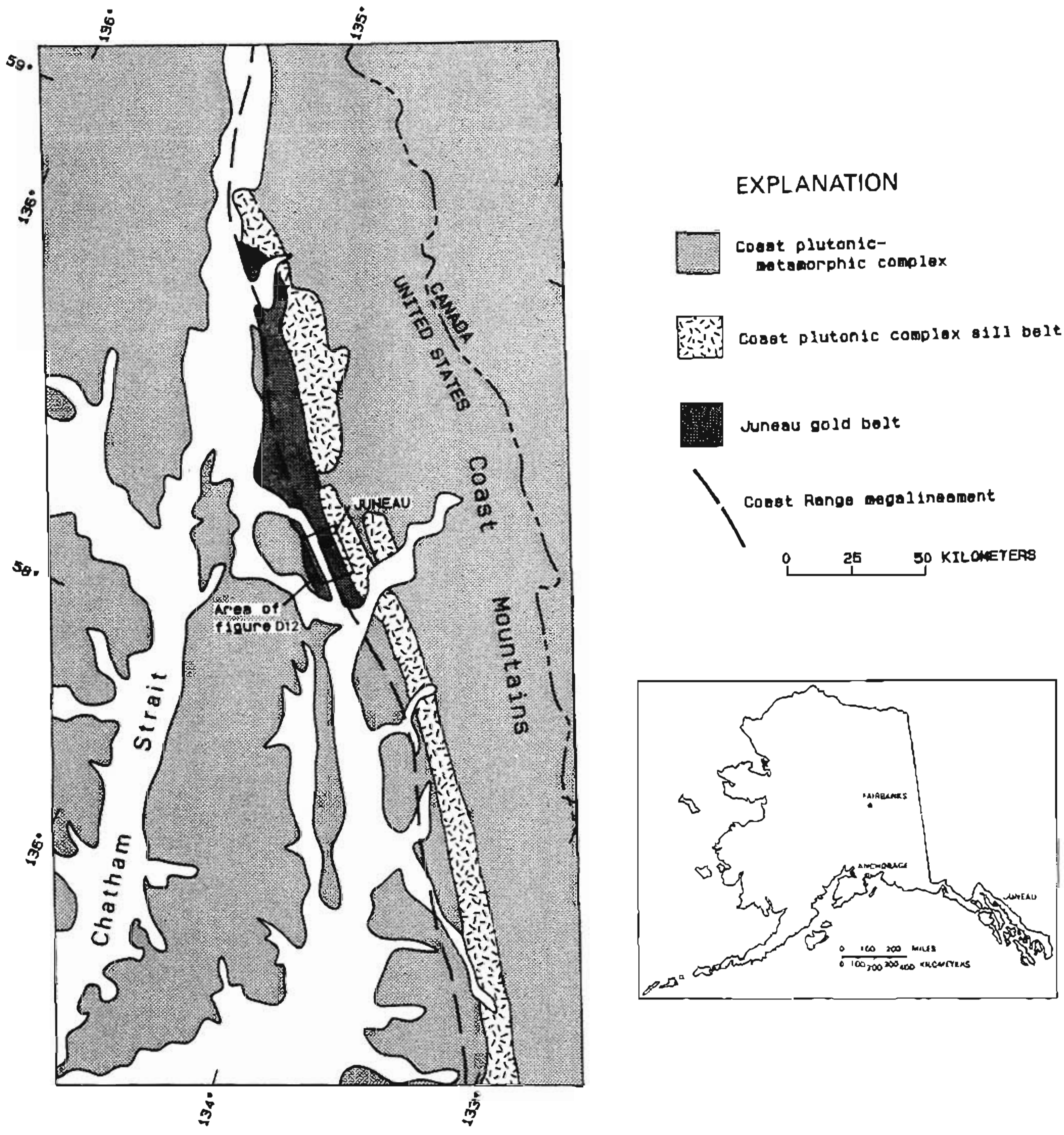

Figure D11. Index map of southeastern Alaska showing the location of Juneau.

Twenhofel, 1952). Mining at the Alaska-Juneau mine ceased in April 1944. At that time a total of 99,000,000 tons of ore had been mined from the A-J system, and the known ore reserves were about 1.4 million oz gold (Stone and Stone, 1980).

The Alaska Mill and Mining company was founded in 1882 and worked the Treadwell mine, of the Treadwell system. This property was acquired by the Alaska Treadwell Gold Mining Company in 1889. The Alaska Mexican Gold Mining Company owned the Mexican mine, and the Alaska United Gold Mining Company owned the 700-Foot and Ready Bullion mines. The companies were financially separate, but the Alaska Treadwell Gold Mining Company managed all the properties. The

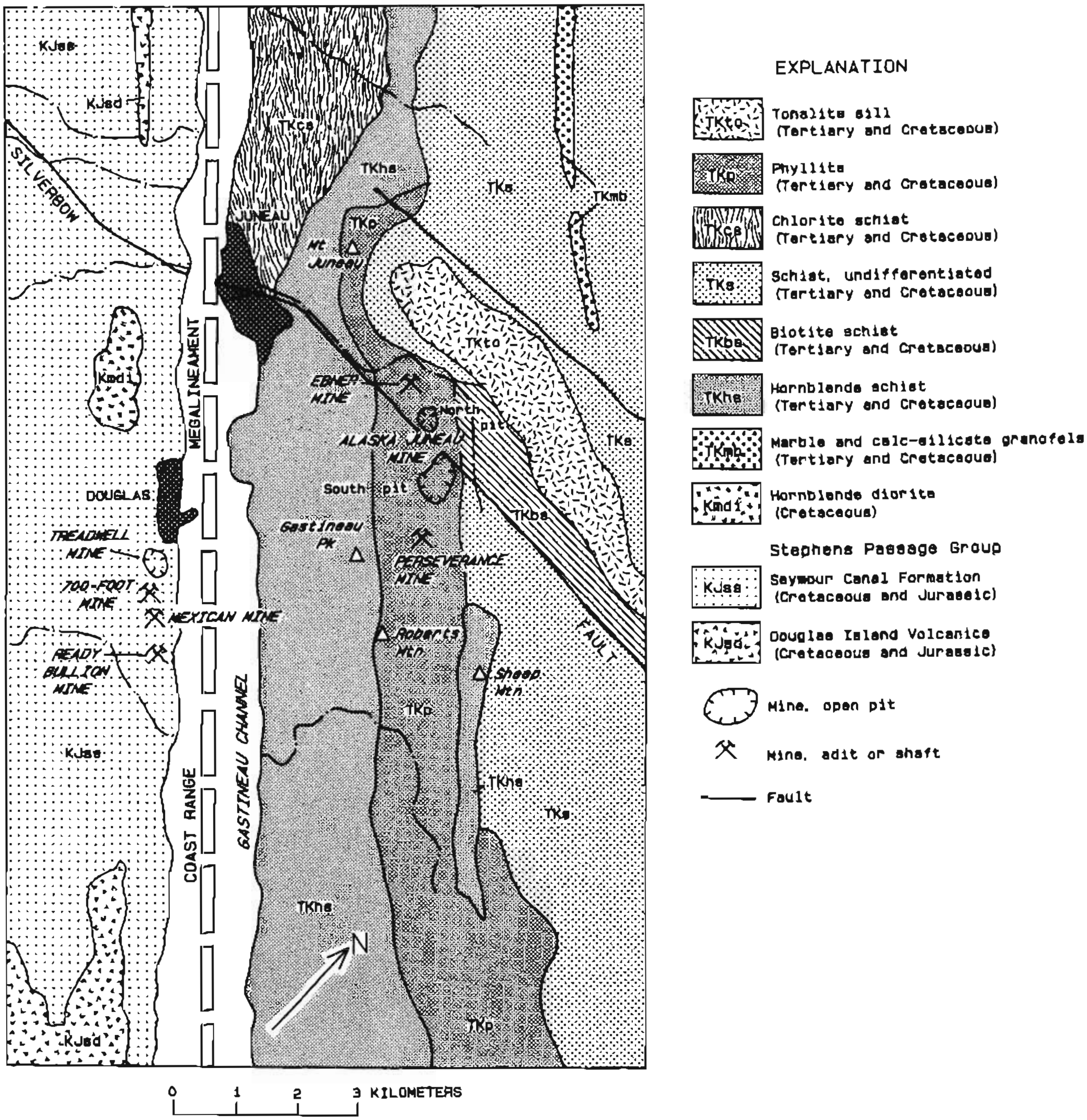

Figure D12. Generalized geologic map of Juneau area showing locations of mines in the A-J and Treadwell systems (from Brew and Ford, 1985).

Treadwell system, comprising the Treadwell, 700-Foot, Mexican, and Ready Bullion mines, was worked to a depth of about 950 m, below which the gold grade became uneconomical. In addition to the underground workings, the Treadwell mine operated an open pit until 1906. At that time the glory hole was 550 m long, 140 m wide, and 150 m deep (Stone and Stone, 1980).

More than half the ore produced from the Treadwell system came from the Alaska-Treadwell mine (Stone and Stone, 1980). The 700-Foot mine was named for the width of the strip of land which separated the Alaska-Treadwell and the Mexican mines. Approximately 247,000 oz gold was produced from the 700-Foot mine (Wells and others, 1985). The Ready

Bullion mine was separated from the Mexican mine by 1,000 m of nearly barren ground on the surface, but productive underground workings from the two mines extend nearly this entire distance (Spencer, 1905). The Ready Bullion and the Mexican mine each produced more than 500,000 oz gold (Wells and others, 1985).

The Alaska-Treadwell, Mexican, and 700-Foot mines partially caved and were flooded by seawater in 1917. The Ready Bullion mine continued to operate until 1922, when decreasing ore tenor forced closure. In 1928 the Treadwell complex was sold to the Alaska-Juneau Gold Mining Co. Total production for the mines in the Treadwell system was approximately 29 million tons of ore containing 3.2 million oz gold, for an average concentration of 0.11 oz Au/ton (Stone and Stone, 1980; Berg, 1984). No figures are available for total silver or lead production.

In 1972 the Alaska Electric Light and Power Company and the City and Borough of Juneau acquired all the properties that constitute the A-J and Treadwell systems (Stone and Stone, 1980). In 1988 the properties were under lease to Echo Bay Mining Company to evaluate the potential for additional development.

COMPARISONS WITH SIMILAR DEPOSITS

The A-J and Treadwell systems comprise a group of mesothermal to hypothermal quartz veins that postdate deformation and regional metamorphism in an accretionary continental margin setting. In the A-J, hydrothermal alteration, vein mineralogy, and chemistry of mineralizing fluids have been considered similar to the California Mother Lode system (Leach, Goldfarb, and Light, 1987). Both the A-J and Treadwell deposits have many features in common with low-sulfide, gold-quartz veins (Cox and Singer, 1986), also described as orogenic gold-quartz veins (Bohlke, 1982); but both deposits also have important features that are not typical of gold-quartz veins. In the case of the A-J deposit, all major features of geologic setting, ore and gangue mineralogy, alteration effects, and ore controls are typical of low-sulfide gold-quartz veins, except for the effects of unusual biotitic alteration, and the effects of carbonate alteration that are less prominent than in most other deposits. In addition, grade and tonnage characteristics of the A-J are strikingly different from those of more than 300 low-sulfide gold-quartz deposits used by Cox and Singer (1986) to define cumulative grade and tonnage curves for this deposit type. The gold grade of ores from the A-J is lower and the tonnage higher than in any deposit in the Cox and Singer data base, and data for the A-J were not included in their grade and tonnage curves.

The Treadwell system has a number of features that are unusual for low-sulfide gold-quartz veins, including character of alteration effects, gangue, and ore minerals. Carbonate is a prominent alteration and gangue phase in the Treadwell system and is typical of low-sulfide gold-quartz deposits. However, at the Treadwell the carbonate is calcite rather than the more common ferroan carbonate. The ore mineral suite includes arsenic-bearing minerals such as realgar, orpiment, and native arsenic, which are more commonly associated with shallower and lower temperature deposits. The most unusual feature, perhaps, is the paucity of quartz in the gangue assemblage. Tonnage and grade values for the Treadwell, however, fall on the curves of Cox and Singer (1986), and the Treadwell was included in their low-sulfide gold-quartz-deposit data base.

Smaller deposits are scattered throughout the Juneau gold belt, which extends for more than 160 km along the western flank of the Coast Mountains, from Comet on the north to Holkham Bay on the south. The gold deposits that define the Juneau gold belt occur along both sides of the Coast Range megalineament and along the western edge of a tonalite sill in the western Coast plutonic-metamorphic complex (Brew and Ford, 1984b). Although little detailed information is available on ore and gangue mineralogy, wallrock alteration effects, grades, production, or reserves for these deposits, they appear to be mostly typical low-sulfide gold-quartz veins, with quartz as the major gangue mineral. Sulfide mineralogy commonly is relatively simple, and is dominated by arsenopyrite, pyrite, pyrrhotite, galena, chalcopyrite, and sphalerite (Spencer, 1906).

ALASKA-JUNEAU SYSTEM

The A-J system occurs in the structurally lowest part of the Perseverance Slate, a 1.5-km-wide belt of carbonaceous and graphitic quartz-sericite phyllite, schist, and black slate with minor carbonaceous limestone and numerous sill-like lenses of amphibolite (fig. D13). The slates are bounded by greenstones to the west and schists to the east, all striking N. 50°–70° W., parallel to the regional structural trend. The slates dip from vertical in Sheep Creek on the south, to about 60° NE. in Silverbow Basin, and to 40° NE. farther to the northwest (Wayland, 1939). The age of the protoliths of the Perseverance Slate and adjacent metavolcanic rocks is interpreted to be Permian(?) and Late Triassic (Brew and Ford, 1977).

The amphibolite lenses within the Perseverance Slate range in size from a few centimeters wide and several meters long to more than 300 m wide and 3 km long. The amphibolites were derived from a gabbroic protolith (composed of hornblende, augite, and

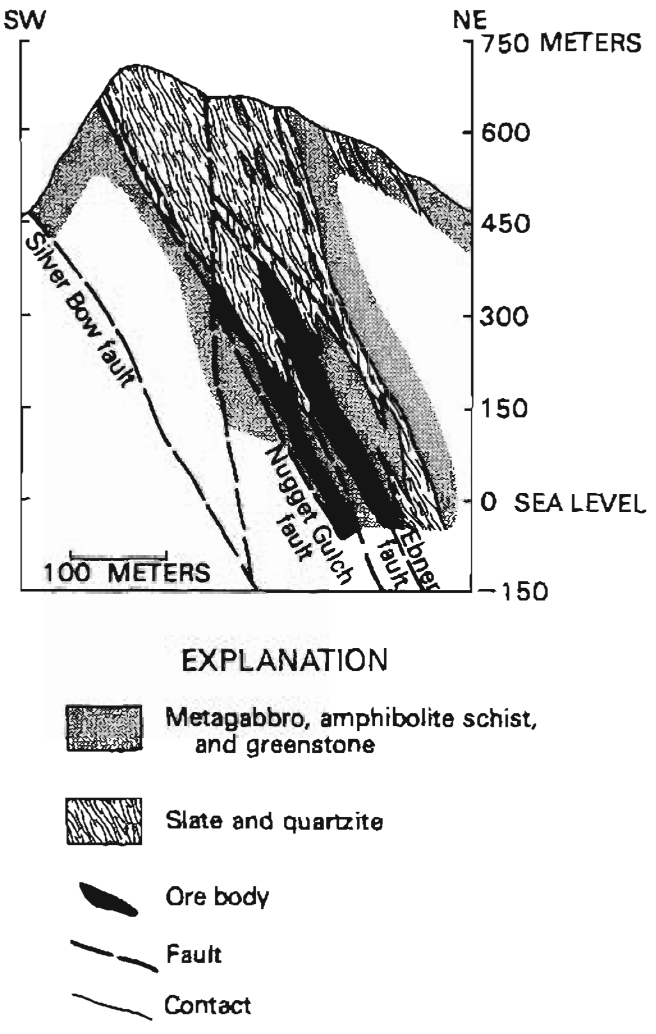

Figure D13. Cross section through the North ore body of the Alaska-Juneau mine (from Wernecke, 1932).

labradorite) during regional metamorphism (Twenhofel, 1952). Two types of amphibolite have been recognized. One is a green, relatively unaltered rock composed of about 50 percent hornblende in a groundmass of plagioclase, quartz, and zoisite. The other type is a brown amphibolite derived from the green amphibolite by hydrothermal alteration associated with the emplacement of the mineralized quartz veins. This hydrothermal alteration formed biotite, ankerite, and sericite with some chlorite and albite at the expense of hornblende and feldspar, and destroyed the schistosity of the amphibolite (Twenhofel, 1952). The brown amphibolite is composed of about 35 percent biotite, 35 percent ankerite, 20 percent feldspar (andesine to oligoclase with minor albite), and varied amounts of pyrrhotite, chlorite, and sericite. Most of the ankerite is later than and follows the quartz veins (Wayland, 1939).

Effects of hydrothermal alteration have been traced as much as 1 km away from the mineralized zone of the A-J system, and they increase progressively toward the center of the system. Initially magnetite, and closer to the deposits both magnetite and ilmenite, disappear at the expense of pyrrhotite±pyrite (Newberry and Brew, 1988).

Numerous faults cut the slates and greenstones in the vicinity of the ore bodies. Most of the faults are parallel or subparallel with the foliation and compositional layering, but splitting and converging of the faults are common (Wayland, 1939). Three sets of joints that predate the mineralized veins have been recognized: N. 30° E., 76° NW.; N. 34° W., 40° SW.; N.-S., 45° W. (Twenhofel, 1952). The Alaska-Juneau deposit has been cut by the Silverbow fault, trending nearly east-west and dipping 75° N., and hundreds of subsidiary faults (Twenhofel, 1952). The Silverbow is an oblique normal fault with the north side (hanging wall) moved about 550 m to the west and downward about the same distance (Wayland, 1939).

The A-J vein system extends laterally 6 km from Mt. Juneau southeast to Sheep Mountain, and is restricted to the lower 100 m of the Perseverence Slate. The system extends vertically from the surface to a depth of more than 700 m and contains numerous gold-bearing quartz veins and stringers from a few centimeters to 1 m in width. Individual veins extend horizontally for a few tens to several hundred meters, and have height-to-width ratios ranging from 1:1 to more than 50:1 (Barton and Light, 1987). Early barren veins reportedly tend to follow the trend of the schistosity (Wayland, 1939). The gold-bearing quartz veins have well-defined walls within both the slate and amphibolite. The veins commonly make an angle of about 20° to the schistosity, strike from north to N. 70° W., and dip nearly vertical (Wayland, 1939). The veins are boudinaged in both the vertical and horizontal planes, indicating extension in more than one direction, and in places have been sheared and rotated (Barton and Light, 1987). Because the veins have a fairly consistent gold content, the most favorable ground is that with the greatest density of veining. The gold grade may be higher in veins near interfingering slate and amphibolite. High gold concentrations do not occur in veins restricted either to the massive green amphibolite or to slate without amphibolite lenses (Twenhofel, 1952).

The veins of the A-J system are about 95 percent quartz with subsidiary ankerite, pyrrhotite, galena, sphalerite, arsenopyrite, pyrite, and gold (Twenhofel, 1952). Wayland (1939, 1960) described the paragenetic sequence of base and precious metals at the Alaska-Juneau mine (fig. D14). The gold in the A-J deposit is contained almost entirely within the quartz stringers and veins (Wayland, 1939). Gold is the last of the metals to have been deposited, and it tends to be concentrated with

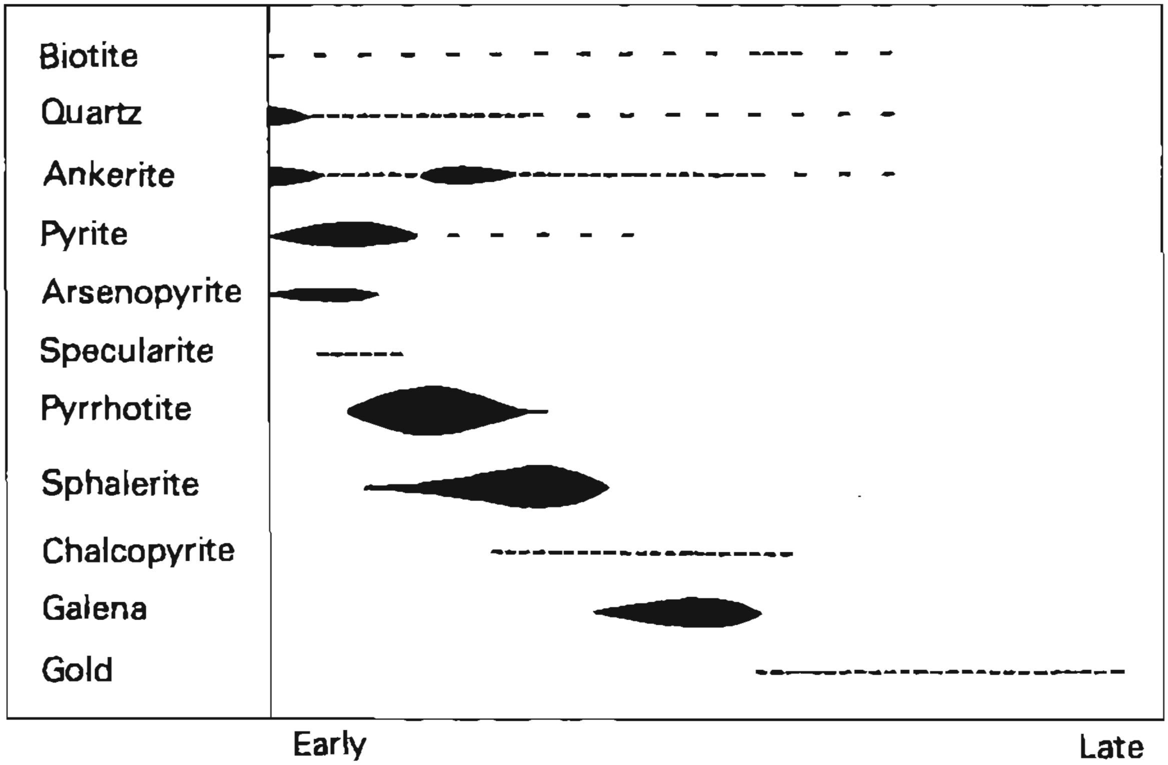

Figure D14. Paragenesis of minerals in the Alaska-Juneau South ore body (from Wayland, 1960).

sulfide minerals along the edges of the larger quartz veins, along the boundaries of sulfide minerals, and in late fractures in ankerite and quartz. Although much of the gold occurs along sulfide boundaries, approximately 90 percent is free gold and is easily released during crushing (Twenhofel, 1952). Silver occurs in recoverable quantities in the A-J deposit. Native silver is not known to occur, and it has been estimated that 23 percent of the silver occurs with gold in electrum, and the remainder is combined with galena (Twenhofel, 1952).

Pyrrhotite is by far the most common sulfide mineral, and occurs in the altered wallrocks as well as in the quartz veins (Wayland, 1939). Pyrrhotite constitutes almost 1 percent of the vein material in the Alaska-Juneau mine, but does not appear to be correlated with gold distribution (Twenhofel, 1952). The abundance of pyrrhotite in the A-J system was interpreted by Newberry and Brew (1987) as one line of evidence supporting an epigenetic rather than syngenetic mineralization. Sphalerite is abundant in the Alaska-Juneau mine; it is essentially contemporaneous with pyrrhotite and predates most of the galena. Galena also is abundant in the Alaska-Juneau mine, and is one of the last sulfides to be deposited. It normally occurs near the center of quartz stringers (Wayland, 1939). Pyrite and arsenopyrite are common sulfide minerals in the A-J deposit and were among the earliest sulfides to be deposited (Wayland, 1939). Chalcopyrite occurs in minor amounts in the A-J deposit, commonly associated with sphalerite (Twenhofel, 1952).

Ankerite, aside from quartz, is the most abundant gangue mineral, and it normally occupies the edges of veins, separating the quartz from the country rock. Ankerite formed later than all the other minerals except gold (Twenhofel, 1952). Sericite occurs both in the host rocks as a metamorphic mineral and as a late-stage hydrothermal mineral along vein edges (Twenhofel, 1952). In general, the abundance of sulfide minerals in the veins increases from the Ebner deposit, where sulfides are minor and pyrrhotite is the dominant species, to the South ore body, where sulfides are abundant and varied. Southeast of the South ore body, at the Perseverance mine, pyrrhotite is still the dominant sulfide, but sphalerite and galena are more abundant and arsenopyrite reaches its greatest abundance. The sulfide content decreases in Sheep Creek (immediately south of the Perseverance mine), where sphalerite and galena dominate. The gold:silver ratio gradually decreases to the southeast. Gold:silver ratios from the Ebner mine were 7:1 (Spencer, 1906) and 6.5:1 (Scott, 1932). Smith (1941) reported a gold:silver ratio of 5.6:1 for the South ore body. At the Perseverance mine, gold:silver ratios vary from 1:1 (Wayland, 1939) to 1:3 and 1:10 (Spencer, 1906).

Analyses of fluid inclusions in sulfide-bearing quartz veins from the South ore body of the Alaska-Juneau mine indicate that the ore fluids can be characterized by the H_2O-CO_2-N_2-NaCl system (Goldfarb and others, 1986). CO_2 is the dominant gas and is estimated to compose 30–60 bulk mole percent of the ore-forming fluids at the Alaska-Juneau mine (Leach, Goldfarb, and Hofstra, 1987). H_2O-rich and CO_2-rich inclusions, interpreted as being coevally trapped, represent immiscible fluids trapped in a boiling system. A minimum trapping pressure of 1.5 Kb, a minimum depth of emplacement of 5.5 km, and a minimum trapping temperature of 230 °C were determined from the intersection of isochores for the two types of fluid inclusions (Goldfarb and others, 1986). The intense hydrofracturing of the metasedimentary host rocks, which contributed to the development of abundant quartz-carbonate veins at the Alaska-Juneau south pit, was probably caused by fluid immiscibility (boiling) of the mineralizing fluids (Leach, Goldfarb, and Light, 1987).

A preliminary oxygen-isotope study yielded $\delta^{18}O$ values ranging from +17.1 per mil to +18.1 per mil for quartz vein material from the Alaska-Juneau mine (four samples). Assuming isotopic equilibrium between quartz and fluid at a minimum temperature of 230 °C for deposition of the vein quartz, the hydrothermal fluids that produced the deposit would have had $\delta^{18}O$ values in the range of +6 to +8 per mil, which is within the range of values inferred for primary magmatic waters (Taylor, 1979). However, if temperatures of deposition of vein quartz significantly exceeded 230 °C, the $\delta^{18}O$ of hydrothermal fluids would be greater than the maximum value of +9 per mil for primary magmatic waters. Fluids with $\delta^{18}O$ in the range of +9 to +11 per mil, which would result from temperatures of deposition in the vicinity of 300 °C, match the range of values for waters isotopically equilibrated with volcanic rocks, volcanogenic sediments, or graywackes under greenschist- to amphibolite-facies conditions (+5 to +13 per mil; Taylor, 1979; Fyfe and Kerrich, 1984). Analyses of hydrothermal sericite from the Alaska-Juneau mine give δD values of −61 per mil and calculated values for fluids in equilibrium of −20 to −30 per mil. These values fall well within the metamorphic water field (R.J. Goldfarb, written commun., 1988).

The age of mineralization at the Alaska-Juneau South pit is believed to be about 55.3±2.1 Ma, based on a K-Ar age of sericite from a gold-bearing vein (Goldfarb and others, 1987). This age is supported by a Rb-Sr isochron at 57 Ma on vein materials (Rainer Newberry, written commun., 1987). Because the gold-bearing quartz veins cut the metamorphic foliation in the slates and phyllites, the maximum age of mineralization in the A-J system is also constrained by the age of the metamorphism, which has been dated at 57–60 Ma by U-Pb and K-Ar techniques (Newberry and Brew, 1988). The tonalite sill of the western Coast plutonic-metamorphic complex (Brew and Ford, 1984b) has been dated at about 67 Ma (Gehrels and others, 1984); it was emplaced shortly after the peak of metamorphism in the area of most intense deformation (Brew and others, 1976; Brew and Ford, 1984b). Compression related to the emplacement of the tonalite sill continued until approximately 60 Ma. Emplacement of the mineralized quartz veins in fractures was postkinematic and followed relaxation of the compressional stress field, and therefore the maximum age of the A-J system must be less than 60 Ma. Igneous rocks dated at 50 Ma (Gehrels and others, 1984) in the Juneau vicinity were emplaced at relatively shallow levels, compared with minimum vein emplacement depths of 5.5 km determined from fluid inclusion trapping conditions (Leach and others, 1986; Leach, Goldfarb, and Light, 1987), suggesting that these intrusions are younger than the veins and thus constrain the minimum age of the mineralizing system.

TREADWELL SYSTEM

The mines in the Treadwell system are in a series of altered and mineralized albite diorite sills that intrude the Seymour Canal Formation along the contact between the black slates that form the footwall (Treadwell Slate) and a greenstone unit that forms the hanging wall (Spencer, 1905). The black slates of the Seymour Canal Formation contain abundant carbonaceous material and are Jurassic to Cretaceous in age (Brew and Ford, 1977). In general, the foliation in the Seymour Canal Formation trends northwest, parallel to the regional structure, and dips about 50°–70° NE. Locally the slate beds have been distorted into small folds a meter or so across, probably formed during the intrusion of the diorite sills (Twenhofel, 1952). The greenstone, which forms the hanging wall of the ore deposits, is about 100 m thick, and is a highly altered diabase or andesite. It is locally schistose, and follows the strike and dip of the foliation in the encompassing slates (Spencer, 1905).

The mineralized diorite sills are several kilometers long and more than a hundred meters thick, and they parallel the regional structure. They are composed mainly of albite, calcite, and quartz, with lesser amounts of biotite, chlorite, epidote, hornblende, magnetite, pyrite, pyrrhotite, rutile, sericite, stibnite, and zoisite (Spencer, 1905). Intrusion of the sills into the Treadwell slate caused the development of some hornfels texture, but contact aureoles are limited in areal extent (Twenhofel, 1952).

Ore zones in the Treadwell system consist of base and precious metals disseminated (1) in the albite diorite sills and (2) in reticulated veins and stringers of calcite and quartz from a few millimeters to a few centimeters in width and constituting about one-fifth of the volume of the sills (Spencer, 1905). Calcite, by far the most abundant mineral, occurs in the veins and stringers and is disseminated throughout the sills. Disseminated quartz rarely occurs in the sills and is restricted essentially to the veins and stringers. Calcite commonly occurs without quartz, but where both minerals occur in the same veinlet, calcite normally occupies the border of the quartz veinlet and is disseminated into the sill rock (Spencer, 1906). Locally, gold-bearing veins and stringers extend out into the slates that form the footwall of the mineralized albite diorite sills (Spencer, 1905).

Three different types of ore have been recognized in the Treadwell system: (1) "white ore" is the most abundant and consists of mineralized and altered albite diorite sill rock; (2) "mixed ore" is formed where small fine-grained sills and stringers of albite diorite have pervaded the slate and where sulfides are disseminated throughout both the slate and sills; (3) "brown ore" is altered and mineralized slate adjacent to the sills and represents a minor portion of the total production (Spencer, 1905, 1906).

Metallic minerals constitute about 2 percent of the Treadwell ores. Pyrite, the most abundant sulfide, both is disseminated throughout the sill and occurs in the veinlets. Gold, chalcopyrite, galena, sphalerite, molybdenite, native arsenic, realgar, and orpiment have all been observed in small quantities (Spencer, 1905). Because the gold is irregularly distributed throughout the albite diorite sills, the major control of ore localization was probably the fracture-induced permeability of the rock. In general, higher gold concentrations tend to be associated with a greater density of quartz and calcite veinlets (Spencer, 1905). Although 60–75 percent of the gold is free milling, visible gold is rare in both the sill rock and the veinlets. Some of the gold is associated with the pyrite, but the distribution of pyrite and the distribution of gold seem to be largely independent (Spencer, 1905).

A preliminary oxygen-isotope study yielded $\delta^{18}O$ values ranging from +16.3 to +20.8 per mil for quartz-calcite-albite vein material from the Treadwell system. Values of δD of –62 per mil for hydrothermal chlorite yield calculated values of –20 to –30 per mil for fluids in equilibrium, and fall well within the metamorphic water field (R.J. Goldfarb, written commun., 1988). These values suggest that temperatures of vein deposition and isotopic composition of fluids were similar to those at the A-J system, and that the mineralizing fluids were released during metamorphism of rocks subducted beneath the Coast Mountains.

Neither the age of the albite diorite sills nor the age of mineralization in the Treadwell system is known. The sills may be as old as or younger than a 90 Ma intrusive event known from northeastern Admiralty Island, some 25 km to the southwest. The sills are not foliated and therefore postdate the major regional metamorphism of the adjacent rocks. Regional studies show that the Seymour Canal Formation, which is Late Jurassic and Early Cretaceous in age (Loney, 1964), underwent low-grade greenschist facies dynamothermal metamorphism sometime before 100 Ma. Metamorphism associated with the deformation of the Perseverance slate (62–69 Ma) overprints the effects of the earlier metamorphic event, and the two may not be distinguishable in the vicinity of the Treadwell system. The maximum age of mineralization in the Treadwell system is therefore interpreted to be no older than 90 Ma and may be younger than 60–69 Ma. The similarity in isotopic composition and paragenesis between the Treadwell and A-J systems suggests that the Treadwell system is equivalent in age to the A-J system.

CONCLUSIONS

The A-J (Alaska-Juneau) system is restricted to a 6-km-long zone in the lowest 100 m of the carbonaceous Perseverance Slate, just above the greenstones of the Gastineau Volcanic Group. The highest gold concentrations are found in quartz veins and stringers near where altered amphibolite lenses finger out into the slate. The slate has both well-developed joint sets and a locally well developed axial plane cleavage. These relationships suggest that lithology and permeability were important factors in localizing ore deposition.

The Treadwell system occurs as reticulated veins and stringers in a highly fractured albite diorite sill 70 m wide and 3 km long. Gold is disseminated throughout the sill and also is hosted in calcite and quartz veins and stringers cutting the dike and footwall slates. The placement of the albite diorite sill between ductile greenstone and slate walls probably intensified the fracturing of the sill and greatly increased the permeability, which contributed to the localization and concentration of the ores.

The postmetamorphic intrusive rocks of the Coast plutonic-metamorphic complex have been thought to be related to the genesis of gold deposits in the Juneau gold belt (Dawson, 1889; Spencer, 1906). Twenhofel and Sainsbury (1958) postulated that mineralization in the Juneau gold belt was spatially related to prominent northwest-trending features, one of which is known as the Coast Range megalineament (Brew and Ford, 1978); the megalineament is interpreted to represent the surface expression of the buried contact between the slates, phyllites, and greenstones to the southwest and the more coarsely crystalline plutonic and metamorphic rocks to the northeast. The location of the A-J and Treadwell systems on either side of this major lineament suggests that it had some regional influence on the migration of ore fluids. Ore distributions in both the A-J and Treadwell systems suggest that the mineralization was postkinematic and structurally controlled, and because the age of regional metamorphism may be the same at both deposits, both systems may have formed at about the same time.

The tonalite sill body closest to the the A-J deposit is well foliated and is enclosed in highly deformed rocks. It is currently interpreted to be prekinematic in relation to the major compressive deformation, while slightly more distant tonalite sill bodies are younger and are late synkinematic with respect to the regional metamorphism (Ford and Brew, 1981). The more distant sill bodies have been dated at 62–67 Ma (Gehrels and others, 1984). The fractures along which the mineralizing fluids were channeled were developed in a noncompressive regime, and postdate the regional metamorphism, both types of tonalite sill bodies, and also the slightly foliated plutons northeast of the tonalite sill that are dated at about 60 Ma (Gehrels and others, 1984). Nearby, 50 Ma intrusions are relatively shallow, based on regional considerations. The estimated emplacement depths of these intrusions are less than those inferred from the study of fluid inclusions in vein material. Still younger intrusions known to occur elsewhere in the Coast Mountains have been dated at about 20 Ma; they are very shallow and certainly postdate the mineralization. These relations are interpreted to limit the age of mineralization at the A-J deposit between 60 Ma and 50 Ma.

During the interval from 56 to 43 Ma, the relative motion along the western margin of southeastern Alaska changed from strongly convergent, with the northeasterly subduction of the Kula Plate at about 120 km/m.y., to transpressive, with the northward migration of the Pacific plate at about 40 km/m.y. (Engebretson and others, 1985). If the mineralization of the A-J and Treadwell systems occurred at about the same time, then both systems probably developed early in this period and were accompanied by uplift of the Coast Mountains. Relaxation of the regional stress field allowed the influx of large volumes of hydrothermal fluids from depth. The rapid migration of fluids caused intense fracturing in the more competent amphibolite lenses in the A-J system and in albite diorite sills in the Treadwell system. Significant decrease in the confining pressure and temperature also promoted boiling of the fluids and precipitation of metals to form the A-J and Treadwell deposits.

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