Alkaline Magmatism and Porphyry Cu-Au Deposits at Galore Creek, Northwestern British Columbia

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INTRODUCTION

Porphyry deposits and prospects containing copper, molybdenum and gold are important historical contributors to the metallic mining industry in British Columbia. Elevated metal prices and recent exploration successes have renewed interest in British Columbia's copper-gold porphyry deposits, in particular the alkalic Cu-Au porphyry class of deposits (e.g., Galore Creek, Mount Polley and Afton-Ajax). These and cospatial calcalkaline Cu-Mo and Cu-Mo-Au porphyry deposits formed outboard of ancestral North America in island-arc tectonic settings in the Late Triassic to Early Jurassic. The alkalic Cu-Au deposits in both the Stikine and Quesnel terranes are the products of a discrete alkaline magmatic event (210–200 Ma) at the end of the Triassic.

In order to better understand the controls on mineralization and maximize exploration efficiencies, a partnership was struck between the British Columbia Ministry of Energy and Mines and exploration companies with a direct interest in refining the alkaline Cu-Au porphyry exploration model (Abacus Mining and Exploration Corp., Imperial Metals Corp., NovaGold Resources Inc.) as it applies to the Iron Mask, Mount Polley and Galore Creek magmatic complexes. Additional funding was obtained through a Rocks to Riches grant provided by the British Columbia and Yukon Chamber of Mines. The new information provided by these studies will update the provincial database and mineral deposit models, and promote Cu-Au porphyry exploration, all of which will ultimately lead to new discoveries and resources in the province.

The Galore Creek project objectives are to

- determine the spatial and temporal relationships between the alkaline (feldspathoid-bearing) volcanic rocks, mineralization and the various intrusive phases of the alkalic Galore Creek magmatic complex;
- characterize mineral zones located peripheral to, and as much as 1000 m vertically above, the Central zone;
- acquire a suite of samples from the various mineralized zones, as well as a suite of least altered volcanic and intrusive rocks, for major and trace element analysis, and compare with published data and data from the Mount Polley and Iron Mask suites; and
- compare these results with those from other alkalic intrusive centres in the province to establish a metallogenic model that will direct exploration.

The Galore Creek camp is located within the lower Stikine River region of northwestern British Columbia, approximately 150 km northeast of Stewart. The property is 75 km northwest of the Eskay Creek gold-silver mine, on the west side of the Cassiar Highway (Fig. 1). It contains twelve known Cu-Au occurrences (MINFILE 104G/90 through 99), that are distributed across an area measuring 5 km by 4 km, and over a vertical range of 1000 m. Three of these, the Central, Junction and Southwest zones, contain resources of 284 million tonnes at 0.67% Cu. NovaGold Resources Inc is currently in an option agreement to earn 100% ownership of the property. In 2003, SpectrumGold completed a 3000 m drill program to test for the presence of increased gold and copper grades in the Central deposit. At that time, a new zone of Cu-Au mineralization, the 'Bountiful zone', was discovered beneath the Central zone and has spurred re-evaluation of the Galore Creek property.

This report summarizes the regional geology and presents some of the preliminary field observations from the 2004 field mapping. The Galore Creek component of the Cu-Au Porphyry Project conducted 1:20 000-scale field mapping and sampling of the western and southern portions of the Galore Creek basin, where overburden is thin and outcrop exposure is good. In addition, regional-scale traverses were started outside the main intrusive complex and traced stratigraphy back into the Galore Creek basin, where potassium metasomatism has typically obliterated primary protoliths. Magnetic susceptibilities of intrusive and volcanic units were measured to better utilize the low-level airborne geophysical survey and aid map compilation. A map of the intrusive complex, together with geochemical analytical results and petrography, will be released as a GeoFile.

PREVIOUS WORK

Forrest Kerr carried out the first geological mapping along the Stikine and Iskut rivers from 1924 to 1929, but it was not until 1948 that his data were published (Kerr, 1948a, b). Kerr proposed the original Permian and pre-Permian subdivision of Paleozoic strata and, from his work in the Taku River valley of the Tulsequah map area, he de-

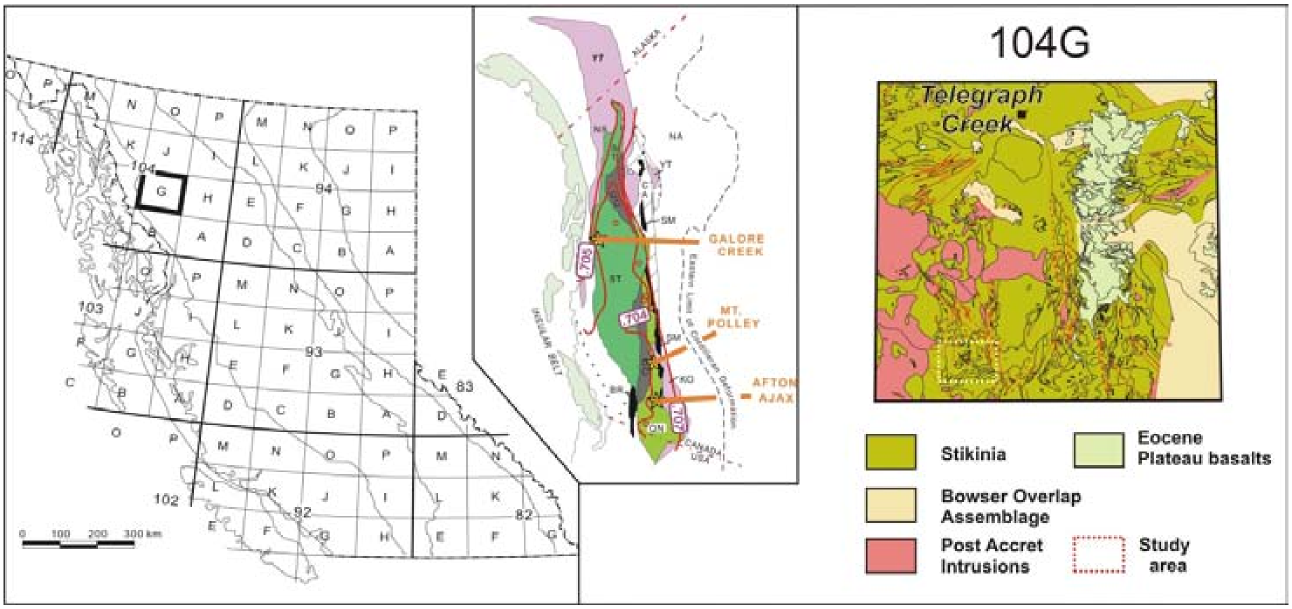

Figure 1. Location of the Galore Creek component of the Cu-Au Porphyry Project in northwestern British Columbia (NTS 104G). Inset is a terrane map of northern Cordillera (*modified from* Wheeler and McFeely, 1991), showing the tectonostratigraphic setting of the three study areas. Mesozoic initial strontium isopleths are from Armstrong (1988). Box on the right shows detailed terrane relationships for NTS 092I and the project area.

fined the Late Triassic Stuhini Group, much of which underlies the current study area. In 1956, a helicopter-supported reconnaissance of the Telegraph Creek map area was conducted by the Geological Survey of Canada (1957, Operation Stikine). Jack Souther masterminded Operation Stikine and produced 1:250 000-scale geological maps of the Telegraph Creek sheet (104G), Tulsequah sheet (104K) and 1:50 000-scale detailed studies of Mount Edziza (1988, 1992). Other work by the Geological Survey of Canada (Fig. 1) includes that of Monger (1970, 1977), Souther (1971, 1972, 1992) and Anderson (1984, 1989).

A. Panteleyev carried out mapping in the immediate area of Galore Creek, in conjunction with a study of the deposit between 1973 and 1975 (Panteleyev, 1973, 1974, 1975, 1976, 1983). Geological mapping was completed at 1:50 000 scale in the Galore Creek area (Sphaler Creek and Flood Glacier map sheets) in 1988 (Logan *et al.*, 1989; Logan and Koyanagi, 1994). Concurrent British Columbia Geological Survey projects have completed 1:50 000-scale map coverage north and west of the Iskut north project area in the Scud River, Yehiniko Lake, Chutine River and Tahltan Lake map areas (Brown *et al.*, 1996).

REGIONAL GEOLOGY

The study area straddles the boundary between the Intermontane Belt and the Coast Belt, and is underlain mainly by rocks of the Stikine Terrane (Stikinia), the westernmost terrane of the Intermontane Belt (Fig. 1). The stratigraphic and plutonic framework of northwestern Stikinia is summarized by Anderson (1993), Gunning (1996) and Logan (2000). It consists of a Paleozoic to Mesozoic sedimentary and volcanoplutonic arc assemblage that includes the Devonian to Permian Stikine assemblage, the Late Triassic Stuhini Group and the Early Jurassic Hazelton Group. These are overlain by Middle Jurassic to early Tertiary successor-basin sediments of the Bowser Lake and Sustut Groups, Late Cretaceous to Tertiary continental volcanic rocks of the Sloko Group, and Late Tertiary to Recent bimodal shield volcanism of the Edziza and Spectrum ranges.

The Stikine Terrane is a composite allochthonous (?) terrane made up of an amalgamation of volcanic island arcs ranging in age from late Paleozoic through Early Jurassic. Modern analogs include the Pacific island arcs from Japan south through the Philippines, or New Guinea to New Zealand. Recent studies suggest that the Stikine terrane developed adjacent to the ancestral margin of North America (McClelland, 1992; Mihalynuk *et al.*, 1994; Gunning 1996) and that parts of the Paleozoic Stikine assemblage are correlative with and depositionally tied to Paleozoic rocks of the Yukon-Tanana Terrane. Depositional ties between the Quesnel and Yukon-Tanana terranes are also known and this, together with the hook-like geometry of the 0.706 initial $^{87}Sr/^{86}Sr$ line around the northern end of Stikinia (Fig. 1), led Nelson and Mihalynuk (1993) and Mihalynuk *et al.* (1994) to propose a single arc model consisting of the Quesnel, Yukon-Tanana, Nisling and Stikine terranes.

Upper Triassic volcanic rocks and paired, alkaline-calcalkaline Cu-Au deposits extend the length of the Canadian Cordillera (Barr *et al.* 1976). In the south, in Quesnellia, the Nicola and Takla groups lie east of the Cache Creek Terrane. Farther north, in Stikinia, the Stuhini and Lewis River groups lie west of the Cache Creek. There is little difference in age, lithology or chemistry of the Triassic strata from one tectonostratigraphic terrane to the next (Barr *et al.*, 1976; de Rosen-Spence, 1985; Mortimer, 1987;

Logan and Koyanagi, 1994; Panteleyev *et al.*, 1996; Nelson and Bellefontaine, 1996). Unconformities separate the Upper Triassic Stuhini Group, which is mainly submarine volcanic rocks, from the Jurassic Hazelton Group, which is mainly subaerial volcanic and sedimentary rocks in northwestern British Columbia. A paraconformity separates the Triassic from Early Jurassic volcanism in north-central Quesnellia (Nelson and Bellefontaine, 1996). A similar hiatus is interpreted at Mount Polley (Logan and Mihalynuk, this volume), where Lower Jurassic sedimentary rocks overlie the Triassic volcanic sequence; however, in southern Quesnellia, the Early Jurassic volcanic rocks of the Rossland Group (Höy and Dunne, 1997) indicate a substantial eastward shift of volcanism from the Triassic magmatic axis.

Galore Creek is one of a number intrusion-related Cu-Au deposits that developed in the Upper Triassic to Lower Jurassic (?) volcanoplutonic-arc rocks of the Quesnel-Stikine arc (Barr *et al.*; 1976; Nelson and Mihalynuk, 2004). Similar deposits extend the length of the Intermontane Belt (Fig. 1). The Cu-Au deposits are associated, in the south, with the Iron Mask batholith (Afton, Ajax, and Crescent) and Copper Mountain intrusives (Copper Mountain, Ingerbelle); to the north, with the Hogem batholith (Lorraine); and, in the Stikine Terrane, with Galore Creek intrusives (Galore Creek).

The deposits at Galore Creek are hosted within shoshonitic submarine volcanic rocks and coeval subvolcanic syenite intrusions of the Upper Triassic Stuhini Group. It is a high-level, silica-undersaturated alkaline porphyry Cu-Au system of latest Triassic age (210 Ma; Mortensen *et al.*, 1995) that lies 38 km southwest of the large calcalkaline Cu-Mo-Au Schaft Creek system.

STUHINI GROUP ROCKS

Upper Triassic Stuhini Group flows, tuffs, volcanic breccias and sedimentary rocks define a volcanic edifice centred on Galore Creek. Contemporaneous sedimentary rocks flank the volcanic centre and, east of the South Scud River fault, a sequence of metavolcanic breccias and massive volcanic rocks is intruded by the coeval calcalkaline Hickman pluton. Stuhini stratigraphy ranges in age from early Carnian to late Norian, based on radiometric dates (Anderson, 1983) and fossil ages (Souther, 1972; Logan and Koyanagi, 1994; Brown *et al.,* 1996).

Volcanic rocks constitute the bulk of the Upper Triassic stratigraphy at Galore Creek, and three different calcalkaline volcanic suites are recognized: a lower subalkaline hornblende-bearing basaltic andesite; a medial subalkaline to alkaline augite-porphyritic basalt; and an uppermost alkaline orthoclase and pseudoleucite-bearing shoshonitic basalt. Stratified, sedimentary facies equivalent units of the lavas were deposited on the flanks of the edifice and contain diagnostic fossils. Carnian fossils are preserved within the lower sedimentary package; the medial and upper sedimentary packages are characterized by conodonts and bivalves of Norian age (Logan and Koyanagi, 1994). Rocks of the medial and upper volcanic subdivisions underlie the Galore Creek basin, host multiple syenite intrusions and Cu-Au mineralization that make up the intrusive-volcanic complex and are, in part, extrusive equivalents of these subvolcanic intrusions.

The Lower volcanic subdivision consists of aphyric and sparse hornblende and plagioclase-phyric flows, breccia and tuff that underlie extensive areas south of Galore Creek and constitute most of the Middle to Upper Triassic country rock that hosts the Hickman batholith (Logan and Koyanagi, 1994; Brown *et al.,* 1996).

The Medial volcanic subdivision is dominated by polylithic volcanic conglomerate, wacke, sandstone, siltstone and fine tuffaceous rocks, and distinctive but subordinate pyroxene-phyric basalt flow breccias and dikes. The clast composition is variable, including pale green, grey or purple, sparsely porphyritic plagioclase andesite, pyroxene porphyry basalt, coarse-bladed plagioclase-pyroxene porphyritic basalt and rarely limestone. The clasts are angular to subrounded and constitute from 15 to 80% of the rock in an arkosic matrix of similar composition. Graded sandstone and siltstone beds and local, thinly laminated, black and orange, calcareous argillite horizons are interbedded with the conglomerate on the ridge west of the head of Galore Creek. They are characterized by soft-sediment slumping, faulting and scour-and-fill structures, and crosscut by sedimentary dikes (Fig. 2). Interlayered

Figure 2. Well-laminated calcareous argillite rip-ups in a chaotic lahar-conglomerate unit. This unit marks the transition from volcanic conglomerates of the Medial subdivision upward into the alkaline volcanic tuffaceous rocks.

with the dominantly epiclastic rocks are pyroxene porphyry flow breccias, pyroxene crystal tuff, and reworked volcanic sandstone containing vitreous pyroxene crystals. The medial unit generally coarsens upwards. Lower units are thin, repetitively graded AE-turbidites. Higher in the section are thick-bedded, chaotic to normally graded lahar-conglomerate and pyroxene-phyric lava flows. The turbidites and paucity of lava flows suggest a distal depositional environment.

The Upper alkaline volcanic subdivision is best exposed west of Copper Canyon. Volcanic rocks at the base of the section (Logan and Koyanagi, 1994, Fig. 12) are pervasively potassium metasomatized and, in some places, may be intrusive in origin. The lower unit is cut by pseudoleucite, potassium feldspar syenite porphyry bodies and younger felsic and diabase dikes. Overlying the lower package are less altered intermediate tuff-breccia, tuffaceous wacke and rare, interbedded orange-weathering grit containing shale rip-up clasts. The unit fines and becomes well bedded upward; the volcanic component also reflects a change to more alkaline magmatism. The top of the section consists of orthoclase and biotite crystal tuffs and fine epiclastics, lithic crystal tuffs, lapilli tuffs and polymictic volcanic conglomerates that are interbedded with well-laminated siltstone and fine-grained sandstone beds. A distinctive accretionary lapilli horizon was recognized near the base of the section (Fig. 3). The epiclastic and tuffaceous beds are characteristically potassium feldspar rich, crossbedded and show both normal and reverse grading. Graded bedding, interpreted to be normal, indicates that the beds are overturned in places (Fig. 4). Interbedded with the silts and tuffs are slump deposits of massive to chaotic maroon silt and sand containing crossbedded rip-up clasts and large angular breccia blocks of fine-grained tuff, some showing soft-sediment plastic deformation. Among the sediments are polylithic conglomerates that contain syenite clasts of the Galore Creek intrusives. Rare clasts of mineralized syenite porphyry occur within the potassium feldspar crystal-rich lapilli tuff unit west of Copper Canyon. A grab sample from a 40 cm block of well mineralized potassium feldspar pseudoleucite porphyry syenite from a lapilli tuff bed returned exceedingly high copper, silver and gold values (6.53 % Cu, 0.21 g/t Au and 174 g/t Ag; JLO04-44-504, *see* Table 1). Orthoclase crystal tuffs contain large potassium feldspar crystals up to 1 by 2 cm in size. Subhedral to euhedral clots and crystals of detrital biotite constitute 2–5% of a number of crystal lithic tuff beds. The euhedral crystals provide evidence for a pyroclastic origin for these rocks, as does the presence of accretionary lapilli. The crosslaminations, rip-up clasts, soft-sediment deformation features and presence of accretionary lapilli could be interpreted as evidence of a base surge or airfall deposit. Argon-argon step heating of biotite from this unit gives a plateau age of 212 Ma (Logan and Koyanagi, 1994).

Figure 3. Accretionary lapilli horizon marks the transition from a lower package of heterolithic breccias and lapilli tuff upwards into potassium feldspar and biotite-rich airfall crystal tuffs, west of Copper Canyon.

Figure 4. Potassium feldspar–rich graded crystal tuff, west of Copper Canyon.

TABLE 1. INDUCTIVELY COUPLED PLASMA – MASS SPECTROMETRY AND INSTRUMENTAL NEUTRON ACTIVATION ANALYTICAL RESULTS FROM SAMPLES COLLECTED IN THE GALORE CREEK AREA.

		Element	Ag	Al	As	Au	Ba	Bi	Ca	Cd	Ce	Co	Cr	Cu	Eu	Fe	Hf	K	La	Li	Lu	Mg	Mn	Mo
		Units	ppm	%	ppm	ppb	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	%	ppm	ppm
		Method	TICP	TICP	INA	INA	INA	TICP	TICP	TICP	INA	TICP	INA	TICP	INA	TICP	TICP	TICP	TICP	TICP	INA	TICP	TICP	TICP
		Det'n Limit	2	0.01	0.5	2	50	0.02	0.01	0.01	3	0.1	5	0.01	0.2	0.01		0.01	0.5		0.05	0.01	1	0.01
Station Number	Easting	Northing																						
JLO04-32-325	349000	6334481	2.5	10.55	4.5	140	3700	0.3	1.97	0.2	7	22	9	10960	0.2	2.93	0.3	4.99	6	78.5	b.d.	0.95	1129	2.1
JLO04-34-355	349638	6336104	10.5	7.69	20.2	177	1800	0.5	2.61	1.1	23	48	51	22920	0.5	3.8	0.9	5.73	14	44	0.14	1.42	484	15
JLO04-35-375	349021	6335717	4.2	6.96	6.2	370	2800	0.2	2.78	0.9	25	17	102	5955.1	0.5	2.38	1.8	5.45	14.2	3.4	0.23	1.11	1344	17.1
JLO04-36-403	350854	6334033	21.5	8.74	3.7	2340	2400	2.1	0.98	3.2	17	21	24	31930	0.2	2.96	0.4	7.37	12.5	52.4	0.08	2.15	1256	1.5
JLO04-39-427	352831	6333162	0.2	2.74	22.5	73	120	b.d.	7.7	0.2	47	85	20	308.7	1.1	29.35	1.4	0.37	27	13.1	0.29	2.83	4766	1.2
JLO04-39-434	352744	6332348	5.8	4.73	21.5	159	1100	0.1	1.84	1.7	17	75	29	20800	0.6	27.06	0.8	3.65	15.3	5.5	0.25	0.76	3357	8.9
JLO04-42-479-3	357785	6332841	45.7	6.69	106	1700	1700	1.3	5.05	14	42	32	13	16550	0.8	6.96	1.7	4.62	33	78.2	0.15	1.78	4333	1.3
JLO04-43-480	349619	6335648	22.6	8.33	18	1010	1900	4.1	2.77	0.3	37	24	35	28330	0.9	4.16	1.4	5.54	26.2	12.1	0.32	2.68	2300	4.1
JLO04-43-484	349825	6335394	0.8	9.58	5.8	37	2000	0.1	0.63	0.6	39	15	50	5673.4	1	3.1	1.5	5.63	23.4	17.2	0.35	0.97	1324	3.3
JLO04-44-497	357170	6333693	0.1	8.21	17	5	2400	b.d.	4.24	0.1	35	15	24	72.1	1.1	6.61	1	5.12	20.4	18.7	0.31	0.33	1536	2.3
JLO04-44-504	356589	6334451	173.5	10.01	69.3	211	2300	0.8	0.36	0.3	20	3	13	65380	0.4	3.14	1.5	6.07	15.8	33.7	0.05	0.46	194	4.3
JLO04-43-480Rep	349619	6335648	22.8	8.22	16.4	1080	2100	4.2	2.79	0.3	35	25	43	30030	0.9	4.26	1.3	5.69	25.4	11.7	0.29	2.72	2333	4.1
Std. WRP1			0.6	1.33	2.2	85	b.d.	0.1	1.51	0.2	7	170	3610	1715	0.4	10.78	0.4	0.09	1.9	3.8	0.07	16.77	1320	0.4
JLO04-43-480			22.6	8.33	18	1010	1900	4.1	2.77	0.3	37	24	35	28330	0.9	4.16	1.4	5.54	26.2	12.1	0.32	2.68	2300	3.3
JLO04-43-480REP			22.8	8.22	16.4	1080	2100	4.2	2.79	0.3	35	25	43	30030	0.9	4.26	1.3	5.69	25.4	11.7	0.29	2.72	2333	4.1
% Difference			0.9	1.3	9.3	6.7	10.0	2.4	0.7	0.0	5.6	4.1	20.5	5.8	0.0	2.4	7.4	2.7	3.1	3.4	9.8	1.5	1.4	21.6

			Na	Nb	Nd	Ni	P	Pb	Rb	S	Sb	Sc	Sm	Sn	Sr	Th	Ti	U	V	W	Y	Yb	Zn	Zr
			%	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
			TICP	TICP	INA	TICP	TICP	TICP	TICP	TICP	TICP	INA	INA	TICP	TICP	INA	TICP	INA	TICP	INA	TICP	INA	TICP	TICP
			0.001		5	0.1	0.001	0.01		0.02	0.02	0.1	0.1		0.5	0.2	0.001	0.5	2	1		0.2	0.1	
Station Number	Easting	Northing																						
JLO04-32-325	349000	6334481	1.54	2.9	b.d.	1.2	0.074	6.7	133.6	0.5	0.7	1.5	0.4	0.8	429	2.4	0.102	1.8	230	4	3.2	0.4	101	8.2
JLO04-34-355	349638	6336104	0.325	10.4	8	9.9	0.173	111.5	118.3	2.5	11.5	5.5	1.2	1.4	412	4.9	0.177	5	211	25	7.9	0.8	65	31.8
JLO04-35-375	349021	6335717	0.779	9	15	69.1	0.116	30.1	116.7	0.2	0.9	14.2	2.3	1.3	283	2.6	0.387	2.5	128	b.d.	16.6	1.4	116	52.4
JLO04-36-403	350854	6334033	0.293	15.8	5	4.9	0.06	53.2	172.6	1.2	1.3	6.9	0.5	0.9	616	1.7	0.353	1.5	232	1	1.9	0.4	224	11.5
JLO04-39-427	352831	6333162	0.395	2	23	31.8	0.603	2.1	17.4	b.d.	0.8	34.4	4	1.7	259	3.7	1.061	b.d.	1166	b.d.	21.6	1.9	374	28.7
JLO04-39-434	352744	6332348	0.627	3.8	b.d.	20.9	0.052	37.4	119.4	b.d.	2.8	7.3	1.2	0.4	516	1.1	0.241	1.1	467	4	14	1.4	1477	20.5
JLO04-42-479-3	357785	6332841	0.545	27.6	21	6.4	0.234	701.2	189.5	2.2	3.1	6.3	1.9	0.8	1083	4.2	0.372	4.7	535	b.d.	9.4	0.9	1478	53.3
JLO04-43-480	349619	6335648	1.257	14.2	15	12	0.241	30.4	165.4	0.9	0.5	28.4	2.6	3.8	576	3.1	0.569	4.3	348	b.d.	20	1.9	210	32.7
JLO04-43-484	349825	6335394	2.276	20.6	18	3.9	0.106	24.8	143.6	0.1	1	17.3	2.8	1.2	571	4.3	0.26	6.5	223	b.d.	16.3	2.4	219	40
JLO04-44-497	357170	6333693	0.247	12.7	18	5	0.118	5.2	122.5	b.d.	1.1	8	3.2	2.1	499	3	0.544	1.2	389	8	15.5	2	50	20.9
JLO04-44-504	356589	6334451	1.519	16.5	b.d.	0.7	0.091	17.3	173.5	1	2.9	4.6	0.8	2	633	3.9	0.189	b.d.	324	2	1.5	0.4	24	57.8
JLO04-43-480Rep	349619	6335648	1.289	13.1	11	12.3	0.248	29.2	179.4	1	0.5	27.2	2.5	0.8	573	2.8	0.566	4.9	350	b.d.	19.7	1.8	210	31.5
Std. WRP1			0.019	1.4	b.d.	3007.1	0.018	4.4	3.4	0.9	0.8	11.6	0.8	0.6	7	b.d.	0.194	b.d.	80	b.d.	4.2	0.5	98	13.7
JLO04-43-480			1.257	14.2	15	12	0.241	30.4	165.4	0.9	0.5	28.4	2.6	0.8	576	3.1	0.569	4.3	348	b.d.	20	1.9	210	32.7
JLO04-43-480REP			1.289	13.1	11	12.3	0.248	29.2	179.4	1	0.5	27.2	2.5	1.1	573	2.8	0.566	4.9	350	b.d.	19.7	1.8	210	31.5
% Difference			2.5	8.1	30.8	2.5	2.9	4.0	8.1	10.5	0.0	4.3	3.9	31.6	0.5	10.2	0.5	13.0	0.6		1.5	5.4	0.0	3.7

Pseudoleucite trachyte breccia flows crop out on the ridge between the Anuk River valley and the head of Galore Creek (Fig. 5). The tuffs consist of a sequence of orthoclase crystal tuffs and crystal-lithic tuffs and flow-banded sills or welded tuffs. The rocks are potassically altered and cut by a pronounced and strong penetrative deformation that has produced foliated and schistose rocks. The north-trending extent of these potassium-rich volcanic units is evident on the potassium radiometric image derived from the low-level airborne geophysical survey (Yarrow and Taylor, 1990).

ORTHOCLASE PORPHYRY SYENITE

The Galore Creek magmatic complex is located in the headwaters of Galore Creek. It comprises a series of orthoclase-porphyritic syenite intrusions that intrude coeval Upper Triassic Stuhini Group volcanic rocks and related sediments. At least 12 main equigranular and orthoclase porphyritic feldspathoid-bearing syenite intrusive units can be identified and have been described (Enns *et al*., 1995).

The early intrusive suite is premineral to intermineral and includes pseudoleucite porphyry and megaporphyry dikes (I-1 and I-2), grey syenite porphyry (I-3), dark syenite porphyry (I-4a, I-4b), and dikes of fine-grained orthoclase syenite megaporphyry (I-5). The early suite is exposed in the south part of the complex. Intrusives I-1, I-2 and I-3 are only exposed in drillcore. Due to their intense hydrothermal alteration, they have been interpreted as the causative intrusion for the main stage of copper mineralization (Sillitoe, 1991a, 1991b; Enns et al., 1995). The I-3 outcrop in lower Dendritic Creek could not be substantiated. I-4 is the most common intrusive in the southern part of the deposit. It is a medium dark grey porphyry with 10–20% white stubby orthoclase phenocrysts (5–20 mm in length) and rare euhedral pseudoleucite phenocrysts up to 5 cm in diameter (Fig. 6). The matrix to I-4 is a mixture of fine-grained orthoclase, biotite and chlorite.

The remaining phases are considerably less altered, crosscut mineralization and are considered to be postmineral. Most of these phases were defined in drillcore from the Central zone, where crosscutting relationships could be observed and projected between holes. In the field, the most commonly encountered phases are the medium-grained equigranular syenite (I-8), an intergrowth of orthoclase, hornblende and epidote and rarely 2–5 mm orthoclase phenocrysts; and the medium-grained orthoclase syenite megaporphyry (I-9a and I-9b), which is equivalent to the epidote syenite megaporphyry of Allen *et al*. (1976) and is the most abundant intrusive phase at Galore Creek. It forms thick (up to 50 m) subhorizontal dikes that dilute the ore in the Central, North Junction, Butte and West Rim zones. It is characterized by 10–30% euhedral orthoclase megacrysts, 10–30 mm in length, in a medium to rarely coarse-grained matrix. Chlorite and biotite pseudo-

Figure 5. I-4 porphyry syenite, showing stubby orthoclase phenocrysts and rare euhedral pseudoleucite phenocrysts, southern part of the Central zone.

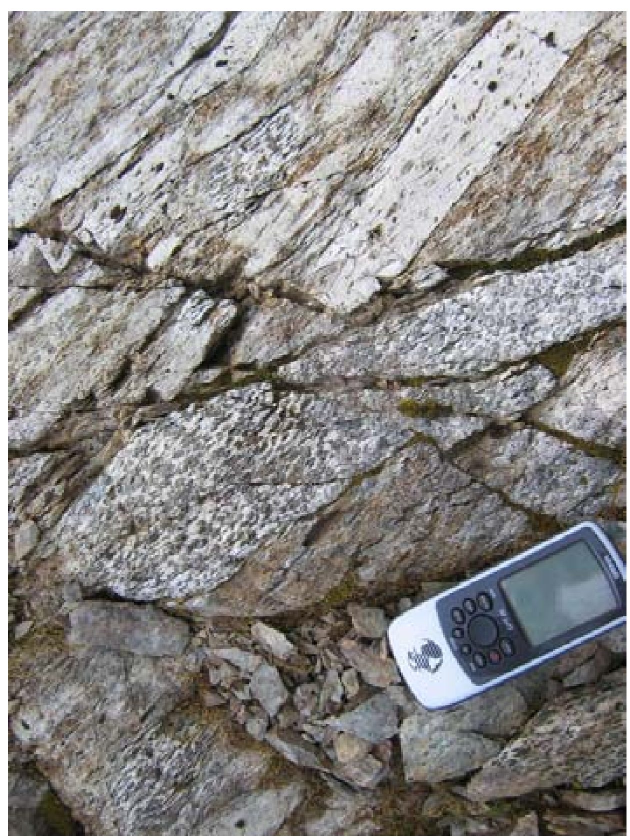

Figure 6. Pseudoleucite trachyte breccia flow on the ridge between the Anuk River Valley and the head of Galore Creek.

morphs hornblende, and variable amounts of epidote and garnet characterize the unit. I-9b can be distinguished from I-9a in hand specimen by the presence of coarse plagioclase and magnetite in the matrix and commonly very large orthoclase phenocrysts (up to 20 cm). I-9a is also typically more potassically altered and pyritic. I-11 is a medium-grained, equigranular, grey to brown intergrowth of orthoclase, biotite and pyroxene, with sparse, acicular white orthoclase phenocrysts (2–7%). It contains miarolitic cavities filled with epidote and garnet. Lavender porphyry (I-12) is a quartz-bearing (Enns *et al*., 1995) syenite. It is characterized by strongly aligned trachytic orthoclase phenocrysts (50–70%) in a lavender-coloured orthoclase matrix.

Uranium-lead ages (Mortensen *et al.*, 1995) from intrusive rocks at Galore Creek range from 210 ± 1 Ma (Pb-Pb isochron, titanite) for an early intermineral syenite porphyry (I-4) to 197.2 ± 1.2 Ma (Pb-Pb isochron, titanite) for a postmineral potassium feldspar porphyry (I-9). These span the Triassic-Jurassic boundary (~200 Ma), using the time scale of Palfy (2000), and suggest a protracted magmatic history for the Galore Creek magmatic complex.

MINERALIZATION AND ALTERATION

Ten porphyry copper-gold deposits are known on the Galore Creek property. The Central and North Junction zones have drill-indicated reserves; the remaining deposits are considerably smaller and less well tested. The deposits are interpreted to be high-level synvolcanic mantos related to alkaline plutonic rocks that intrude and breach the volcanic edifice (Allen *et al.*, 1976).

Central Zone

The alteration mineralogy and zonation developed around the Central zone have been well documented and described by Barr (1966), Allen *et al.* (1976), Panteleyev (1976) and Enns *et al.* (1995), and references therein. The zone extends 1800 m north-northeasterly and varies in width from 200 to 500 m. The deposit dips steeply to the west. It is divided into a core zone and north and south zones. Although the metasomatic overprint (calcsilicate mineral assemblage) at Galore Creek is unusual, the distribution of sulphides, precious metals and magnetite is consistent with the expected zoning pattern for alkalic porphyry deposits (Jones and Leveille, 1989; McMillan, 1991).

Prograde and retrograde alteration mineral assemblages characterize the hydrothermal system that was centred on the Central zone. Early, hot, dominantly magmatic fluids caused potassium silicate alteration and the deposition of biotite, magnetite, orthoclase, bornite and chalcopyrite (Fig. 7). The potassium silicate alteration is preserved in the northern and southern parts of the Central zone. Cooling and collapse of the hydrothermal system downward produced patchy propylitic alteration (epidote, chlorite, calcite and pyrite), which is developed peripheral to the mineralization. This was followed by a late-stage (?) or separate hydrothermal fluid that caused calcic-potassic alteration. This assemblage consists of pervasive white orthoclase, coarse biotite, garnet, anhydrite, diopside and apatite (Fig. 8). The calcic-potassic alteration is centred above the magmatic breccia in Dendritic Creek at the core of the Central zone and is interpreted to have emanated from this centre. A late, lower temperature (?) alteration (SAC), characterized by an assemblage of sericite, anhydrite, carbonate and pyrite±hematite (specular) is developed along the margins of the Central, Junction and Butte zones (Fig. 9).

Disseminated pyrite is the most abundant sulphide mineral. Chalcopyrite and bornite, in the ratio 10:1, are the main copper minerals. Sphalerite and galena are associated within garnet-rich areas, and trace amounts of molybdenite, native silver, native gold and tetrahedrite have been noted (Allen, 1966). Magnetite occurs in veinlets with or without chalcopyrite and often cements breccias. Chalcocite, cuprite, native copper and tenorite are secondary copper minerals (Logan and Koyanagi, 1994).

Gold is generally associated with higher grades of copper mineralization. There is not always a strong correlation; many areas of high copper lack appreciable gold. However, higher gold grades are associated with bornite in the north and south parts of the Central zone.

Figure 7. Potassium silicate alteration of a volcanic breccia altered and preferentially replaced by biotite, magnetite and orthoclase, southern end of Central Zone. Inset shows enlargement of bornite and chalcopyrite mineralization

Figure 8. Calcic-potassic alteration in the orthomagmatic breccia located on the west side of the Central Zone, Dendritic Creek. Pervasive white potassium metasomatism, with coarse intergrowths of biotite, garnet, anhydrite and apatite, replace the matrix to the breccia.

Copper Canyon

The Copper Canyon showing is located approximately 8 km due east of the Galore Creek deposit. It is owned by Eagle Plains Resources. It was tested by seven diamond-drill holes (1010 m) in 1957 by the American Metal Company Limited. At that time, geological reserves of 27 million tonnes with an average grade of 0.72% copper and 0.43 g/t gold were inferred (Spencer and Dobell, 1958). In 1990, Consolidated Rhodes Resources Ltd. completed 3784 m of diamond-drilling in thirteen holes. NovaGold, under an option agreement with Eagle Plains Resources, completed eight diamond-drill holes totalling 3017 m in 2004. Drilling confirmed and expanded the near-surface copper-gold-silver mineralization on the property, which is associated with a syenite porphyry and a hydrothermal system that is similar to but smaller than that at Galore Creek. The Copper Canyon area has been mapped in detail by Leary (1990) and Otto and Smithson (2004).

The deposit is hosted by Late Triassic alkaline flows, tuffs, epiclastics and syenite intrusives. To the east, Middle Triassic sediments and Lower Permian limestones are thrust westward over these volcanics at the head of Copper Canyon Creek. Two northwesterly-trending dikes of syenite porphyry crop out in the lower part of the creek. The

Figure 9. Alteration characterized by an assemblage of sericite, anhydrite, carbonate (SAC) and pyrite±hematite (specular) overprints an I-5 at the portal to the North Junction Zone.

porphyry is similar to the dark syenite porphyry at Galore Creek. It contains potassium feldspar megacrysts up to 4 cm in length, abundant biotite and disseminated pyrite. An intrusive breccia phase or brecciated intrusive is developed locally. Biotite was collected from the magmatic breccia for radiometric dating; results are pending.

STRUCTURE

The orientations of layered rocks around the Galore Creek magmatic complex outline a broad domal structure, possibly related to intrusion but probably reflecting younger deformational events. The Galore Creek area is flanked on the east by the north-trending, east-dipping Copper Canyon thrust fault, which forms the west-verging component of the regional Scud River fault, which has been interpreted to represent a positive flower structure (Logan and Koyanagi, 1994). The western flank is characterized by north-trending upright folds and a well-developed north-trending, west-dipping mylonite zone. Penetrative deformation of the Triassic rocks is rare and restricted to discrete shear zones or folds in sedimentary rocks. Shear sense gives an apparent top-to-the-west sense of motion (Fig. 10). Folds are broad, open structures and generally plunge southerly. These structures postdate mineralization. The Cone Mountain thrust fault is a northwest-trending, east-dipping mylonite zone with similar tops-to-the-west–directed thrusting (Brown *et al.,* 1996). The footwall to the mylonite is foliated granodiorite (185 Ma), which provides a lower limit to the age of thrusting.

Well-bedded sedimentary and water-lain crystal tuffaceous rocks, exposed along the western edge of the complex and at Copper Canyon, permit a structural analysis of the rocks in the area. With the exception of a thick pack-

Photo 9. Discrete brittle shear zone developed in volcanic conglomerates along the western wall of the Galore Creek basin. Rotation of clasts gives an apparent tops-to-the-west sense of shear.

age of crystal-rich tuffs at Copper Canyon, all other bedding measurements are upright.

Thrusts at Copper Canyon postdate mineralization and may coincide with shears to the west of the complex.

Late dikes, D-1 through D-4, trend 90° and 125°, have north and south dips, and crosscut alteration, mineralization and all I-1 through I-12 syenite dikes.

CHEMISTRY

Samples were steel milled at the British Columbia Geological Survey Branch Laboratory in Victoria. Splits were shipped for analysis to TeckCominco Laboratories, Vancouver for major and trace element abundances (Ba, Rb, Sr, Nb, Zr and Y) by X-ray fluorescence (XRF); ACME Analytical, Vancouver for trace element analyses using inductively coupled plasma – emission spectrometry (ICP-ES); and Actlabs, Ancaster, Ontario for trace element analyses using instrumental neutron activation analysis (INAA). A subset of these samples has also been sent to Memorial University, Newfoundland for trace element analysis using inductively coupled plasma – mass spectrometry (ICP-MS). Results are pending.

CONCLUSIONS

A Late Triassic volcanic centre is preserved at Galore Creek. Sulphide deposition within it was related to a dynamic system of synvolcanic faults, syenite intrusions, explosive breccias and comagmatic extrusive volcanics. Because dikes, sills and explosive breccias dominate, together with pseudoleucite-bearing intrusives, this is envisioned to have taken place in a high-level setting, possibly within the throat of a volcano. Radiometric ages (Mortensen *et al.,* 1995) indicate a prolonged alkaline magmatic history for the intrusive complex, with the bulk of copper-gold mineralization occurring early. Intense potassium metasomatism and copper-gold mineralization are synvolcanic and latest Triassic in age (Logan and Koyanagi, 1994). Extrusive equivalent rocks of the potassium porphyritic syenite constitute the upper stratigraphy package of the Stuhini Group at Galore Creek (Fig. 11). These rocks are predominantly potassium feldspar and biotite crystal-rich pyroclastic and epiclastic rocks. Accretionary lapilli and depositional bed forms are interpreted to be base surge deposits and indicate subaerial deposition.

No single mineralization-alteration zonation pattern is apparent that would tie all the mineral occurrences at Galore to a single central hydrothermal system (i.e., centred over the Central Zone), nor is there any apparent relation between elevation and either sulphide or alteration mineral assemblages.

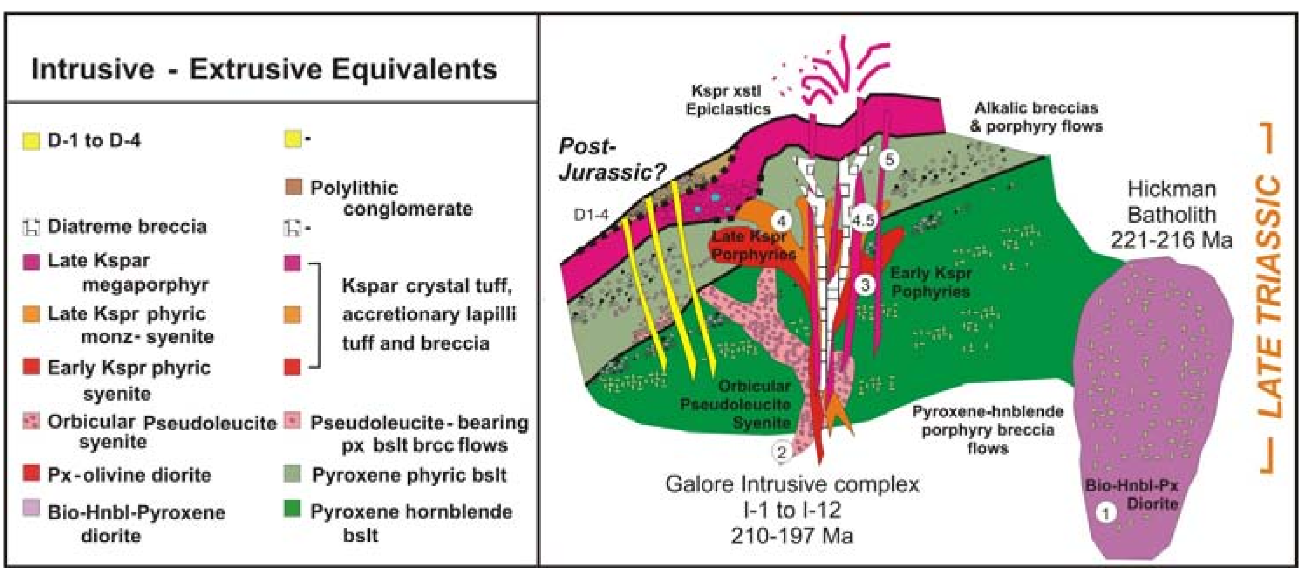

Figure 11. Schematic representation of the Late Triassic volcanic and magmatic complex at Galore Creek, showing relative ages of events.

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