Magmatic History of the Kerr-Sulphurets-Mitchell Copper-Gold Porphyry District, Northwestern British Columbia (NTS 104B)

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Introduction

Porphyry deposits contain the world's most important reserves of Cu and are important sources of Au, Mo, Ag and Re (e.g., Sillitoe, 2010). Globally, these deposits are concentrated along convergent plate margins, including western Canada. The economic importance of porphyry Cu-Au and related magmatic-hydrothermal deposits to Canada is profound, and the total of past production, reserves and resources of Cu-Au deposits in the Canadian Cordillera has likely surpassed $200 billion in net contained metal value (Lydon, 2007). Furthermore, a recent study, based on statistical modelling, estimated that only 60% of the total Cu contained within porphyry deposits in western Canada has been discovered to date (Mihalasky et al., 2011).

Porphyry deposits in British Columbia (BC) are located mainly within two volcanic-arc terranes, the Quesnel and Stikine terranes, where most porphyry mineralization occurred within a relatively short (~15 m.y.) time span during the Late Triassic and Early Jurassic (Figure 1; Logan and Mihalynuk, 2014). The Kerr-Sulphurets-Mitchell (KSM) project, owned by Seabridge Gold Inc., is located approximately 65 km northwest of the town of Stewart in the Iskut–Stikine River region of northwestern BC (Figure 2). The KSM project is situated within the Stikine terrane and features four distinct centres of early Jurassic Cu-Au-Ag-Mo porphyry mineralization, located along a northerly trend and contained within an area measuring roughly 2 km by 10 km. From south to north, these deposits are Kerr, Sulphurets, Mitchell and Iron Cap. The KSM project has proven and probable reserves totalling 1.08 million kilograms (38 million ounces) of Au, 4.5 billion kilograms (9.9 billion pounds) of Cu, 5.41 million kilograms (191 million ounces) of Ag and 96.6 million kilograms (213 million pounds) of Mo, for a total of 2.2 billion tonnes averaging 0.55 g/t Au, 0.21% Cu, 2.6 g/t Ag and 42.6 ppm Mo (Seabridge Gold Inc., 2016). The KSM district represents one of the largest undeveloped Cu-Au deposits in the world, with significant potential economic importance for the surrounding region of northwestern BC.

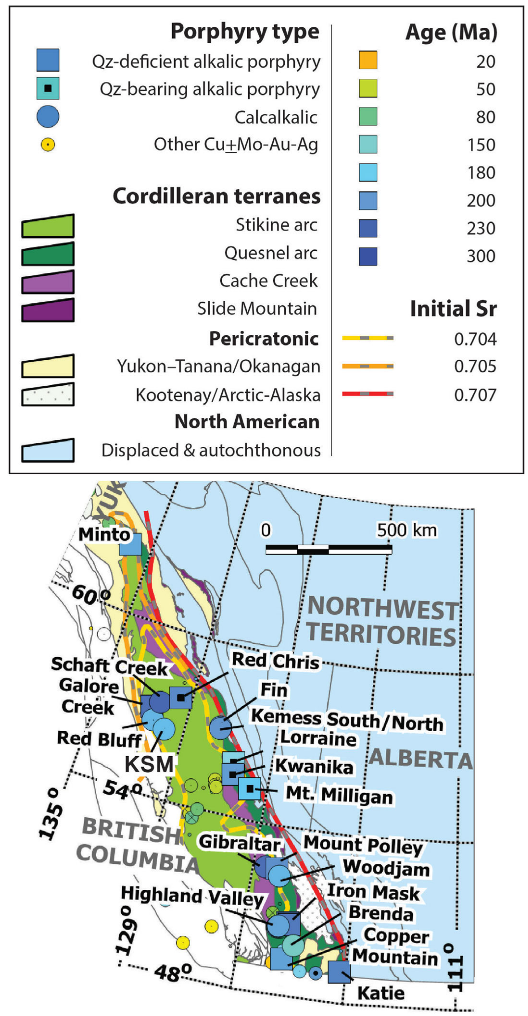

Figure 1. Locations of the principal porphyry deposits in the cordillera of western Canada, including the KSM district in northwestern BC (modified from Logan and Mihalynuk, 2014); shapes of porphyry-deposit symbols reflect the classification of the deposit, with alkalic deposits represented by squares and calcalkalic deposits by circles; symbols are also colour coded according to age.

Keywords: *British Columbia, Stikine terrane, Early Jurassic, porphyry deposit, igneous petrology, calcalkaline, magmatism*

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Fundamentally, porphyry Cu-Au deposits result from the emplacement of porphyry intrusions and accompanying metalliferous hydrothermal fluids (e.g., Titley and Beane, 1981). A single porphyry deposit may contain a range of plutonic bodies, including precursor plutons, multiple syn-mineral intrusive phases and post-mineral dikes or stocks. Unravelling the magmatic phases of a porphyry deposit is critical for an understanding of the evolution of the ore system, including the distribution of contained metals. To date, studies of the intrusive rocks at KSM have been marred by problems common to Mesozoic magmatic-hydrothermal deposits in active tectonostratigraphic terranes: hydrothermal alteration, deformation, faulting and low-grade metamorphism. Issues such as texturally destructive phyllic alteration, penetrative foliation and extensive remobilization of major and trace elements by hydrothermal fluids can result in the partial to total destruction of the primary mineralogy and textures in large swaths of the deposits, and masking of lithogeochemical signatures. The primary aim of this ongoing study is to establish the magmatic history of the district, by cataloguing, describing and determining the chronology and spatial extent of the intrusive phases at each of the four porphyry centres in the KSM district. This will be accomplished through 1) relogging and sampling of drillcore at each of the four deposits; 2) petrographic analysis of the intrusive phases at each deposit, to determine primary mineralogy; 3) whole-rock geochemistry; 4) geochronology; and 5) refractory-mineral geochemistry. In addition, the authors aim to unravel the spatial and temporal relationships between the intrusive phases and hydrothermal alteration and mineralization, with the objective of gaining new insight into the primary controls on mineralization within the KSM district.

Regional Geology

The KSM district, located in the western Stikine terrane (Figure 1), is situated on an approximately 60 km long, discontinuous, northerly trend of mineralization centres (Figure 2; Nelson and Kyba, 2014). Major mineralized deposits along this trend consist of porphyry, epithermal and volcanogenic massive-sulphide (VMS) deposits, including Red Mountain, Silbak-Premier, Granduc, Scottie Gold, Big Missouri, Brucejack, KSM, Treaty and Eskay Creek (Figure 2). These deposits are hosted mainly within the volcaniclastic and sedimentary strata of the Lower Jurassic Hazelton Group and are often related to early Jurassic intrusions, including the 197–187 Ma Texas Creek plutonic suite (Alldrick, 1993; Logan and Mihalynuk, 2014). The Texas Creek plutonic suite includes the Premier porphyry intrusions, named for the syn-mineral intrusions at the Premier mine (Figure 2; Alldrick, 1993). Premier porphyry intrusions are characterized by K-feldspar megacrysts and plagioclase phenocrysts in a fine-grained groundmass (Alldrick, 1993); as will be discussed in the 'Kerr Deposit' and 'Mitchell Deposit' sections, roughly contemporaneous intrusions of similar mineralogy and texture have been noted within the KSM district. The Hazelton Group, which records several successive pulses of arc volcanism, unconformably overlies the Triassic Stuhini Group, which is composed of arc and marine sedimentary strata (Nelson and Kyba, 2014). Several younger plutons unrelated to mineralization, Eocene to Middle Jurassic in age, are also found within the region.

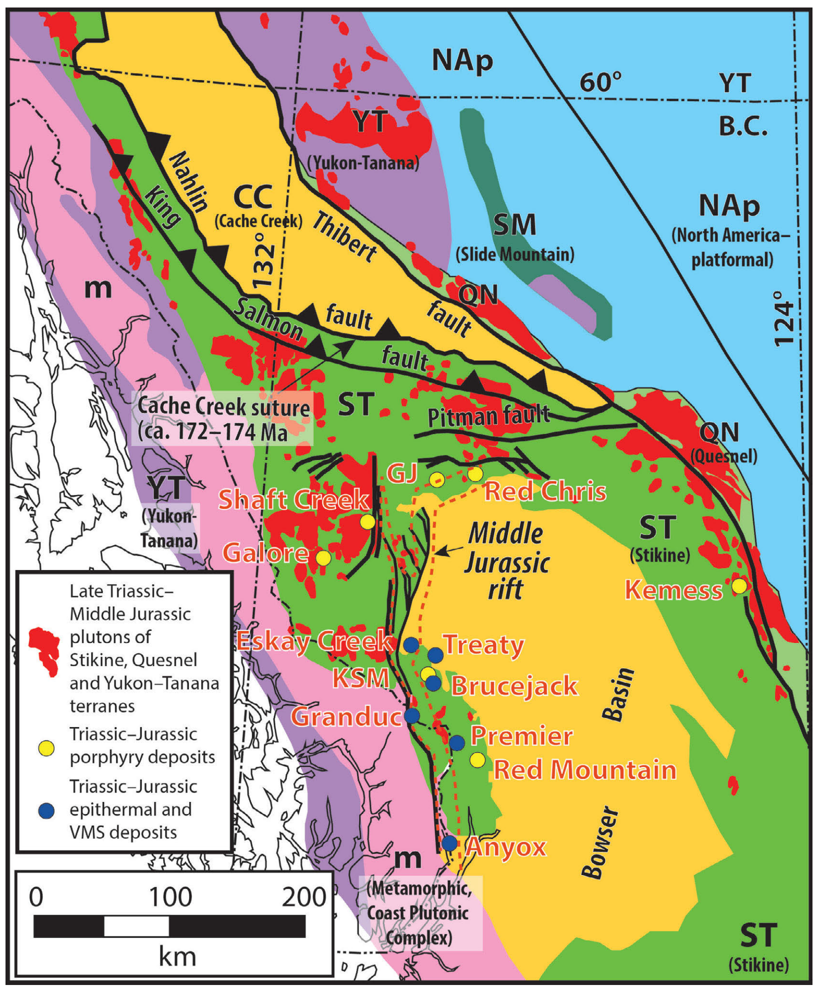


Figure 2. Tectonostratigraphy of the northern Stikine terrane, northwestern BC, showing the locations of major faults and Triassic–Jurassic magmatic-hydrothermal deposits (modified from Nelson et al., 2013); note that the KSM district is situated along a rough alignment of several of these deposits, extending from Red Mountain to Eskay Creek. Abbreviations: CC, Cache Creek terrane; m, Metamorphic, Coast Plutonic Complex; NAp, North America – platformal; QN, Quesnel terrane; ST, Stikine terrane; VMS, volcanogenic massive-sulphide; YT, Yukon-Tanana terrane.

The western part of the Stikine terrane is a structurally complex region, with important northerly- to northeasterly-trending structures resulting from mid-Cretaceous sinistral transpression associated with the Skeena fold-and-thrust belt (Figure 2; Nelson and Kyba, 2014). Structural controls on mineralization have also been proposed at several magmatic-hydrothermal deposits within the region, including Silbak-Premier, Big Missouri and Scottie Gold (Alldrick, 1993).

District Geology

The KSM district is composed mainly of Late Triassic Stuhini Group and Early Jurassic Hazelton Group volcaniclastic and sedimentary basement strata, with numerous Early Jurassic intrusions ranging in composition from diorite to syenite. The structural geology of the region is complex, largely due to Cretaceous deformation caused by the development of the Skeena fold-and-thrust belt. Imbricate thrust faults, including the Sulphurets thrust fault (STF) and the Mitchell thrust fault (MTF), have dismembered the district into multiple panels. Differential strain accommodation within the district has also resulted in localized zones of intense deformation and foliation, most notably within zones of strong phyllic alteration (and, thus, relatively low competency) within the Kerr and Mitchell deposits (Febbo et al., 2015).

As previously mentioned, the KSM district includes four Cu-Au-Ag-Mo porphyry deposits with defined resources on property owned by Seabridge Gold Inc. (Figure 3). Adjoining the KSM project, Pretium Resources Inc. owns the Brucejack epithermal Au system and Snowfield Cu-Au porphyry deposit (Figure 3). The Snowfield deposit, which contains measured and indicated resources of 1.37 billion tonnes averaging 0.59 g/t Au and 0.10% Cu, for a total of 25.9 million ounces Au and 2.98 billion pounds Cu (Pretium Resources, 2016), is actually the displaced cap of the Mitchell deposit, which was transported approximately 2 km ESE by the Mitchell thrust fault (Febbo et al., 2015). The occurrence of multiple Cu-Au porphyry deposits within the KSM district, as well as their approximate northerly alignment, is not unusual; global porphyry districts commonly feature clusters or alignments of ore deposits, each separated by hundreds to thousands of metres, distributed over a total distance of up to 30 km (Sillitoe, 2010). Alignments may occur either parallel or orthogonal to the magmatic arc, and porphyry deposits throughout a single district may display significant ranges of formational age (e.g., up to ~18 m.y. in the Cadia district; Wilson et al., 2007; Sillitoe, 2010).

Global Cu-Au porphyry deposits can be broadly classified into two principal groups: 1) calcalkalic porphyry deposits, and 2) comparatively rare alkalic porphyry deposits (e.g., Titley and Beane, 1981). British Columbia and the southwest Pacific are the two regions where alkalic Cu-Au porphyry deposits are relatively common (Bissig and Cooke, 2014). As of 2011, a total of 431 alkalic prospects and 904 calcalkalic prospects had been documented in BC (BC Geological Survey, 2011). The characteristic styles of hydrothermal alteration and mineralization of archetypal calcalkalic porphyry deposits differ markedly from alkalic equivalents, so the implementation of strategic and successful mineral-exploration campaigns for porphyry Cu-Au deposits in BC hinges upon the correct identification of the porphyry class within the district.

Although the porphyry deposits of the KSM district have, in the past, been referred to as alkalic (e.g., Bissig and Cooke, 2014), the four deposits with defined reserves at KSM display distinctly calcalkaline features. Notably, as will be discussed in the deposit descriptions, the four deposits contain abundant disseminated pyrite (pyrite > chalcopyrite) and considerable molybdenite. Kerr, Sulphurets and Mitchell feature extensive peripheral propylitic alteration zones. Furthermore, the Kerr, Mitchell and Iron Cap deposits also feature zones of strong phyllic alteration, as well as quartz-stockwork zones with >50% quartz veins ('A-veins' and 'B-veins', based upon standard porphyry vein nomenclature; e.g. Gustafson and Hunt, 1975; Sillitoe, 2010). The KSM district, therefore, is dominated by calc-alkaline porphyry Cu-Au mineralization. However, certain zones of relatively weak mineralization within the KSM district, peripheral to the calcalkaline porphyry deposits, display features that are more consistent with typical alkalic deposits. These zones are associated with monzonite to syenite porphyry intrusions (Figure 4), little quartz veining, potassic alteration and a reddening of feldspars via hematite dusting, all of which are characteristics typical of alkalic porphyry deposits (e.g., Logan and Mihalynuk, 2014). The total metal contained within these apparently alkalic zones, however, is subordinate to the mineralization found within the footwall of the STF, which hosts the bulk of the ore at KSM.

KSM Cu-Au Porphyry Deposits

This section contains brief overviews of the Kerr, Sulphurets, Mitchell and Iron Cap Cu-Au porphyry deposits, covering the morphology, the principal hydrothermal alteration assemblages, the degree of deformation, and the range of important intrusions encountered at each deposit. All of the deposits are roughly contemporaneous in age and hosted by wallrocks of the Early Jurassic Hazelton Group and/or Late Triassic Stuhini Group (Figure 3). Figure 5 shows, in plan view, the lateral distribution of Au and Cu at each of the four deposits. The lateral extent and orientation of mineralization is different at each deposit, with Kerr and Sulphurets rather elongate, and Mitchell displaying concentric zoning of metals (Figure 5). Thus, while the four deposits display certain distinct similarities, they also feature notable differences, resulting in a unique character for each deposit.

Kerr Deposit

Located in the southern part of the KSM district, the Kerr deposit contains probable reserves of 242 million tonnes averaging 0.45% Cu and 0.24 g/t Au, for a total of 1.09 billion kilograms (2.4 billion pounds) of Cu and 54.9 million grams (1.9 million ounces) of Au (Seabridge Gold Inc., 2016). The Deep Kerr zone, which is the deeper extension of the Kerr deposit, contains an inferred resource of 782 million tonnes averaging 0.54% Cu and 0.33 g/t Au, for a total of 4.2 billion kilograms (9.3 billion pounds) of Cu and 232 million grams (8.2 million ounces) of Au (Seabridge Gold Inc., 2016). The Kerr deposit has a roughly planar, north-striking and steeply west-dipping form (Figure 5), reflecting the morphologies of the Kerr intrusions themselves: a suite of steeply west-dipping dikes. The morphologies of certain porphyry Cu-Au orebodies replicate the forms of their porphyry intrusions (Sillitoe, 2010), especially those emplaced at shallow crustal levels (Proffett, 2009). Porphyry deposits with narrow elongate shapes similar to that of Kerr have also been noted elsewhere in the world (e.g., Hugo Dummett, Mongolia; Khashgerel et al., 2008).

The wallrocks to the dikes comprise a range of sedimentary and volcaniclastic strata, including finely bedded argillite, mudstone, massive sandstone, conglomerate, turbidite sequences and various volcaniclastic units, which likely encompass both the Stuhini and Hazelton groups (Bridge, 1993; Rosset and Hart, 2015). The zones of strongest mineralization in the Kerr deposit occur within the porphyry dikes. However, the wallrocks can also carry significant mineralization, with the grade typically decreasing with increasing distance from the dikes. There are two principal zones of increased intrusion density, or dike swarms, within the Kerr deposit, that correlate to two zones of higher grade: an ‘eastern limb’ and a ‘western limb’ of mineralization, which are separated by a central septum of wallrock.

The range of different intrusive phases found at Kerr is, in approximate chronological order from oldest to youngest:

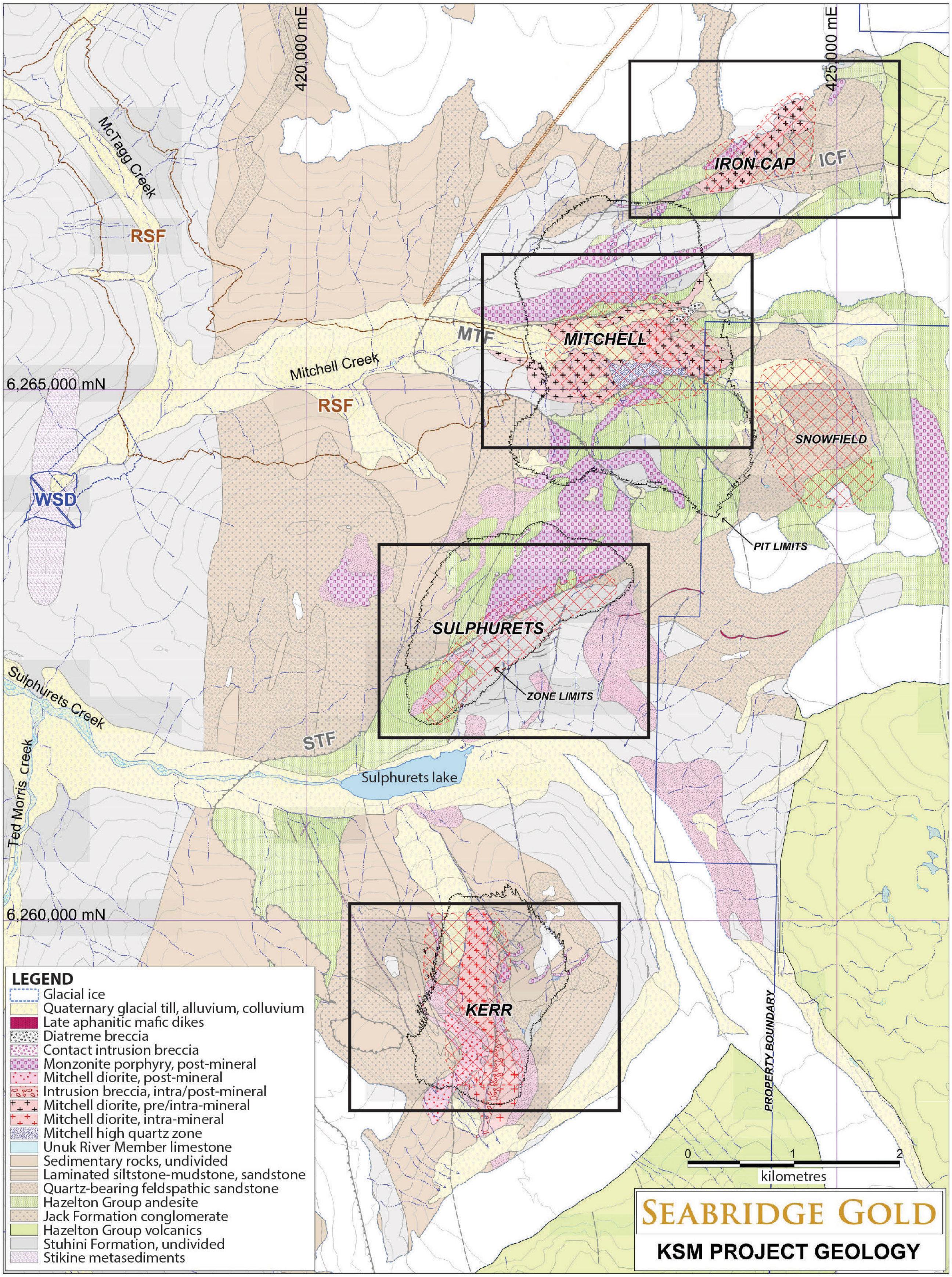
- high-quartz-vein zones, with >80% quartz veins, where the nature of the intrusive protolith is largely obscured by the veins, primarily A-veins (Figure 6)
- plagioclase-hornblende–phyric, fine- to medium-grained subporphyritic intrusions, with >10% quartz veins (A-veins and B-veins) that typically envelop pods of the high-quartz-vein zones and are well mineralized (Figure 6)
- plagioclase–K-feldspar–hornblende–phyric, medium-grained subporphyritic intrusions, typically with potassic alteration and well mineralized
- plagioclase-hornblende–phyric, fine- to medium-grained subporphyritic intrusions, with <10% quartz veins and variable mineralization (Figure 6)
- augite-plagioclase–phyric dikes, sometimes megacrystic, that are typically unmineralized or very weakly mineralized
- K-feldspar–megacrystic (up to ~2 cm), plagioclase-hornblende–phyric dikes, that resemble the Premier porphyry intrusions described by Alldrick (1993), that are typically unmineralized (Figure 6)
- aphanitic to very fine grained mafic dikes, with pervasive chlorite alteration, that are post-mineral
- lamprophyre dike that is post-mineral

As discussed by Rosset and Hart (2014) and Bridge (1993), the Kerr deposit features early potassic alteration, characterized by an assemblage of chloritized hydrothermal biotite±K-feldspar±magnetite, centred upon the dike swarms but also affecting proximal wallrocks. Propylitic alteration (chlorite±epidote) is distal to potassic alteration. Chlorite-sericite-pyrite alteration commonly overprints these earlier assemblages, varying in intensity from weak to intense and affecting both intrusions and wallrock. The bornite and some of the sulphosalts at Kerr, accompanied by dickite±pyrophillite, were formed within intermediate- to high-sulphidation alteration zones, which typically overlap with the high-quartz-vein zones. Regions with networks of anhydrite veins and veinlets are common at Kerr. In near-surface parts of the deposit, the hydration of anhydrite to gypsum, and eventual dissolution of the latter, have led to the formation of apparent rubble zones.

Mineralization at Kerr is primarily hypogene, although small amounts of supergene mineralization, including chalcocite, occur in the near-surface environment (Bridge, 1993). Hypogene mineralization includes chalcopyrite, pyrite, bornite, molybdenite, enargite, tennantite, tetrahedrite and base-metal sulphides, all closely associated with quartz veins, as well as pervasive disseminated pyrite. Quartz-stockwork zones are commonly, but not exclusively, associated with the highest grade zones at Kerr. See Rosset and Hart (2015) for a further overview of vein types and mineralization at Kerr.

Finally, the Kerr deposit features considerable deformation related to the development of the Cretaceous Skeena fold-and-thrust belt. Zones with strong sericitic alteration in particular, within both intrusive and wallrock protoliths, have

Figure 3. Geology of the Kerr-Sulphurets-Mitchell district, showing the locations of Seabridge Gold’s Kerr, Sulphurets, Mitchell and Iron Cap deposits, as well as Pretium Resources’ Snowfield deposit (courtesy of Seabridge Gold Inc.). The black rectangles indicate the locations of the deposit maps in Figure 5. Abbreviations: MTF, Mitchell thrust fault; STF, Sulphurets thrust fault. Place names with the generic in lower case are unofficial.



420,000 mE
425,000 mE
McTagg Creek
RSF
IRON CAP
ICF
MITCHELL
MTF
Mitchell Creek
6,265,000 mN
RSF
SNOWFIELD
WSD
PIT LIMITS
SULPHURETS
ZONE LIMITS
Sulphurets Creek
STF
Sulphurets lake
Ted Morris creek
6,260,000 mN
KERR
PROPERTY BOUNDARY
LEGEND
Glacial ice
Quaternary glacial till, alluvium, colluvium
Late aphanitic mafic dikes
Diatreme breccia
Contact intrusion breccia
Monzonite porphyry, post-mineral
Mitchell diorite, post-mineral
Intrusion breccia, intra/post-mineral
Mitchell diorite, pre/intra-mineral
Mitchell diorite, intra-mineral
Mitchell high quartz zone
Unuk River Member limestone
Sedimentary rocks, undivided
Laminated siltstone-mudstone, sandstone
Quartz-bearing feldspathic sandstone
Hazelton Group andesite
Jack Formation conglomerate
Hazelton Group volcanics
Stuhini Formation, undivided
Stikine metasediments
0
1
2
kilometres
SEABRIDGE GOLD
KSM PROJECT GEOLOGY

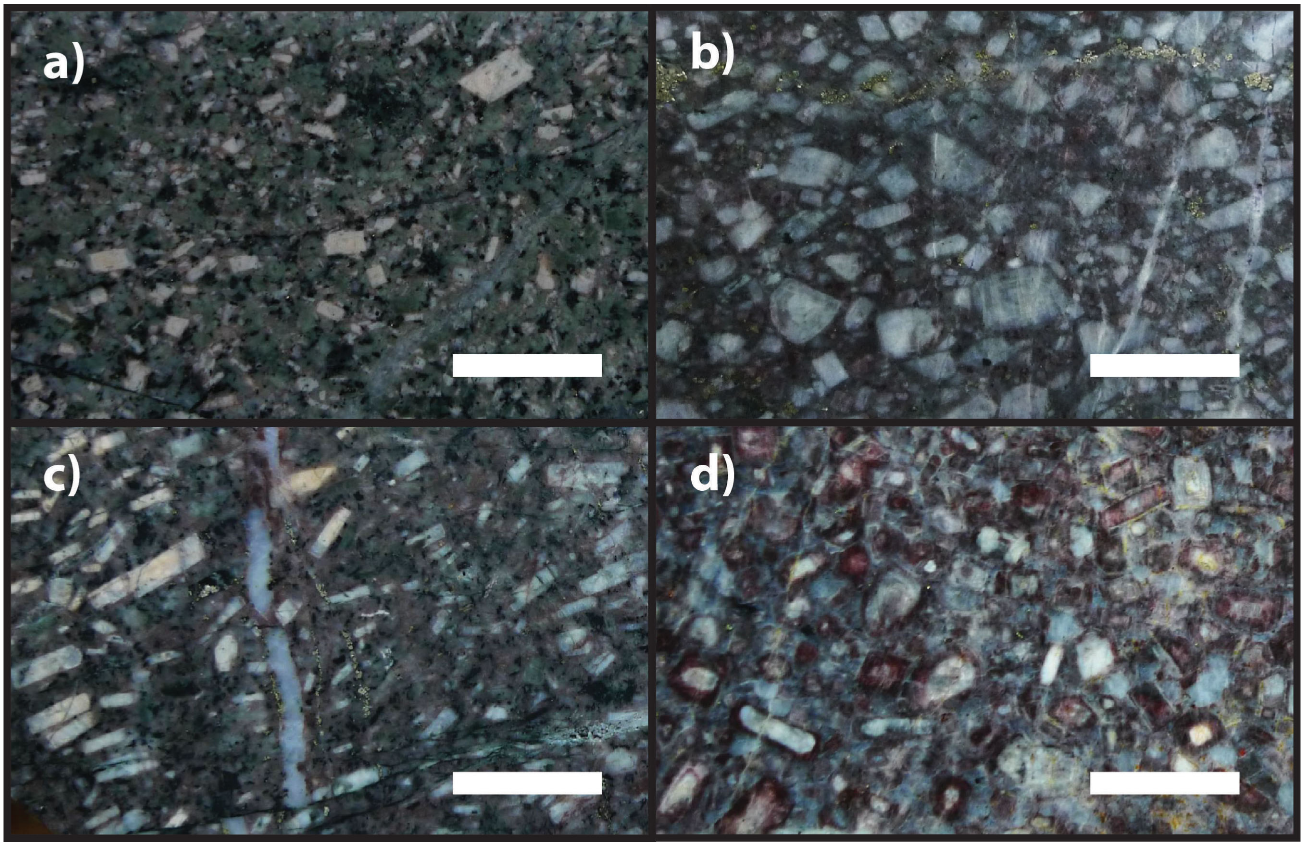


Figure 4. Hand-specimen photographs of weakly mineralized syenite and monzonite porphyry intrusions in the Kerr-Sulphurets-Mitchell district: **a)** intrusion northeast of the Kerr deposit (diamond-drill hole MQ-14-07, 621.1 m depth); **b)** intrusion peripheral to the Iron Cap deposit (IC-10-034, 353.4 m); **c)** and **d)** intrusions in the hangingwall of the Mitchell thrust fault, above the Mitchell deposit (c – M-15-130, 474.5 m; d – M-11-128, 535.2 m). Scale bars are 2 cm in length.

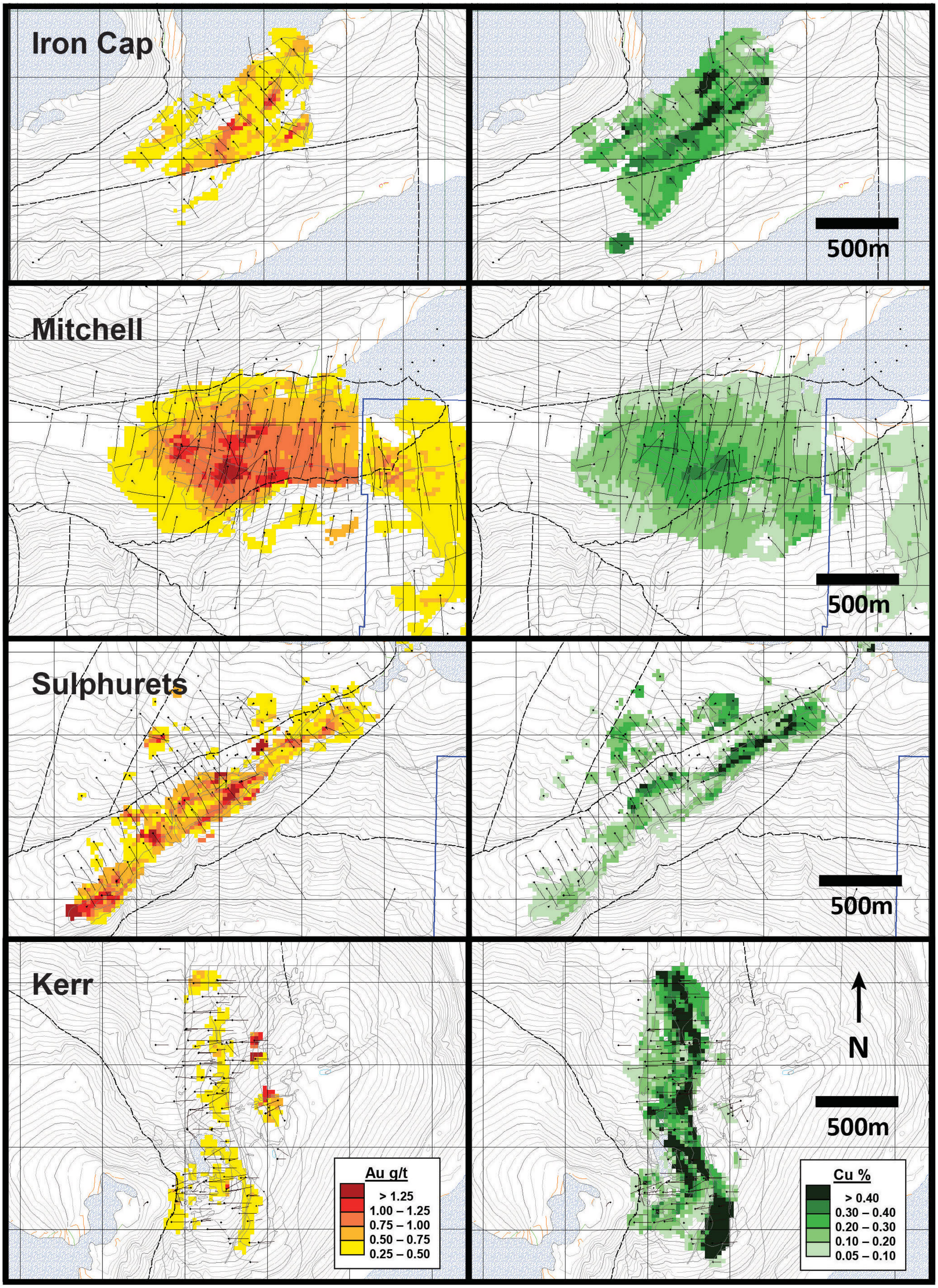
been extensively folded and foliated. Areas with strong anhydrite veining sometimes appear brecciated.

Sulphurets Deposit

The Sulphurets deposit, located approximately 2 km north of the Kerr deposit (Figure 3), contains probable reserves of 304 million tonnes averaging 0.59 g/t Au, 0.22% Cu, 0.8 g/t Ag and 51.6 ppm Mo (Seabridge Gold Inc., 2016). In plan view, Sulphurets is elongated in a northeasterly direction and is truncated to the south by the Sulphurets cliff (Figures 3, 5). The Sulphurets orebody is cut by the Sulphurets thrust fault (STF) and related splays, and features mineralization in both the hangingwall and footwall of the STF. The geology of the two panels is, however, quite different. In the hangingwall of the STF, mineralization is closely associated with monzonite to syenite porphyry intrusions (Figure 6) that commonly display potassic alteration and reddish hematite dusting—features typically associated with alkalic Cu-Au porphyries. These intrusions are not observed in the footwall of the STF, where intrusions are volumetrically subordinate and mineralization is hosted primarily within sedimentary wallrock. The wallrock is composed of a range of sedimentary rock types, including massive mudstone, massive to bedded siltstone and sandstone, and polymictic pebbly conglomerate beds. Mineralized wallrocks commonly show strong hornfels development, with patches of fine, dark brown hydrothermal biotite, or dark chlorite alteration. Peripheral to the well-mineralized zone, propylitic chlorite±epidote alteration dominates, and the degree of hornfels development diminishes.

The intrusions observed below the STF at Sulphurets are typically shallowly-dipping dikes, primarily fine- to medium-grained, subporphyritic, plagioclase-hornblende–phyric dioritic intrusions with chlorite-dominant alteration, and plagioclase–K-feldspar–hornblende–phyric monzodiorite porphyry intrusions with <5% K-feldspar phenocrysts (Figure 6). No monzonite or syenite intrusions resembling the mineralized intrusions in the hangingwall are observed in the panels immediately below the STF. Due to uncertainty in the total displacement along the STF, the original spatial relationship, or genetic link (if any), between the mineralization in the hangingwall and footwall of

Figure 5. Plan views of, from top to bottom, the Iron Cap, Mitchell, Sulphurets and Kerr deposits, showing the distribution and intensity of the Au grade (left) and Cu grade (right) for each deposit (courtesy of Seabridge Gold Inc.) See Figure 3 for location of each deposit within the district.


Iron Cap
500m
Mitchell
500m
Sulphurets
500m
Kerr
N
500m
Au g/t
> 1.25
1.00 – 1.25
0.75 – 1.00
0.50 – 0.75
0.25 – 0.50
Cu %
> 0.40
0.30 – 0.40
0.20 – 0.30
0.10 – 0.20
0.05 – 0.10

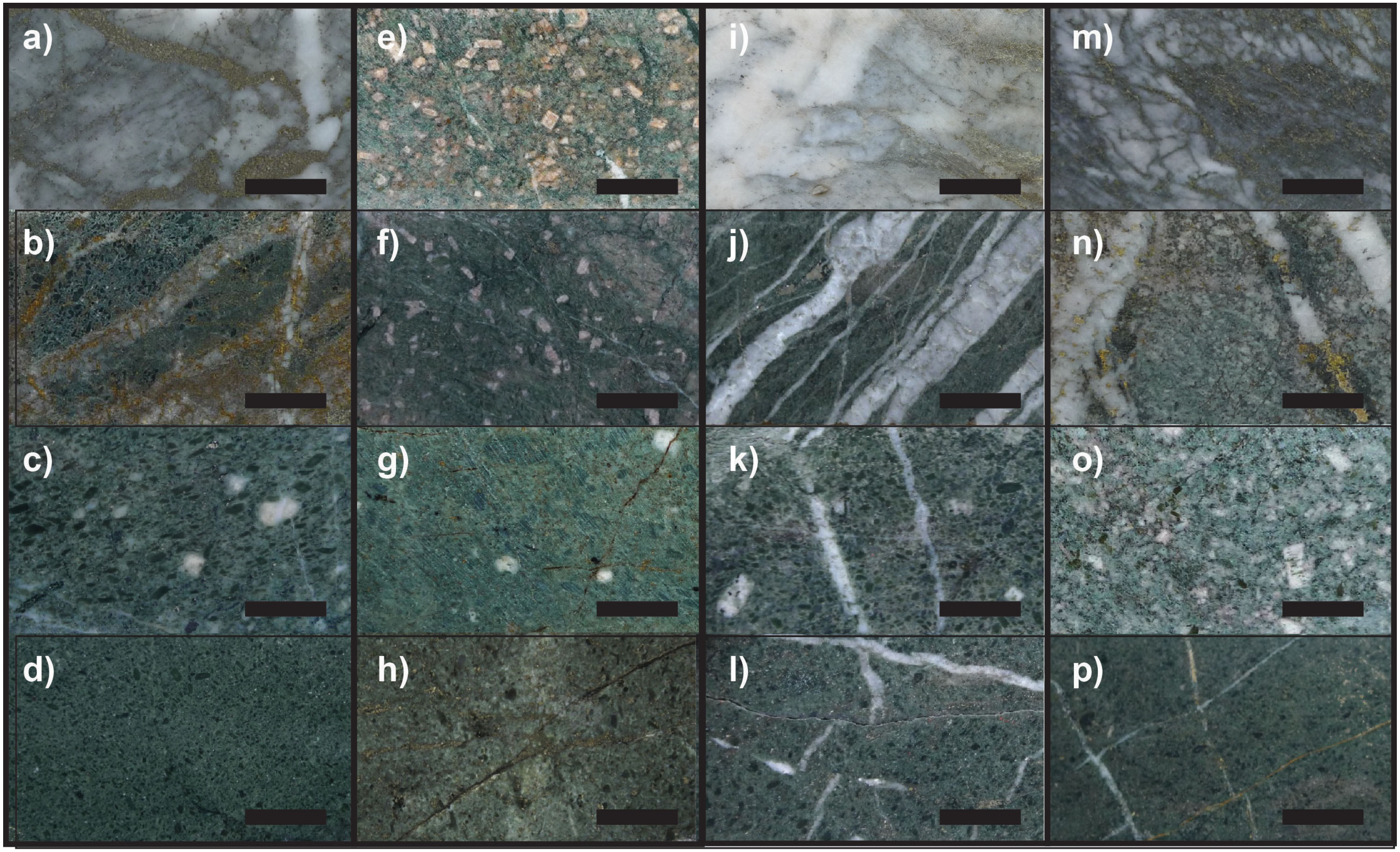


Figure 6. Typical intrusive phases of the Kerr (a, b, c, d), Sulphurets (e, f, g, h), Mitchell (i, j, k, l) and Iron Cap (m, n, o, p) deposits: **a)** K-13-29, 749.5 m (diamond-drill hole and depth); **b)** K-13-29, 461.8 m; **c)** K-13-23, 1416 m; **d)** K-13-31A, 608.4 m; **e)** S-12-75, 159.6 m; **f)** S-14-79, 42.2 m; **g)** S-11-52, 286.2 m; **h)** S-11-62, 109 m; **i)** M-08-090, 325.5 m; **j)** M-08-094, 293.6 m; **k)** M-08-073, 546.0 m; **l)** M-08-073, 199.9 m; **m)** IC-16-062, 236.4 m; **n)** IC-13-051, 919.0 m; **o)** IC-13-051A, 1165 m; **p)** IC-12-047, 306.0 m. All photographs are shown at the same scale and the scale bars are 2 cm in length.

the STF at Sulphurets is currently unclear. However, the total displacement on the STF is likely significant, and probably exceeds 1 km.

The Sulphurets deposit is dissimilar to the other three deposits with defined reserves at KSM in several important ways. Firstly, the Sulphurets orebody straddles the STF, whereas the other KSM deposits are uniquely in the footwall of this thrust fault. Furthermore, there are no quartz-stockwork zones at Sulphurets, and typically only minor quartz veining (<2%). Finally, Sulphurets lacks the zones of extensive phyllic alteration found at Kerr, Mitchell and Iron Cap, although it still features abundant disseminated pyrite. Altogether, the characteristics of Sulphurets above the STF are more consistent with an alkalic classification, whereas an appropriate classification for the largely wallrock-hosted mineralization below the STF is still pending. However, the principal dikes below the STF at Sulphurets texturally and mineralogically resemble syn-mineral porphyry intrusions found at the distinctly calcalkaline Kerr and Mitchell deposits. An ongoing aim of this study is to test the potential affinity between the porphyry intrusions at these neighbouring deposits via petrography and geochemistry.

Mitchell Deposit

The Mitchell deposit, located between the Sulphurets and Iron Cap deposits, currently holds the largest Au reserves of the four KSM porphyry deposits, with measured and indicated resources of 1.794 billion tonnes averaging 0.60 g/t Au, 0.16% Cu, 3.1 g/t Ag and 58 ppm Mo, for a total of 964 million grams (34 million ounces) of Au and 3.0 billion kilograms (6.6 billion pounds) of Cu (Seabridge Gold, 2016). The Mitchell deposit forms a roughly cylindrical orebody plunging steeply to the northwest (Figure 5). As previously mentioned, the neighbouring Snowfield deposit is the displaced cap of the Mitchell deposit, dismembered by the Mitchell thrust fault (~1600 m total offset) during the Cretaceous (Febbo et al., 2015).

Unlike the Kerr deposit, in which mineralization is partially hosted within wallrock adjacent to the syn-mineral intrusions, mineralization at Mitchell is almost entirely intrusion hosted. The major intrusive phases at Mitchell are, in approximate chronological order from oldest to youngest:

- high-quartz zones, with >80% quartz veins, where the nature of the intrusive protolith is largely obscured by the veins (primarily A-veins Figure 6)
- plagioclase-hornblende–phyric, fine- to medium-grained subporphyritic intrusions, with >30% quartz veins (A-veins and B-veins) that typically envelop pods of the high-quartz-vein zones and are well mineralized (Figure 6)
- plagioclase-hornblende–phyric, fine- to medium-grained subporphyritic intrusions with <10% quartz veins and variable mineralization (Figure 6)
- plagioclase–K-feldspar–hornblende–quartz–phyric, medium-grained intrusions, with occasional K-feldspar phenocrysts up to approximately 1 cm in size, that are similar to the Premier porphyry intrusions described by Alldrick (1993) and typically weakly mineralized (Figure 6)
- aphanitic to very fine grained mafic dikes, with pervasive chlorite alteration, that are post-mineral

The principal styles of hydrothermal alteration at Mitchell are early K-feldspar+magnetite+biotite potassic alteration and peripheral chlorite±epidote alteration. Extensive zones of chlorite+sericite alteration overprint sections of the Mitchell deposit, including areas of strong sericite+pyrite phyllic alteration, especially in the southern and eastern parts of the deposit (Febbo et al., 2015). The Mitchell deposit contains a central high-quartz zone, with >50% quartz A-veins and B-veins (Febbo et al., 2015). This zone, as well as the plagioclase-hornblende–phyric porphyry stocks and dikes containing >10% quartz A-veins and B-veins, host the bulk of the mineralization. Molybdenite-bearing quartz veins are concentrated in a halo around the centre of the deposit. Finally, a pipe-like brecciated zone of high-sulphidation bornite+pyrite+tennantite+tetrahedrite+dickite/pyrophyllite, with abundant fragmented anhydrite veins, occurs near the centre of the deposit. Veining and mineralization in the Mitchell deposit are described in further detail by Febbo et al. (2015).

Although the Kerr and Mitchell deposits are on completely opposite sides of the morphological spectrum, they share many important similarities: early high-quartz-vein zones (>50% quartz veins), partially overprinted by late high-sulphidation assemblages of bornite+pyrite+tennantite+tetrahedrite±dickite/pyrophyllite; very similar plagioclase-hornblende–phyric syn-mineral intrusions; late syn-mineral to post-mineral K-feldspar–phyric dikes; and zones of strong anhydrite veining. These similarities indicate that the Kerr and Mitchell deposits formed by similar genetic processes.

Weak mineralization is also found immediately north of the Mitchell deposit, above the MTF, associated with monzonite to syenite porphyry intrusions, low quartz-vein densities and reddish hematite dusting (Figure 4). As the displacement along the MTF is constrained by the modern positions of the Snowfield and Mitchell orebodies, which the MTF dismembered, it is possible to estimate that these weakly mineralized alkalic intrusions north of the deposit were originally situated ~1600 m west-northwest of the deposit. Thus, the mineralization within these alkalic intrusions probably was not generated by the Mitchell hydrothermal system.

Iron Cap Deposit

The northernmost Cu-Au porphyry deposit in the KSM district, Iron Cap, is a roughly cylindrical orebody plunging steeply to the northwest. Iron Cap is composed of numerous stocks and dikes hosted within sedimentary and volcaniclastic wallrock. The wallrock comprises mainly massive mudstone, sandstone, polymict pebbly conglomerate and volcanic breccia. As is the case with the Kerr deposit, the zones of strongest mineralization at Iron Cap are contained within syn-mineral porphyry intrusions, although significant mineralization is also hosted by the surrounding wallrock. Iron Cap features central potassic alteration, with hydrothermal K-feldspar and magnetite in the monzonite intrusions, whereas the plagioclase-hornblende–phyric intrusions commonly display chlorite±sericite–dominant alteration. The wallrocks are commonly altered to hornfels and often display strong silicification in addition to sericite+pyrite alteration.

The Iron Cap intrusions include the following:

- plagioclase-hornblende–phyric, fine- to medium-grained subporphyritic intrusions, with little to no quartz veining, that are pre-mineral or early syn-mineral (Figure 6)
- high-quartz-vein zones, with >80% quartz veins, where the nature of the intrusive protolith is largely obscured by the veins primarily A-veins that are well mineralized and syn-mineral (Figure 6)
- plagioclase–K-feldspar–hornblende–phyric, medium-grained monzonite intrusions, with seriate texture, 10–30% K-feldspar phenocrysts, 2–50% quartz veins and variable mineralization, that are syn-mineral (Figure 6)
- aphanitic to very fine grained mafic dikes, with pervasive chlorite alteration, that are post-mineral

Within the Kerr and Mitchell deposits, the dioritic plagioclase-hornblende–phyric intrusions are commonly well mineralized and often contain significant volumes of quartz veins. The analogous intrusions at Iron Cap, however, are only weakly mineralized to unmineralized and are apparently precursors to the monzonite stocks and dikes, which are commonly very well mineralized. The Iron Cap deposit also presents interesting similarities to the Red Chris deposit, another Late Triassic–Early Jurassic porphyry deposit within the Stikine terrane (Figure 2), which features pre-mineral plagioclase-hornblende–phyric diorite and syn-mineral monzonite intrusions (Rees et al., 2015).

Future Work

This ongoing study will utilize a range of techniques to further unravel the magmatic history of the KSM district, including whole-rock geochemistry, petrography, refractory-mineral geochemistry, and geochronology, to accurately classify, order and compare the intrusions found at each of the KSM deposits. Furthermore, as the KSM district contains many texturally destructive features, including extensive deformation and hydrothermal alteration, the authors will seek to gain insights into the intrusive history at KSM through the study of primary refractory trace-mineral phases, such as zircon and apatite. The geochemistry of these resistive minerals contains valuable records of conditions within the parental magma, and allows researchers to gain insights into the intrusive histories of areas where poor textural preservation precludes the possibility of traditional petrographic and lithogeochemical studies.

Finally, although the KSM district is dominated by calc-alkaline porphyry mineralization, zones containing features typical of alkalic porphyry mineralization are also represented. The authors will aim to understand the genetic and temporal relationships between these two styles of mineralization within the KSM deposits and peripheral areas, and investigate whether these relationships may be linked to the fertility, or unusually Au-rich nature, of the district. Finally, they will investigate how the Early Jurassic magmatism within the district resulted in the formation of such a large, and unusually Au-rich, suite of porphyry deposits.

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