Overview of the Sulphurets area, northwestern British Columbia

R.V. KIRKHAM
Geological Survey of Canada, Vancouver, British Columbia

J. MARGOLIS
Homestake Mining Company, Sparks, Nevada

ABSTRACT

The Sulphurets area in the Coast Mountains of northwestern British Columbia is underlain by sedimentary and volcanic rocks of the Upper Triassic Stuhini Group, the Early Jurassic Mitchell Intrusions, sedimentary rocks of the Lower Jurassic Jack formation (?), dominantly volcanic rocks of the Lower and Middle Jurassic Hazelton Group, and dominantly sedimentary rocks of the Middle and Upper Jurassic Bowser Lake Group. The area contains widespread pyritic alteration zones and several stockwork and disseminated porphyry copper-gold, disseminated gold, and precious metal vein deposits. Porphyry copper-gold deposits probably formed about 192 Ma to 195 Ma and were related to the emplacement of Mitchell Intrusions. Alteration zones and mineral deposits have been cut by thrust and high-angle normal faults and have been subjected to low greenschist facies metamorphism. Most sericitic and chloritic alteration zones have well-developed schistosities.

Remote location, hostile climate, and steep rugged terrain with extensive ice and snow cover have made exploration and potential development difficult. Nevertheless, the area is richly mineralized and continues to offer exploration opportunities.

Introduction

The Sulphurets area, centred at about 56°30′ latitude and 130°15′ longitude in NTS 104B/8 and 9, is located in rugged terrain on the eastern side of the Coast Mountains about 70 km north of Stewart, British Columbia (Fig. 1). Access is mainly by helicopter, but a barge on Bowser Lake and tractor road on the Knipple Glacier have been used to transport freight to the Brucejack Lake area. The area is undergoing active deglaciation with rapidly downwasting glaciers and steep slopes with permanent snow and icefields, bare rock exposures, and alpine vegetation above 1000 m elevation, and forests, thick underbrush, and fast-flowing streams at lower elevations. Active, bedrock landslide scarps are present on the south side of the Mitchell Glacier.

The Sulphurets area contains large, conspicuous pyritic gossans that attracted the attention of early prospectors. In 1935, Bruce and Jack Johnstone staked the area as the 'Big Showing'. Large squared claim posts observed at that time indicated even earlier activity (Mandy, 1936). Small-scale placer gold production has been obtained from gravels at the mouth of Sulphurets Creek where it enters the Unuk River and from Mitchell Creek gravels close to where it joins Sulphurets Creek (Fig. 1). Since the late 1950s, the area was explored first for copper, then molybdenum and gold, and most recently, for both gold and copper. The Newhawk joint venture (60% Newhawk Gold Mines Ltd.; 40% Granduc Mining Corporation) is currently exploring precious metal veins in the Brucejack Lake area (Bruceside property) and Newhawk Gold Mines Ltd. (42% Homestake Canada Inc.) was also evaluating the bulk-tonnage Snowfield gold deposit (Margolis and Britten, this volume). Until the end of 1992, Placer Dome Inc. explored the Kerr and Sulphurets Gold porphyry deposits (Fig. 2; Ditson et al., this volume; Fowler and Wells, this volume). Geological resources of deposits are provided in Table 1; however, many prospective parts of the region have received limited exploration. The inaccessible remote location, hostile climate, and rugged terrain have hindered exploration and development.

TABLE 1. Identified resources in the Sulphurets area

Deposit	Type	Thousands of tonnes (st = short tons)	Grade	Comments
Kerr	porphyry	135 000	0.76% Cu; 0.34 g/t Au	Drill-indicated resource; Ditson et al. (this volume)
Mitchell	porphyry	200 000	0.2% Cu; 0.86 g/t Au	Geological estimate; Margolis (1993)
Snowfield	disseminated adularia-sericite-type Au	7030 (7750 st)	2.8 g/t Au (0.083 oz/t)	Geological inventory, Newhawk Gold Mines Ltd., 1985
West zone	vein	749 (826 st)	15.4 g/t Au (0.45 oz/t); 648 g/t Ag (18.9 oz/t)	Proven and probable geologic reserves, Newhawk Gold Mines Ltd., October 25, 1990
Shore zone	vein	83.7 (92.3 st)	12.7 g/t Au (0.371 oz/t); 158 g/t Ag (4.6 oz/t)	Proven and probable geologic reserves, Newhawk Gold Mines Ltd., October 25, 1990

Published reports on this area include Mandy (1936), Kirkham (1963, 1991, 1992), Simpson (1983), Grove (1986), Alldrick and Britton (1988), Britton and Alldrick (1988), Alldrick et al. (1989), Anderson (1989), Anderson and Thorkelson (1990), Henderson et al. (1992), Roach and Macdonald (1992), Lewis et al. (1993), Macdonald (1993), Bridge (1993), Margolis (1993), and Davies et al. (1994). This paper, an introduction to the area, is based on field and laboratory work by the first author (1960-61 and 1986-93) and second author (1991-92), on the above published work, and on discussions with many colleagues who are working, or have worked, in the area.

Regional Geology

Regional Setting and Tectonics

The Sulphurets area lies along the eastern side of the Coast Mountains, approximately 25 km east of the Coast Plutonic Complex, a north-northwesterly trending belt of Cretaceous to Early Tertiary intrusions and high-grade metamorphic rocks (Crawford et al., 1987). The area lies within the western part of Stikinia, the largest of several terranes of the Intermontane Belt, that was possibly accreted to the North American continental margin in the Middle Jurassic (Monger et al., 1982; Cordey et al., 1987; Rusmore et al., 1988; Ricketts et al., 1992). Isotopic studies of igneous and sedimentary rocks in Stikinia show a primitive, mantle-derived signature, unlike the thickened, sialic crust underlying regions east of the Intermontane Belt (Samson et al., 1989). In the Iskut River and

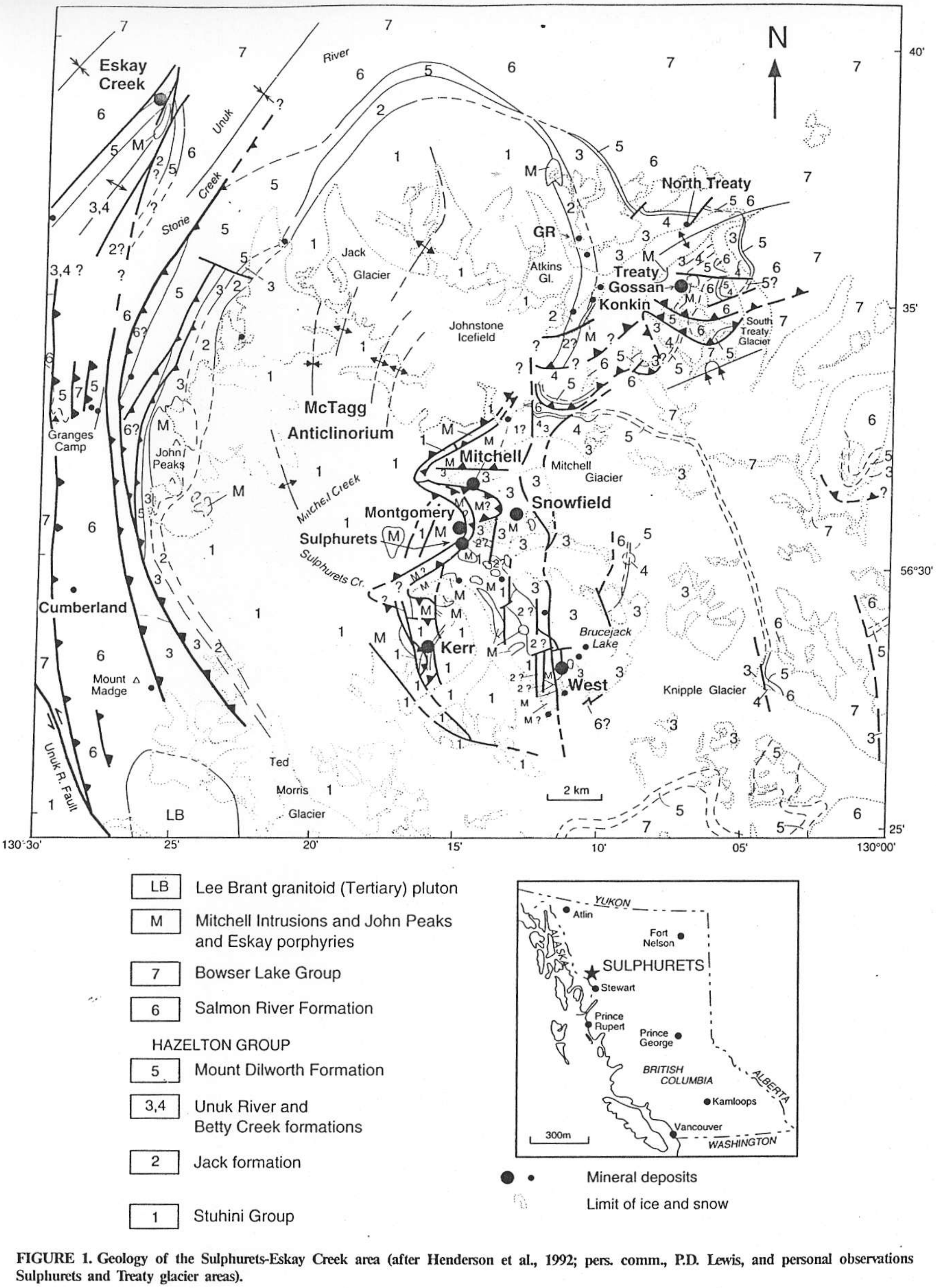


FIGURE 1. Geology of the Sulphurets-Eskay Creek area (after Henderson et al., 1992; pers. comm., P.D. Lewis, and personal observations Sulphurets and Treaty glacier areas).

Stikine River areas to the north and the Oweegee Peak area to the east of Sulphurets, Devonian through Permian volcanic and sedimentary arc rocks of the "Stikine assemblage" form the basement to younger Triassic and Jurassic volcanic and sedimentary sequences of the Stikine terrane (Brown et al., 1991). In the Iskut River - Sulphurets region, Late Triassic (Carnian to Norian) Stuhini Group rocks are overlain with angular unconformity by those of the Lower to Middle Jurassic Hazelton Group. These rocks were also deposited

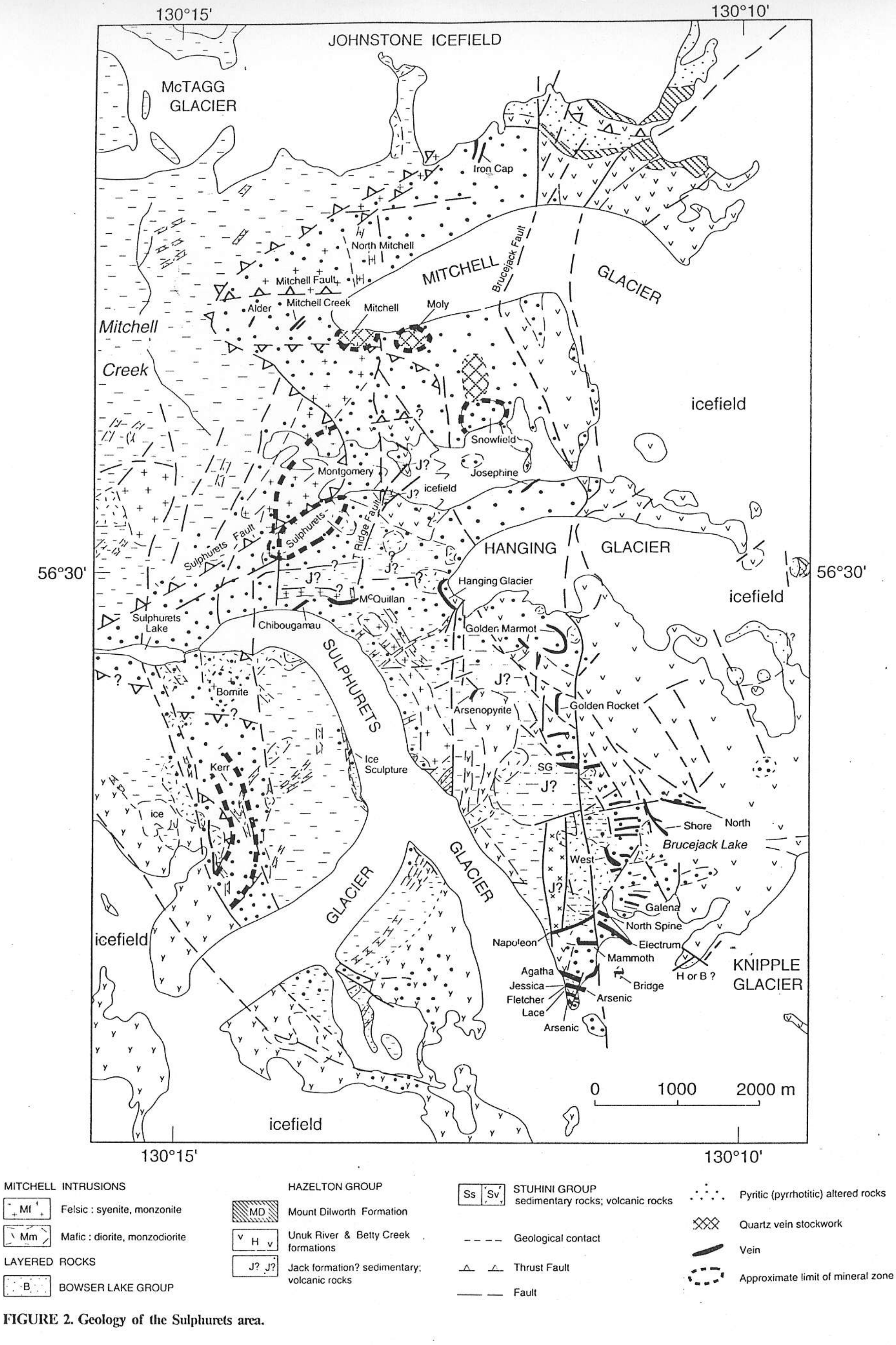


FIGURE 2. Geology of the Sulphurets area.

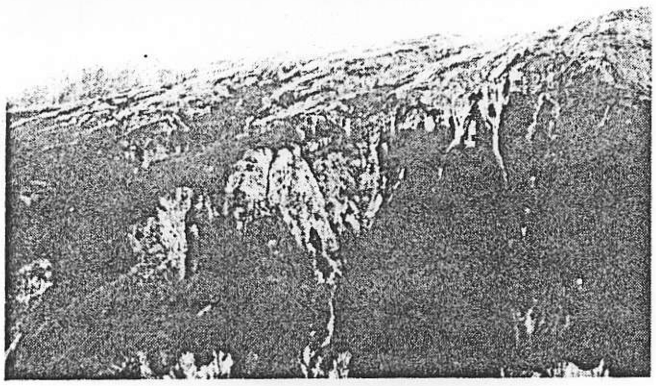


FIGURE 3. View to the north of Mitchell-Sulphurets ridge showing the Sulphurets zone and the trace of the Sulphurets Fault (centre of the photograph at the top of the bare cliffs; GSC Photo 1995-017E).

in island-arc settings (Grove, 1986; Britton and Alldrick, 1988; Anderson and Thorkelson, 1990). Overlying these older sequences and exposed to the east and north is the Bowser Lake Group, a Middle Jurassic through Middle Cretaceous marine and continental clastic sedimentary succession (Anderson and Thorkelson, 1990; Evenchick, 1991).

The Intermontane Belt in northwestern British Columbia has experienced several major tectonic events, including one in the Late Triassic to Early Jurassic, one during the Middle Jurassic accretion of Stikinia, and another during the Late Jurassic through Late Cretaceous, possibly coinciding with accretion of the Insular terranes west of the Coast Plutonic Complex (Evenchick, 1991; Ricketts et al., 1992). The Late Jurassic through Late Cretaceous event resulted in a widespread, generally east-verging fold and thrust belt affecting the Bowser Lake Group and older sequences, termed the Skeena Fold Belt by Evenchick (1991). Angular to disconformable unconformities exist below and locally within the Hazelton Group, indicating that deformation and erosion occurred during the latest Triassic and/or earliest Jurassic (Henderson et al., 1992; Greig, 1992).

Stratigraphy

The Sulphurets area is underlain by Upper Triassic sedimentary and volcanic rocks of the Stuhini Group; Lower Jurassic sedimentary rocks of the Jack formation(?); Lower and Middle Jurassic, dominantly volcanic and lesser sedimentary rocks of the Hazelton Group; and Middle to Upper Jurassic, dominantly sedimentary rocks of the Bowser Lake Group (Fig. 1; Henderson et al., 1992). The Stuhini Group includes dark grey distal turbiditic siltstone and minor dark interbedded micritic limestone; alkalic pyroxene- and hornblende-phyric massive and pillowed basaltic flows, breccia, and tuff; and thick sequences of immature conglomerate and sedimentary breccia. Stuhini Group rocks are overlain unconformably by granitoid-clast conglomerate and limy fossiliferous sandstone and siltstone of the Lower Jurassic Jack formation (Henderson et al., 1992). The Jack formation has been traced from its type locality at the Jack Glacier to the Konkin nunatak on the west side of the Treaty Glacier about 6 km north of the Sulphurets area (Fig. 1). Arenaceous rocks between Stuhini Group turbidites and Hazelton Group volcanic rocks in the Sulphurets area have been correlated tentatively with the Jack formation (Fig. 2). A massive arenaceous unit west of Brucejack Lake is similar to massive arenite on the Konkin nunatak between inverted Stuhini Group turbidites and upright Jack formation.

The Jack formation is overlain, apparently conformably, by volcanic and minor sedimentary rocks of the Lower and Middle Jurassic Hazelton Group. Thick massive plagioclase (± hornblende, K-feldspar, and pyroxene)-phyric andesitic and dacitic flows, breccias, and intrusive-extrusive flow domes with minor siltstone and mudstone layers dominate in the lower part of the Hazelton volcanic pile (Unuk River Formation; Alldrick, 1993). These rocks are overlain by distinctive, well-bedded, variegated grey, green, and maroon andesitic and dacitic pyroclastic and epiclastic rocks, mafic flows, and dark carbonaceous mudstone with minor chert and limestone (Betty Creek Formation; Grove, 1986; Alldrick, 1993). These units locally are disconformably overlain by dacitic and rhyolitic tuff, welded ash-flow tuff, volcanic breccia, flow-layered lava domes, and interbedded, limy fossiliferous sandstone of the Mount Dilworth Formation (Alldrick, 1985, 1993). Hematitic diagenetically-oxidized strata and accretionary lapilli within the upper parts of the Hazelton Group (Betty Creek Formation; Grove,1986; Alldrick, 1993), welded tuff in the Mount Dilworth Formation and petrified wood indicate that parts of the upper Hazelton Group were emergent. Margolis (1993), however, proposed that distinctive hematitic and chloritic alteration in Betty Creek pyroclastic flows beneath the Mount Dilworth Formation formed by interaction of the flows with heated seawater, and that the units were deposited in shallow seawater, also shown by abundant marine fauna in various other parts of the section. Evidence, therefore, indicates both shallow marine and emergent volcanic environments.

The Hazelton Group is overlain conformably to disconformably by dominantly sedimentary rocks, mainly black carbonaceous mudstone and medium to dark grey turbidites of the Middle to Upper Jurassic Bowser Lake Group. The lowermost unit of the Bowser Lake Group is the Salmon River Formation, characterized by black carbonaceous pyritic mudstone; light and dark tuffaceous siltstone ("pajama beds"); local pillowed, columnar-jointed, and brecciated amygdaloidal basalt; and, immediately overlying Mount Dilworth Formation rhyolite, a thin unit of grey, rusty-weathering, limy, fossiliferous sandstone. Primarily because of a gradational upper contact, Britton (1991) and Henderson et al. (1992) put the Salmon River Formation in the Bowser Lake Group; however, Anderson and Thorkelson (1990) and Alldrick (1993) both place the Salmon River Formation within the Hazelton Group. About 17 km northwest of the Sulphurets area, the Salmon River Formation hosts the volcanic-exhalative, epithermal Eskay Creek precious- and base-metal deposit which started production in January 1995 (Fig. 1).

Structure and Metamorphism

Rocks in the Sulphurets area have been affected by folding, faulting, penetrative cleavage formation, and low-grade regional metamorphism (Kirkham, 1963; Henderson et al., 1992; Margolis,1993). Within the broad McTagg anticlinorium Stuhini Group rocks have been deformed into a series of upright folds with local areas of well-developed, steeply-dipping, north-striking flattening and elongation fabrics (Fig. 1; Henderson et al., 1992). On the north side of Mitchell Creek these folded Stuhini Group rocks are cut by numerous east-northeast-striking planar dikes that were probably feeders to overlying Hazelton Group volcanic units. The unconformably overlying Jack formation and Hazelton and Bowser Lake group rocks, with moderate to steep dips, wrap gently around the north-plunging McTagg anticlinorium (Henderson et al., 1992). However, in the Jack Glacier area northwest of the Sulphurets area, the Jack formation contains well-developed flattening fabrics along the northwest side of the anticlinorium (Fig. 1). Rocks on the west side of the anticlinorium are cut by westerly-directed thrusts and overturned folds, and the east side by east- to southeasterly-directed thrusts and overturned folds (Fig. 1; Henderson et al., 1992; Lewis, 1992; Margolis, 1993; D. Thorkelson and P. Lewis, pers. comm., 1990, 1991). These thrusts and overturned folds are probably part of the Cretaceous Skeena Fold Belt (Evenchick, 1991; Lewis, 1992). East- and southeast-vergent thrusts of the Skeena Fold Belt are common in the main Sulphurets area, affecting Bowser Lake Group and older rocks. Faults, such as the Sulphurets thrust (Fig. 3) and underlying Mitchell thrust, post-date mineralization and locally juxtapose deeper parts of hydrothermal systems above shallower parts (Fig. 2).

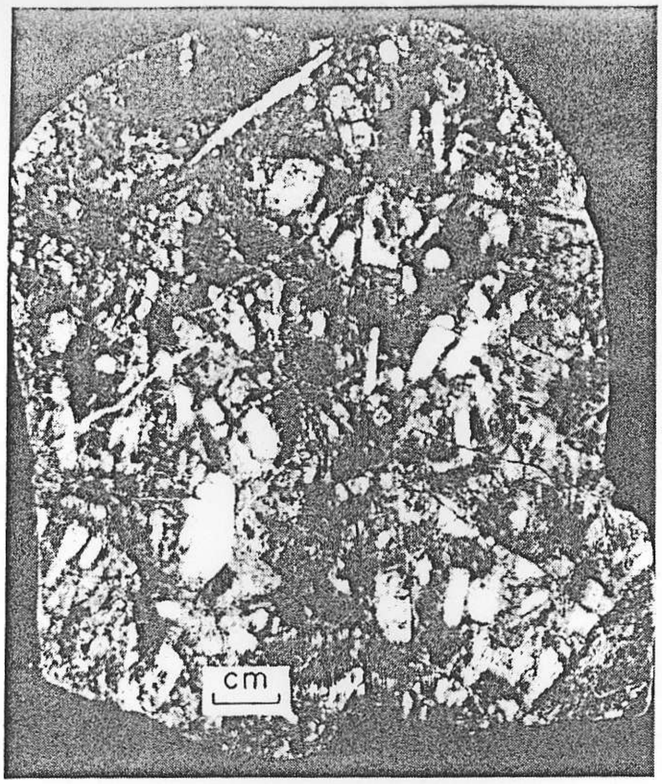


FIGURE 4. Potassic K-feldspar-phyric quartz syenite porphyry cut by intermineral, maroon, aplitic low-silica granite, north of Mitchell Glacier (GSC Photo 1995-017F).

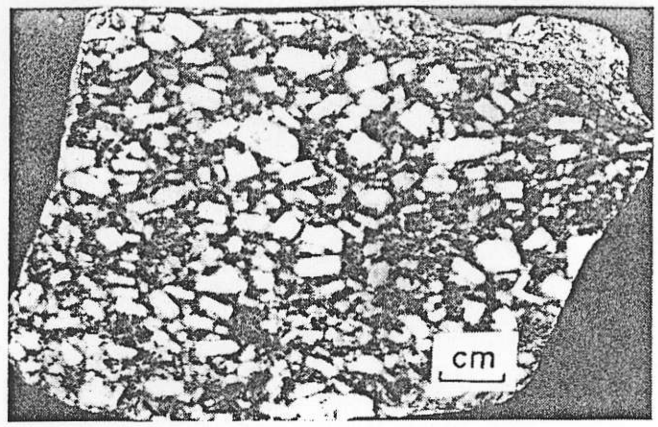


FIGURE 5. Sodic Sulphurets porphyry with perthitic albite and hornblende phenocrysts, north of Sulphurets Glacier (GSC Photo 1992-184B).

The Ridge Fault is a steeply-dipping, northerly- to northeasterly-trending system exposed near the top of Mitchell-Sulphurets ridge in the centre of the area (Fig. 2). The fault comprises several branches each showing an apparent west-side up sense of motion, with displacements on individual branches in the order of 50 m to greater than 100 m. A foliated sericitic and chloritic alteration zone follows the east branch of the fault, indicating that at least this branch existed at the time of alteration. Moreover, as relatively weakly altered rocks are juxtaposed against highly altered rocks along the fault, significant movement must also postdate the alteration.

The Brucejack Fault is a late, steeply-dipping, northerly-striking structure which transects the Sulphurets area (Fig. 2). Movement on the Brucejack Fault is probably complex and has been difficult to determine. Structural fabrics and offset contacts north of the Mitchell Glacier indicate an apparent east-side down, dip-slip displacement of greater than 500 m with a dextral component (Kirkham, 1963; Margolis, 1993). Near Brucejack Lake, contacts are offset dextrally about 100 m, but the slip direction is uncertain (Britton and Alldrick, 1988; Kirkham, 1992; Davies et al., 1994). The Brucejack Fault and many other late, northerly-striking faults with relatively minor displacements, cut thrust faults and alteration zones.

Most altered and unaltered rocks in the Sulphurets area contain a postmineral cleavage (foliation) of variable orientation (Kirkham, 1963; Margolis, 1993; Bridge, 1993). The intensity of cleavage development in altered rocks is directly proportional to the concentration of phyllosilicates, chiefly hydrothermal sericite, pyrophyllite, and chlorite. Potassically-altered rocks are unfoliated, owing to a low content of phyllosilicates and an abundance of equant, fine-grained hydrothermal K-feldspar; similarly, intermediate to felsic intrusions are unfoliated. Pyrite grains within foliated rocks have well-developed pressure shadows (Margolis, 1993) indicating that the pyrite predates cleavage formation. Sericite extracted from unusually large pressure shadows at the West zone yielded an argon-argon (Ar-Ar) age of 110 ± 2 Ma, a minimum age for pressure-shadow formation (see radiometric dating below). Mineralized quartz-vein networks within foliated quartz-sericite-pyrite-chlorite altered rocks in the Mitchell Glacier area display abundant evidence of significant post-mineralization deformation, including: isoclinally-folded veins with fold axes within foliation planes; transposition of veins into foliation planes with extension cracks perpendicular to the foliation; isolated, detached, vein lenses parallel to foliations, which wrap around the lenses; rootless isoclinally-folded veins; and other small-scale post-mineral deformation features outlined by Margolis (1993).

Metamorphic grade in the Sulphurets area is lower greenschist facies, as indicated by epidote, calcite, quartz, and chlorite and the absence of biotite, hornblende, and actinolite within andesitic volcanic rocks and sedimentary rocks outside of areas of hydrothermal alteration (facies definitions of Yardley, 1989). The presence of pyrophyllite and kaolinite (see Margolis and Britten, this volume) indicates that metamorphic temperatures did not greatly exceed about 275°C, assuming 3 km burial (Evans and Guggenhein, 1988; Hemley et al., 1980).

Shallowly-dipping quartz veins cut sharply across foliated and unfoliated altered and mineralized rocks, mineralized veins, and unaltered rocks throughout the region. The veins typically form en-echelon arrays dipping 25° to 40° southeast and contain vertical or steeply-oriented crystal fibres; in thin section crack-seal textures are apparent. Arrays of sigmoidally-folded veins show top-to-the-southeast sense of shear (Margolis, 1993), based on the criteria outlined in Ramsey and Huber (1983). The mineral assemblages in the veins are similar to those of the host rock, indicating local fluid migration into the extension cracks, probably during low-grade metamorphism. The vertical fibres and shallow dips of the veins are consistent with vertical extension and horizontal compression which would occur during thrusting (Hodgson, 1989). Furthermore, the dominance of southeast dips and top-to-the-southeast shear is consistent with the veins having formed during the southeast-vergent thrusting that produced the Sulphurets and Mitchell thrusts of the Late Mesozoic Skeena Fold Belt (Evenchick, 1991; Lewis, 1992). As outlined under "radiometric dates" below, this metamorphism peaked at 110 Ma, coinciding with the Skeena deformation.

Mitchell Intrusions

Many small dikes, sills, and plugs of Early Jurassic age occur in the Sulphurets area, and these have been called the Mitchell Intrusions (Kirkham, 1963). Dioritic plagioclase (± hornblende) porphyry, diorite, monzodiorite, monzonite porphyry, syenite porphyry, quartz syenite porphyry (Fig. 4), porphyritic aplitic low-silica granite (Fig. 4), sodic albite-hornblende porphyry (Fig.5), and K-feldspar megacrystic porphyry (two-feldspar "Premier porphyry"; Alldrick, 1993) occur in the area (Fig. 2). Premineral, intermineral, and post-mineral intrusions occur in the vicinity of the copper-gold deposits. In the central and western part of the altered area, monzonitic, syenitic, and granitic intrusions show a close spatial and temporal relationship to the porphyry copper and gold mineralization (Fig. 2).

TABLE 2. Radiometric dates for the Sulphurets area

Unit	Sample number	Location	Age (Ma)	Method	Reference
kersantite dike	1(ddh 89-12)	Kerr	51 ± 2	K-Ar whole rock	Bridge (1993)
sericite from pyrite pressure shadow	S494	West zone	110.2 ± 2.3	Ar^{39}-Ar^{40} plateau	Margolis (1993)
massive dense sericite	KQ-89-1	West zone	110.4 ± 2.6	K-Ar sericite	Kirkham (1989)
sericite	S93	Mitchell valley	112 ± 1.9	Ar^{39}-Ar^{40} plateau	Margolis (1993)
sericite-pyrite-altered monzonite	2 (ddh KS-125)	Kerr	124 ± 4	K-Ar whole rock	Bridge (1993)
extrusive K-feldspar-plagioclase porphyry	KQ-91-80B	Knippie Glacier east of Brucejack Lake	184.9 ± 5.9	Pb-Pb zircon	Mortensen and Kirkham, unpublished
disaggregated felsic dike	AJM-ISK91-399	south of Brucejack Lake	185 ± 1	U-Pb zircon	Macdonald (1993)
felsic flow dome	AJM-ISK91-388	south of Brucejack Lake	185.6 ± 1	U-Pb zircon	Macdonald (1993)
K-feldspar megacrystic dike	KQ-90-152	south of Hanging Glacier	188 ± 0.5	U-Pb zircon	McNicoll and Kirkham, unpublished
hydrothermal tourmaline	S412	south side of Mitchell valley	200 ± 20	Ar^{39}-Ar^{40} plateau	Margolis (1993)
K-feldspar megacrystic plagioclase-hornblende porphyry	S238	east of Snowfield deposit	189.6 ± 2.2	U-Pb zircon	Margolis (1993)
K-feldspar	S238		~114	Ar^{39}-Ar^{40} plateau	Margolis (1993)
Sulphurets Porphyry (albite-hornblende porphyry)	KQ-90-154C	west of Hanging Glacier	191.4 ± 5.3	Pb-Pb zircon	Mortensen and Kirkham, unpublished
feldspar porphyry		Montgomery (Main Copper)	191.8 ± 6.5 to −1.0	U-Pb zircon	Macdonald, unpublished (see Fowler and Wells, this volume)
potassically altered quartz syenite	S462	southwest side of Mitchell Glacier	192.7 + 5.4 to −3.6	U-Pb zircon	Margolis (1993)
syenite-granite porphyry	KQ-89-89/90A	north of Mitchell Glacier	193.9 ± 0.5	U-Pb zircon	Mortensen and Kirkham, unpublished
altered plagioclase-hornblende porphyry	KQ-90-151A	south of Hanging Glacier	194 ± 1	U-Pb zircon	McNicoll and Kirkham, unpublished
K-feldspar megacrystic, plagioclase-hornblende porphyry	00-Iskut	Kerr	195 ± 1.5	U-Pb zircon	Bridge (1993)
altered quartz monzonite		Raewyn zone Sulphurets deposit	196 + 17 to −32	U-Pb zircon	Macdonald, unpublished (see Fowler and Wells, this volume)
syenodiorite	Iskut-lapp	Kerr	197 ± 3	U-Pb zircon	Bridge (1993)

Radiometric Dates

Table 2 is a compilation of radiometric dates for the Sulphurets area. Samples from the central and western parts of the area, with U-Pb zircon ages in the range of 193 Ma to 197 Ma, are from intrusions that cut Stuhini Group rocks and are probably related to copper and gold mineralization. Porphyry copper (gold) mineralization west of the Hanging Glacier is bracketed between about 194 Ma and 188 Ma. An unmineralized K-feldspar megacrystic porphyry ("Premier porphyry"; sample KQ-90-152) cuts an intense pyritic stockwork with modest amounts of chalcopyrite and has an age of 188 ± 0.5 Ma. An intensely altered pyritic, chalcopyrite-bearing plagioclase-hornblende porphyry (KQ-90-151A) from the same area has an age of 194 ± 1 Ma. The mixed trachytoid syenite-aplitic granite sample (KQ-86-89/90A) north of the Mitchell Glacier, dated at 193.9 ± 0.5 Ma has intermineral relationships and magmatic-hydrothermal features indicating that this is probably the age of copper deposition in this area. The age of 192.7 + 5.4 to 3.6 Ma (S462) on a similar intrusive rock south of the Mitchell Glacier and 196 + 17 to 32 Ma (Raewyn zone, Sulphurets deposit) and 195 ± 1.5 Ma and 197 ± 3 Ma (Kerr deposit) (Table 2) dates support a general age of about 192 Ma to 195 Ma for porphyry copper-gold deposition in the area.

K-Ar ages of K-feldspar and sericite have been reset by a heating event that waned by about 110 Ma. K-feldspar phenocrysts from a 189.6 ± 2 Ma (U-Pb, zircon, S238) intrusion are reset, yielding an Ar-Ar plateau age of about 114 Ma. Hydrothermal sericites from strongly altered and mineralized rocks yield similar Ar-Ar and K-Ar ages near 110 Ma, even though causative intrusions are Lower Jurassic (Table 2). The only hydrothermal mineral found to be refractory to subsequent heating is hydrothermal tourmaline, which yielded a high error, Ar-Ar plateau age of 200 ± 20 Ma, which overlaps with the age of the mineralization-related intrusive rocks (Table 2). A sample of sericite which grew within a pyrite pressure shadow during post-pyrite cleavage formation at the West zone also yielded an age near 110 Ma (sample S494, Table 2). This suggests that the cleavage formed after Early Jurassic pyrite formation but prior to or about 110 Ma.

Potassium-argon dating in the Stewart area south of Sulphurets also indicates a mid-Cretaceous metamorphic event which peaked by 110 ± 10 Ma (Alldrick et al., 1987; Alldrick, 1993). Metamorphism of this age is synchronous with Skeena Fold Belt deformation (Evenchick, 1991).

The 185 Ma to 188 Ma ages for Hazelton Group extrusive rocks in the Brucejack Lake area indicate that parts of the Hazelton Group apparently postdate the main period of porphyry copper-gold deposition. Advanced argillic alteration with natroalunite and minor amounts of native sulphur in the Treaty Glacier area affects Mount Dilworth Formation rhyolite units that might be as young as lower

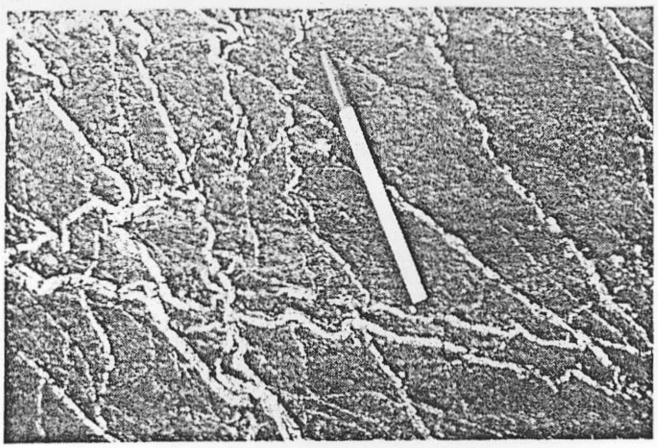


FIGURE 6a. Contorted pyrite-chalcopyrite-tennantite-molybdenite-bearing quartz-vein stockwork, north side of the Mitchell zone (GSC Photo 1992-184EE).

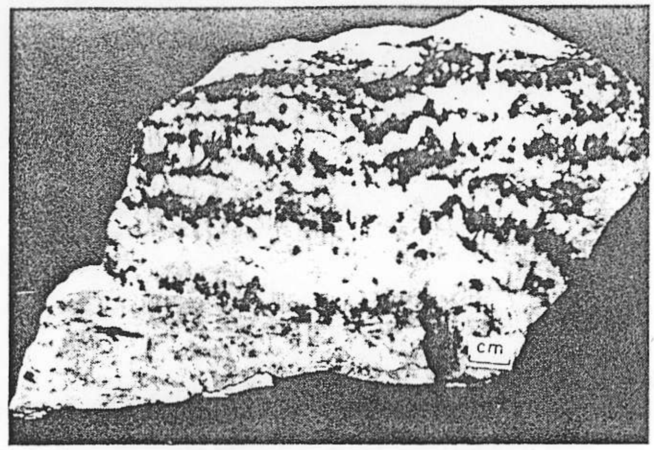


FIGURE 7. Crustified, high-grade quartz-adularia-sericite vein with galena, sphalerite, pyrargyrite, electrum, and acanthite, Josephine zone (GSC Photo 1995-017G; Fig. 2).

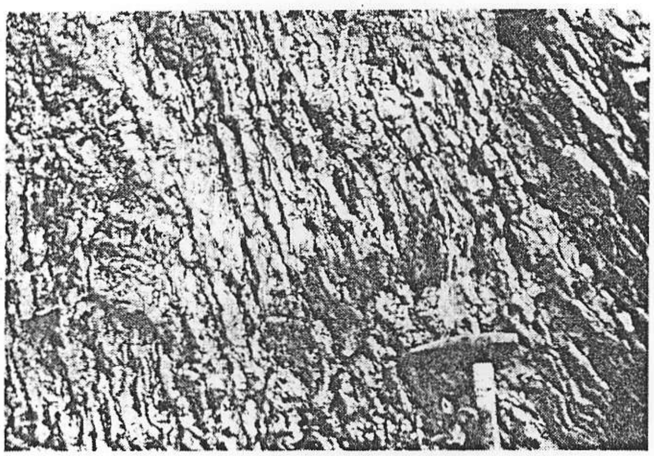


FIGURE 6b. Intense auriferous sheeted quartz vein system ("stockwork") Mitchell zone (GSC Photo 1995-017C; Fig. 2).

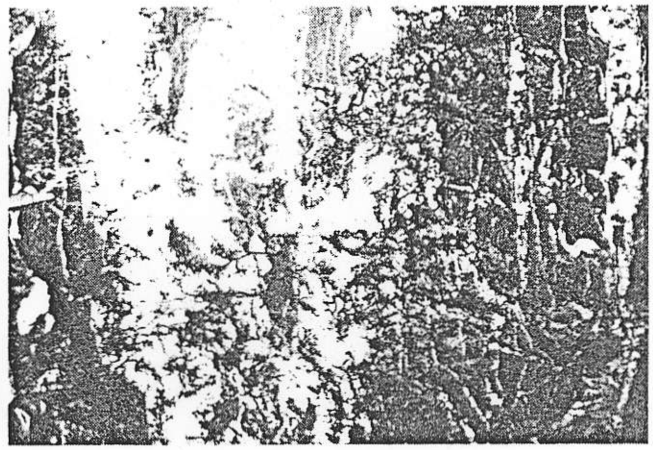


FIGURE 8. High-grade, tetrahedrite-pyrargyrite-rich Au-Ag-quartz-calcite vein, West zone, Brucejack Lake (GSC Photo 1992-184Q; Fig. 2).

Middle Jurassic (pers. com., J. Mortensen, 1994). These dates indicate that hydrothermal alteration in the region occurred over a span of greater than 15 Ma.

Mineral Deposits

Selected types of mineral deposits in the Sulphurets area with examples are listed in Table 3. Many of these deposits have been found only recently and they are incompletely explored and documented. Articles in this volume by Ditson et al., Fowler and Wells, and Margolis and Britten describe the main deposits.

Porphyry copper-gold deposits and occurrences are distributed over 9 km north-south along the western side of the altered area; deposits from south to north include Kerr, Sulphurets, Montgomery (Main Copper), Mitchell (Fig. 6), and North Mitchell (Fig. 2). The Snowfield zone south of the Mitchell Glacier (Fig. 2) is a disseminated gold deposit in sericite-chlorite-pyrite altered andesitic basalt, probably part of the lower Hazelton Group (Margolis and Britten, this volume).

Pyritic veins and breccias in the Iron Cap area and in the Alder zone (Fig. 2; Margolis, 1993) contain high-grade gold introduced with later galena, sphalerite, quartz, and barite and might be similar to those in the Red Mountain area near Stewart (Rhys et al., this volume) and Stonehouse deposit on Johnny Mountain in the Iskut River area. Several gold-bearing quartz-carbonate veins are characterized by arsenopyrite, minor chalcopyrite, and low-silver contents. These veins probably formed in a "transitional" environment between porphyry and epithermal deposition (e.g., Panteleyev, 1991). Minor auriferous pyrrhotitic veins with small amounts of chalcopyrite

TABLE 3. Mineral deposit types

Type	Example
Porphyry Cu-Au	Kerr, Montgomery (Main), Sulphurets-Raewyn, Sulphurets-Breccia, Mitchell, North Mitchell
Disseminated Au	Snowfield
Pyritic vein and breccia with gold overprint	Iron Cap, Alder
Pyrrhotite Au (Cu)	Ice Sculpture
Quartz-arsenopyrite gold vein	Arsenopyrite, Arsenic, Napoleon
Au-Ag quartz (± barite) vein	West, Shore, Galena, SG, Josephine
Ag-Sb vein, breccia vein	Atikins Glacier
Advanced argillic (high sulphidation)	Treaty nunatak and North Treaty gossans
Volcanic-exhalative, epithermal precious and base metal	Eskay Creek (northwest of Sulphurets area)
Au-Cu shear zone	Chibougamau

in the Ice Sculpture showing (Fig. 2) might be similar to the Snip gold deposit in the Iskut River area and Scottie Gold deposit near Summit Lake north of Stewart. These veins also have a "transitional" or "mesothermal" character.

Epithermal deposits are of different types. The Josephine Au-Ag occurrence is a crustified quartz-adularia-sericite, low-sulphidation-type vein containing galena, sphalerite, pyrargyrite, electrum, and acanthite (Fig. 7). North of the Sulphurets area, the Treaty nunatak and North Treaty gossans are typical pyritic, advanced argillic high-sulphidation-type epithermal alteration zones (Fig. 1; Thompson and Lewis, 1992). However, to date only very minor gold, silver, arsenic, and antimony occurrences have been found in these alteration zones. Nearby, north of Atkins Glacier (Fig. 1) narrow epithermal quartz-carbonate veins and breccias of a low-sulphidation type with antimony, arsenic, silver, and minor gold cut Jack formation and Hazelton Group rocks. Advanced argillic alteration with no significant mineralization is also preserved at high levels in the porphyry system in the Mitchell Valley area (Margolis, 1993; Margolis and Britten, this volume). The volcanic-exhalative, epithermal Eskay Creek sulphide-sulphosalt deposit (Fig. 1; Britton et al., 1990), with a reserve of 1.1 million tonnes grading 65 g/t Au; 2950 g/t Ag; some Pb; 5.6% Zn and 0.77% Cu (Mining Journal, October 8, 1993, p. 243), commenced production in January 1995. It occurs at the top of the Mount Dilworth Formation rhyolite and base of the Salmon River Formation in dark carbonaceous, pyritic mudstone with marine fossils and is overlain by mafic pillow lava of the Salmon River Formation and turbiditic sedimentary rocks of the Bowser Lake Group. The Eskay Creek deposit was formed apparently in a submarine environment whereas the advanced argillic alteration zones, which also cut Mount Dilworth Formation rhyolite, in the Treaty Glacier area about 15 km to the east, evidently were formed in a subaerial to marginal marine environment as indicated above.

The age and environment of formation of the gold-silver quartz (± carbonate, barite, adularia) veins (Fig. 8) in the Brucejack Lake area have not been well constrained. These veins occur in pyritic, sericitic altered rocks near the base of the Hazelton Group (Kirkham, 1992; Davies et al., 1994). These precious-metal veins show evidence of brittle-ductile conditions of formation and some veins cut the schistosity in sericitic-pyritic altered host rocks, indicating synmineral deformation.

The Chibougamau gold-copper zone (Fig. 2) is a brittle-ductile chloritic-sericitic shear zone with high pyrite and chalcopyrite contents developed along a west-dipping reverse fault. Wallrocks in the immediate area are pyrite, sericite, and carbonate altered but have negligible gold and copper contents. The relative timing of deformation and sulphide emplacement has not been established but this occurrence has many similarities to the shear zone-hosted Cu-Au deposits in the Chapais-Chibougamau region of Quebec (Guha and Chown, 1984).

Alteration

Hydrothermal alteration is intense in the region. Figure 9 shows general alteration and metal distribution patterns. Potassic K-feldspar (biotite, magnetite, hematite) alteration associated with copper and gold is widespread in Stuhini Group rocks and Mitchell Intrusions in the western part of the altered area. Pyrite is the dominant sulphide with lesser amounts of chalcopyrite, tennantite, and minor amounts of molybdenite and other sulphides. Pyritic, propyliticallyaltered rocks surround the potassically-altered copper- and goldmineralized areas. Sericitic, pyritic alteration is widespread in the eastern part of the altered area and affects Hazelton Group and Jack formation (?) rocks as well as Stuhini Group rocks and the Mitchell Intrusions (Fig. 9a). Widely dispersed, sparse molybdenite and various types of precious and basemetal deposits occur in this altered area (Fig. 9b). On the west side of the Iron Cap area, siliceous, intensely altered rocks with fluorite locally contain significant concentrations of molybdenite (>0.3% Mo) with trace amounts of tungsten (Fig. 9b). This area has received only limited exploration.

Discussion and Conclusions

The Sulphurets area contains large Early Jurassic porphyry copper-gold (-molybdenum) and several types of precious-metal deposits. The area has been subjected to complex postmineral faulting and lower greenschist facies metamorphism in the late Mesozoic.

Exploration and geological studies of the deposits have been underway for decades and are still in progress. Despite the remote, harsh environment this intensely altered area continues to offer exploration targets and to yield new secrets.

Acknowledgments

This work was done over a long period of time and has involved several companies and many people who have provided support, information and ideas, and individuals who have helped with the work. Steve Roach and Ron Wells helped compile preliminary geological maps for the area. Jack and Mariette Henderson, Tom Wright, and John Payne helped with mapping and structural and stratigraphic studies. Don Harris and Bruce Ballantyne have been part of ongoing mineralogical and lithogeochemical studies, respectively. Jim Mortensen, Vicki McNicoll, and Richard Friedman have provided precise U-Pb zircon dates, which have been essential in unraveling the complex geological history of the area. The University of British Columbia Mineral Deposit Research Unit is thanked for U-Pb zircon dates and frank open discussions and sharing of data with Peter Lewis and other staff members. Of the many people who have contributed to this work, Hal Norman, Vic Preto, Lloyd Iverson, Erik Ostensoe, Ed Kruchkowski, Dane Bridge, Walter Melnyk, Bob Hewton, Brian Butterworth, John Kowalchuck, Glen Shevchenko, Norm Tribe, Ken Hicks, Tom Drown, Scott Casselman, Wes Raven, Alex Walus, Gerry McArthur, Jim Millar, Dani Alldrick, Jim Britton, Ron Wells, Bob Anderson, Don McLeod, Fred Hewitt, Barry Way, Dave Visagie, Mike Glatiotis, Barry McDonough, Brian Fowler, Ed Kimura, Ron Britten, and Andrew Kaip deserve special mention.

All companies working in the area have given full support, providing access to their properties, information, and logistical help. Geological Survey of Canada Industrial Partnership Program projects in 1992-93 with the Newhawk joint venture and Placer Dome Inc. permitted the first author to complete mapping in the area and facilitated preparation of five 1:5,000 scale preliminary geological maps, which will provide a foundation for other studies. Bev Vanlier kindly helped process the manuscript; Richard Lancaster and Kim Nguyen helped prepare the diagrams; and Peter Lewis, Dani Alldrick, Dave Sinclair, and Tom Schroeter have read the manuscript and made many constructive comments. This paper is Geological Survey of Canada contribution No. 65494.

REFERENCES

ALLDRICK, D.J., 1985. Stratigraphy and petrology of the Stewart mining camp (104B/1). *In* Geological Fieldwork 1984. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1985-1, p. 316-341.

ALLDRICK, D.J., 1993. Geology and metallogeny of the Stewart mining camp, northwestern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 85, 105 p.

ALLDRICK, D.J. and BRITTON, J.M., 1988. Geology and mineral deposits of the Sulphurets area (NTS 104A/5, 104A/12, 104B/8 and 104B/9). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File Map 19884.

ALLDRICK, D.J., BROWN, D.A., HARAKAL, J.E., MORTENSEN, J.K. and ARMSTRONG, R.L., 1987. Geochronology of the Stewart mining camp. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-1, p. 81-92.

ALLDRICK, D.J., BRITTON, J.M., WEBSTER, I.C.L. and RUSSELL, C.W.P., 1989. Geology and mineral deposits of the Unuk River area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File Map 1989-10.

ANDERSON, R.G., 1989. A stratigraphic, plutonic, and structural framework for the Iskut River map area, northwestern British Columbia. *In* Current Research, Part E. Geological Survey of Canada, Paper 89-1E, p. 145-154.

ANDERSON, R.G. and THORKELSON, D.J., 1990. Mesozoic stratigraphy and setting for some mineral deposits in Iskut River map area, northwestern British Columbia. *In* Current Research, Part E. Geological Survey of Canada, Paper 90-1E, p. 131-139.

BRIDGE, D.J., 1993. The deformed Early Jurassic Kerr copper-gold porphyry deposit, Sulphurets gold camp, northwestern British Columbia. Unpublished M.Sc. thesis. The University of British Columbia, Vancouver, British Columbia, 303 p.

BRITTON, J.M., 1991. Stratigraphic notes from the Iskut-Sulphurets Project area (104B). *In* Geological Fieldwork 1990. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1991-1, p. 131-137.

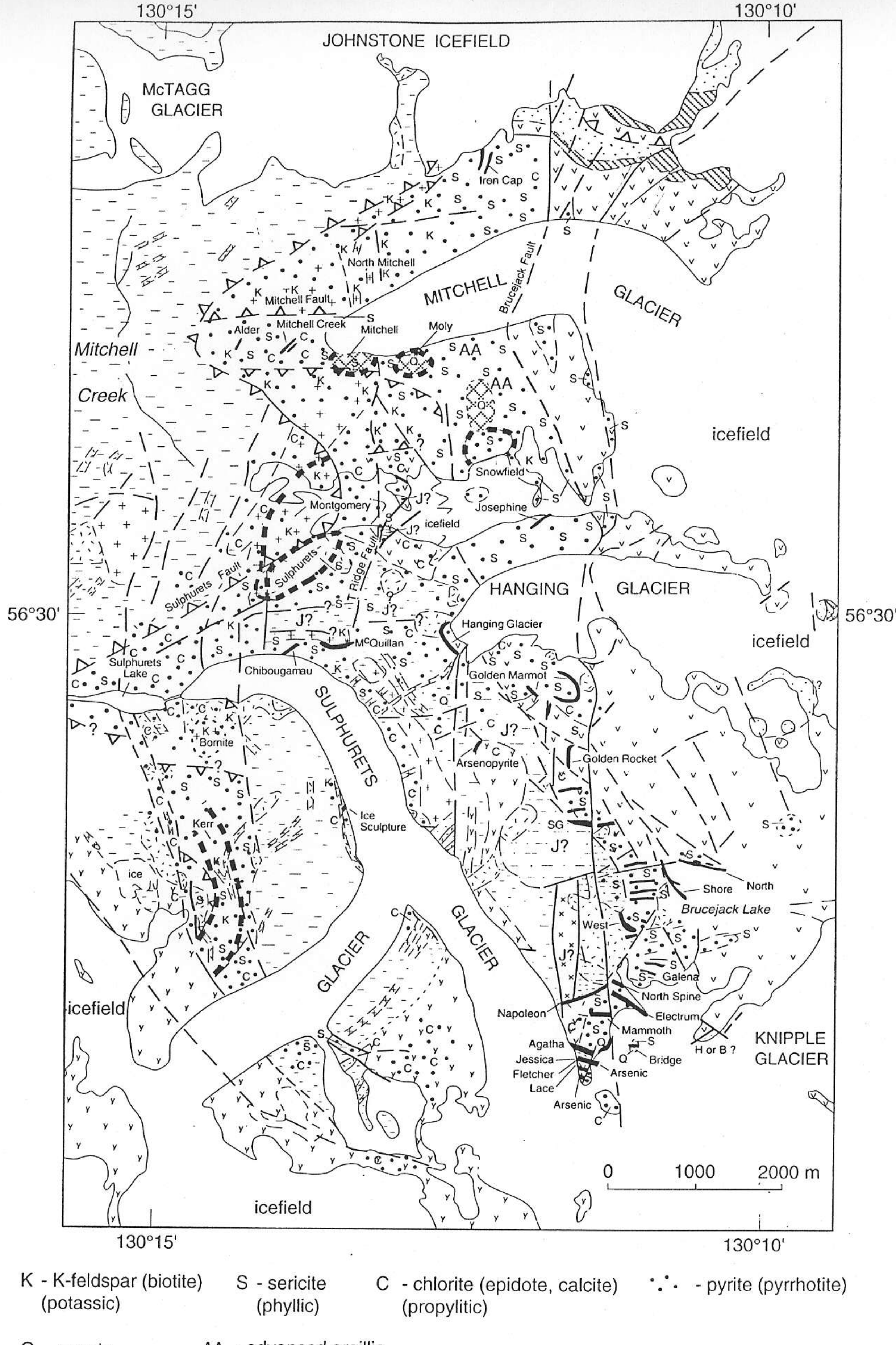
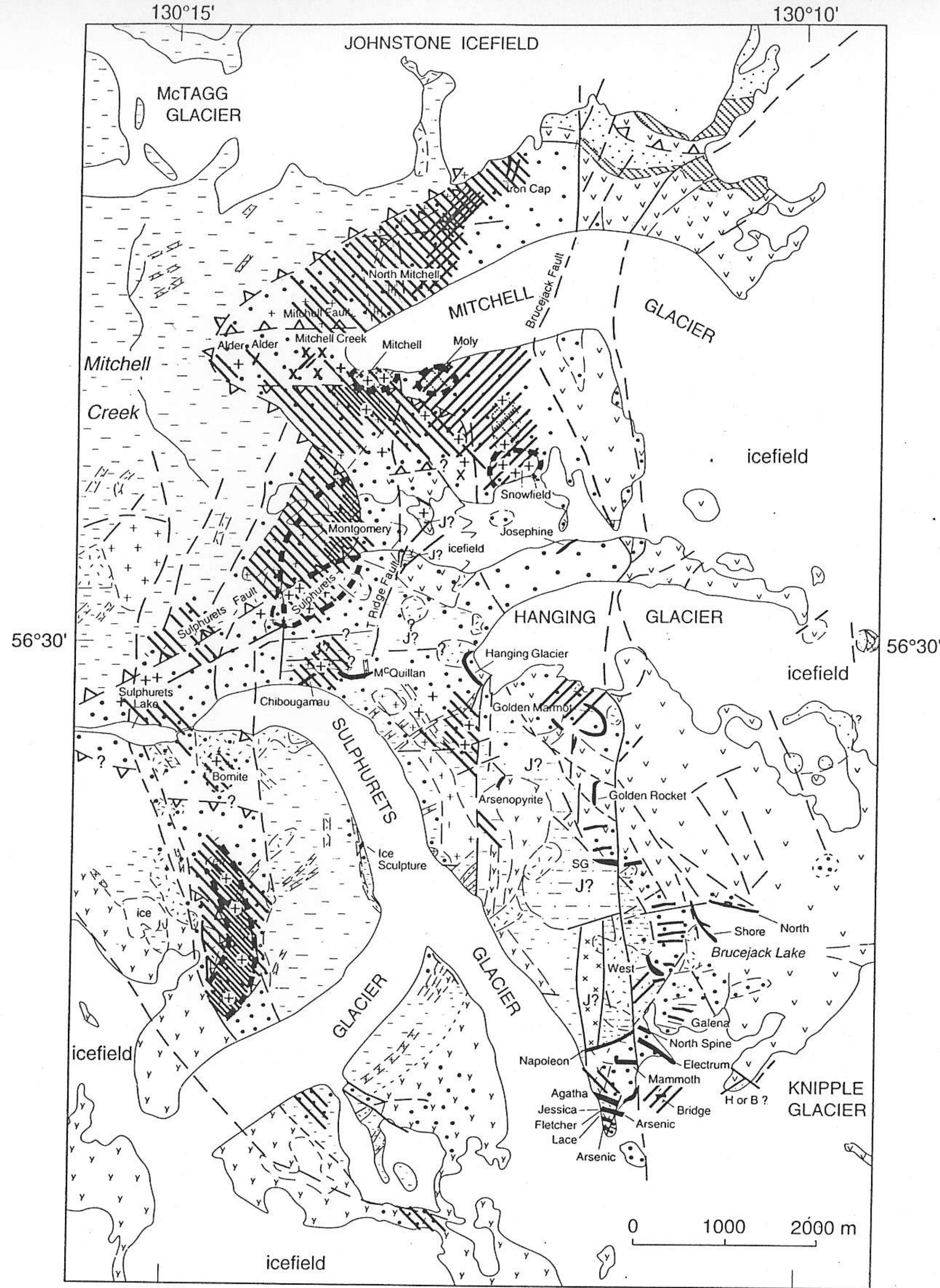


FIGURE 9a. Map showing the generalized distribution of alteration and pyrite (pyrrhotite).



- copper; - molybdenum; - weak, intense

- gold and - silver (disseminated, stockwork)

-approximate limit of mineral zone; - Au,Ag(vein, stockwork)

FIGURE 9b. Metal zones.

BRITTON, J.M. and ALLDRICK, D.J., 1988. Sulphurets map area. *In* Geological Fieldwork 1987. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1988-1, p. 199-209.

BRITTON, J.M., BLACKWELL, J.D. and SCHROETER, T.G., 1990. Eskay Creek. *In* Exploration in British Columbia 1989. British Columbia Ministry of Energy, Mines and Petroleum Resources, p. 197-223.

BROWN, D.A., LOGAN, J.M., GUNNING, M.H., ORCHARD, M.J. and BAMBER, W.E., 1991. Stratigraphic evolution of the Paleozoic Stikine assemblage in the Stikine and Iskut rivers area, northwestern British Columbia. Canadian Journal of Earth Sciences, 28, p. 958-972.

CORDEY, F., MORTIMER, N., DEWEVER, P. and MONGER, J.W.H., 1987. Significance of Jurassic radiolarians from the Cache Creek terrane, British Columbia. Geology, 15, p. 1151-1154.

CRAWFORD, M.L., HOLLISTER, L.S. and WOODSWORTH, G.J., 1987. Crustal deformation and regional metamorphism across a terrane boundary, Coast Plutonic Complex, British Columbia. Tectonics, 6, p. 343-361.

DAVIES, A., MACDONALD, A.J. and LEWIS, P.D., 1994. Stratigraphic and structural setting of mineral deposits in the Brucejack Lake area, northwestern British Columbia. *In* Current Research 1994-A, Geological Survey of Canada, p. 37-43.

DITSON, G.M., WELLS, R.C. and BRIDGE, D.J., 1995. Kerr: The geology and evolution of a deformed porphyry copper-gold deposit, northwestern British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

EVANS, B.W. and GUGGENHEIM, S., 1988. Talc, pyrophyllite, and related minerals. *In* Hydrous Phyllosilicates. *Edited by* S.W. Bailey. Reviews in Mineralogy Volume 19, Mineralogical Society of America, p. 225-294.

EVENCHICK, C.A., 1991. Geometry, evolution, and tectonic framework of the Skeena Fold Belt, north central British Columbia. Tectonics, 10, p. 527-546.

FOWLER, B.P. and WELLS, R.C., 1995. The Sulphurets Gold zone, northwestern British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum Special Volume 46.

GREIG, C.J., 1992. Fieldwork in the Oweegee and Snowslide ranges and Kinskuch Lake area, northwestern British Columbia. *In* Current Research, Part A. Geological Survey of Canada, Paper 92-1A, p. 145-155.

GROVE, E.W., 1986. Geology and mineral deposits of the Unuk River-Salmon River-Anyox area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 63, 434 p.

GUHA, J. and CHOWN, E.H. (Editors), 1984. Chibougamau — Stratigraphy and Mineralization. Canadian Institute of Mining and Metallurgy, Special Volume 34, 534 p.

HEMLEY, J.J., MONTOYA, J.W., MARINENKO, J.W. and LUCE, R.W., 1980. Equilibria in the system $Al_2O_3SiO_2$-H_2O and some general implications for alteration/mineralization processes. Economic Geology, 75, p. 210-228.

HENDERSON, J.R., KIRKHAM, R.V., HENDERSON, M.N., PAYNE, J.G., WRIGHT, W.O. and WRIGHT, R.L., 1992. Stratigraphy and structure of the Sulphurets area, British Columbia. *In* Current Research, Part A. Geological Survey of Canada, Paper 92-1A, p.323-332.

HODGSON, C.J., 1989. The structure of shear-related, vein-type gold deposits: A review. Ore Geology Reviews, 4, p. 231-273.

KIRKHAM, R.V., 1963. The geology and mineral deposits in the vicinity of the Mitchell and Sulphurets glaciers, northwestern British Columbia. Unpublished M.Sc. thesis. The University of British Columbia, Vancouver, British Columbia, 122 p.

KIRKHAM, R.V., 1991. Provisional geology of the Mitchell-Sulphurets region, northwestern British Columbia (104B/8,9). Geological Survey of Canada, Open File 2416 (1:20,000).

KIRKHAM, R.V., 1992. Preliminary geological map of the Brucejack Creek area, British Columbia (part of 104B/8). Geological Survey of Canada, Open File 2550 (1:5,000).

LEWIS, P.D., 1992. Structural geology of the Prout plateau, Iskut River map area, British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1992-1, p. 521-527.

LEWIS, P.D., THOMPSON, J.F.H., NADARAJU, G., ANDERSON, R.G. and JOHANNSON, G.G., 1993. Lower and Middle Jurassic stratigraphy in the Treaty Glacier area and geological setting of the Treaty alteration system, northwestern British Columbia. *In* Current Research, Part A. Geological Survey of Canada, Paper 93-1A, p. 75-86.

MACDONALD, A.J., 1993. Lithostratigraphy and geochronometry, Brucejack Lake, northwestern British Columbia (104B/8E). *In* Geological Fieldwork 1992. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1993-1, p. 315-323.

MANDY, J.T., 1936. Unuk River area. *In* British Columbia Department of Mines Annual Report, 1935, p. B7-12.

MARGOLIS, J., 1993. Geology and intrusion-related copper-gold mineralization, Sulphurets, British Columbia. Unpublished Ph.D. dissertation. The University of Oregon, Eugene, Oregon, 289 p.

MARGOLIS, J. and BRITTEN, R.M., 1995. Porphyry-style and epithermal copper-molybdenum-gold-silver mineralization in the northern and southeastern Sulphurets district, northwestern British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

MONGER, J.W.H., PRICE, R.A. and TEMPELMAN-KLUIT, D.J., 1982. Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera. Geology, 10, p. 70-75.

PANTELEYEV, A., 1991. Gold in the Canadian Cordillera — A focus on the epithermal and deeper environments. *In* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, p. 163-212.

RAMSEY, I.G. and HUBER, M.I., 1983. The Techniques of Modern Structural Geology, Volume 1: Strain Analysis. Academic Press, 307 p.

RHYS, D.A., SIEB, M., FROSTAD, S.R., SWANSON, C.L., PREFONTAINE, M.A., MORTENSEN, J.K. and SMIT, H.Q., 1995. Geology and setting of the Red Mountain gold-silver deposits, northwestern British Columbia. *In* Porphyry Deposits of the Northwestern Cordillera of North America. *Edited by* T.G. Schroeter. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46.

RICKETTS, B.D., EVENCHICK, C.A., ANDERSON, R.G. and MURPHY, D.C., 1992. Bowser Basin, northern British Columbia: Constraints on the timing of initial subsidence and Stikinia North America terrane interactions. Geology, 20, p. 1119-1122.

ROACH, S. and MACDONALD, A.J., 1992. Silver-gold vein mineralization, West Zone, Brucejack Lake, northwestern British Columbia. *In* Geological Fieldwork 1991. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1992-1, p. 503-511.

RUSMORE, M.E., POTTER, C.J. and UMHOEFER, P.J., 1988. Middle Jurassic terrane accretion along the western edge of the Intermontane superterrane, southwestern British Columbia. Geology, 16, p. 891-894.

SAMSON, S.D., McCLELLAND, W.C., PATCHETT, P.J., GEHRELS, G.E. and ANDERSON, R.G., 1989. Evidence from neodymium isotopes for mantle contributions to Phanerozoic crustal genesis in the Canadian Cordillera. Nature, 337, p. 705-709.

SIMPSON, T.M., 1983. The geology and hydrothermal alteration of the Sulphurets deposits, northwest British Columbia. Unpublished M.Sc. thesis. University of Idaho, Moscow, Idaho, 95 p.

THOMPSON, J.F.H. and LEWIS, P.D., 1992. Advanced argillic alteration at Treaty Glacier, northwestern British Columbia (104B/9). *In* Geological Fieldwork 1991. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1992-1, p. 543-547.

YARDLEY, B.W.D., 1989. An Introduction to Metamorphic Petrology. Longman Earth Science Series, John Wiley and Sons, 248 p.