PORPHYRY Cu-Au: ALKALIC L03

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Refer to preface for general references and formatting significance.
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IDENTIFICATION

SYNONYMS: Porphyry copper, porphyry Cu-Au, diorite porphyry copper.

COMMODITIES (*BYPRODUCTS*): Cu, Au (*Ag*).

EXAMPLES: **(Yukon): Minto (115I 021), Def (115I 022), Williams Creek? (115I 008);** (British Columbia - *Canada/International*): Iron Mask batholith deposits - Afton (092INE023), Ajax (092INE012, 013), Mt. Polley (Cariboo Bell, 093A008), Mt. Milligan (093N196, 194), Copper Mt./Ingerbelle (092HSE001, 004), Galore Creek (104G090), Lorraine? (093N002); *Ok Tedi (Papua New Guinea); Tai Parit and Marian? (Philippines).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks, veinlets and disseminations of pyrite, chalcopyrite, bornite and magnetite occur in large zones of economically bulk-mineable mineralization in or adjoining porphyritic intrusions of diorite to syenite composition. The mineralization is spatially, temporally and genetically associated with hydrothermal alteration of the intrusive bodies and hostrocks.

TECTONIC SETTING(S): In orogenic belts at convergent plate boundaries, commonly oceanic volcanic island arcs overlying oceanic crust. Chemically distinct magmatism with alkalic intrusions varying in composition from gabbro, diorite and monzonite to nepheline syenite intrusions and coeval shoshonitic volcanic rocks, takes place at certain times in segments of some island arcs. The magmas are introduced along the axis of the arc or in cross-arc structures that coincide with deep-seated faults. The alkalic magmas appear to form where there is slow subduction in steeply dipping, tectonically thickened lithospheric slabs, possibly when polarity reversals (or `flips') take place in the subduction zones. In British Columbia all known deposits are found in Quesnellia and Stikinia terranes.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High level (epizonal) stock emplacement levels in magmatic arcs, commonly oceanic volcanic island arcs with alkalic (shoshonitic) basic flows to intermediate and felsic pyroclastic rocks. Commonly the high-level stocks and related dykes intrude their coeval and cogenetic volcanic piles.

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AGE OF MINERALIZATION: Deposits in the Canadian Cordillera are restricted to the Late Triassic/Early Jurassic (215-180 Ma) with seemingly two clusters around 205-200 and ~ 185 Ma. In southwest Pacific island arcs, deposits are Tertiary to Quaternary in age. **Jurassic intrusive rocks host the Minto and Def deposits in Yukon.**

HOST/ASSOCIATED ROCK TYPES: Intrusions range from fine-through coarse-grained, equigranular to coarsely porphyritic and, locally, pegmatitic high-level stocks and dyke complexes. Commonly there is multiple emplacement of successive intrusive phases and a wide variety of breccias. Compositions range from (alkalic) gabbro to syenite. The syenitic rocks vary from silica-undersaturated to saturated compositions. The most undersaturated nepheline normative rocks contain modal nepheline and, more commonly, pseudoleucite. The silica-undersaturated suites are referred to as nepheline alkalic whereas rocks with silica near-saturation, or slight silica over saturation, are termed quartz alkalic (Lang *et al*., 1993). Coeval volcanic rocks are basic to intermediate alkalic varieties of the high-K basalt and shoshonite series and rarely phonolites.

DEPOSIT FORM: Stockworks and veinlets, minor disseminations and replacements throughout large areas of hydrothermally altered rock, commonly coincident wholly or in part with hydrothermal or intrusion breccias. Deposit boundaries are determined by economic factors that outline ore zones within larger areas of low-grade, laterally zoned mineralization.

TEXTURE/STRUCTURE: Veinlets and stockworks; breccia, sulphide and magnetite grains in fractures and along fracture selvages; disseminated sulphides as interstitial or grain and lithic clast replacements. Hydrothermally altered rocks can contain coarse-grained assemblages including feldspathic and calcsilicate replacements ('porphyroid' textures) and open space filling with fine to coarse, granular and rarely pegmatitic textures.

ORE MINERALOGY [Principal and *subordinate*]: Chalcopyrite, pyrite and magnetite; bornite, chalcocite and *rare galena, sphalerite, tellurides, tetrahderite, gold and silver*. Pyrite is less abundant than chalcopyrite in ore zones.

GANGUE MINERALOGY: Biotite, K-feldspar and sericite; garnet, clinopyroxene (diopsidic) and anhydrite. Quartz veins are absent but hydrothermal magnetite veinlets are abundant.

ALTERATION MINERALOGY: Biotite, K-feldspar, sericite, anhydrite/gypsum, magnetite, hematite, actinolite, chlorite, epidote and carbonate. Some alkalic systems contain abundant garnet including the Ti-rich andradite variety - melanite, diopside, plagioclase, scapolite, prehnite, pseudoleucite and apatite; rare barite, fluorite, sodalite, rutile and late-stage quartz. Central and early formed potassic zones, with K-feldspar and generally abundant secondary biotite and anhydrite, commonly coincide with ore. These rocks can contain zones with relatively high-temperature calcsilicate minerals diopside and garnet. Outward there can be flanking zones in basic volcanic rocks with abundant biotite that grades into extensive, marginal propylitic zones. The older alteration assemblages can be overprinted by phyllic sericite-pyrite and, less commonly, sericite-clay-carbonate-pyrite alteration. In some deposits, generally at depth in silica-saturated types, there can be either extensive or local central zones of sodic alteration containing characteristic albite with epidote, pyrite, diopside, actinolite and rarer scapolite and prehnite.

ORE CONTROLS: Igneous contacts, both internal between intrusive phases and external with wallrocks; cupolas and the uppermost, bifurcating parts of stocks, dyke swarms and volcanic vents. Breccias, mainly early formed intrusive and hydrothermal types. Zones of most intensely developed fracturing give rise to ore-grade vein stockworks.

ASSOCIATED DEPOSIT TYPES: Skarn copper (K01); Au-Ag and base metal bearing mantos (M01, M04), replacements and breccias in carbonate and non-carbonate rocks; magnetite-apatite breccias (D07); epithermal Au-Ag : both high and low sulphidation types (H04, H05) and alkalic, Te and

F-rich epithermal deposits (H08); auriferous and polymetallic base metal quartz and quartz-carbonate veins (I01, I05); placer Au (C01, C02).

COMMENTS: Subdivision of porphyry deposits is made on the basis of metal content, mainly ratios between Cu, Au and Mo. This is a purely arbitrary, economically based criterion; there are few differences in the style of mineralization between the deposits. Differences in composition between the hostrock alkalic and calcalkalic intrusions and subtle, but significant, differences in alteration mineralogy and zoning patterns provide fundamental geologically based contrasts between deposit model types. Porphyry copper deposits associated with calcalkaline hostrocks are described in mineral deposit profile L04.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Alkalic cupriferous systems do not contain economically recoverable Mo (< 100 ppm) but do contain elevated Au (> 0.3 g/t) and Ag (>2 g/t). Cu grades vary widely but commonly exceed 0.5 % and rarely 1 %. Many contain elevated Ti, V, P, F, Ba, Sr, Rb, Nb, Te, Pb, Zn, PGE and have high CO_2 content. Leaching and supergene enrichment effects are generally slight and surface outcroppings normally have little of the copper remobilized. Where present, secondary minerals are malachite, azurite, lesser copper oxide and rare sulphate minerals; in some deposits native copper is economically significant (e.g. Afton, Kemess).

GEOPHYSICAL SIGNATURE: Ore zones, particularly those with high Au content, are frequently found in association with magnetite-rich rocks and can be located by magnetic surveys. Pyritic haloes surrounding cupriferous rocks respond well to induced polarization surveys. The more intensely hydrothermally altered rocks produce resistivity lows.

OTHER EXPLORATION GUIDES: Porphyry deposits are marked by large-scale, markedly zoned metal and alteration assemblages. Central parts of mineralized zones appear to have higher Au/Cu ratios than the margins. The alkalic porphyry Cu deposits are found exclusively in Later Triassic and Early Jurassic volcanic arc terranes in which emergent subaerial rocks are present. The presence of hydrothermally altered clasts in coarse pyroclastic deposits can be used to locate mineralized intrusive centres.

ECONOMIC FACTORS

GRADE AND TONNAGE:

- Worldwide according to Cox and Singer (U.S. Geological Survey Open File Report 88-46, 1988) 20 typical porphyry Cu-Au deposits, including both calcalkaline and some alkalic types, contain on average: 160 Mt with 0.55 % Cu, 0.003 % Mo, 0.38 g/t Au and 1.7 g/t Ag.
- British Columbia alkalic porphyry deposits range from <10 to >300 Mt and contain from 0.2 to 1.5 % Cu, 0.2 to 0.6 g/t Au and >2 g/t Ag; Mo contents are negligible. Median values for 22 British Columbia deposits with reported reserves (with a heavy weighting from a number of small deposits in the Iron Mask batholith) are 15.5 Mt with 0.58 % Cu, 0.3 g/t Au and >2 g/t Ag.

END USES: Production of chalcopyrite or chalcopyrite-bornite concentrates with significant Au credits.

IMPORTANCE: Porphyry deposits contain the largest reserves of Cu and close to 50 % of Au reserves in British Columbia; alkalic porphyry systems contain elevated Au values.

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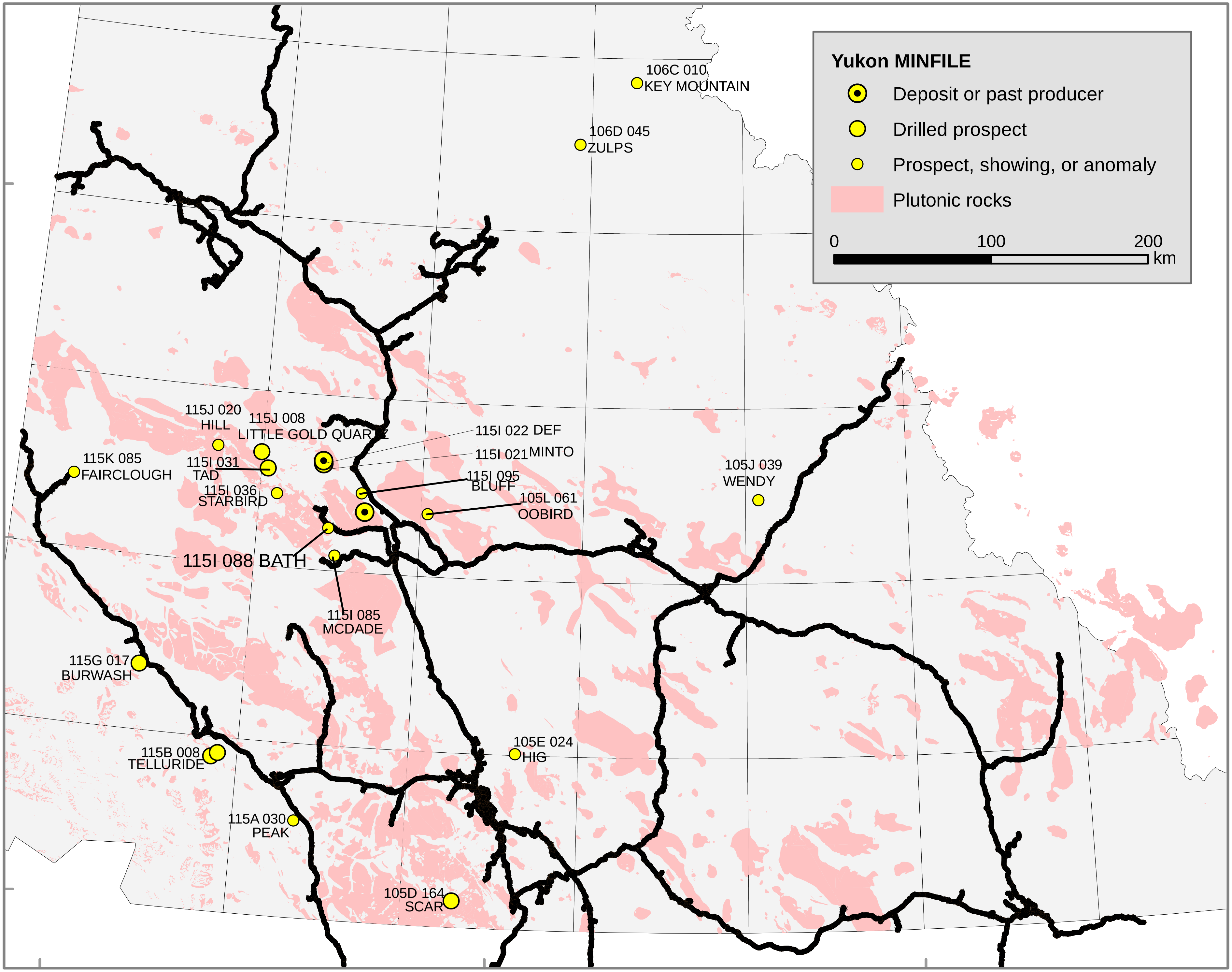
L03 - Alkalic porphyry Cu-Au - BC and Yukon deposits

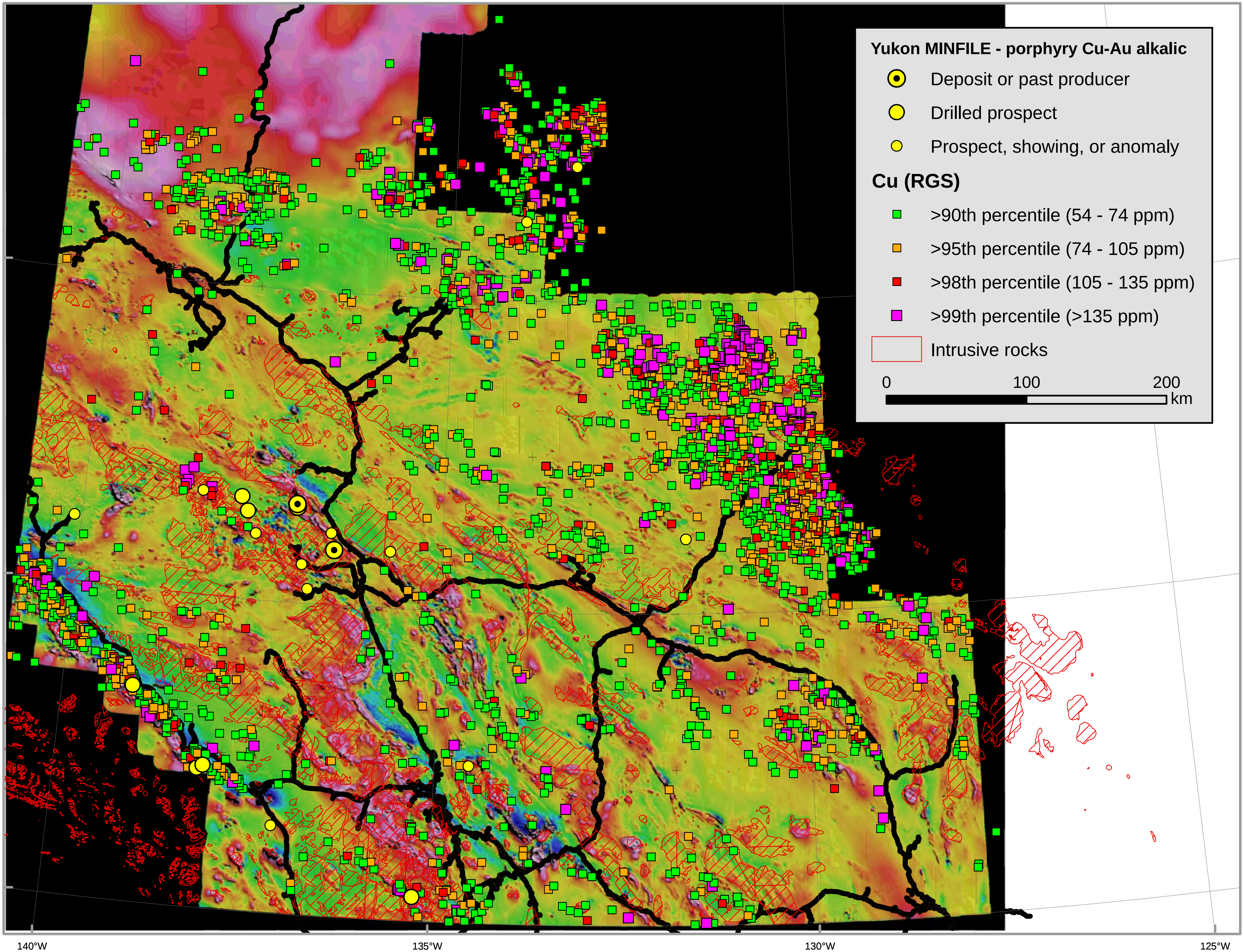
Deposit	Country	tonnes	Au (g/t)	Ag (g/t)	Cu (%)
IRON MASK	CNBC	165 555	0.71	2.79	1.48
VOIGT	CNBC	220 394	1.79		0.50
COL	CNBC	2 032 000			0.60
MISTY	CNBC	3 000 000			0.60
GALAXY	CNBC	3 174 898	0.21		0.65
RAINBOW	CNBC	4 467 000		4.00	0.66
VIRGINIA	CNBC	6 260 000	0.17		0.36
TAM	CNBC	7 000 000			0.60
MINTO	CNYK	7 980 000	0.62	9.30	2.13
RONDA	CNBC	9 072 000			0.70
ALABAMA	CNBC	9 200 000	0.20		0.32
LORRAINE	CNBC	10 000 000	0.21		0.67
PRIMER	CNBC	20 900 000			0.20
COPPER MOUNTAIN	CNBC	32 400 000	1.17	17.00	0.75
INGER BELLE	CNBC	42 625 840	0.17	0.70	0.37
CHUCHUA	CNBC	50 000 000	0.25		0.22
AXECHI	CNBC	57 500 000			0.50
AFTON	CNBC	68 735 660	0.47	2.10	0.63
MOUNT POLLEY	CNBC	77 594 000	0.45		0.33
GALORE CREEK	CNBC	125 000 000	0.40	7.70	1.06
MOUNT MILLIGAN	CNBC	329 000 000	0.45		0.22

Yukon MINFILE

MINFILE	NAMES	STATUS
115I 008	WILLIAMS CREEK, BOY	DEPOSIT
115I 021	MINTO	DEPOSIT
115I 022	DEF, MINTO	DEPOSIT
115J 008	HAYES, SONORA GULCH	DRILLED PROSPECT
105O 051	BURMEISTER, LUCKY JOE	DRILLED PROSPECT
105E 024	HIG	DRILLED PROSPECT
105L 061	OOBIRD	SHOWING
115P 062	COBBLE	SHOWING
115I 088	BATH	ANOMALY



Map of Yukon showing alkalic porphyry Cu-Au occurrences and the distribution of plutonic rocks



Map of Yukon showing alkalic Cu-Au porphyry occurrences, Cu regional geochemistry, regional magnetics and the distribution of plutonic rocks