CHAPTER F: ECONOMIC GEOLOGY OF THE LADUE RIVER-MOUNT FAIRPLAY AREA

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INTRODUCTION

The Ladue River-Mount Fairplay map area hosts a variety of prospects and occurrences related to several different mineral systems active in discrete phases during the Permian, middle Cretaceous, and latest Cretaceous-early Paleogene (fig. 1). Base-metal soil anomalies and local massive sulfide at the Ladue prospect group occur within the Klondike assemblage and may represent a Permian volcanogenic massive sulfide system. Voluminous felsic to intermediate magmatism at around 110–100 Ma is associated with only limited magmatic-hydrothermal mineralization, such as the incompletely understood Pushbush and Dennis-Ladue prospects. Polymetallic and precious-metals-bearing mineralization in the Moosehorn Range (Honks, Goodrich Porphyry, and Move prospects; Longline gold deposit in Yukon) is hosted within a mid-Cretaceous granodiorite batholith but, at ca. 93 Ma, mineralization at the Longline deposit postdates magmatism and contains lead sourced from the metamorphic country rock rather than the host plutonic rocks (Joyce, 2002). Latest Cretaceous (71–66 Ma) intrusions of intermediate, sub-alkaline composition have the greatest metallogenic significance; regionally, they are associated with the Manh Choh (formerly Peak/Tetlin) gold–silver-copper (Au–Ag-Cu) skarn deposit, the East Taurus copper–molybdenum (Cu–Mo) porphyry deposit, and the Road Metal polymetallic intrusion-related prospect. Within the map area, Oreo Mountain is an early stage Cu–Mo porphyry prospect, while Pat may be a satellite of the broader Taurus-Bluff porphyry system. Alkaline intrusions at Mount Fairplay (Section 35 prospect) are locally enriched in uranium, thorium, rare earth elements, niobium, and zirconium (U–Th–REE–Nb–Zr).

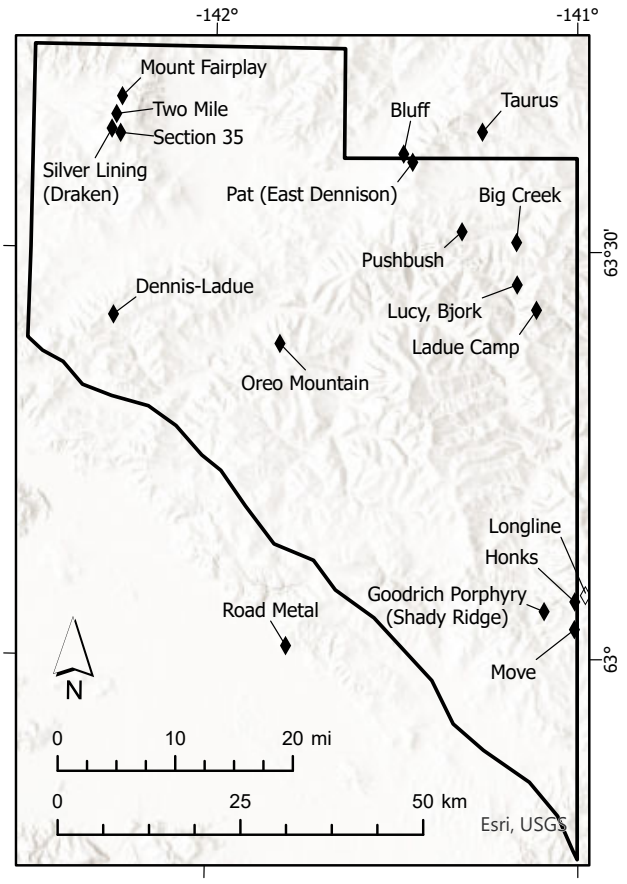

Figure 1. Map illustrating the locations of prospects mentioned in this chapter.

Stratabound Mineralization Hosted by Paleozoic Rocks

Ladue Prospect Group (Bjork, Ladue Camp)

The Ladue prospect group, including the Ladue Camp and Bjork (also known as Lucy) prospects, were discovered by Cities Service Minerals Corporation in 1976 during regional exploration for porphyry Cu-Mo systems. The prospects have base-metal soil anomalies (up to 2,100 parts per million [ppm] lead [Pb], 2,550 ppm zinc [Zn], and 331 ppm Cu; Cities Service Minerals Corp., 1980) and

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are associated with metamorphosed mafic and felsic volcanic rocks and carbonaceous sedimentary rocks. These features led to the exploration of the property as a potential syngenetic base-metal mineral system. Subsequent exploration of the heavily covered area relied on airborne and ground-based electromagnetic (EM) geophysical surveys. Cities Service tested a coincident EM and geochemical anomaly at Ladue Camp with a 197-m (645-foot) diamond drill hole, intercepting "several thin bands of massive sulfide" within graphite schist (unit Pkgs), terminating in meta-andesite (also known in industry reports as greenschist; probably unit Pkmb of this report); the company concluded that the graphitic schist was the source of the EM anomaly (Cities Service, 1980). U.S. Borax reached a similar conclusion after 1978–1979 exploration work at the Bjork prospect, including three shallow 29– to 34-m-long (95– to 110-foot) drill holes, which encountered greenschist (chlorite-actinolite schist) with graphitic schist interbeds. U.S. Borax concluded that the geochemical anomaly arose from disseminated chalcopyrite, galena, and sphalerite in the local metamorphic rocks (Henricksen and Ashleman, 1980). Noranda explored the Lucy (Bjork) claims in 1982, confirming anomalous Cu, Pb, and Zn enrichment in soils in a weakly conductive horizon lying at the transition between mafic metavolcanics rocks and the overlying graphitic metasedimentary rocks (Dunbier, 1980).

Big Creek

The Big Creek prospect is underlain by greenschist and interlayered siliceous, micaceous, and graphitic schists of the Klondike assemblage (units Pkmb and Pks). Cities Service Minerals Corporation staked the prospect in 1976 following discovery of a strong Cu–Zn–Pb–Ag–Au soil geochemical anomaly. Follow-up work by Cities Service and U.S. Borax (1978–1979) included further sampling, geophysical surveying, and shallow core drilling using a "Winkie" field-portable core drill. The drilling encountered greenschist and sericite schist but failed to identify the source of the soil anomaly. Trace pyrite was observed throughout much of the core. Cuttings from the core drilling were sampled at 10-foot intervals and were largely below detection; however, one interval assayed 450 ppm Cu and 108 ppm Mo (Henricksen and Ashleman, 1980). This geochemical result suggests porphyry Cu-Mo mineralization (similar in style to the Taurus prospect 17 km to the north), but there are no corresponding geological observations (such as porphyry dikes, porphyry-style alteration, Cu- or Mo-sulfide-bearing quartz veinlets) from core or surface to support this interpretation.

Mid-Cretaceous Mineral Systems

Pushbush

DGGS geologists visited and sampled the Pushbush prospect but did not have access to any reports beyond the brief descriptions of Singer and others (1976; site 11) and Eberlein and others (1977; page 102). The Alaska Resource Data File (U.S. Geological Survey, 2018) references two drill holes, but we were unable to confirm these in the field or the literature. Our examination of the prospect located a single trench exposing molybdenite-bearing quartz veinlets hosted by silicified and sericitized gneiss, plus local disseminated pyrite and chalcopyrite. We mapped two igneous units in the prospect vicinity, mid-Cretaceous porphyry (assigned to unit Kmi) and Paleogene rhyolite dikes or volcanic rocks (assigned to unit Pefp). A sample of the unit Kmi, quartz-veined and brecciated quartz-feldspar-biotite porphyry, carried minor disseminated pyrite and chalcopyrite; it was the only DGGS sample from the prospect that carried anomalous Cu (305 ppm Cu; sample 19ET102 of Wypych and others, 2019). Feldspar phenocrysts are altered to sericite and biotite phenocrysts are altered to chlorite. U-Pb zircon dating of this sample yielded an age of 110.7 ± 2.5 Ma (sample 19ET102; Wildland and others, 2021). Unit Pefp rhyolite occurs throughout the prospect area; it carries up to 1 percent pyrite and has a weakly altered appearance, but it was found to be barren of Cu-Mo mineralization (Wypych and others, 2019). A sample of this unit from the prospect area yielded a U-Pb zircon age of 57.1 ± 1.2 Ma (19KS100; Wildland and others, 2021).

Dennis-Ladue

The Dennis-Ladue prospect comprises quartz veins, vein breccias, and intense silicification associated with a composite felsic stock (USGS, 2018, and references therein), which we infer based on our mapping to be mid-Cretaceous granite porphyry (unit Kgp). DGGS sampled vuggy quartz-sulfide vein material in the general prospect vicinity (40 parts per billion [ppb] gold and weakly anomalous arsenic (As); sample 19ET209 of Wypych and others, 2019), but did not otherwise succeed in relocating the prospect. The Dennis-Ladue prospect lies on land belonging to Doyon Limited.

Moosehorn Ridge Area

Mineralization in the Moosehorn Ridge area comprises multiple mineralization styles of probable mid-Cretaceous age. The district is bisected by the Alaska-Yukon border, with the Canadian portion having seen higher levels of placer gold production, exploration interest, and scientific study. Joyce (2002) completed a detailed economic geology study of the Longline gold deposit (5 km east of the Goodrich Porphyry prospect), concluding, based on Pb-isotopic evidence, that the metals in the veins were not derived from the mid-Cretaceous intrusions that dominate local bedrock. By extension, we believe that future work on the Alaska portion of the Moosehorn Ridge area, including the Goodrich Porphyry prospect, should consider an orogenic origin for the mineralization in addition to the magmatic-hydrothermal model suggested by the associated intrusive host rocks.

Goodrich Porphyry (Shady Ridge)

Porphyry Cu–Mo exploration by Cities Services Minerals Corporation during the late 1970's resulted in the discovery of the Shady Ridge prospect, a greater than one-kilometer-diameter Cu–Mo–Zn–Ag soil anomaly. This anomaly was rediscovered by Blue Moose Exploration (BME) in the early 2000s and explored as the Goodrich Porphyry prospect. BME and 2010 joint-venture partner Millrock Resources, Inc., conducted extensive soil sampling in the area, trenched across the Goodrich Porphyry, and drilled 33 shallow churn drill holes to access bedrock below frozen cover. Rock sampling results reported by BME indicate locally high values of many elements, as illustrated by one trench grab sample assaying 195 ppm Mo, 10.3 ppm Ag, 337 ppm Cu, 3677 ppm Pb, 693 ppm Zn, 128 ppm As, 213 ppm antimony (Sb), and 2.59 ppm mercury (Hg) (Blue Moose Exploration, 2015). The prospect geology, as synthesized during a brief visit by DGGS, is characterized by granodiorite country rock (unit Kgd) intruded by mid-Cretaceous felsic to intermediate dikes (unit Kma). A gouge-filled, northeast-trending fault transects the soil anomaly and is well exposed in the trench. Mo-enriched samples collected by DGGS are pervasively weathered and iron oxide-stained granodiorite cut by quartz veinlets (19ET014 and 19ET015 of Wypych and others [2019]); if present, sericitic or argillic alteration is impossible to differentiate from weathering. Felsic dikes were barren of mineralization despite being locally veined, iron-stained, and possibly altered to sericitic or argillic assemblages.

Honks

The Honks gold prospect lies about 4 km (2.5 miles) east of the Goodrich Porphyry prospect. It comprises gold-bearing quartz veins cutting granodiorite (unit Kgd); andesite dikes occur in the vicinity but have uncertain relationship to the mineralization. The prospect was explored by BME and trenched and sampled under joint venture with Millrock Resources. Trenches visited by DGGS showed vuggy, quartz–pyrite–arsenopyrite veinlets several centimeters thick with sericitized margins; granodiorite away from the veinlets was unaltered (19JEA007; Wypych and others, 2019). Trench sampling by Millrock returned numerous mineralized samples grading 0.1–0.5 ppm Au, 1–8 ppm Ag, greater than 1 percent As, 5–340 ppm bismuth (Bi), and 10–26 ppm Sb (Blue Moose Exploration, 2015). An $^{40}Ar/^{39}Ar$ age for the sericite is pending, however, the mineralization is thought to be mid-Cretaceous based on similarities to mineralization at the Longline deposit 1.5 km to the east on the Yukon side of the Alaska-Canada border, where muscovite from

gold-bearing veins yielded $^{40}Ar/^{39}Ar$ ages around 93 Ma (Joyce, 2002).

The creek immediately south of the Honks prospect hosts a placer gold deposit characterized by minimally transported, delicate wire and crystalline gold (site 14 of Singer and others, 1976). In 1990, Canada Tungsten conducted a placer gold drill program that defined a resource of 5,880 ounces of gold in 325,784 cubic yards of material. In 2010, a small placer mining operation exploited this resource (Blue Moose Exploration, 2015).

Move

Public records describe the Move prospect as an early-stage lode gold exploration property (U.S. Geological Survey, 2018; Eberlein and others, 1977). DGGS did not have access to any detailed information on this prospect, however, we visited a trench in the general vicinity of the ARDF location prospect and found vuggy, iron- and Cu-oxide-stained quartz veinlets cutting granodiorite (unit Kgd). A grab sample of this material assayed 35.8 ppm Ag, 63 ppb Au, 64 ppm As, 315 ppm Pb, and 749 ppm Zn (19TJN004; Wypych and others, 2019); as such, this prospect may be similar to the Honks and Goodrich Porphyry prospects described above, as well as the Longline prospect described by Joyce (2002).

LATE CRETACEOUS-EARLY PALEOGENE MINERAL SYSTEMS

Oreo Mountain

Cities Service Minerals Corporation discovered the Oreo Mountain Cu–Mo prospect in 1976 during follow-up work on soil anomalies generated by regional exploration the previous year. The prospect remained known as a poorly exposed, approximately 4-km by 1.5-km Cu–Mo–Ag soil anomaly until 2007 when Full Metal Minerals re-staked the prospect and conducted a few years of surface work. In 2011, DGGS published an airborne magnetic and electromagnetic survey of the Ladue area (Burns and others, 2020) showing a strong aeromagnetic anomaly associated with the area of the Oreo prospect. In 2018, Tubutulik Mining Company re-staked the prospect and optioned it to Kennecott Exploration. Kennecott completed additional surface work, including soil sampling and trenching, and, in 2019 drilled six diamond drill holes ranging in depth from 150 to 186 m (fig. 2). All six holes encountered broad intercepts of low-grade Cu mineralization, and strong Mo mineralization was encountered in parts of several holes (Kennecott Exploration, 2019).

Cu–Mo mineralization intercepted at Oreo is hosted mostly within a medium-grained, magnetite-bearing granodiorite (Kennecott Exploration, 2019), which we assign to the Late Cretaceous granodiorite unit (lKgd) of this map. A DGGS surface sample of granodiorite porphyry with disseminated chalcopyrite yielded a U-Pb zircon age of 71.4 ± 0.2 Ma (19TJN243), and a second sample of altered intrusive rock from the prospect trench area yielded an age of 72.1 ± 1.6 Ma (19RN282; Wildland and others, 2021). A large body of coarse-grained, K-feldspar porphyritic granite (unit lKpg) outcrops on the ridges to the south and west, separated from the prospect by a west-northwesterly trending fault (fig. 2). This intrusion projects under mineralization and was intersected below the granodiorite (lKgd) at the end of many of the drill holes; it is locally altered but essentially barren. U-Pb zircon dating of the K-feldspar-porphyritic granite indicates an age of 68.8 ± 1.5 Ma, slightly younger than the granodiorite porphyry intrusions associated with mineralization (sample 19RN287; Wildland and others, 2021). Kennecott Exploration (2019) also observed veined and mineralized diorite xenoliths within both granodiorite and K-feldspar porphyritic granite intrusions. Finally, drilling intercepted barren, apparently post-mineralization rhyolite dikes cutting mineralized granodiorite (Kennecott Exploration, 2019); we interpret these as corresponding to spherulitic rhyolite (PEfp) sampled from surface in the prospect area, dated at 58.6 ± 1.4 Ma (sample 19ET277; Wildland and others, 2021).

Mineralization was observed in granodiorite and the adjacent metamorphic country rock, and it occurs primarily as thin quartz and K-feldspar veinlets with pyrite ± chalcopyrite ± bornite

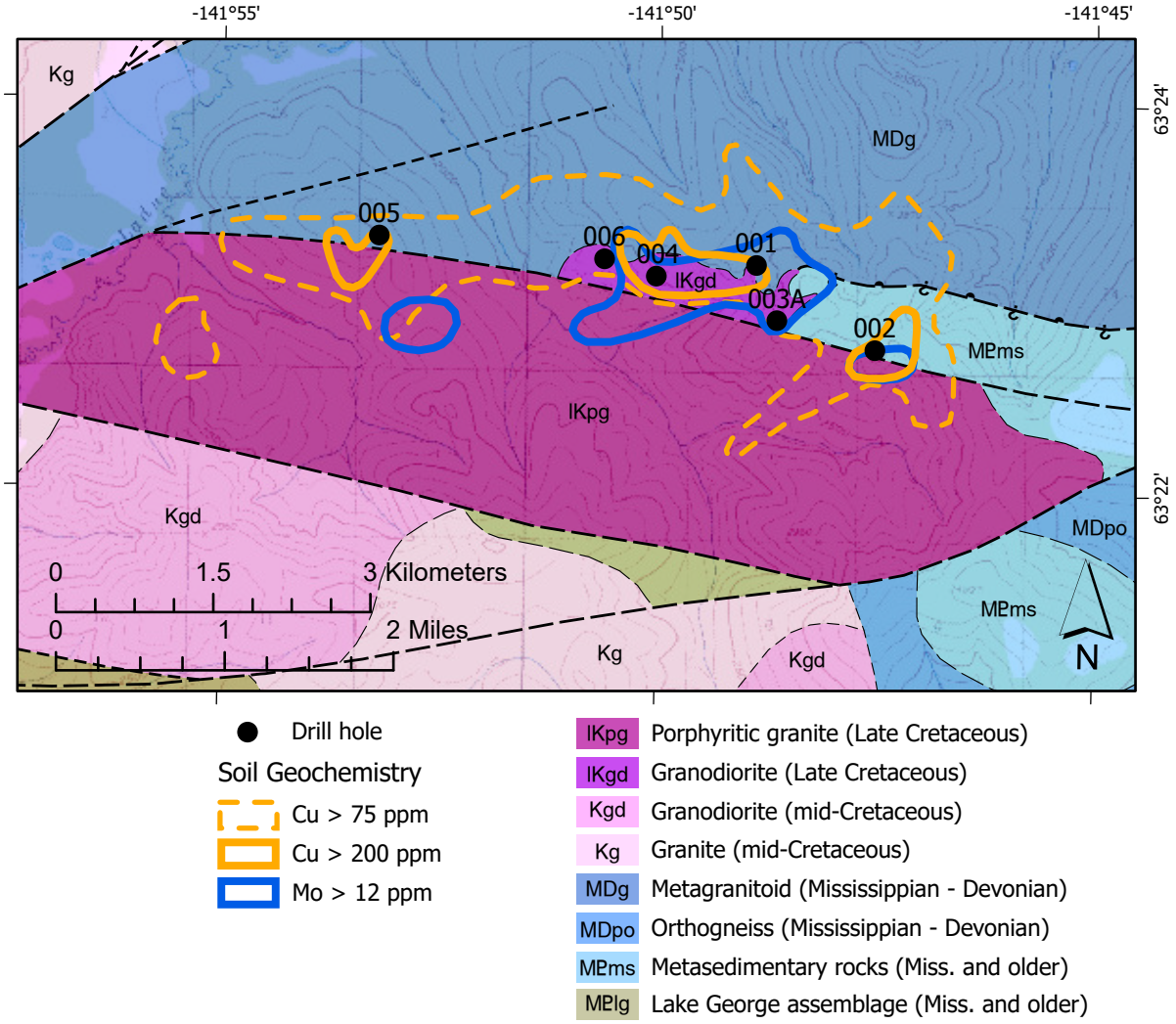

Figure 2. Oreo prospect Cu and Mo soil anomalies and 2019 drill hole locations (Kennecott Exploration, 2019; Hedderly-Smith, 2020) plotted with DGGS geologic map (this study).

± magnetite; disseminated pyrite and chalcopyrite were found locally (fig. 3). Molybdenite was observed primarily in veinlets. Alteration includes potassic assemblages of K-feldspar and biotite associated mainly with veinlets and vein selvages; zones of strong molybdenite mineralization were associated with increased potassic alteration. One drill hole intercepted a broad zone of moderate, magnetite-destructive sericite and/or clay alteration accompanying (or overprinting) veinlet-hosted quartz–pyrite–chalcopyrite–molybdenite–magnetite mineralization. Other alteration includes chlorite–sericite and propylitic assemblages affecting both intrusive and metamorphic country rocks (Kennecott Exploration, 2019).

Pat Claims

Cities Service Minerals Corporation located the Pat (also known as East Dennison) prospect at the source of USGS stream-sediment anomalies generated by the Alaska Mineral Resource Assessment Program (AMRAP; Foster and others, 1976) in the adjacent drainages (Cities Service, 1980; Henricksen and Ashleman, 1980). Cities Service and U.S. Borax completed prospecting and sampling work in the late 1970s; Kenorland Minerals conducted surface sampling in 2018 and included the prospect in a property-wide airborne time-domain EM survey (Werdon and others, 2021). As described by Henricksen and Ashleman (1980) and confirmed by DGGS during 2018

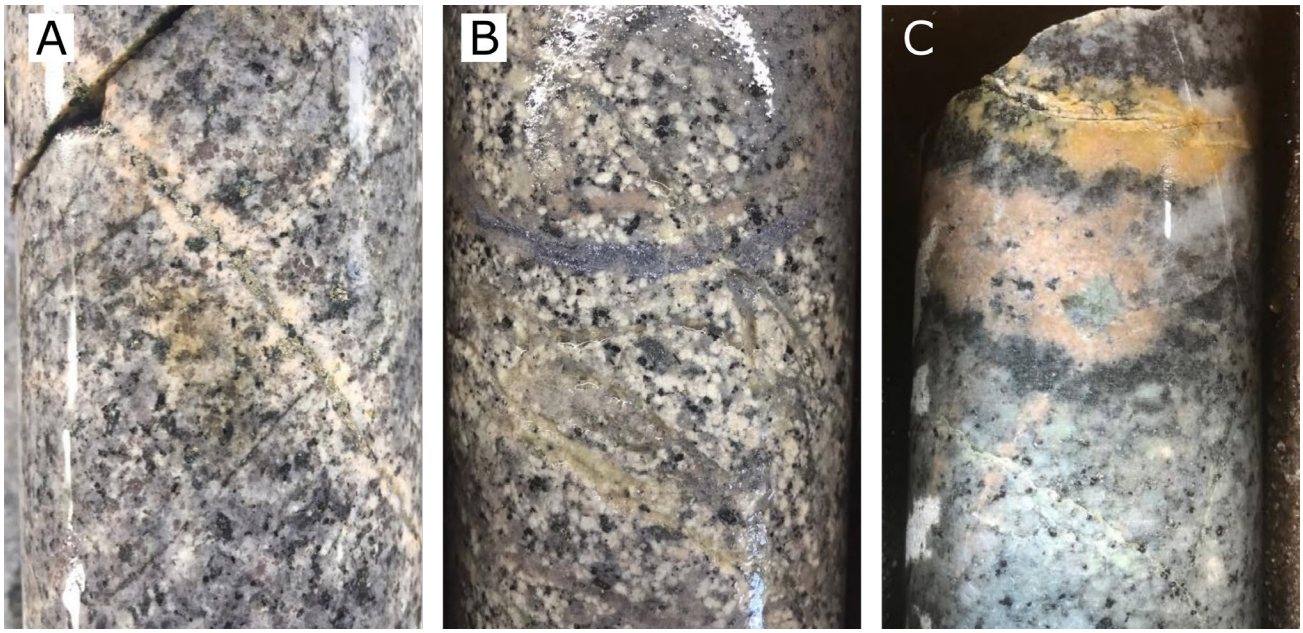

Figure 3. Drill core photographs of mineralization and potassic alteration at the Oreo prospect. **A.** Quartz-pyrite-molybdenite-chalcopyrite ± magnetite veins with K-feldspar alteration selvage (drill hole OREO-001). **B.** Quartz-molybdenite mineralization in granodiorite (drill hole OREO-003A). **C.** Quartz-K-feldspar vein with molybdenite, pyrite, magnetite, and chalcopyrite; vein selvage is secondary biotite (drill hole OREO-003A). Host rock in all photos is Late Cretaceous granodiorite, unit lKgd. All photos and descriptions are from Kennecott Exploration (2019).

fieldwork, the prospect is hosted by Mesozoic intrusive rock (herein mapped as Late Cretaceous granodiorite, unit lKgd) intruding gneiss of the Lake George assemblage. Mineralization comprises quartz ± tourmaline ± pyrite veins, breccias, and pervasive, texturally destructive tourmaline-sericite replacements within the intrusive rock and at its contact with the gneiss. Samples of this style of mineralization are enriched in Ag–Pb–Bi–As–Sb; DGGS sampling returned Ag values up to 10.15 ppm (18KS095, Wypych and others, 2018). Cities Service (1980) described the tourmaline-bearing veins as associated with a northeast-trending fault that controls similar alteration to the Taurus area. Locally intense sericite alteration at the prospect yielded an $^{40}Ar/^{39}Ar$ age of 65.8 Ma (Doug C. Kreiner [U.S. Geological Survey], personal commun., 2018).

Mount Fairplay

The Mount Fairplay prospect lies immediately north of the Mount Fairplay alkalic intrusive complex. Reconnaissance and surface exploration has been undertaken by several companies since the 1970s, including Cities Service Minerals Corporation, Bear Creek Mining Company, Kerr McGee, RAA, and WGM (Kerin, 1976; Adams, 2009). DGGS sampling during 2019 located one or more granite porphyry dikes (unit lKfd) intruding augen orthogneiss (unit MDag). As mapped, these dikes are separated from the alkalic plutonic rocks by a north-side-down high-angle fault of unknown displacement. The granite porphyry contains 1–5 percent disseminated or veinlet-hosted pyrite, as well as disseminated rosettes or veinlets of tourmaline. Weak to moderate sericitic alteration and minor silicification also are present. Geochemical results show sporadic enrichment in a variety of elements, including up to 46 ppm Mo with 16.2 ppm Bi (19ET335), and 64 ppb Au with 667 ppm Cu (19RN359; Wypych and others, 2019). A sample of this intrusion yielded a U-Pb zircon age of 70.5 ± 1.6 Ma (19RN359; Wildland and others, 2021).

Silver Lining

The Silver Lining prospect, also known as the Draken property, is located at milepost 30 along the Taylor Highway and is exposed by roadcuts on the uphill side of the road. It was first located in 1990 by prospectors William and Dawna DeHaven and has been explored by surface rock and soil sampling. The prospect is hosted within Late Cretaceous quartz monzonite (unit lKgqm). As described by Adams (2009) the prospect comprises a series of widely spaced (greater than 3 m, locally 30–60 cm), sheeted, tabular, and through-going sulfide-rich quartz veins ranging from 1 to 4 cm thick. The veins strike southwest, with azimuths of 215°–240° and northwesterly dips 65°–75°). Open fractures lined with euhedral quartz are present locally; elsewhere, there is evidence for minor shearing, gouge, and slickenlines along the veins. Sulfide infill, in decreasing order of abundance, includes arsenopyrite, pyrite, galena, and chalcopyrite. Veins are crudely zoned, with arsenopyrite towards the margins and chalcopyrite along vein centers. The veins are bordered by 2- to 30-cm-wide alteration halos of bleaching (argillic alteration), silicification, and chloritization; these halos are largely barren of gold. Selective sampling at the prospect in 2006 yielded grades as high 0.832 ppm Au, 65.7 ppm Ag, 5,942 ppm As, 170 ppm Bi, 5.09 percent Cu, 1.42 percent Pb, 2.24 percent tungsten (W), and 1.17 percent Zn (Adams, 2009). Mineralization likely formed in the earliest Paleogene during the cooling of the granite-quartz monzonite pluton (lKgqm), dated at 66.5 ± 1.1 Ma (U-Pb zircon; Dusel-Bacon and others, 2015).

Two Mile

The Two Mile prospect lies on the Taylor Highway approximately 2 km north of the Silver Lining prospect. Mineralization is very similar to that at Silver Lining, except that the veins strike more northerly (azimuth 22°, dip 80° to the east), wall rock alteration is more intense, and the values for Au and As are much lower. Selective sampling in 2006 returned values of 1.2 percent Cu and 284 ppm Mo in separate samples (Adams, 2009).

Section 35

The Section 35 occurrence, which has seen only limited surface sampling, comprises a small exposure of alkali-feldspar syenite (unit lKafs of this report; perthosite ring dike of Kerin [1976]) that is enriched in U, Th, Nb, Zr, and REE. DGGS sampled the occurrence in 2019, the best result being a sample carrying 125 ppm Nb, 1,030 ppm Zr, 261 ppm Th, 92 ppm U, and REE including 165 ppm lanthanum, 294 ppm cerium, and 81 ppm neodymium (605 ppm total REE; 19AW318, Wypych and others, 2019); Adams (2009) found similar values. Enrichment of these elements is due to both magmatic fractionation and hydrothermal processes. Newberry (2020) examined the mineralogy of the prospect in detail, observing that primary magmatic minerals apatite and ilmenite are enriched in REE and Nb, respectively. Fine-grained secondary allanite, monazite, and cheralite occur in association with apatite that has been depleted of REE by hydrothermal alteration. The bulk of Nb and light REE appear to be concentrated in secondary titanite forming as an alteration product of primary mafic minerals and ilmenite. Titanite at the occurrence is notably enriched in fluorine (F), and samples from the best-mineralized alkali-feldspar syenite contain fluorite; F- and chlorine (Cl)-rich hydrothermal fluids are important to the formation of magmatic-associated REE deposits. Newberry (2020) concludes that the observed volume and intensity of F and Cl metasomatism at Mount Fairplay are limited in surface exposures, further adding that the host rocks are not of the "miaskitic" family of alkalic rocks typically associated with some REE deposits.

PROSPECT LOCATIONS

Table 1. Best-known locations of prospects in the map area.

Prospect	Latitude	Longitude
Ladue Camp	63.429	-141.113
Lucy, Bjork	63.460	-141.166
Big Creek	63.512	-141.168
Goodrich Porphyry (Shady Ridge)	63.059	-141.091
Honks	63.071	-141.008
Move	63.037	-141.009
Pushbush	63.525	-141.318
Dennis-Ladue	63.419	-142.272
Oreo Mountain	63.386	-141.815
Pat (East Dennison)	63.610	-141.455
Section 35	63.642	-142.262
Silver Lining/Draken	63.647	-142.286
Two Mile	63.665	-142.274
Mount Fairplay	63.687	-142.259

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