GEOLOGY AND GOLD MINERALIZATION AT THE DONLIN CREEK PROSPECTS, SOUTHWESTERN ALASKA

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SUMMARY

The Donlin Creek property in southwestern Alaska is a large gold system with mineralization extending more than 6 mi (9.6 km) in a northeast/southwest direction. The Queen–Lewis–ACMA area in the southern part of the property has the largest gold resource identified to date, with an estimated measured and indicated resource of 5.4 million oz (167.8 tonnes) of gold at a grade of 0.088 oz/ton gold (3.0 g/tonne). Total estimated gold resource at Donlin Creek, including the inferred category, is 11.5 million oz (357.7 tonnes). Mineralization is open to depth and along strike.

Gold mineralization parallels a 5-mi-long (8.2-km-long) Late Cretaceous to early Tertiary bimodal rhyodacitic and mafic dike swarm intruding mid-Cretaceous Kuskokwim Group interbedded graywacke and shale. Intrusive contacts are highly irregular along strike and there are both sill- and dike-like components. Dike morphologies dominate in the northeastern Lewis and Rochelieu areas, whereas igneous sills are dominant in the 400 Area, and the southern Lewis and ACMA areas. Gold mineralization is associated with disseminated sulfides, sulfide veinlets and quartz–carbonate–sulfide veining in sericite-altered igneous rocks and sedimentary rocks. There is a consistent positive correlation between zones of high fault and fracture density, areas of intense sericite alteration, and high gold grades. Alteration (sericite formation) and felsic dike crystallization (biotite formation) ages by $^{40}Ar/^{39}Ar$ dating overlap and are interpreted to indicate that crystallization of the dikes was closely followed by sericite and carbonate alteration accompanied by pyrite–arsenopyrite–gold mineraliza-tion. Stable isotope and fluid inclusion results suggest that fluids responsible for sericite alteration (and at least part of the mineralization) at Donlin Creek formed by mixing of magmatic water and meteoric water. Interpretation of sulfur isotopes suggests that at least some sulfur is derived from clastic sedimentary rocks.

Gold mineralization is structurally controlled and refractory (arsenopyrite-hosted). Higher-grade mineralization occurs at the juxtaposition of favorable lithology (most favorable is rhyodacite, least favorable is shale) and mineralized shear zones/faults (355°–040° trends with moderate to steep, easterly dips). North-trending structures appear to be normal faults having minor displacement (east–west extensional event). Earlier, northwesterly trending thrust faults, occurring along shale beds also have minimal displacements but only minor gold mineralization. Deformation has been minimal since mineralization.

INTRODUCTION

Plutonic-hosted gold deposits have become an important exploration target in Alaska since the discovery and subsequent operation of the five-million-ounce Fort Knox gold deposit. The Fort Knox deposit near Fairbanks remains the best-documented intrusive-hosted gold deposit in Alaska. Other plutonic-hosted gold deposits in Alaska vary dramatically from the Fort Knox model in fundamental aspects such as ore mineralogy and alteration styles (McCoy and others, 1997). Nevertheless, most recent exploration for plutonic-hosted gold deposits in Alaska has focused on the Yukon–Tanana uplands of the eastern Interior. The discovery of the Donlin Creek gold deposit in southwestern Alaska emphasizes that potential for world-class gold deposits in Alaska is not restricted to the Yukon–Tanana uplands.

The Donlin Creek property, in the Kuskokwim Mountains of southwestern Alaska, is approximately 300 mi (480 km) west of Anchorage and 15 mi (20 km) north of the village of Crooked Creek on the Kuskokwim River (fig. 1, inset), the closest navigable waterway. The property is on approximately 42 mi^2 (109 km^2) of privately owned Native land. Calista Corp., a regional Native corporation, has patent to subsurface rights, and The Kuskokwim Corp., a Native village corporation, has patent to surface rights. The project is controlled 100 percent by Placer Dome Inc. under a lease agreement signed with Calista Corp. in March 1995. Calista has the right to earn up to a 15 percent interest in the project upon completion of a positive feasibility study. Locus of exploration activity is in the SE¼ T. 23 N., R. 49 W., Seward Meridian (62°03'N latitude, 158°10'W longitude). The property has a 5,400-ft-long (1,650-m-long) gravel airstrip for access and an 80-person camp on

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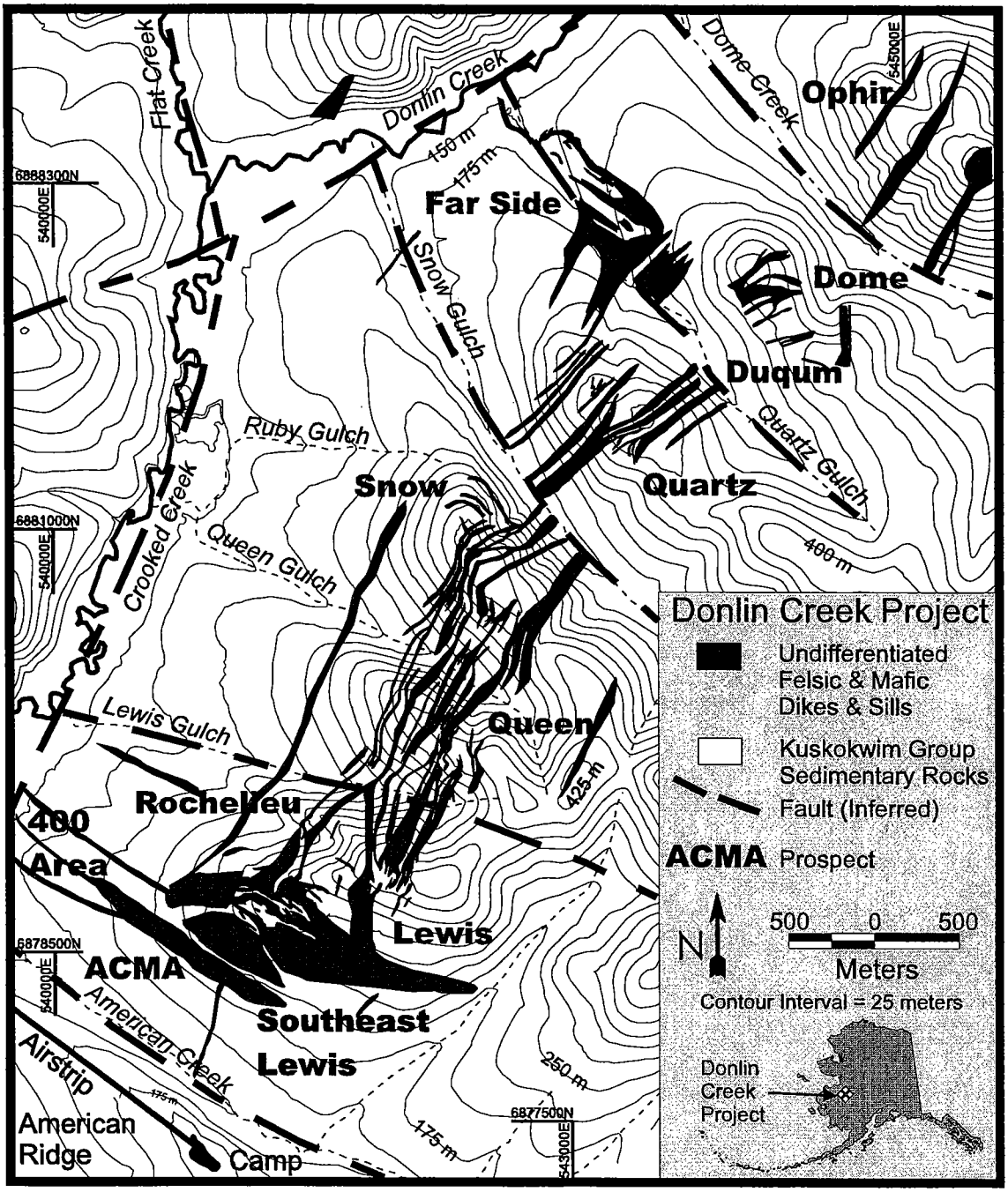

Figure 1. *Simplified geology of the Donlin Creek property and location of gold prospects. Topographic base from aerial survey flown by Aeromap U.S. for Placer Dome Exploration, Inc. Grid marks are Universal Transverse Mercator (UTM) projection 1927 North American datum, zone 4. Geology modified from maps by Western Gold Exploration and Mining Co. and Placer Dome Exploration, Inc. Inset map shows location of the Donlin Creek project in southwestern Alaska.*

American Ridge, immediately south of the exploration area (fig. 1).

The Donlin Creek project is in an area of low topographic relief on the western flank of the Kuskokwim Mountains. Elevations range from 500 to 1,500 ft (150–460 m) above sea level. Ridges are well rounded and ridgetops are typically covered with rubble crop and alpine tundra. Soil solifluction lobes blanket virtually all hillsides; these hillsides are forested with black spruce, tamarack, alder, birch, and larch. Soft muskeg, stunted black spruce forest, and discontinuous permafrost are common at lower elevations in poorly drained areas.

Placer gold was discovered near the Donlin Creek property in 1909 and significant lode exploration at Donlin Creek began in the 1980s. WestGold Exploration and Mining Co. identified eight gold prospects over a 3-mi (5-km) strike length through extensive soil sampling (over 10,000 samples), trenching, and drill programs in 1988 and 1989. These prospects, from north to south, were named Far Side (formerly called Carolyn), Dome, Quartz, Snow, Queen, Rochelieu, Upper Lewis, and Lower Lewis (fig. 1).

Placer Dome began working at Donlin Creek in 1995 and spent approximately $26 million on the Donlin Creek project from 1995 to 1998. Based on WestGold's work, the Lewis–Rochelieu area was deemed the most favorable target for a large bulk tonnage gold deposit and exploration by Placer Dome Exploration Inc. has focused there. Placer Dome's exploration efforts have been largely drill focused, with approximately 39,000 ft (11,900 m) of reverse-circulation drilling and 249,280 ft (76,000 m) of NQ- and HQ-diameter core drilling from 1995 to 1998. Placer Dome also completed 13,850 ft (4,200 m) of excavator and bulldozer trenching, airborne and ground geophysical surveys, and a soil-sampling program. Placer Dome has discovered several additional prospects on the Donlin Creek property, including Duqum, 400 Area, and ACMA (fig. 1). Placer Dome Exploration Inc. is continuing exploration efforts at present.

Extensive core drilling by Placer Dome Exploration Inc. from 1995 through 1998 defined a large gold resource extending from the Queen prospect through the Lewis (formerly Upper Lewis), Rochelieu, Southwest Lewis (formerly Lower Lewis), and Southeast Lewis (formerly Lower Lewis) prospects to the ACMA area. The Queen–Lewis area has the largest gold resource identified at the Donlin Creek property, defined by over 175 core holes with drill spacing varying from 165 to 650 ft (50 to 200 m) centers. Placer Dome announced an estimated measured and indicated resource of 5.4 million oz (167.8 tonnes) of gold contained in 51.7 million tons (57 million tonnes) of gold-bearing material grading 0.088 oz/ton (3 g/tonne) gold, using a 0.06 oz/ton (2 g/tonne) gold cutoff. The total estimated gold resource at Donlin Creek, including the inferred category, increased to 11.5 million oz (357.7 tonnes) with an average grade of 0.085 oz/ton (2.91 g/tonne) gold at a cutoff grade of 0.04 oz/ton (1.5 g/tonne) gold (Placer Dome press release, 2/18/99).

REGIONAL GEOLOGY

The regional geology of southwestern Alaska is summarized in Decker and others (1994), Patton and others (1994), and Szumigala (1993, 1996). Metamorphosed Early Proterozoic sedimentary and plutonic rocks occur as isolated exposures in southwestern Alaska and serve as depositional basement for Paleozoic units of the Ruby, Innoko, and Farewell terranes. The Farewell terrane, a nearly continuous sequence of Paleozoic continental margin rocks over 18,000 ft (5,500 m) thick, underlies much of the southwestern Alaska Range and northern Kuskokwim Mountains and unconformably overlies Early Proterozoic units. The predominantly Upper Cretaceous Kuskokwim Group, a post-accretionary basin-fill flysch sequence, is the most extensively exposed unit in the region and is interpreted to have formed one continuous marine embayment that stitched together most of the terranes of southern and western Alaska by Albian time. The Kuskokwim Group consists largely of interbedded lithofeldspathic sandstone and shale, and in large part rests unconformably on all older rock units. The Kuskokwim Group is at least 7.5 mi (12 km) thick in the region surrounding Donlin Creek and the underlying basement rocks are unknown. Late Cretaceous to early Tertiary plutonic and volcanic rocks intrude and/or overlie all of the younger units.

Two major northeast-trending faults traverse southwestern Alaska, the Denali–Farewell fault system to the south, and the Iditarod–Nixon Fork fault to the north. Latest Cretaceous and Tertiary right-lateral offsets of 56 mi (90 km) to less than 94 mi (150 km) occurred on both faults (Bundtzen and Gilbert, 1983; Miller and Bundtzen, 1988). Numerous high-angle faults are parallel and conjugate to these large faults. Pre-Tertiary rocks have undergone at least two folding phases: open to isoclinal folds with 1–2 mile (2–3 km) amplitudes and northeast-trending axes, and later broad folds with 15 mi (25 km) wavelengths and north-northeast-trending fold axes. Regional structural elements have been modeled by right lateral wrench fault tectonics with accompanying compressional and tensional stresses (Miller and Bundtzen, 1988).

The Kuskokwim Mountains represent one of several latest Cretaceous to earliest Tertiary magmatic belts found in southern and western Alaska. The Kuskokwim Mountains belt consists of calc-alkaline to alkaline basaltic to rhyolitic volcanic fields, isolated calc-alkaline stocks, felsic to mafic dike swarms, and sub-alkaline to

alkaline volcano–plutonic complexes (Moll-Stalcup, 1994). Plutonic rocks of the Kuskokwim Mountains magmatic belt extend over a northeast-trending area of approximately 540 mi by 120 mi (900 km by 200 km). Potassium-Argon (K-Ar) dates from igneous rocks in the Kuskokwim Mountains belt range from 58 to 77 Ma, whereas K-Ar dates for plutonic rocks range from 61 to 73 Ma, with an average age of 69 Ma (Szumigala, 1996, 1993). Geochemical characteristics of the igneous rocks suggest a common arc related petrogenesis for the Kuskokwim igneous centers (Szumigala, 1993). Most plutons of the Kuskokwim Mountains magmatic belt have quartz-monzonitic to monzonitic compositions and are calc-alkaline. Petrographic, magnetic susceptibility, and compositional data for plutonic rocks fit criteria for ilmenite series granitoids and geochemical signatures are compatible with I-type granitoids. Field relationships and limited laboratory measurements indicate the intrusions were emplaced at maximum depths of 0.6 to 2.5 mi (1 to 4 km). On the basis of previous K-Ar dating, mineralization is contemporaneous with plutonism at several localities in the Kuskokwim region (Szumigala, 1993).

PROPERTY GEOLOGY

Graywacke and shale of the Kuskokwim Group occur in subequal proportions at Donlin Creek (fig. 2). Kuskokwim Group rocks generally strike east to northwest (280° to 320°) and dip moderately (40° to 60°) to the south. Graywacke varies from a light gray to dark gray color, from fine-grained sandstone to fine-grained conglomerate, is massively bedded to 40 ft (12 m) thickness and breaks into blocks. Shale and siltstone units have prominent bedding and are good bedding indicators when present in core. Shale and siltstone units are black, carbonaceous, and occasionally contain fine-grained (diagenetic?) pyrite.

A northeast-trending, anastomosing, felsic (rhyodacite) and mafic (alkali basalt/andesite) dike swarm intrudes the Kuskokwim Group sedimentary rocks at Donlin Creek and crops out over approximately 5 mi (8.2 km) of strike length from American Creek to Ophir Creek (figs. 1, 2). In general, igneous units in the Northeast Lewis and Rochelieu areas are dikes with northeast strikes and moderate southeast dips that are clearly discordant to bedding. Igneous units in the Southeast and Southwest Lewis and ACMA areas are mostly sills with northwest strikes and moderate to steep southwest dips. This morphological change is reflected in the bedrock geologic map by the thick mass of rhyodacite present in the southern Lewis area (figs. 1, 2).

In detail, individual rhyodacite body orientations vary greatly. Igneous rocks occur as dikes, sills, and fault-bounded bodies. Igneous units are highly irregular along strike and can have both sill and dike components. Some sills may be thin apophyses to larger dikes. Sills commonly occur below thick shale horizons within the sedimentary rock package. Regional contact relationships between sedimentary and igneous rocks are typically sharp and generally without metamorphic or metasomatic effects. Chilled margins on igneous bodies occasionally occur along all contact types. Individual dikes may be up to 200 ft (60 m) wide, but the average width is 35 to 70 ft (10–20 m). There is no drill evidence that these dikes coalesce into a larger plutonic body within 1,300 ft (400 m) of the surface.

IGNEOUS LITHOLOGIES

Donlin Creek intrusive units comprise a dike swarm; hence, conflicting age relationships are likely. Individual dikes and sills pinch and swell throughout the prospect areas. Igneous units in the Donlin Creek area have been divided into five field categories: aphanitic rhyodacite porphyry (RDA), crystalline rhyodacite (RDX), fine-grained rhyodacite porphyry (RDF), rhyolite (RHY), and mafic dikes (MD).

Rhyodacite porphyry with aphanitic groundmass and porphyritic phenocrysts (RDA) and rhyodacite with medium- to coarse-grained crystalline texture (RDX) are the most common igneous units, representing approximately 80 percent of the dike volume. RDA and RDX can have gradational contacts, probably as textural differences within one dike, but contacts with distinct chilled margins also occur. Overall, the rhyodacite units have similar mineralogy and characteristics. Textures are typical for hypabyssal igneous rocks and vary from porphyritic with very fine-grained matrix ("volcanic") to almost coarse-grained equigranular ("plutonic"). Color varies from light gray to dark blue-gray and phenocrysts compose approximately 50 percent of rock volume. Quartz phenocrysts are subrounded to equant, vary from 0.04 to 0.31 in (1 to 8 mm) diameter and represent 10 to 20 volume percent. Quartz phenocrysts are typically partially to completely resorbed, embayed, and surrounded by sericite. Feldspar phenocrysts range from 0.02 to 0.39 in (0.5 to 10 mm) diameter (average 0.15 to 0.20 in [4–5 mm]) and 5 to 40 rock volume percent. There is a 1:1 to 1:2 ratio between plagioclase and orthoclase. Biotite phenocrysts are similar in size to quartz and feldspar phenocrysts and comprise 2 to 5 volume percent. Trace amounts of rutile, sphene, apatite, titanium oxide, allanite (?) and zircon are present. Red garnet phenocrysts are present in some core samples, but they are extremely rare overall (less than 10 garnets reported in 250,000 feet [76.2 km] of drilling). Graphite spherules up

Figure 2 (right). *Geologic map of the Queen, Rochelieu and Lewis prospects, Donlin Creek property.*