A New Metallotect: Late Neogene porphyry Cu-Mo mineralization in British Columbia

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Abstract

Late Neogene porphyry Cu-Mo mineralization hosted by the Klaskish Plutonic Suite (*new formal name*) on northern Vancouver Island occupies a unique position in the forearc of the Cascadia subduction zone (Nixon et al., 2020). The Klaskish granitoid plutons and Alert Bay volcanic rocks comprise the Brooks magmatic suite, that forms a northeast-oriented zone, the Brooks-Haddington tract, extending for 65 km across the island from the Pacific coast to Queen Charlotte Strait in the east. The southern part of the Brooks-Haddington tract is marked by a narrow (10 km) structural corridor, the Brooks Peninsula fault zone, which hosts the mineralized Klaskish intrusions. The northern part of the tract is occupied by eroded edifices of the Alert Bay volcanic suite.

High-precision U-Pb zircon and Re-Os molybdenite dates for mineralized stocks of the Klaskish Plutonic Suite (ca. 7-4.6 Ma) confirm that their emplacement was coeval with older phases of Alert Bay volcanism (8-2.5 Ma), and that porphyry Cu-Mo magmatic-hydrothermal systems are genetically linked to pluton emplacement and crystallization. Neogene plutons associated with porphyry Mo/Cu-Mo mineralization elsewhere in British Columbia are restricted to the Pemberton arc in the southeastern Coast Mountains, where pluton ages diminish progressively northwards.

The late Neogene porphyry Cu-Mo mineralizing systems in the Pemberton arc and forearc evolution of northern Vancouver Island are linked to the plate tectonic evolution of the northern Cascadia subduction zone, notably plate-edge effects generated by subduction of the Juan de Fuca plate and newly redefined Nootka fault zone in the oceanic crust. The young porphyry Cu-Mo mineralization forms a well-defined metallotect that is underexplored and rich in opportunities for discovering economic porphyry deposits.

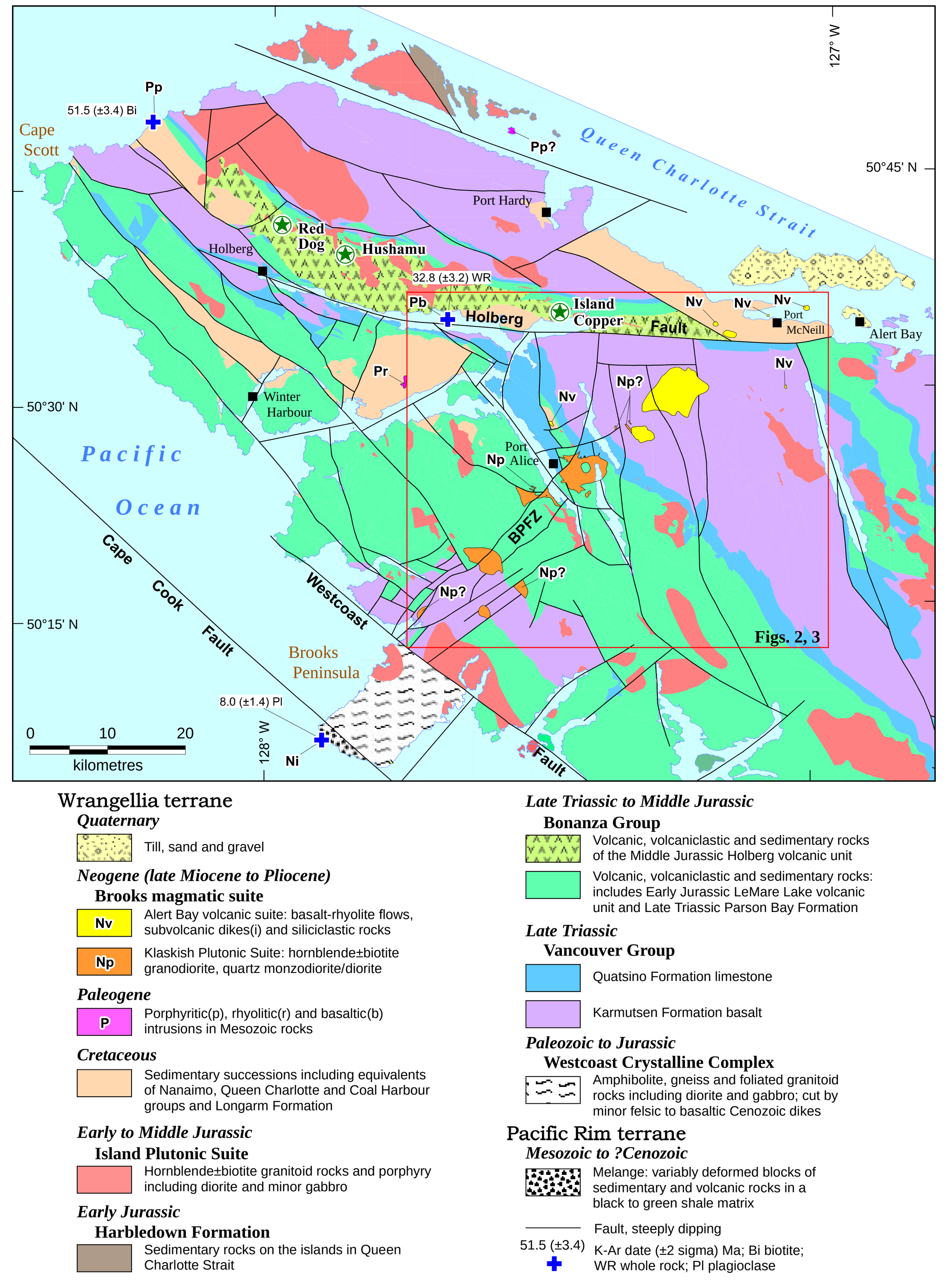

Fig. 1. Generalized bedrock geology of northern Vancouver Island showing the principal Mesozoic-Cenozoic stratigraphic and intrusive units (after Muller et al., 1974; Nixon et al., 2011a-e). K-Ar dates are given for Paleogene and late Neogene localities situated outside Figs. 2 and 3 (red inset box). Geochronological data are from Muller et al. (1974) and Armstrong et al. (1985) corrected for modern decay constants (Breitsprecher and Mortensen, 2004). Middle Jurassic Cu-Mo-Au porphyry deposits (green stars) at the former Island Copper mine (1971-1995), Red Dog and Hushamu deposits are shown for reference. BPFZ, Brooks Peninsula fault zone.

Regional Geology

Northern Vancouver Island is underlain by a faulted, westerly to southerly dipping, homoclinal succession of early Mesozoic strata intruded by granitoid plutons and overlain unconformably by the eroded remnants of Cretaceous stratigraphy (Fig. 1). The oldest exposed rocks of the Late Triassic Vancouver Group are overlain by arc-related volcanosedimentary strata of the Bonanza Group including Early to Middle Jurassic LeMare Lake and Holberg volcanic units and coeval intrusions of the Island Plutonic Suite (Fig. 1). Paleogene rhyolitic to basaltic dikes (ca. 51-33 Ma) locally intrude Cretaceous and older units (Fig. 1).

The Westcoast Crystalline complex on the Brooks Peninsula comprises lower crustal meta-igneous/sedimentary rocks cut by undeformed Cenozoic dikes; one such basaltic dike (ca. 8 Ma) belongs to the Alert Bay volcanic suite (Fig. 1).

Late Neogene Magmatism

The late Neogene **Brooks magmatic suite** (*new informal name*) comprises **Alert Bay volcanic rocks** and the **Klaskish Plutonic Suite** (*new formal name*) and occupies a northeast-oriented zone, the **Brooks-Haddington tract**, that extends 65 km across northern Vancouver Island (Fig. 1).

The southern part of this tract forms a 10-km-wide structural corridor, the **Brooks Peninsula fault zone**, which hosts the Klaskish Plutonic Suite. Farther north, the tract widens to ~15 km where Alert Bay volcanic rocks are cut by N-trending faults (Fig. 1).

Intrusions of the Klaskish Plutonic Suite are mainly granodiorite to quartz diorite; Alert Bay volcanic rocks range from basalt to rhyolite.

Geochronology

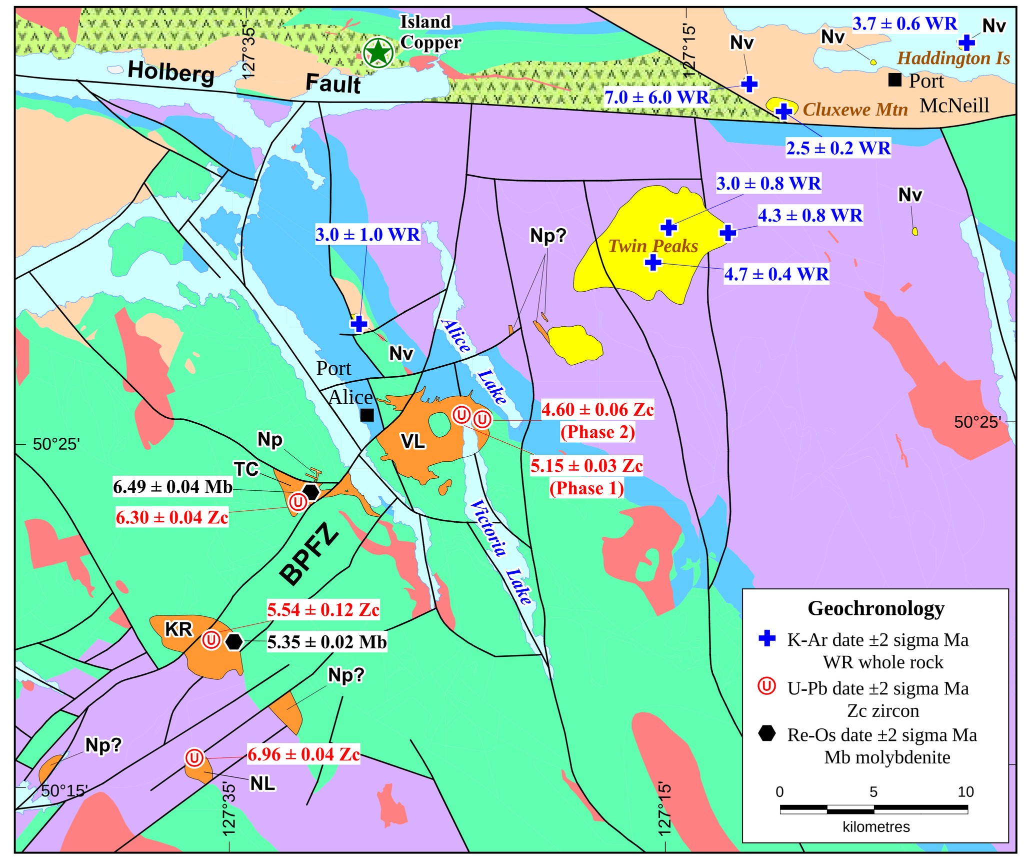

Fig. 2. Geochronological data for the late Neogene (latest Miocene-Pliocene) Brooks magmatic suite. K-Ar dates are from Armstrong et al. (1985); U-Pb and Re-Os dates from Nixon et al. (2011c-d and this study). NL, Nasparti Lake pluton; KR, Klaskish River pluton; TC, Teeta Creek pluton; VL, Victoria Lake pluton. Geological units and other symbols are as in Fig. 1.

K-Ar dates for the Alert Bay volcanic suite range from ca. 8 Ma for a basaltic dike at the tip of the Brooks Peninsula to ca. 2.5 Ma for rhyolite at Cluxewe Mountain near Port McNeill (Figs. 1 and 2).

High-precision 206Pb/238U crystallization ages for zircon have been determined for four intrusions in the Klaskish Plutonic Suite: the Klaskish River, Nasparti Lake, Teeta Creek and Victoria Lake plutons (Fig. 2).

Pluton crystallization ages range from ca. 7 Ma at Nasparti Lake to ca. 4.6 Ma at Victoria Lake, the youngest of two intrusive phases in the Victoria Lake pluton.

The K-Ar and U-Pb dating results (latest Miocene-Pliocene) appear to indicate a decreasing age progression from southwest to northeast within the Brooks magmatic suite.

High-precision Re-Os age determinations on molybdenite in the Klaskish and Teeta plutons are within ~200,000 years of the U-Pb zircon dates, indicating that porphyry Cu-Mo mineralization is genetically linked to the emplacement and crystallization of the Klaskish Plutonic Suite.

Porphyry/Skarn Mineralization: Northern Vancouver Island

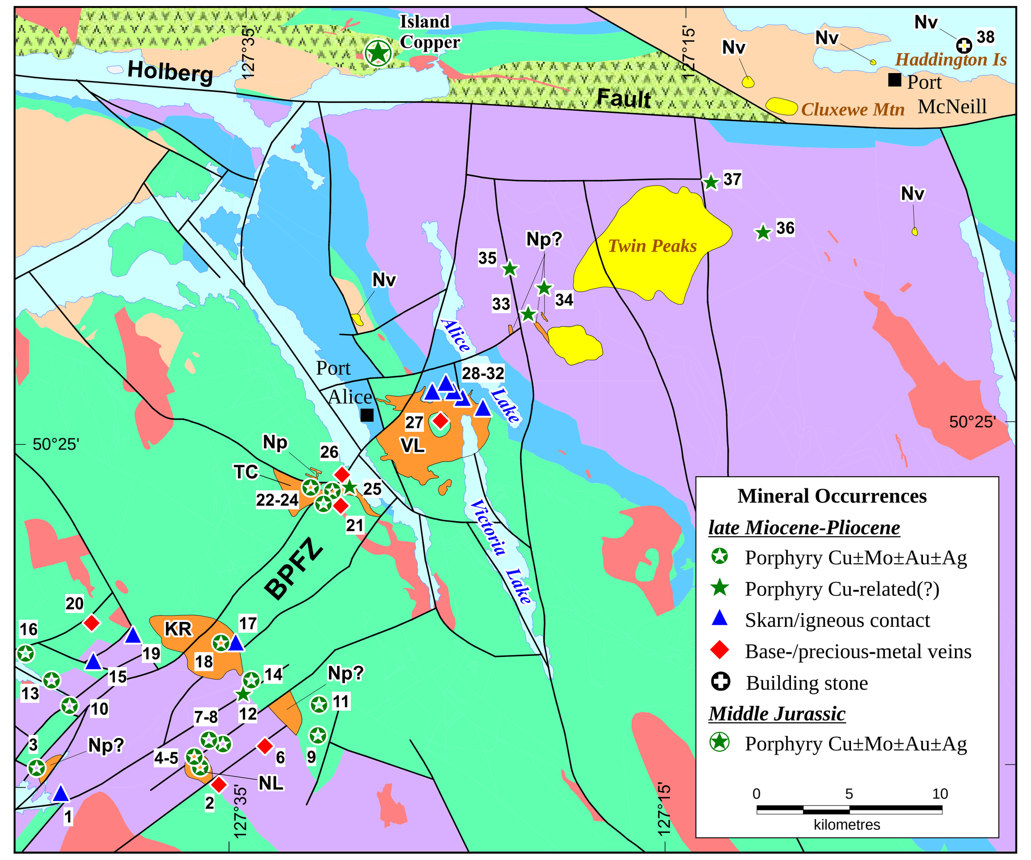

Fig. 3. Porphyry copper, skarn and vein mineral occurrences spatially associated with the Brooks-Haddington tract. Mineral occurrences are taken from the MINFILE database and numbered according to Table 1. Age of the mineralization is based on direct dating results (Fig. 2) or the spatial association with inferred late Neogene intrusions. Geological units and other symbols as in Figs. 1 and 2.

Mineral occurrences (n=38) compiled from the MINFILE database that are spatially associated with the Brooks-Haddington tract are listed in Table 1 and shown in Fig. 3. We have inferred an alternative deposit type based on the MINFILE descriptions for a number of these occurrences.

Table 1. Late Neogene mineral occurrences in the Brooks-Haddington tract and Coast Belt and selected Middle Jurassic porphyry deposits

ID[1]	MINFILE	Name	Commodities[2]	MINFILE Deposit Type	Alternate Deposit Type[3]	Status	UTM X[4]	UTM Y[4]
	Late Neogene (late Miocene-Pliocene) - Brooks Peninsula Fault Zone (Fig. 3)							
1	092L 251	BROOKS	Cu, Pb, Zn	Cu skarn		Showing	591084	5566868
2	092L 334	NASPARTI LAKE	Cu	Cu±Ag quartz veins/ volcanic redbed Cu	Cu-Ag veins	Showing	599632	5567393
3	092L 258	PABLO 24-2	Cu, Ag	Porphyry Cu±Mo±Au	Porphyry Cu-Ag	Showing	589772	5568298
4	092L 330	LOIS	Cu, Mo, Zn, Pb, Au, Ag, Co	Porphyry Cu±Mo±Au		Prospect	598624	5568331
5	092L 447	NIC MSV	Ag, Cu, Zn	Vein/stockwork Cu-Ag-Au	Porphyry Cu-related	Showing	598297	5568912
6	092L 331	LONDON 1	ma, Fe, Cu, Zn	Unknown	Cu-Zn veins	Showing	602128	5569479
7	092L 228	IRON COP	Cu, Co, Ag, Au, Fe	Porphyry Cu±Mo±Au	Porphyry Cu-Ag-Au	Prospect	599848	5569590
8	092L 446	BERKINSHIRE	Au, Ag, Cu	Vein/stockwork Cu-Ag-Au	Porphyry Cu-Ag-Au	Prospect	599091	5569823
9	092L 001	HEART	Cu, Fe	Porphyry Cu±Mo±Au		Showing	604988	5570060
10	092L 449	KLASKINO 2	Cu, Ag	Vein/stockwork Cu-Ag)	Porphyry Cu-Ag	Showing	591555	5571665
11	092L 182	RH 1-24	Cu, Mo	Porphyry Cu±Mo±Au		Showing	605050	5571915
12	092L 265	FANG	Cu	Unknown	Porphyry Cu-related?	Prospect	600945	5572299
13	092L 237	RUF 41	Cu, Mo, Ag	Skarn	Porphyry Cu-Mo-Ag±Au	Showing	590582	5573039
14	092L 448	NIC EAST	Ag, Cu	Vein/stockwork Cu-Ag-Au	Porphyry Cu-related	Showing	601386	5573049
15	092L 191	JARR	Cu	Skarn	Cu skarn	Showing	592841	5574004
16	092L 144	SINKER	Cu, Ni, Co, Mo	Unknown	Cu skarn/porphyry Cu-related?	Showing	588777	5574491
17	092L 445	NIC NORTH SKARN	Cu, Au, Ag, Fe	Cu skarn		Showing	600538	5575010
18	092L 266	TENT	Cu, Mo, Au, Ag	Porphyry Cu±Mo±Au		Showing	599745	5575057
19	092L 176	BRAD	Cu	skarn	Cu skarn	Showing	594991	5575433
20	092L 259	MAHATTA	Au, Ag, Cu	Ag-Pb-Zn±Au veins		Showing	592744	5576134
21	092L 054	QUATSINO KING (L.676)	Cu, Au, Ag, Zn	Cu±Ag quartz veins	Cu-Ag-Au veins	Showing	606221	5582598
22	092L 235	STAR 24	Cu, Mo	Porphyry Cu±Mo±Au	Porphyry Cu-Mo-Ag±Au	Showing	605288	5582826
23	092L 453	STAR 22	Au, Ag	Vein/stockwork Cu-Ag-Au	Porphyry Cu-Ag-Au	Showing	605773	5583269
24	092L 454	JRB NO.1	Au	Unknown	Porphyry Cu-Mo-Au	Showing	604722	5583464
25	092L 455	JR 2	Au, Zn	Vein/stockwork Zn-Au	Porphyry Cu-related?	Showing	606636	5583564
26	092L 053	PAYSTREAK	Cu, Zn, Au, Ag	Cu±Ag quartz veins	Cu-Ag-Au veins	Showing	606294	5583897
27	092L 466	PANDORA	Ag, Pb, Zn	Pb-Zn-Ag veins		Showing	611618	5587066
28	092L 057	PILGRIM (L.2035)	Zn, Ag, Au, Pb, Cd	Pb-Zn skarn	Zn-Pb-Ag-Au skarn	Developed Prospect	613914	5587702
29	092L 056	JUNE (L.180)	Fe, Cu, Au, Ag, S, Zn, Pb, ma	Skarn/porphyry	Fe-Cu-Ag skarn	Prospect	612817	5588234
30	092L 314	BIG ZINC	Zn	Pb-Zn Skarn		Showing	611172	5588570
31	092L 112	MINERVA FR. (L.171,183)	Zn, Cu, Fe, ma	Skarn	Zn-Cu skarn	Prospect	612316	5588595
32	092L 055	ALICE LAKE	Au, Ag, Pb, Zn	Manto Ag-Pb-Zn	Ag-Pb-Zn-Au manto	Prospect	611912	5589049
33	092L 234	ECILA	Cu, ma, Fe	Industrial mineral	Porphyry Cu-related?	Showing	616366	5592854
34	092L 232	BLUE	Cu	Unknown	Porphyry Cu-related?	Showing	617222	5594263
35	092L 233	BLUE 44	Cu	Unknown	Porphyry Cu-related?	Showing	615366	5595304
36	092L 321	KEOGH	Cu, Mo, Ni	Igneous contact	Porphyry Cu-Mo-related?	Showing	629076	5597260
37	092L 141	WALT	Cu	Volcanic redbed Cu	Porphyry Cu-related?	Showing	626252	5599973
38	092L 146	HADDINGTON ISLAND	Building stone	Building stone		Past Producer	640181	5607187
	Middle Jurassic - northern Vancouver Island (Fig. 1)							
	092L 158	ISLAND COPPER	Cu Mo, Ag, Au, Zn, Pb, Re	Porphyry Cu±Mo±Au		Past Producer	607924	5606424
	092L 240	HUSHAMU	Cu, Au, Mo	Porphyry Cu±Mo±Au		Developed Prospect	580687	5614338
	092L 200	RED DOG	Cu, Au, Mo, Ag	Porphyry Cu±Mo±Au		Developed Prospect	572566	5618142
	Late Neogene (Miocene) - Coast Crystalline Complex (Fig. 4)						UTM X[5]	UTM Y[5]
39	092N 029	HOODOO NORTH	Mo, Ag, Zn, Pb, wo	Porphyry Mo		Prospect	319015	5692727
40	092N 028	HANNAH 8,10,11	Au, Ag, Cu, Mo	Porphyry Cu±Mo±Au		Prospect	332349	5684913
41	092JW 005	SALAL CREEK	Mo, Cu, Zn, Pb	Porphyry Mo		Prospect	471141	5622907
42	092JW 015	FALL	Mo	Porphyry Mo		Showing	465288	5612194
43	092JSE034	ROGERS CREEK	Cu, Ag, Mo, Au	Unknown	Porphyry Cu-Mo±Au±Ag	Showing	539513	5544583
44	092HSW037	MARY JANE	Mo, Au, Ag, Cu	Porphyry Mo		Showing	595706	5455678
45	092HSW065	MOUNT CHEAM 2	Cu, Zn	Skarn	Cu skarn	Showing	594700	5450688
46	092HSW007	LUCKY FOUR (L.989)	Cu, Mo, Ag, Au	Cu skarn		Developed Prospect	603402	5446427

[1] Label shown on Figs. 3 and 4; [2] wo, wollastonite, ma, magnetite; [3] Deposit Type inferred in this study; [4] UTM Zone 9 NAD 1983; [5] UTM Zone 10 NAD 1983

Porphyry Cu-Mo(±Au-Ag) mineralization is hosted by the Klaskish, Nasparti and Teeta plutons and is widespread in the Brooks Peninsula fault zone (Fig. 3).

Sulphide minerals are chalcopyrite-pyrite-molybdenite ± bornite-sphalerite-arsenopyrite with minor galena and rare native gold. Quartz stockworks that carry molybdenite locally have anomalous values of Au and Ag.

Hydrothermal breccia pipes cut the Teeta Creek pluton and mineralization has been interpreted as part of an epithermal system above a porphyry system at depth. Historical drill results have yielded an intersection of 146 metres at 0.256% Cu.

Cu-Fe sulphide mineralization hosted by Karmutsen basalt in the northern part of the Brooks-Haddington tract near Twin Peaks may represent vestiges of late Neogene porphyry mineralization.

Skarn mineralization at the margins of Klaskish plutons typically contains pyrrhotite-sphalerite-galena-bornite-pyrite-arsenopyrite. A cluster of skarn deposits in Quatsino limestone at the contact with the Victoria Lake pluton has an historical resource of 46,266 tonnes of ore grading 8.7% Zn and 32.6 g/t Ag.

Base- and precious-metal veins and stockworks commonly occur adjacent to faults and peripheral to plutons that host porphyry Cu-Mo mineralization.

Porphyry/Skarn Mineralization: Coast Belt

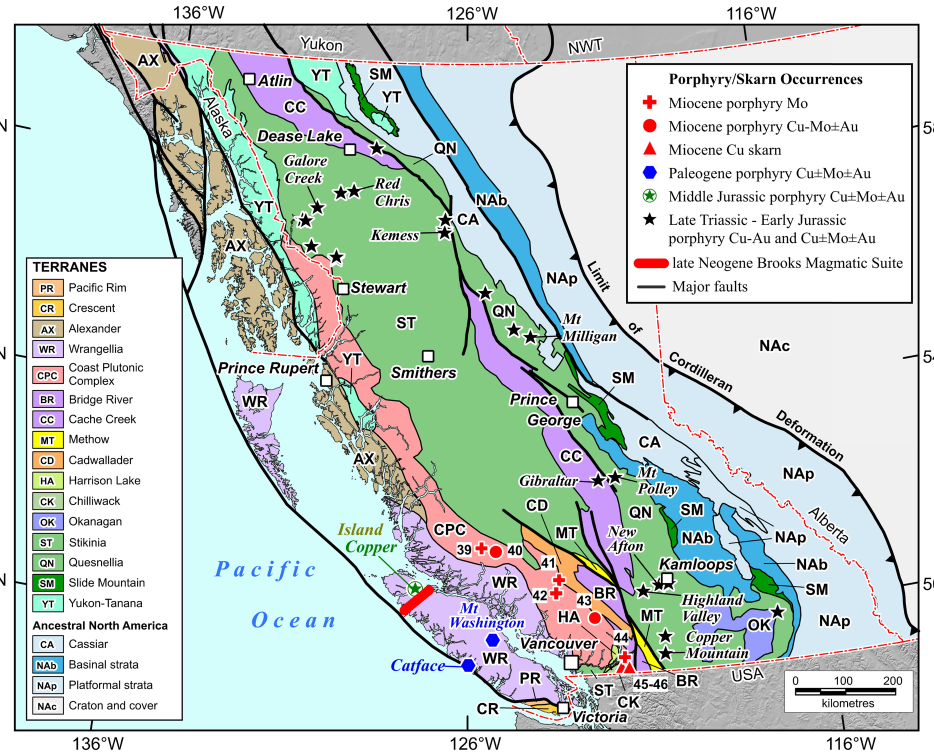

Fig. 4. Distribution of selected Mesozoic-Cenozoic porphyry copper and skarn occurrences in British Columbia and their terrane affiliation. Named Late Triassic–Early Jurassic deposits identify operating mines or deposits at an advanced stage of development in 2018 (Clarke et al., 2019). Numbered Miocene occurrences are listed in Table 1. Mesozoic porphyry copper deposits after Logan and Mihalynuk (2014); Cenozoic mineral occurrences compiled from the MINFILE database; terranes after Colpron and Nelson (2011) and Nelson et al. (2013). Note that late Neogene porphyry/skarn occurrences are confined to the southeastern part of the Coast Plutonic Complex and the forearc region of the Brooks-Haddington tract.

Beyond Vancouver Island, the youngest porphyry Cu-Mo and skarn occurrences in the province are spatially associated with Miocene plutons in the Pemberton magmatic arc in the southeastern Coast Mountains (Fig. 4; Table 1).

K-Ar and U-Pb dating studies indicate a northward decrease in the age of Pemberton plutons (and associated mineralization) from 35 Ma near the US border (phase of the Chilliwack batholith) to 7 Ma in the north (Franklin Glacier stock).

The distribution of Neogene plutons and their porphyry Cu-Mo/Mo mineralization in the Pemberton arc and northern Vancouver Island are manifestations of a common plate tectonic evolutionary history (Fig. 5).

Plate reconstructions indicate that the Juan de Fuca ridge occupied a stable position offshore the Brooks Peninsula from about 8 Ma to 3.5 Ma (Fig. 5A). The subducted edge of the Juan de Fuca plate was inferred to have a northeast trajectory beneath the Brooks Peninsula.

The inception of the Nootka fault zone at 3.5 Ma spalled off a fragment of the Juan de Fuca plate during a plate reorganization and formed the Explorer plate. The widened landward extension of the Nootka fault zone currently underlies the Brooks magmatic suite (Fig. 5B).

Plate Tectonic Setting

Late Neogene to Present plate configurations at the northern termination of the Cascadia subduction zone (after Savard et al., 2019) showing the distribution of late Neogene porphyry Cu-Mo and Mo systems in the Pemberton arc and forearc region of northern Vancouver Island.

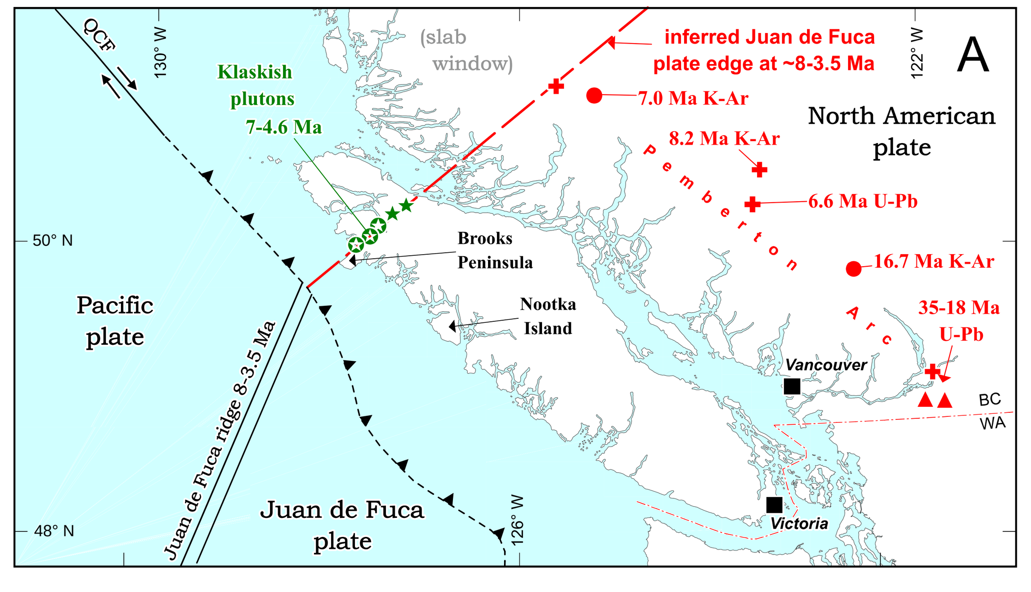

Fig. 5A. Inferred position of the Juan de Fuca ridge (Pacific-Juan de Fuca-North America triple junction) offshore of the Brooks Peninsula and subducted plate edge at 8-3.5 Ma (Riddihough, 1977; this study). Note that a slab-absent region (slab window) exists north of the subducted Juan de Fuca plate edge at this time. Isotopic age dates for mineralized plutons in the Pemberton arc are from Mullen et al. (2018, U-Pb zircon) and Wanless et al. (1978, K-Ar, corrected for the decay constants of Steiger, R. H., and Jäger, E., 1977, by Breitsprecker and Mortensen, 2004). Age determinations for the Klaskish Plutonic Suite in the Brooks-Haddington tract on northern Vancouver Island are from this study and Nixon et al. (2011c-d).

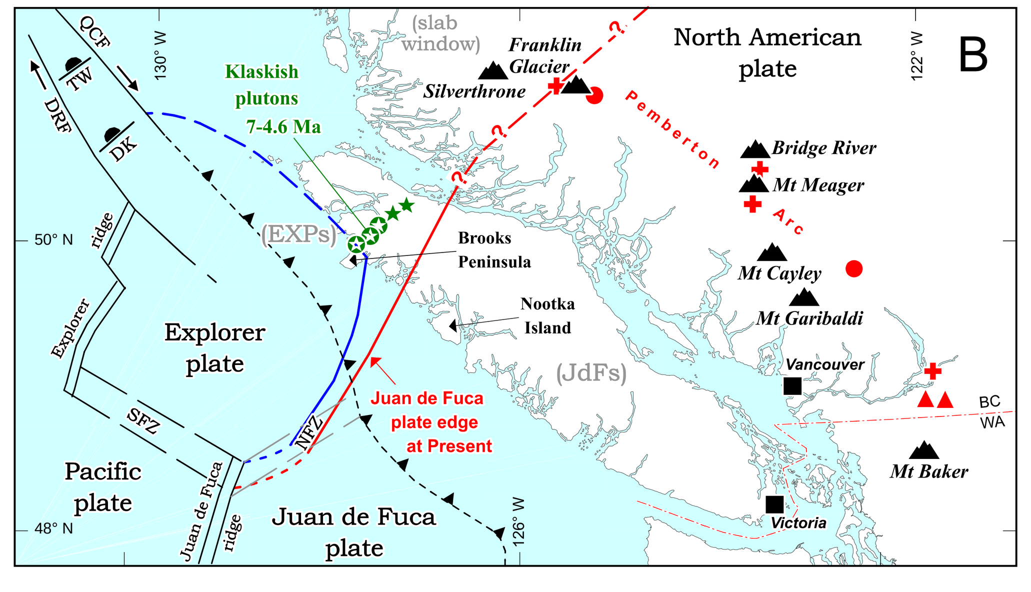

Fig. 5B. Plate configuration at Present showing the redefined location of the Nootka fault zone (NFZ, solid red and blue lines; Rohr et al., 2018) extrapolated to its present position under Vancouver Island according to the relative convergence velocities of these plates with respect to North America (Savard et al., 2019). The Nootka fault zone was initiated at ~3.5 Ma and delineates the boundary between the Explorer and Juan de Fuca plates. Also shown are the inferred extension of the Nootka fault zone (NFZ) to the Juan de Fuca ridge (short-dash red and blue lines); the subducted leading edge of the Explorer plate (long-dash blue line; Savard et al., 2019) and inferred position of the Juan de Fuca plate edge (long-dash red line); the subducted portions of the Explorer (EXPs) and Juan de Fuca (JdFs) plates and slab window to the north; the traditionally depicted orientation of the Nootka fault zone (grey dashed lines); the limit of deformation in the Cascadia subduction zone (dashed barbed line); and modern volcanoes of the northern Cascade arc (Garibaldi belt). Symbols as in Figs. 3 and 4. Other abbreviations: QCF, Queen Charlotte fault; DRF, Dellwood-Revere fault; DK, Dellwood Knolls; TW, Tuzo Wilson seamounts; SFZ, Sovanco fracture zone.

The inferred position of the subducted edge of the Juan de Fuca plate at 8-3.5 Ma underlies the loci of Alert Bay volcanism, Klaskish plutonism and related porphyry Cu-Mo systems in the Brooks magmatic suite that define the Brooks-Haddington tract.

The projected edge of the slab at this time coincides with porphyry mineralization in the Cascadia forearc and defines the northern limit of porphyry Mo/Cu-Mo systems in the Pemberton arc.

The late Neogene Klaskish plutons and porphyry Cu-Mo systems (7-4.6 Ma) are coeval with the older rocks of the Alert bay volcanic suite (8-4.7 Ma) and early development of the Brooks Peninsula fault zone.

The eastward younging of Alert Bay volcanism and northerly oriented faults in the eastern part of the Brooks-Haddington tract may reflect the eastward motion of the subducted Juan de Fuca plate edge relative to North America and evolving Nootka fault zone from 3.5 Ma to Present.

Summary

The foundation for this study was laid by a diverse array of previous work on northern Vancouver Island and in the offshore region that included regional mapping, paleontological, geochronological, geochemical and geophysical studies, mineral occurrence data gathered by the exploration community and made available through the MINFILE and ARIS databases, and plate tectonic reconstructions. Building on this infrastructure, our study advances the understanding of the mineral potential of northern Vancouver Island in several respects.

Late Neogene magmatism on northern Vancouver Island is restricted to the Brooks magmatic suite, which comprises volcanic (Alert Bay) and plutonic (Klaskish Plutonic Suite) components. Magmatism developed above the subducted edge of the Juan de Fuca plate and landward extension of the Nootka fault zone. The Klaskish Plutonic Suite occupies an anomalous forearc setting in the Cascadia subduction zone and hosts porphyry Cu-Mo mineralization. High-precision U-Pb and Re-Os dating of Klaskish plutons confirms that these intrusions are coeval with the older volcanic rocks of the Alert Bay suite and establishes a genetic relationship between pluton emplacement, crystallization and mineralization. The dating is crucial for distinguishing these Neogene plutons from Early to Middle Jurassic intrusions of the Island Plutonic Suite which are proven ground for major porphyry Cu-Mo-Au-Ag deposits. The underexplored late Neogene Klaskish metallogenic belt occupies a well-defined structural zone, the Brooks Peninsula fault zone, and this young metallotect offers fertile ground for future economic discoveries.

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