Quartz vein gold mineralization in the Klondike Schist: The Mitchell-Sheba system, central Klondike district, Yukon

Tim Liverton[1]
Consultant

William Mann[2]
Klondike Star Mineral Corporation

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ABSTRACT

The Mitchell-Sheba occurrence is a gold, silver and base metal-bearing quartz vein system contained within a thrust slice of mafic schist that forms part of the Klondike Schist. The vein system formed late in the D4 folding event or subsequently thereafter. Mineralization occurs as gold + silver, base metal sulphides and sulphosalts within quartz veins. Low-grade gold associated with pyrite mineralization is hosted within the surrounding chlorite schist. The mafic rocks are interpreted to be metavolcanic in origin and have reached upper greenschist facies metamorphism. Hydrothermal sericite-carbonate alteration of the host rocks is associated with mineralization and is reflected in the whole rock geochemistry. The prospect underlies one of the larger soil geochemical anomalies in the Klondike region.

[1]*timliv@northwestel.net*
[2]*mann@klondikestar.ca*

INTRODUCTION

This paper describes the geological setting of one of the most significant gold-silver bedrock occurrences in the Klondike goldfields, the Mitchell-Sheba vein system. The structural setting, lithology and lithogeochemistry of this system are described in this paper. Mafic metavolcanic rocks that are interpreted to have reached upper greenschist facies metamorphism host the gold-silver mineralization, which occurs in the hanging wall of a regional thrust fault that locally contains slivers of ultramafic rock. The authors explored the property in the period between 2006 and 2008 for Klondike Star Mineral Corp. (Liverton, 2007) whom held the property under option.

In the two decades following the discovery of placer gold in Bonanza Creek in 1896, drainages radiating from King Solomon Dome were thoroughly prospected. Many prospectors sought a bedrock source for the gold, and one of their early finds was a gold-bearing quartz vein system about 1200 m north-northeast of the King Solomon Dome summit. The Mitchell and Sheba veins are rumoured to have initially yielded spectacular surface samples; occurrences on these veins, the KSD, J.A.E. and others (Yukon MINFILE 115O 068), have been intermittently trenched and bulk-sampled since their discovery. The Mitchell-Sheba veins are one of two Klondike area prospects where significant gold has been extracted from bedrock and therefore are likely an important source of placer gold.

REGIONAL GEOLOGY AND STRUCTURE

The Mitchell, Sheba and Orekon prospects (herein the study area) are 30 km southeast of Dawson City. The regional bedrock unit is the Klondike Schist, a widespread Middle to Late Permian unit of the Yukon-Tanana terrane. The greenschist facies siliciclastic metasedimentary and bimodal metavolcanic rocks form a thrust stack (Mortensen, 1990, 1996; Mackenzie *et al.*, 2007; Mackenzie *et al.*, 2008a). These rocks and the coeval Sulphur Creek orthogneiss, located 15 km to the southwest, are remnants of a short-lived arc overlying the north and west-dipping subduction of the Slide Mountain Ocean (269 to 253 Ma Klondike cycle of Nelson *et al.*, 2006), which represents the last magmatic cycle of Yukon-Tanana terrane before its accretion to the margin of Laurentia.

Less than 1 km east of the study area (Fig. 1), a road-cut exposes a thrust slice of Klondike Schist overlying altered ultramafic rocks interpreted as a sliver of Slide Mountain terrane (Mortensen, 1996). The rocks within the study area are structurally near the base of the hanging wall. The dominant lithology is chloritic schist (here referred to as the mafic schist unit), one of the three broad lithologic groupings of the Klondike Schist (Mortensen, 1990, 1996).

The structural geology of the Klondike district as described by MacKenzie *et al.* (2007) hosts four generations of deformation. D_1 isoclinal folding (S_1) transposes original bedding (S_0) such that hinges of this generation appear as intrafolial cm-scale folds. The second ductile deformation event produced isoclinal recumbent folds (Fig. 2a) and pervasive penetrative foliation (S_2). Hinges of these folds have decimetre-scale wavelength and are locally apparent within the Klondike Schist and are particularly well developed at the Orekon prospect (Fig. 1). Ductile folding (D_3) during thrust stacking produced recumbent folds with a spaced cleavage (S_3) that are well developed in the muscovite-rich schist (Fig. 2b). A phacoidal cleavage is exhibited in some thrust fault zones.

Folding of D_4 generation is of mesoscopic-scale kink or box-fold style that has axial trends from ten to eighty degrees different to those of F_3 axes. D_3 folding occurred in a ductile regime whereas D_4 folding formed near the brittle-ductile transition. Quartz veins were formed locally during D_2 to late D_4. Only the undeformed late D_4 mesothermal quartz veins contain obvious gold mineralization. Younger brittle faults with gouge zones are exposed in several trenches throughout the Klondike. The Klondike region has not been glaciated, and outcrops in the study area are variably oxidized.

MAFIC SCHIST UNIT

LITHOLOGY

Outcrops in the study area vary from quartz-feldspar-muscovite ± chlorite in the eastern slopes, to chlorite-quartz-feldspar-epidote-actinolite ± biotite (Fig. 3a) at the ridge crest along the Mitchell-Sheba trend. The most mafic schist, containing quartz, feldspar, chlorite, epidote and actinolite, is consistent with derivation from a basic volcanic protolith. Analyses of major oxide contents and trace elements (Table 1) are consistent with basaltic protoliths. The muscovite schist is interpreted to have been derived from clay-rich siliciclastic metasediments which contained a volcanic component. The chlorite schists are likely metavolcanic flows with possible sub-volcanic intrusions.

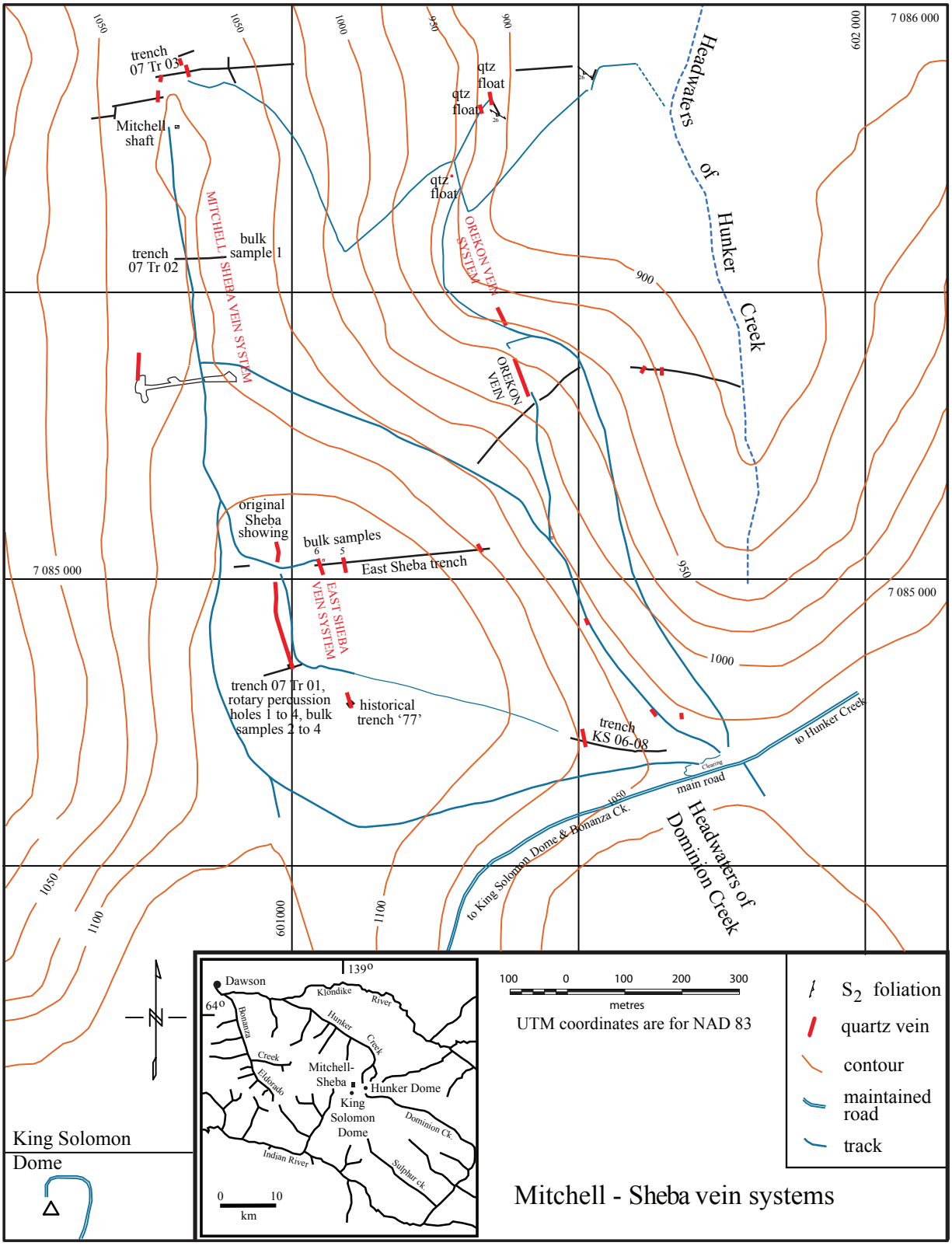

Figure 1. *Quartz vein systems at the JAE property.*

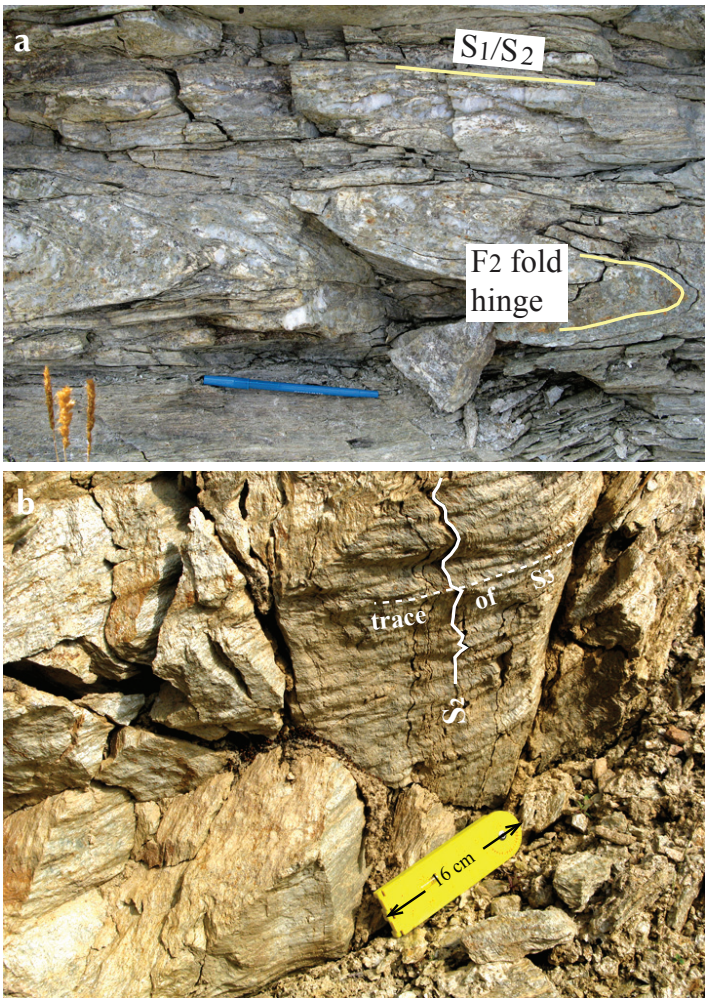

Figure 2. (a) *Recumbent F_2 folds at the Orekon prospect. Pen is 16 cm long.* ***(b)*** *F_3 crenulation folding; trench is 185 m northeast of the Mitchell shaft.*

PETROGRAPHY

The mafic schists comprise quartz, feldspar, chlorite, epidote, plus bluish actinolite in some lithologies (Figs. 3a,b), notably along the crest of the Mitchell ridge. A strong metamorphic foliation (S_2) was observed and where euhedral amphiboles are present, they are aligned within this fabric. The amphibole crystals are interpreted to be metamorphic in origin rather than porphyroblasts derived from original phenocrysts. Biotite occurs infrequently within the mafic schist unit that comprises the thrust sheet present at the JAE property.

In the most 'mafic' schist the S_2 foliation, defined by preferred orientation of biotite and chlorite, curves around spherical masses of epidote that are interpreted to be retrogressed garnet (Fig. 3c). This indicates that the rocks reached upper greenschist facies metamorphism. Relatively coarse plagioclase porphyroblasts with myrmekitic rims (Fig. 3d) are interpreted to be relict phenocrysts.

DISCUSSION

It is uncertain whether the emplacement of the Klondike's largest late-tectonic quartz vein system was due to the mafic schist behaving in a more brittle manner compared to the more incompetent quartz-rich muscovite schist. It is plausible that during the late to post-D_4 deformation (*i.e.*, in a brittle regime) the basic rocks had accommodated extension and possibly strike-slip movement which resulted in the formation of a major vein system. Another possibility is that the Sheba vein system has followed the axial plane of a major F_4 fold whereby one wavelength is in the order of hundreds of metres. The lack of rock exposure to the west of the ridge does not allow for adequate determination of fabric elements that could establish or refute these interpretations.

Table 1*. Major oxide and trace element analyses.*

Sample number	Metres from west end	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	MgO %	Na2O %	K2O %	Cr2O3 %	TiO2 %	MnO %	P2O5 %	SrO %	BaO %	C %	S %	LOI %	Total %	Ba ppm	Ce ppm	Co ppm	Cs ppm	Dy ppm	Er ppm	Eu ppm
B26	35.1	51.37	17.99	10.50	1.99	6.18	5.38	0.34	0.005	0.82	0.1	0.11			0.42	0.04	5.20	100.02	124.4	16.2	32.0	0.2	3.48	2.11	0.81
B28	30.0	48.56	18.76	12.04	1.83	6.03	4.07	1.86	0.006	0.98	0.11	0.14			0.40	0.26	5.40	99.88	549.2	18.6	42.2	1.4	3.71	2.37	1.03
C35	38.6	51.00	19.85	9.63	1.73	4.81	6.08	1.15	<0.01	0.72	0.11	<0.01	0.01	0.02	0.28	0.01	4.31	99.40	202.0	8.8	32.9	1.4	2.29	1.41	0.74
B18	45.5	48.36	17.64	8.90	5.08	5.02	1.72	3.83	0.005	0.84	0.14	0.05			1.22	0.21	8.30	100.02	892.9	16.1	18.7	1.4	3.43	2.17	0.84
B11	48.3	40.52	18.22	10.97	7.43	6.00	0.63	4.54	0.007	0.92	0.16	0.12			1.73	0.30	10.30	100.03	1401.4	16.2	36.1	2.9	3.21	2.01	0.66

		Ga ppm	Gd ppm	Hf ppm	Ho ppm	La ppm	Lu ppm	Nb ppm	Nd ppm	Ni ppm	Pr ppm	Rb ppm	Sm ppm	Sr ppm	Ta ppm	Tb ppm	Th ppm	Tm ppm	U ppm	V ppm	W ppm	Y ppm	Yb ppm	Zr ppm
B26		18.4	2.98	1.8	0.68	6.5	0.29	1.6	11.1	31	2.22	10.1	2.7	48.9	0.1	0.60	1.30	0.30	0.60	275	6.5	20.70	1.87	58
B28		23.1	3.30	2.5	0.75	7.1	0.34	1.9	11.8	26	2.51	68.9	3.0	67.3	0.1	0.66	1.80	0.34	0.90	401	10.3	22.60	2.20	75
C35		16.1	2.01	1.7	0.46	3.6	0.23	1.2	6.1	21	1.31	38.9	1.7	75.0	0.1	0.37	1.17	0.24	0.41	218	16.0	12.00	1.37	59
B18		17.2	2.95	2.1	0.71	6.0	0.30	1.5	10.5	21	2.18	102.0	2.7	239.7	0.1	0.57	1.20	0.28	0.50	274	9.4	20.10	1.92	61
B11		21.1	2.92	2.1	0.66	6.0	0.29	1.6	10.6	28	2.24	114.9	2.7	358.4	0.1	0.55	1.50	0.29	0.60	335	13.4	19.30	1.91	66

Analyses were obtained by Li metaborate fusion/ICPMS for major elements, with fusion/ICPMS for traces. 'B' prefix specimens were analysed by Eco Tech laboratory and 'C' by ALS Chemex

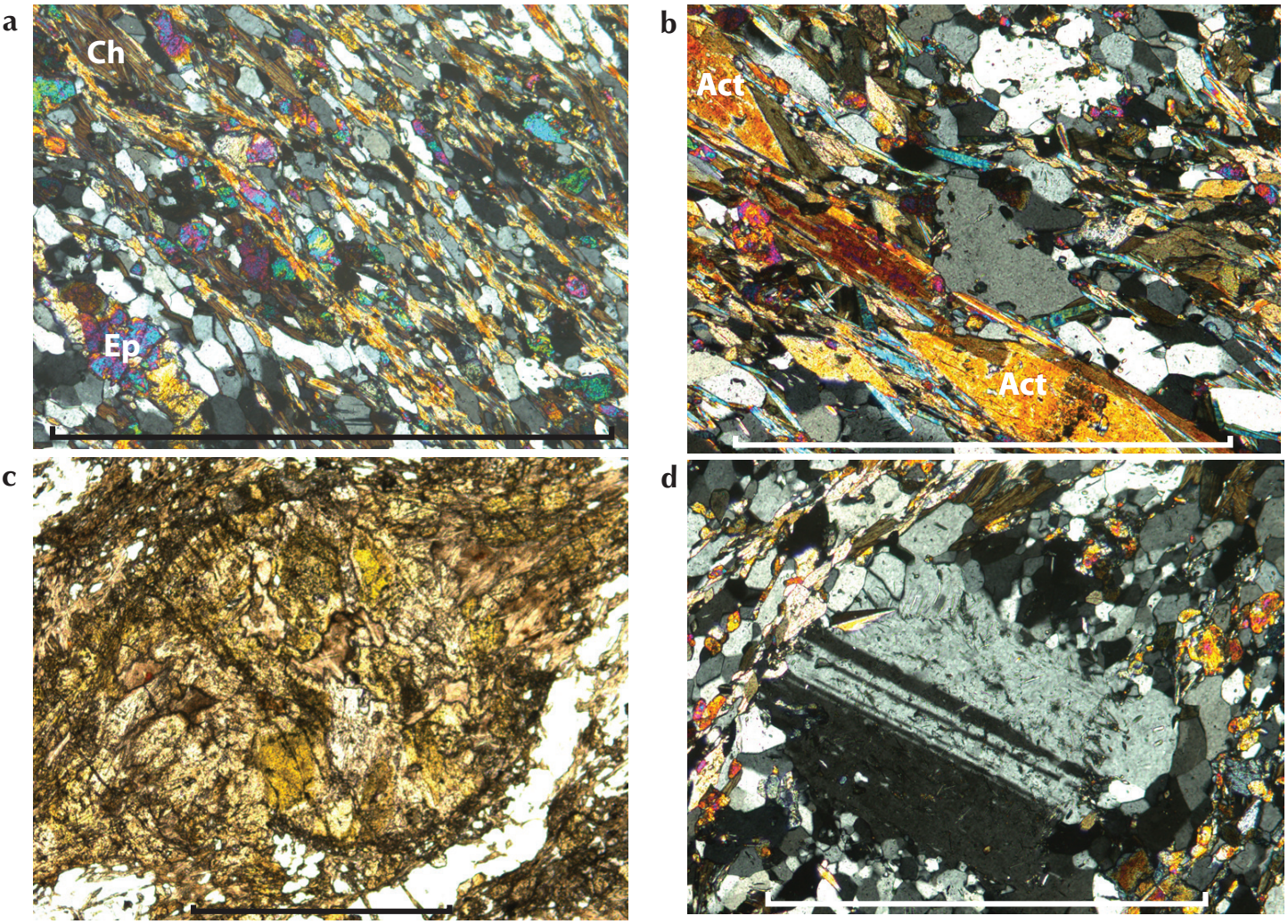

Figure 3. ***(a)*** *Epidote-chlorite-quartz-feldspar schist. Trench 07Tr03 at the Mitchell prospect, 47.7 m from west end of trench. Thin section under crossed polarizers. Epidote (Ep) and chlorite (Ch, dark and showing cleavage in the monochrome image) define the S2 foliation.* ***(b)*** *Euhedral actinolite (Act) in quartz-feldspar-epidote-chlorite-amphibole schist. Trench 07Tr03 35.1m from west end of trench. Thin section under crossed polarizers. Presence of actinolite amphibole which is blue under plane polarized light in this lithology is likely a reflection of protolith chemistry rather than an indicator of high pressure metamorphism.* ***(c)*** *Spherical mass of epidote (pseudomorph after garnet?) in carbonate-altered, epidote-chlorite quartz feldspar schist. The various thrust sheets of the Klondike Schist show some evidence of variation in metamorphic grade. Trench 07Tr03 at the Mitchell prospect, 46.7 m from west end of trench. Thin section under plane polarized light.* ***(d)*** *Plagioclase porphyroblast in quartz-feldspar-epidote-chlorite-amphibole schist. This is interpreted to be a remnant phenocryst in a basalt protolith. Same specimen as (3c). Thin section under crossed polarizers. Scale-bar on these images represents 1 mm.*

QUARTZ VEIN SYSTEMS

The Mitchell-Sheba system is a kilometre-long zone of anastomosing and stockwork veins that coalesce into massive 2 m-thick veins over tens of metres strike length at the Mitchell and Sheba prospects. The East Sheba and Orekon veins are parallel structures located 80 and 500 m to the east, respectively (Fig. 1). Orientation of these veins is consistent with their formation late in the D_4 ductile to brittle folding parallel to the northwesterly axial planes of this fold generation (Mackenzie *et al.*, 2008b). In the South Sheba area several examples of centimetre-scale quartz veins following axial planes of mesoscopic-scale F_4 kink folds may be observed. One such example from Trench 07Tr01 is shown in Figure 4. Also note various S_4 orientations and similarity to vein attitudes shown in Figure 5.

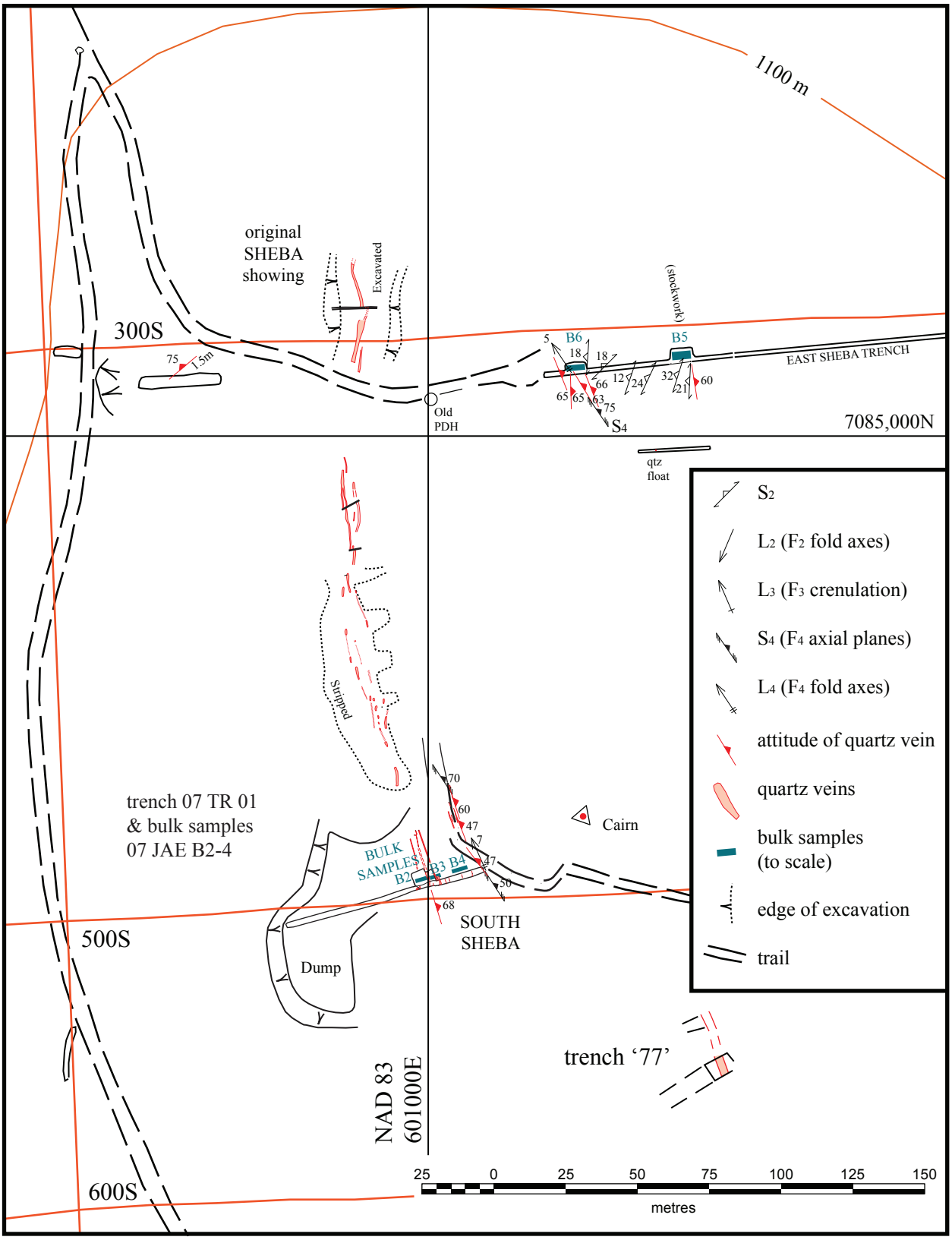

Figure 4. *Detailed map of the Sheba prospect.*

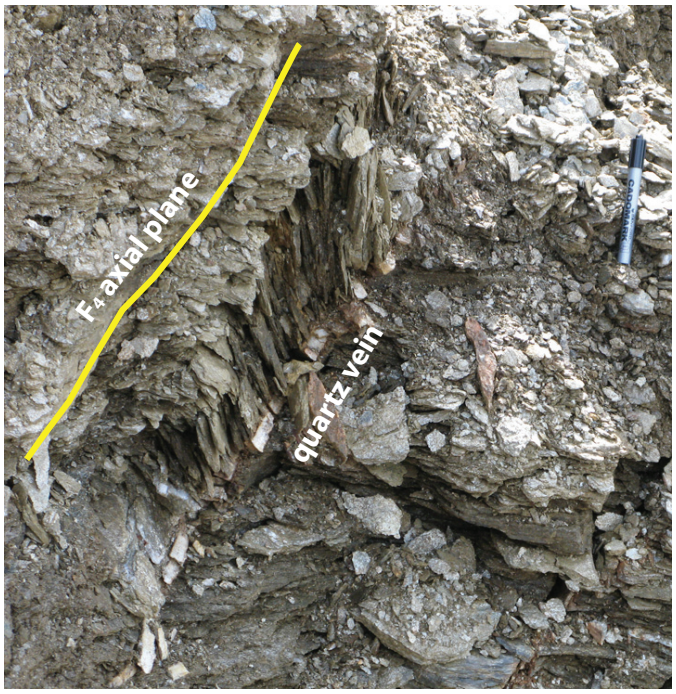

Figure 5. *Example of a quartz vein following the orientation of F_4 axial surfaces. East end of trench 07Tr01. Several examples of quartz veins following the orientation of S_4 may be seen in the South Sheba area. Marker pen is 13 cm long.*

In addition to the obvious north-northwest-striking, near vertical structures that form the Mitchell-Sheba, East Sheba and Orekon veins, a set of flat-lying, northwest-dipping, intersecting veins have also been observed adjacent (33 m south) to the Mitchell shaft and at the stockwork system in the East Sheba trench. Although these veins are <10 cm thick, they are economically significant because they contain free gold.

The largest vein in the East Sheba stockwork has a 20 cm-wide gouge zone along its western margin indicating late movement under a brittle faulting regime. Fault movement with gouge zones along vein margins is also observed at the Orekon vein and un-named veins to the east of the Mitchell prospect.

The Dome Lode vein occurrence (Yukon MINFILE 115O 067), located about 2 km south-southeast of the Mitchell-Sheba system, occurs in a similar geological setting.

MINERALIZATION WITHIN THE VEIN SYSTEMS

The historical Mitchell and Sheba prospects produced small tonnages of spectacular Au and Ag grades from 'pods' of massive sulphides that were <15 m in strike length. A small tonnage of hand-sorted high-grade ore was shipped from the Mitchell shaft (Yukon MINFILE 115O 068) and Sheba prospect (Hulstein, 1988). Detailed mapping of the Sheba prospect (Fig. 4 - north end) indicates that the 'pod' of high-grade galena-chalcopyrite-tetrahedrite mineralization occurred at a bend in the massive part of the vein system. This could indicate that minor strike-slip motion (a releasing bend) produced an extensional environment that allowed for formation of the more massive portion of the vein system.

In the East Sheba trench, two mineralized vein systems are exposed. Four decimetre-scale quartz veins are found at the west end of the trench and a stockwork zone 5.5 m wide is formed by steep east-dipping veins parallel to the Sheba vein, with shallow west-dipping cm-scale veins. The separate vein system at the west end of the trench contains ≤1 mm grains and crystals of pyrite, arsenopyrite, galena, chalcopyrite and tetrahedrite. Selvedges to these veins contain pyrite crystals that penetrate up to 10 cm into the muscovite schist wallrock. The stockwork zone veins extend 42 to 50 m from the west end of the East Sheba trench and are formed in comparatively massive mafic schist. Carbonate alteration is obvious in hand specimen, and occurs 2 m on either side of the zone, with petrographic specimens indicating up to 20% modal carbonate for a further 2 m on the eastern side. Within the stockwork, the metamorphic fabric (S_2) of the country rock has been completely obliterated by randomly oriented sericite and brown carbonate alteration. Both pyrite (up to 20 mm across) and finer grained arsenopyrite are common (Figs. 6a,b). In comparison, the relatively unaltered chlorite schist and muscovite schist elsewhere in the East Sheba trench show a strong foliation (Figs. 6c,d). Assays of the selvedge rock (single hand specimens selected for petrography) reported from trace amounts to 12.2 g/t gold.

Gold grade of the schist between individual quartz veins (selvedges) appears highly variable. Analyses of the petrographic specimens from the East Sheba stockwork zone indicate grades from 0.03 to 12 g/t Au for samples that contain no quartz vein material. At the South Sheba zone, Trench 07Tr01, chip samples were taken across the zone that contains four major and fifteen minor east-dipping quartz veins. The intervening schist assayed up to 0.11 g/t. Additional subparallel veins, with thicknesses ranging from a few cm to 1.5 m, are exposed in road cuts and trenches in the study area, but have unknown extents. Gold on the property is often coarse, as it is elsewhere in the Klondike, creating a 'nugget effect' making gold resource evaluation challenging. A program

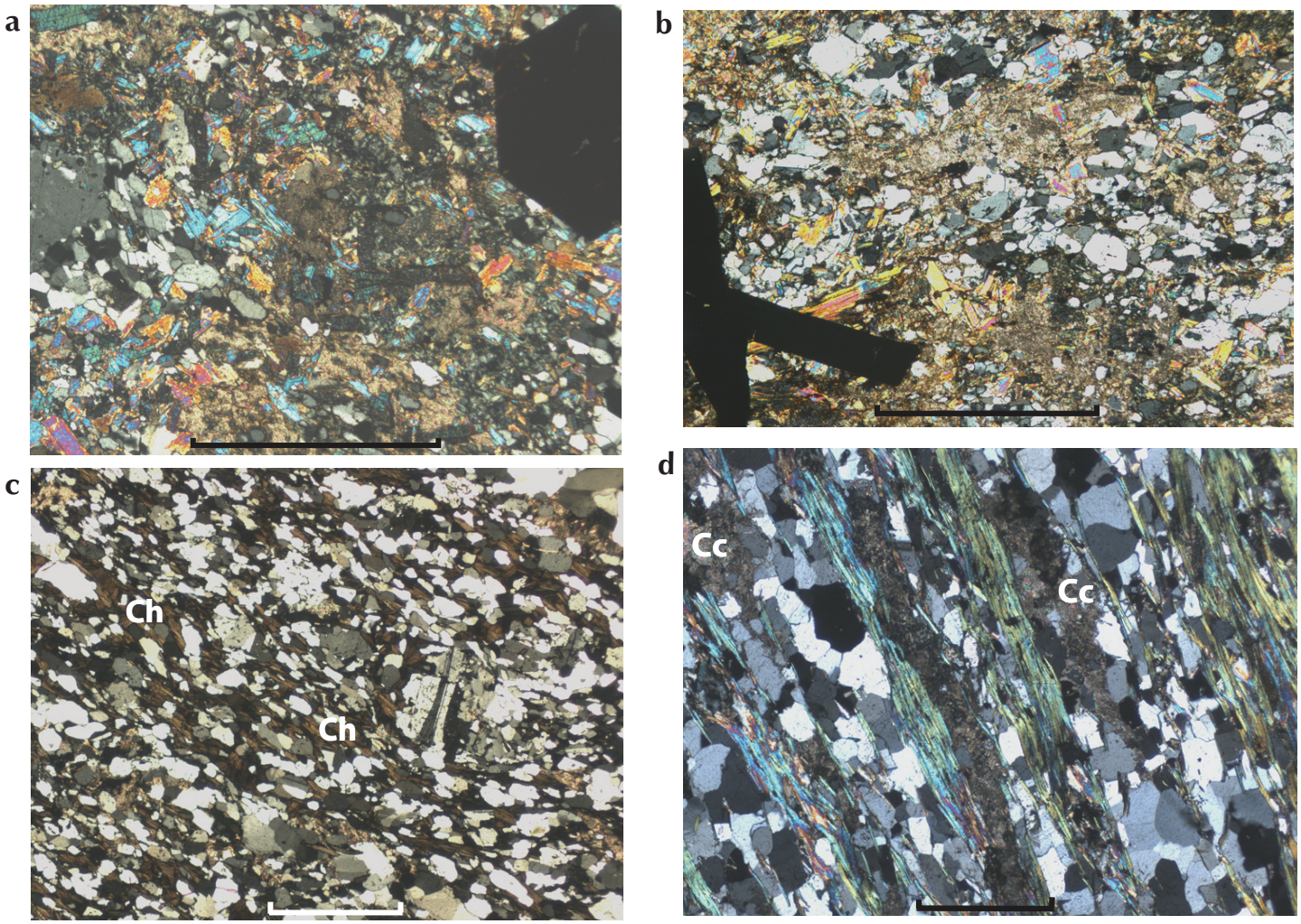

Figure 6. (a) *Pyrite crystal in heavily carbonate-sericite altered schist. East Sheba trench, 47.7 m from west end. Thin section under crossed polarizers. Note that the muscovite 'flakes' are coarse-grained and randomly oriented rather than defining a S2 foliation as in unaltered schist – they are interpreted to be sericite alteration.* ***(b)*** *Arsenopyrite crystals in heavily carbonate altered schist. East Sheba trench, 39.0 m from west end. Thin section under crossed polarizers. As in (a) the metamorphic foliation has been destroyed.* ***(c)*** *Unaltered chlorite-quartz-feldspar schist. The S2 foliation is produced by preferred orientation of chlorite (Ch, dark, showing cleavage in the monochrome image). East Sheba trench, 28.0 m from west end. One plagioclase porphyroblast may be seen. Thin section under crossed polarizers.* ***(d)*** *Muscovite-quartz-feldspar schist with slight carbonate alteration. East Sheba trench, 25.1 m from west end. Thin section under crossed polarizers. A distinct S2 foliation is produced by the mica layers. Cc = carbonate. The scale-bar in these images is 1 mm.*

Table 2. *Results from bulk sampling.*

Sample no.	Zone	UTM (NAD 83) Easting	UTM Northing	Weight kg	Au g/t	Rock type
06-JAE-B1	Hunker Dome Trench	601510	7084727	2276	3.99	quartz vein in rusty schist
06-JAE-B2	Mitchell	600790	7085815	5729	1.30	pyritic schist, no veins
07-JAE-B1	Speed Bump (Meneluk)	600852	7085574	4211	0.26	quartz vein with galena
07-JAE-B2	South Sheba	600999	7084844	6103	0.27	quartz veins and rusty schist
07-JAE-B3	South Sheba	601004	7084844	5862	0.09	quartz veins and rusty schist
07-JAE-B4	South Sheba	601013	7084847	2095	0.10	quartz veins and rusty schist
07-JAE-B5	Sheba East	601090	7085028	7249	0.73	quartz veins and rusty schist
07-JAE-B6	Sheba East	601050	7085024	6088	0.50	quartz veins and rusty schist

of bulk sampling, with gravity concentration and analysis of products, was undertaken to accurately assess gold grade and size distribution. The bulk sampling results are summarized in Table 2.

Elsewhere on the property, other ≤1 m-thick veins (*e.g.*, Orekon and the veins dubbed 'trench 77' in Figure 1; possibly the southern extension of the east Sheba system) have quartz with massive galena cores. This Pb precipitation is interpreted as the last mineralizing event in the vein system.

GEOCHEMISTRY

GEOCHEMISTRY OF THE MAFIC HOST ROCK

The composition of the chlorite schists was determined by analysis of slightly altered to unaltered schist from the East Sheba trench. Five of these analyses are presented in Table 1. These rocks are believed to have a basaltic protolith and therefore, the results are plotted on trace element discrimination diagrams (Fig. 7) to determine the paleotectonic setting. The chlorite schist analyses plot in the field for island arc tholeiites or volcanic arc basalts on the diagrams.

GEOCHEMISTRY OF THE VEIN WALLROCK AND ALTERATION

Analyses of chip samples from the East Sheba trench indicate that gold values correlate strongly with arsenic (Fig. 8), which is consistent with the observation of arsenopyrite or tetrahedrite-tennantite within the quartz veins and within the sericite-carbonate alteration zone of the stockwork. Increase in the sulphur and 'total carbon' content of the rock reflects pyrite-arsenopyrite mineralization and carbonate alteration within this zone. However, when the ratio C/S is plotted, the carbonate

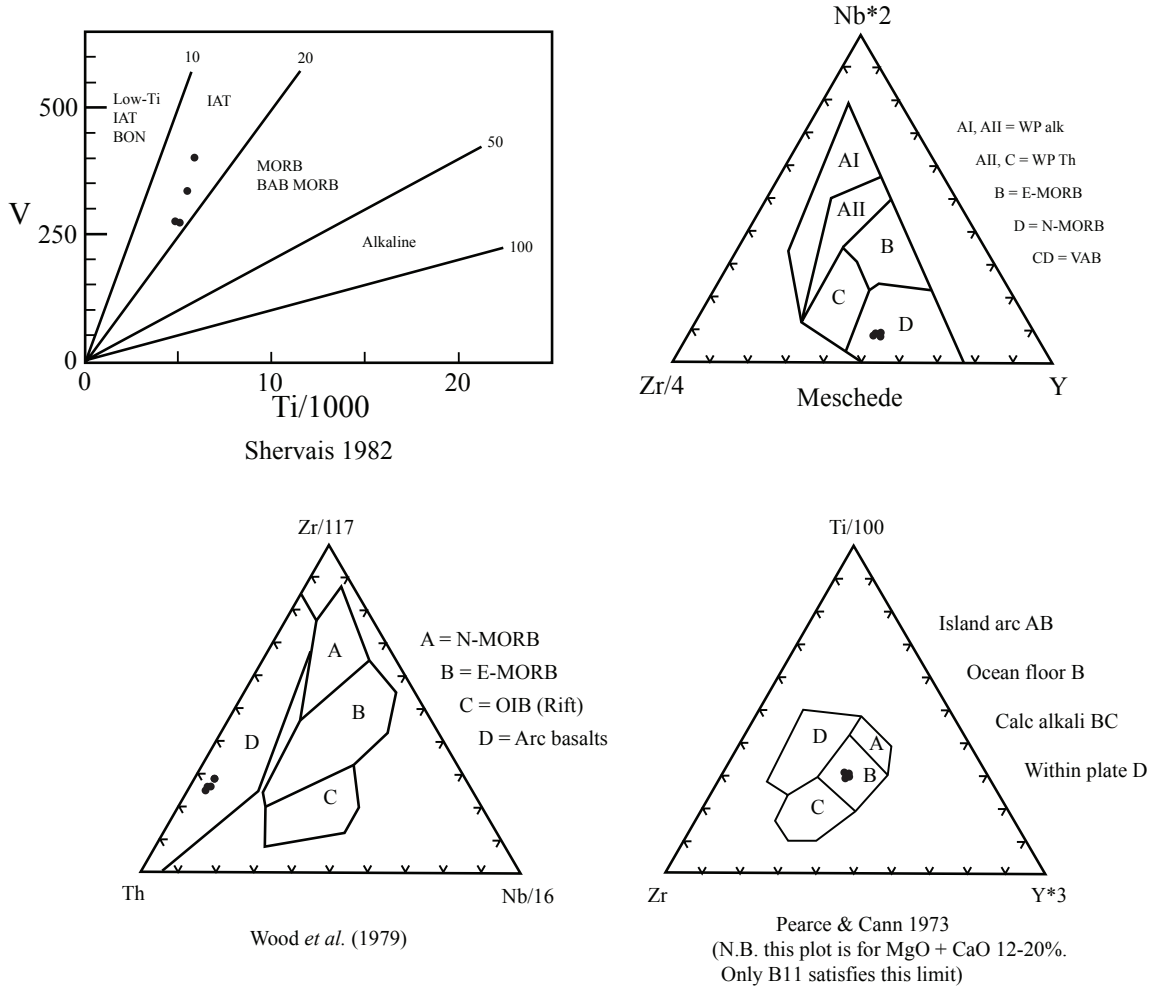

Figure 7. *Trace element discriminant diagrams for relatively unaltered chlorite schist.*

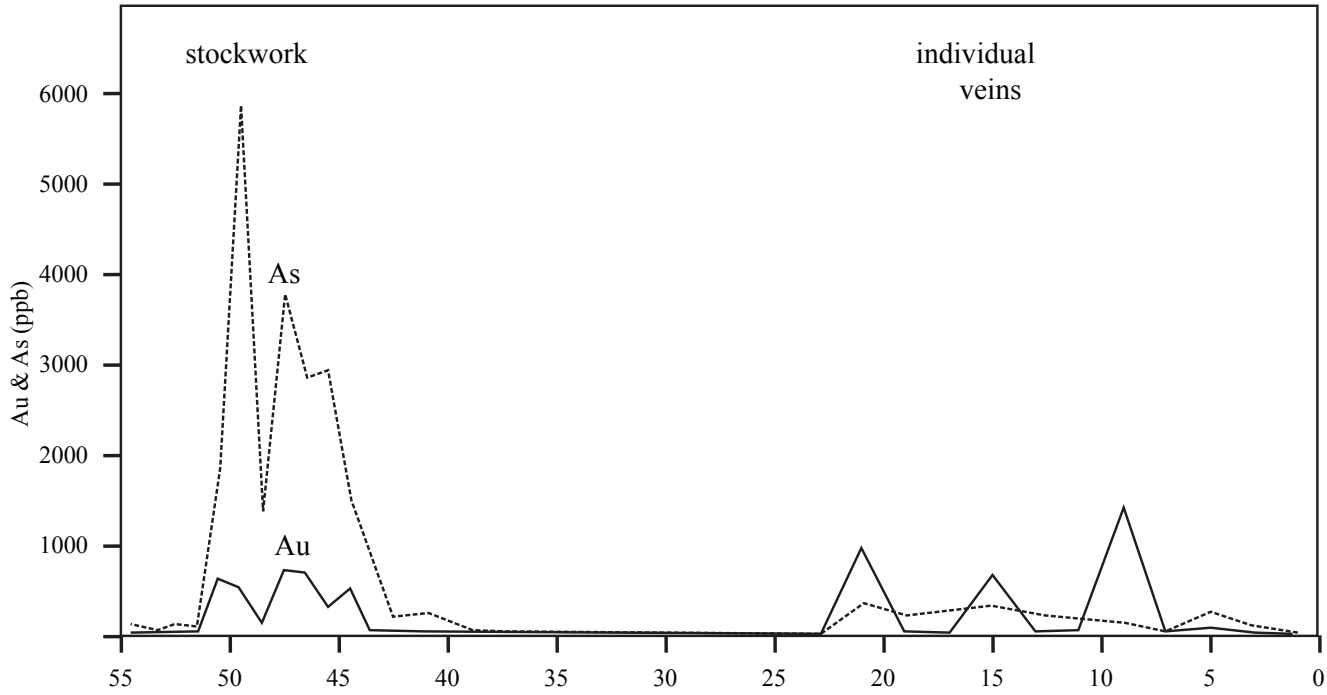

Figure 8. *Gold (Au) and arsenic (As) values from analyses of rock chip samples for the East Sheba trench, including both the stockwork and western vein zones.*

alteration at the margin of the zone is emphasized (Figs. 9a,b). Where whole-rock analysis is employed, this element ratio could prove a useful indicator for mineralized zones; however, typically exploration geochemistry trace element analytical packages are preferred due to cost considerations. The sericite alteration is reflected in the K/Na ratio for the whole-rock analyses (Fig. 9c). Increase in K relative to Na is obvious in samples analysed from within the region of intense quartz veining (42 to 48 m from the west end of the trench). No metre-scale potassic selvedge to the stockwork is indicated by this ratio. At the detailed rock sampling scale, Cu, Pb, Zn, Ag, Sb and As show a close relationship with anomalous gold. Furthermore, all of these elements could potentially indicate mineralized zones.

EXPLORATION GEOCHEMISTRY OF THE VEIN AREA

These prospects are contained within one of the largest soil geochemical anomalies found in the Klondike (Stevens, 1997). This previous work reports results from over 1700 samples of -80 mesh soil collected from the B or C soil horizons in the area. Samples were analysed by multi-element inductively coupled plasma mass-spectrometry (ICP-MS). The anomaly consists of elevated Au, As, Ag and Pb (and to a lesser extent elements such as Cu, Ba, Zn), which are coincident with the Mitchell and Sheba zones and the Dome Lode area, extending over an area roughly 2 by 4 km. The anomaly comprises broad but erratic gold (<20 ppb to 915 ppb), strong arsenic near Sheba and Dome Lode, weaker arsenic near Mitchell and strong silver and lead along the Sheba trend. Lead is also elevated near the Orekon vein. The anomaly extends beyond the study area to the northwest and southeast.

For regional soil sampling Pb may be the best indicator of the location of vein systems. However, correlation with gold content may not be strong since the larger veins have cores of massive galena that are related to the latest mineralizing event. Gold would have been introduced early in the vein-forming process and in the vein selvedges (*e.g*, Hoymann and Friedrich, 1992).

DISCUSSION

EXPLORATION SIGNIFICANCE

The vein systems of the JAE offer two targets for mineralization: 1) small, very high-grade 'pods' such as those at the original Mitchell and Sheba showings; and 2) quartz vein plus disseminated mineralization that is of low-grade but has potential for large bulk tonnages. Pyritic alteration zones associated with the vein systems

are considered important for the economic potential of the gold-bearing system as they have greater width and continuity than the quartz veins. The pyritic zones show continuity in induced polarization (IP) geophysical surveys and additional IP work is recommended (Mark, 1991).

The Mitchell and Sheba vein system occurs roughly on trend with the Hunker Dome or Dome Lode occurrence (Yukon MINFILE 115O 067), approximately 2 km to the south-southeast. Four quartz-gold veins are reported at Dome Lode, and a 790 m adit was driven under these veins during 1909 and 1910. The veins at Dome Lode are not as well exposed as those at Mitchell and Sheba, and bedrock is covered by overburden between them; however, the geochemical anomaly connects the two occurrences.

These veins are considered to be of orogenic or mesothermal nature (Mortensen, 1996).

The vein system was emplaced either late in the D_4 deformation of the Klondike Schist or subsequently as a brittle extensional event. Mineralization consists of Au with Ag, Pb, Cu, As and Sb sulphides and sulphosalts in the quartz veins and lower grade Au + pyrite within the immediately surrounding schist.

The well mineralized Mitchell and Sheba trend is one of the strongest gold-bearing structures in the Klondike region and occurs within one of the strongest geochemical anomalies. This property is located at the headwaters of some very rich placer gold streams, but has been minimally tested by drilling. None of the drilling has targeted the Mitchell prospect, which appears to be the best gold target on the claims. Considerable exploration potential exists to the southeast towards the Dome Lode prospect, and on trend in both directions.

ACKNOWLEDGEMENTS

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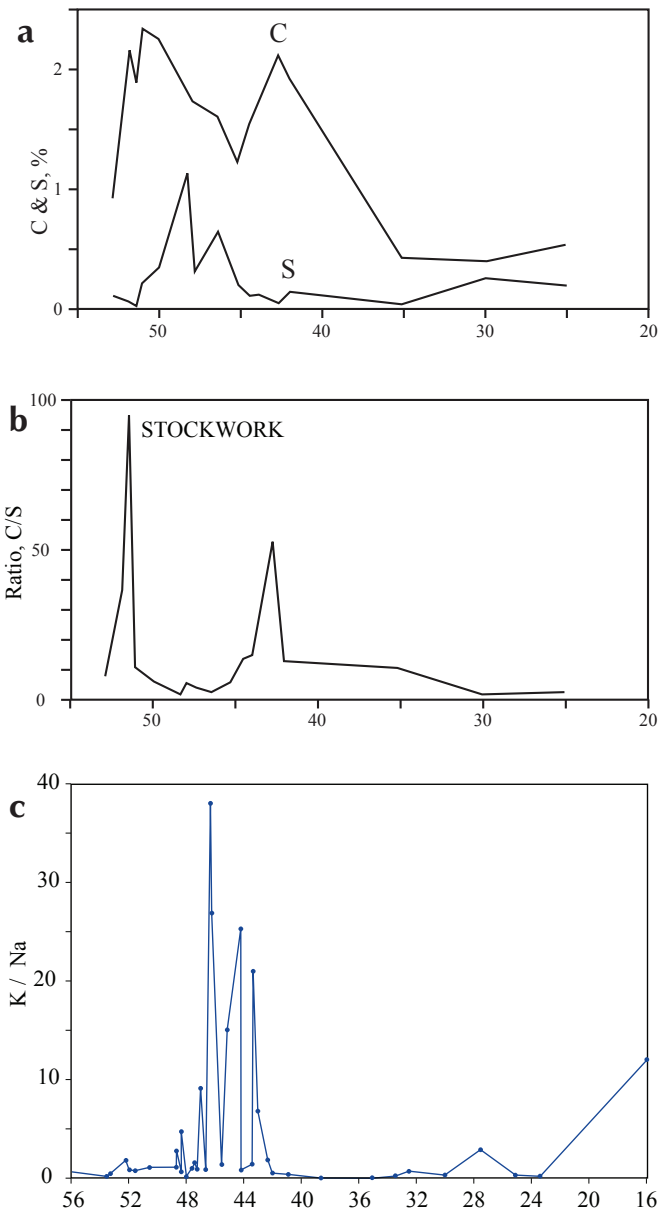

Figure 9. ***(a)*** *Total sulphur (S) and carbon (C) values and their ratios from whole-rock analyses of petrographic specimens (single ≤1 kg hand samples) taken across the East Sheba stockwork zone. Increase in total C indicates carbonate alteration and S predominantly the pyrite mineralization.* ***(b)*** *The element ratio emphasizes the carbonate alteration at the margin of this mineralized zone.* ***(c)*** *The K/Na ratio also emphasizes the sericite alteration within the stockwork zone.*

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