

Tectonic setting of Late Cretaceous precious metal and mercury metallogensis, Kuskokwim Mineral Belt, southwestern Alaska

By Marti L. Miller¹, Dwight C. Bradley¹, Richard J. Goldfarb², and T.K. Bundtzen³

¹ U.S. Geological Survey, 4200 University Dr., Anchorage, AK 99508

² U.S. Geological Survey, Box 25046, MS 973, Denver, CO 80225

³ Pacific Rim Geological Consulting, P.O. Box 81906, Fairbanks, AK 99708

Introduction

A major episode of epigenetic mineral deposit formation occurred in Late Cretaceous time in what is now southwestern Alaska. Several large-scale tectonic factors came together during a relatively short time frame, leading to a widespread pulse of magmatism and mineralization at ~70 Ma. Gold and mercury deposits delineate the ~190,000 km² Kuskokwim Mineral Belt (Fig. 1). Total production includes approximately 100,000 kg (3.2 million oz) of gold (mainly from placers), 16,000 kg of silver, and 1.3 million kg of lode mercury.

The Kuskokwim Mineral Belt (first defined by Bundtzen and Miller, 1997) lies within a broad zone of dextral strike-slip faults that have been active since at least Late Cretaceous time (Miller and others, 2002). The belt occupies a back-arc position along the north Pacific continental margin, about 350-450 km inboard of the present-day Aleutian subduction zone. The southwestern Alaska dextral faults lie at the western end of a continental-scale, strike-slip system that curves around the Canadian-Alaskan continental margin.

Geologic setting

Southwestern Alaska is underlain by a variety of Jurassic and older terranes that were assembled by mid-Cretaceous time and overlapped by Upper Cretaceous flysch (Decker and others, 1994). The older terranes include Paleoproterozoic metamorphic rocks (e.g. Kilbuck terrane), a Neoproterozoic to Jurassic microcontinental fragment (Farewell terrane), and Paleozoic to Mesozoic oceanic and arc assemblages (e.g. Goodnews and Togiak terranes). The overlapping Kuskokwim Group, primarily composed of turbidites, was deposited into a basin that subsided between some of the terranes; this unit forms the dominant bedrock of the Kuskokwim Mineral Belt. These sediments were deposited from ~95 Ma to ~76 Ma. The waning stages of deposition were accompanied by minor volcanism, marking the beginning of a period of magmatism during which numerous intrusive igneous complexes and subaerial volcanic rocks were emplaced. Although the magmatism was widespread and relatively continuous between 76 and 63 Ma, it peaked dramatically ~70 Ma.

The latest Cretaceous intrusive rocks are of two groups, both spatially associated with mineralization: volcanic-plutonic complexes and structurally controlled hypabyssal dikes, sills, and stocks. The volcanic-plutonic complexes consist of quartz monzonitic plutons and subaerial mafic to felsic volcanic rocks; their chemistry indicates a mantle component. The structurally controlled dikes, sills, and stocks are felsic to intermediate and commonly peraluminous in composition. They are the same age as the volcanic-plutonic complexes, but their geochemical signature indicates melted continental crust.

Gold and mercury deposits

Two important mineral deposit types also formed at ~70 Ma: (1) precious metal-bearing, boron-rich, high-temperature deposits genetically related to the volcanic-plutonic complexes, and (2) epizonal, lower temperature deposits (mercury \pm gold), many of which are structurally associated with relatively competent sill/dike systems that make favorable hosts.

The precious metal-bearing intrusion-related deposit type is typified by the Shotgun prospect, which is hosted by quartz-feldspar porphyry thought to be related to a main granodiorite stock. The porphyry is cut by ~70 Ma gold-bearing quartz veins, breccias, and stockworks, which contain arsenopyrite, pyrite, pyrrhotite and chalcopyrite (Rombach and Newberry, 2001).

The epizonal deposits are primarily mercury-antimony systems such as Red Devil and Cinnabar Creek, but are also interpreted to include some gold-dominant deposits, such as the giant Donlin Creek system. Red Devil, Alaska's largest mercury mine, closed in the 1970s after producing over 1.2 million kg of mercury. The ore consists of cinnabar in quartz-carbonate veinlets, but abundant stibnite was found deeper in the system. Smaller deposits of this type are found throughout the region and many are notably anomalous in gold. They are mainly hosted in Kuskokwim Group sedimentary rocks at or near high-angle structures, and are locally spatially associated with intermediate to mafic dikes. At Cinnabar Creek, the mercury ore is notable in that it contains native mercury in addition to cinnabar.

Some of the epizonal deposits contain economic amounts of gold. The best example is the Donlin deposit, which now has a measured and indicated resource of 914,000 kg (29.4 million oz) of gold. Donlin consists of about 16 prospects spatially associated with an 8-km-long dike/sill complex. The dikes are hypabyssal porphyritic intrusions of mainly granitic composition. Metalliferous quartz veinlets fill brittle, extensional fractures in the dikes and were formed within a few million years of crystallization of the dikes. The ore-forming fluids were derived by either devolatilization of flysch above rising mantle melts deep in the Kuskokwim basin or by exsolution from a flysch melt magma (Goldfarb and others, 2004).

Structural setting of deposits

The Kuskokwim Mineral Belt lies in a broad zone of northeast-striking, dextral strike-slip faults that have been active intermittently since about 95 million years ago. The Iditarod-Nixon Fork fault shows at least 90 km of dextral offset since the Late Cretaceous and the Denali fault system, in this part of Alaska, shows dextral offset of at least 134 km (Miller and others, 2002). Most significantly, that study indicated that strike-slip motion on these faults was taking place *at the same time as* the ~70 Ma igneous activity and coeval hydrothermal mineral deposition. Some of the deposits are spatially associated with strike-slip faults; others lie between the master faults. Intrusion-related gold deposits that lie along the main faults exhibit structural features suggesting they were formed synkinematically during dextral strike-slip. For example, at the Fortyseven Creek gold-tungsten deposit vein orientations are consistent with dextral strike-slip on the Denali fault. In contrast, structural data for two ~70 Ma deposits (Donlin Creek and Red Devil) that lie between the first-order faults suggest a roughly north-south principal compression direction, perpendicular to that expected in a dextral regime near the main strike-slip

faults. At Donlin Creek, the earliest deformation was reported by Ebert and others (2000) to be approximately north-south oriented compression. At Red Devil, northwest-striking mineralized dextral faults are consistent with a roughly north-south principal compression direction, again perpendicular to what would be expected in a dextral regime on the main northeast-striking master faults. This apparent contradiction may find an explanation in strain partitioning.

Tectonic framework

To understand the regional tectonic framework during the critical latest Cretaceous time, it is useful to work back through the history of interactions between southwestern Alaska and the plates of the Pacific. Such interactions are not straightforward, even for the current situation. At present, the North America-Pacific plate boundary is a *dextral* transform along most of its length (e.g. San Andreas and Queen Charlotte faults), but in southwestern Alaska, the plate boundary is a subduction zone with a minor *sinistral* component of obliquity. Inboard of the plate boundary, the Denali fault zone has Neogene dextral offsets along its entire length, even above the sinistral oblique subduction zone. Dextral strike-slip in this region thus requires another explanation besides oblique subduction, but can be explained by a push from the rear (Miller and others, 2002), tectonic extrusion toward a free face in the Bering Sea (Redfield and others, 2006), or a combination of the two.

Uncertainties mount further back in time. At ~55 Ma, dextral motion in southwestern Alaska may have been accentuated by “megakinking” during postulated oroclinal bending. At ~60 Ma, the identity of the subducting plate comes into question, as discussed in depth by Miller and others (2002). The three alternatives, each of which has specific plate kinematic implications, are the Kula, the Farallon, or the newly proposed Resurrection Plate (our preferred model).

Some of the tectonic factors operating during the critical ~70 Ma episode of widespread metallogenesis are known, but questions remain. Subduction was most certainly occurring along the Gulf of Alaska margin at this time, based on the presence of the Chugach accretionary complex and subduction-related igneous rocks in the western Alaska Range. Dextral strike-slip was likely driven by oblique plate convergence, perhaps in concert with escape tectonics. Late Cretaceous dextral displacement enhanced crustal dilation and fluid migration. It is still not clear why (1) the 70 Ma magmatism occurred over such a wide area, (2) both mantle and continental crustal melts were present, and (3) the region of elevated geotherms was so extensive. Geometric complexities involving a curved margin, the consumption of the Kula and then Resurrection Plates, and possible escape on the “free” western face led to a complicated set of forces that likely played a role in ore genesis.

References

- Bundtzen, T.K., and Miller, M.L., 1997, Precious metals associated with Late Cretaceous-early Tertiary igneous rocks of southwestern Alaska: Economic Geology, Monograph 9, p. 242-286.

- Decker, John, Bergman, S.C., Blodgett, R.B., Box, S.E., Bundtzen, T.K., Clough, J.G., Coonrad, W.L., Gilbert, W.G., Miller, M.L., Murphy, J.M., Robinson, M.S., and Wallace, W.K., 1994, Geology of southwestern Alaska, chap. 9, *in* Plafker, George, and Berg, H.C., eds., *The geology of Alaska: Boulder, Colo., Geological Society of America, The Geology of North America, v. G-1, p. 285-310.*
- Ebert, S., Miller, L., Petsel, S., Dodd, S., and Kowalczyk, P., 2000, Geology, mineralization, and exploration at the Donlin Creek project, southwestern Alaska: Vancouver, British Columbia and Yukon Chamber of Mines, Special Vol. 2, p. 99-114.
- Goldfarb, R.J., Ayuso, Robert, Miller, M.L., Ebert, S.W., Marsh, E.E., Petsel, S.A., Miller, L.D., Bradley, D.C., Johnson, Craig, and McClelland, William, 2004, The Late Cretaceous Donlin Creek gold deposit, southwestern Alaska: Controls on epizonal ore formation: *Economic Geology*, v. 99, no. 4, p. 643-671.
- Miller, M.L., Bradley, D.C., Bundtzen, T.K., and McClelland, William, 2002, Late Cretaceous through Cenozoic strike-slip tectonics of southwestern Alaska: *Journal of Geology*, v. 110, p. 247-270.
- Rombach, C.S., and Newberry, R.J., 2001, Shotgun deposit: Granite porphyry-hosted gold-arsenic mineralization in southwestern Alaska, USA: *Mineralium Deposita*, v. 36, p. 607-621.
- Redfield, T.F., Scholl, D.W., Beck, M.E., Fitzgerald, P.G., 2006, The extrusion of Alaska: past, present, and future: *Eos Transactions AGU 87, Fall Meeting Suppl., Abst T43D-1682.*

Figure 1. Map of Alaska showing major strike-slip faults and the Kuskokwim Mineral Belt.

