Disseminated gold mineralization associated with orogenic veins in the Klondike Schist, Yukon

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ABSTRACT

Disseminated gold, without quartz veins, occurs in some types of Klondike Schist, typically near mineralized orogenic veins. The disseminated gold and sulphide minerals (mainly pyrite) are associated with a distinctive chlorite alteration and weak silicification of host rock. In drill core sections that contain mineralized discordant quartz veins there is a crude association between gold and arsenic. In sections that contain disseminated sulphide minerals and gold without quartz veins there is no apparent association between gold and arsenic. Compared to the Otago Schist, New Zealand, a similar orogenic belt that has gold mineralization without coeval magmatism, the Klondike Schist has much lower levels of arsenic in mineralized schist (up to 1000 times less) and in unmineralized host schist (typically 10 times less). The disseminated sulphide minerals associated with Klondike veins are important as they extend the exploration target for these veins.

RÉUMÉ

On trouve de l'or disséminé, en l'absence de filons de quartz, dans certains types de Schiste de Klondike, généralement près de filons mésothermaux minéralisés. L'or disséminé et des minéraux sulfurés (surtout de la pyrite) sont associés à une chloritisation distincte et à une silicification faible de la roche encaissante. Des carottes contenant des filons de quartz discordants minéralisés présentent une association grossière entre l'or et l'arsenic. Des carottes contenant de l'or et des minéraux sulfurés disséminés, en l'absence de filons de quartz, ne présentent aucune association apparente entre l'or et l'arsenic. Comparativement au Schiste d'Otago de la Nouvelle Zélande, qui constitue une ceinture orogénique similaire renfermant des minéralisations en or sans aucun magmatisme contemporain, le Schiste de Klondike présente des concentrations d'arsenic beaucoup plus faibles dans le schiste minéralisé (jusqu'à 1000 fois inférieures) et dans le schiste encaissant non minéralisé (généralement dix fois inférieures). Les minéraux sulfurés disséminés associés aux filons de Klondike sont importants, car ils élargissent le cadre d'exploration ciblant ces filons.

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INTRODUCTION

The placer gold deposits of the Klondike goldfield (Fig. 1) have produced approximately 20 million ounces (600 million grams) since their discovery in 1896 (Government of Yukon, 2007). The ultimate source of these extremely rich deposits is presumed to be orogenic (mesothermal) quartz veins hosted in the underlying Klondike Schist (Tyrell, 1907; Rushton *et al.*, 1993; Knight *et al.*, 1999; Lowey, 2005). The relationship between placer gold and gold-bearing quartz veins is well established on an individual catchment scale, and placer-gold compositions correspond closely to gold in nearby schist-hosted discordant quartz veins (Knight *et al.*, 1999; Mortensen *et al.*, 2005). These quartz veins have mesothermal characteristics (Rushton *et al.*, 1993) and are hosted in local sites of extension, controlled principally by post-metamorphic compressional structures (MacKenzie *et al.*, 2007). The relative timing of the veins has now been placed in a structural framework coincident with the evolution of the Klondike Schist (MacKenzie *et al.*, 2007, 2008 (this volume)). The timing of vein emplacement is not associated with any igneous activity. Since their discovery in the late 1890s, gold-bearing quartz veins in the Klondike have been the target of many exploration programs, and for the past four years they have constituted the main focus of an extensive drilling program by Klondike Star Mineral Corporation.

The Otago Schist in South Island, New Zealand, has a similar geological history to the Klondike and hosts hydrothermal gold mineralization that formed during the latter stages of metamorphism as rocks were uplifted through the brittle-ductile transition. Like the Klondike, gold mineralization in Otago is not associated with any coeval magmatism. Both metamorphic belts share a similar history of early placer mining followed by the discovery of gold-bearing quartz veins. For over a hundred years the principal source of mined hardrock gold in Otago was schist-hosted gold-bearing quartz veins (Williams, 1974). Hardrock miners typically handpicked high-grade quartz veins and ignored the softer (commonly uneconomic) host schist. This changed in the 1990s with the development of the currently active Macraes mine, an approximately 6-million-ounce (200-million-g) deposit that is dominated by low-grade disseminated gold with subordinate small (typically metre-scale) gold-bearing quartz veins (Mitchell *et al.*, 2006). The bulk of mined material at Macraes, the largest gold mine in New Zealand, is auriferous sulphide-mineral-impregnated schist with only minor gold-bearing quartz veins. Hence the current focus of gold exploration in Otago is this newly recognized disseminated style of mineralization.

Due to its many similarities with Otago, the Klondike Schist is highly prospective for this style of mineralization and large-volume, low-grade gold deposits. This paper outlines the results of an ongoing investigation by the authors into the association of disseminated gold without quartz veins in the Klondike Schist. This research is supported by Klondike Star Mineral Corporation.

REGIONAL GEOLOGY

The Klondike goldfield is underlain by highly deformed, greenschist-facies, Paleozoic metasedimentary and meta-igneous rocks of the Klondike Schist and Finlayson assemblage that form part of the Yukon-Tanana terrane, and lesser amounts of little metamorphosed ultramafic rocks of the Slide Mountain terrane (Fig. 1; Mortensen, 1990, 1996). Regional-scale thrust faulting in the Early Jurassic (Mortensen, 1996) stacked these rocks into a series of thrust slices that are locally separated by lenses of sheared ultramafic rocks. They were then uplifted through the brittle-ductile transition in the Jurassic and unconformably overlain by locally derived sedimentary and volcanogenic rocks in the Late Cretaceous (Mortensen, 1996). The Klondike goldfield was then offset approximately 450 km along the Tintina fault (Fig. 1, Gabrielse *et al.*, 2006). Erosion and minor regional uplift continued in the late Tertiary and resulted in the deposition of the Pliocene White Channel Gravels and their contained placer gold deposits (Lowey, 2005).

STRUCTURAL CONTROLS ON VEIN FORMATION

Mesothermal gold vein formation occurred in the latter stages of Jurassic compressional deformation after the Klondike Schist was uplifted through the brittle-ductile transition and prior to the main stage of Cretaceous extension (MacKenzie *et al.*, 2007, in press; MacKenzie *et al.*, this volume). Gold-bearing veins are widely dispersed throughout the uppermost slices of Klondike Schist and are hosted in a wide variety of small extensional sites controlled by pre-existing structures in the schist. The veins crosscut metamorphic and thrust-related fabrics in the schist and are controlled principally by axial surface fractures associated with a phase of post-metamorphic kink-folding (MacKenzie *et al.*, 2007). Normal faults locally overprint and offset the veins.

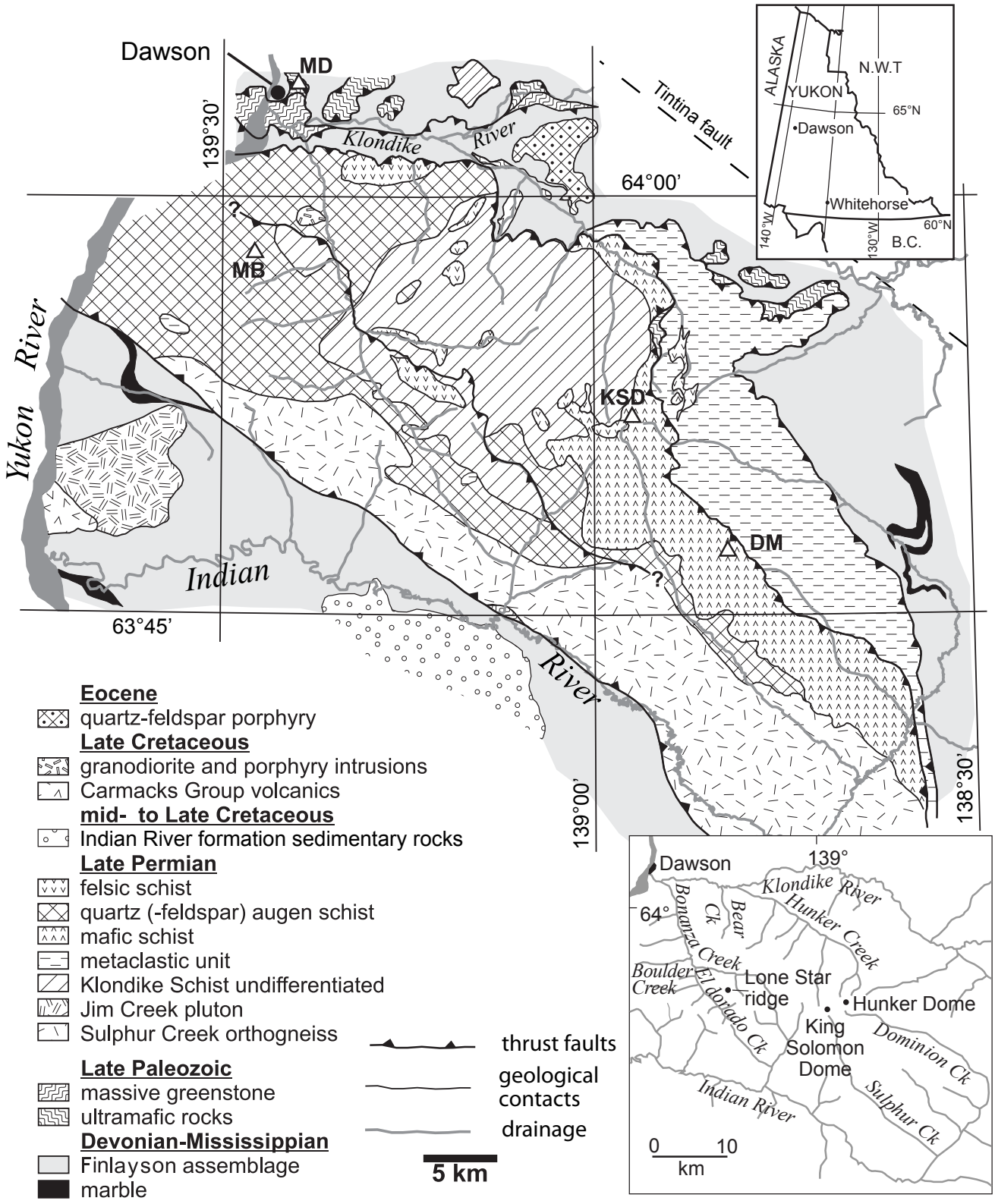

Figure 1. *Geological map of the Klondike District, central western Yukon (after MacKenzie et al., in press). KSD = King Solomon Dome; MD = Midnight Dome; DM = Dominion Mountain; MB = Mount Bronson. Top right inset map outlines the study area within Yukon, while bottom right inset map depicts the major drainages and physiographic features in the study area.*

QUARTZ VEINS IN KLONDIKE SCHIST

Gold-bearing quartz veins in the Klondike Schist are extension veins that infill a variety of pre-existing extensional structures (MacKenzie *et al.*, in press). The veins typically consist of massive milky quartz, with some clear euhedral crystals protruding into open-space cavities (Fig. 2). Calcite, galena, sphalerite and chalcopyrite are rare accessory minerals in some veins. Visible gold, up to millimetre-scale, is fairly common (Figs. 2 and 3). Some veins contain breccia fragments of schist wallrock, which can extend several centimetres from vein margins. These fragments are typically silicified and may contain fine-grained disseminated pyrite. Minor sericite alteration affects some fragments and host rock up to 1 cm from the veins (MacKenzie *et al.*, in press).

AURIFEROUS KLONDIKE SCHIST

Disseminated mineralization is associated with quartz veins and chloritic schist in the King Solomon Dome area (Fig. 1), where euhedral pyrite crystals up to several millimetres long extend tens of centimetres from vein margins. In the Lone Star ridge area (Fig. 1) extensive zones of disseminated euhedral pyrite and gold (up to several grams/tonne) extend out from mineralized quartz veins hosted in highly deformed micaceous schists. The schist-hosted disseminated sulphide minerals in both of these areas form an otherwise subtle alteration halo that extends centimetres to metres out from the auriferous veins.

Recent drilling by Klondike Star Corporation in the Lone Star ridge area (Lone Star and Victoria occurrences, Yukon MINFILE[1], 115O 072 and 115O 146) has intersected gold-mineralized intervals in drill core associated with spotty chlorite alteration and finely disseminated pyrite (*e.g.*,, Fig. 4a,c). This distinctive alteration occurs in segregated schist consisting of millimetre to centimetre-wide alternating layers of quartz and feldspar and micaceous layers composed of metamorphic muscovite and chlorite. Altered samples are weakly to moderately silicified along foliation surfaces with millimetre-scale clots of chlorite concentrated along micaceous layers. The pyrite is fine-grained (< 1 mm) and typically concentrated along foliation surfaces. Some samples contain minor amounts of iron-carbonate and trace amounts of magnetite.

DISSEMINATED GOLD AND THE ASSOCIATION WITH ARSENIC

The association between spotty chlorite alteration and gold is evident in drillholes 05LS02 and 05LS09 (Fig. 4a,c). Anomalous gold grades over 1 ppm occur in chlorite-altered intervals in the first 80 m of drillhole 05LS02 (Fig. 4a) and in several chlorite-altered zones in the first 100 m of drillhole 05LS09 (Fig. 4c). The chlorite-altered zones do not generally contain quartz veins but at different depths away from these zones there are crosscutting quartz veins in both drillholes with anomalous gold >0.1 ppm. Drillhole 05LS08, shown for

[1]*http://www.geology.gov.yk.ca/databases_gis.html*

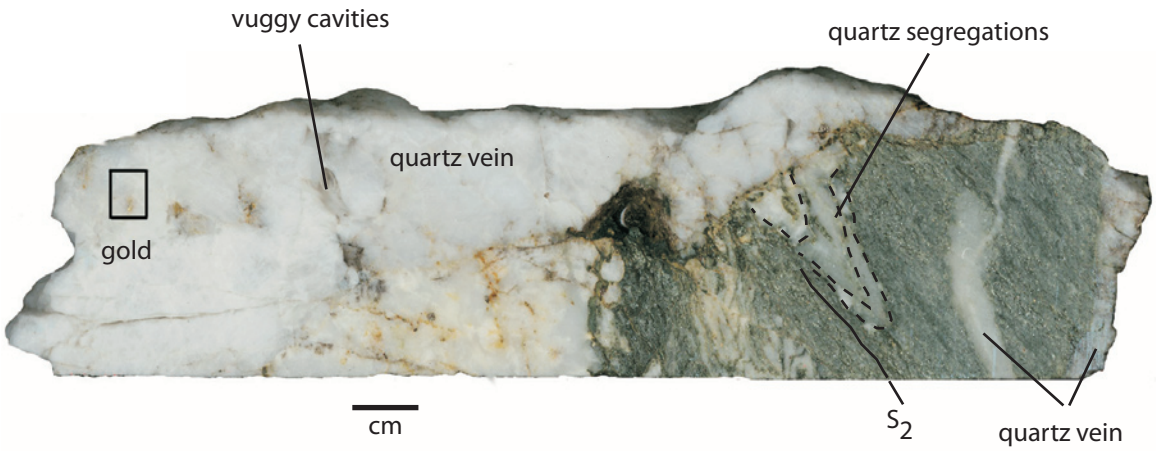

Figure 2. *Diamond drill core of quartzofeldspathic schist from Lone Star ridge. Metamorphic segregations (S_2) are crosscut by discordant quartz veins. The larger vein with euhedral quartz cavities contains visible gold outlined in black box.*

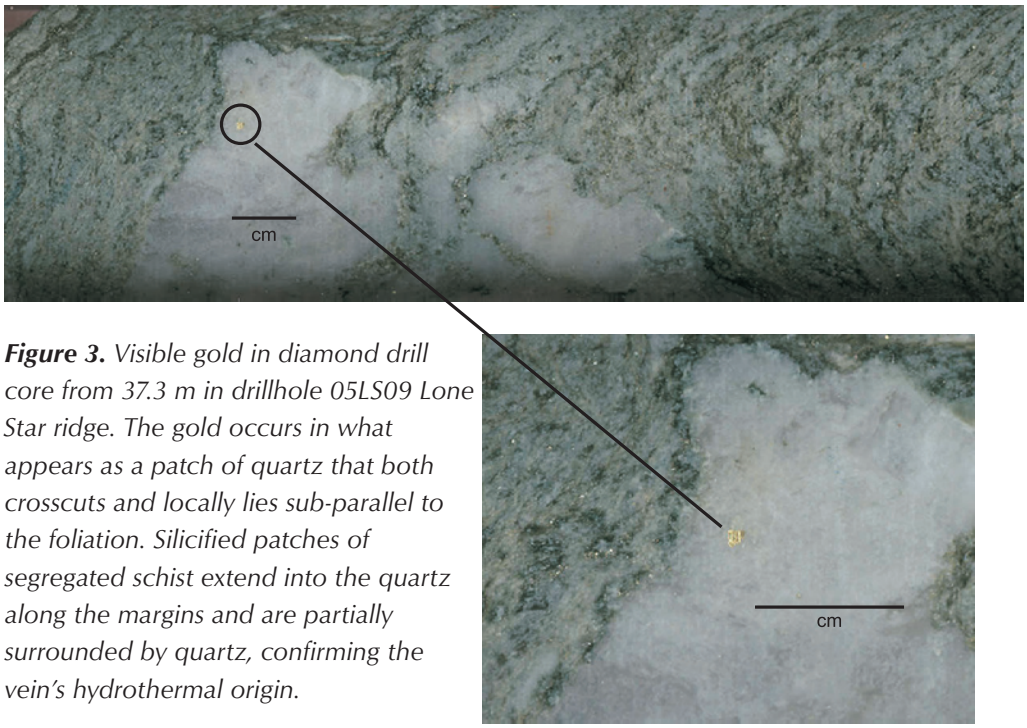

Figure 3. *Visible gold in diamond drill core from 37.3 m in drillhole 05LS09 Lone Star ridge. The gold occurs in what appears as a patch of quartz that both crosscuts and locally lies sub-parallel to the foliation. Silicified patches of segregated schist extend into the quartz along the margins and are partially surrounded by quartz, confirming the vein's hydrothermal origin.*

comparison (Fig. 4b), is a typical mineralized hole with millimetre to centimetre-scale quartz veins and without any logged chlorite alteration. The lower portion of this hole (>80 m) is generally barren and gives a good indication of background levels for gold (< 2 ppb) and arsenic (< 2 ppm).

The chlorite-altered zone from 69 to 70 m depth in hole 05LS02 returned an overall grade of 1.1986 ppm Au and 0.8 ppm As (fire assay, ICP finish with detection limits of 0.5 ppb Au and 0.5 ppm As). This 1-m interval was examined in detail to determine the distribution of gold on a centimetre-scale (Fig. 5). The interval was divided approximately every 2.5 cm down the hole into 39 separate samples that were then analysed at the ALS Chemex laboratory in Vancouver using procedure Au-AA25 with a detection limit of 10 ppb Au. The interval near 69.45 m (Fig. 5c) assayed >100 ppm Au and may be associated with a centimetre-scale quartz vein in this interval. Other intervals, however, *e.g.,* 69.58 to 69.71 m (Fig. 5d), contain alteration without quartz veins and gold up to >10 ppm. Overall the 69 to 70-m interval is consistently well mineralized with 20 of the 39 samples containing >0.5 ppm Au and 18 samples >1 ppm Au. Many of these mineralized samples are characterized by the distinctive spotty chlorite alteration and finely disseminated pyrite without quartz veins.

In Lone Star drillholes, arsenic is typical of many of the common anomalous trace elements (*e.g.,* copper, lead, zinc) and shows no obvious correlation with gold. For mineralized drillholes 05LS02 and 05LS09 containing chlorite alteration, the linear correlation between arsenic and gold is very poor (Fig. 6a, c) with $r^2 = 0.0002$ and $r^2 = 0.0001$ respectively (where r = coefficient of linear correlation and r^2 = proportion of the total variability of arsenic values that can be accounted for by gold values). Drillhole 05LS08 with mineralized quartz veins and no logged chlorite alteration shows a weak to moderate correlation between gold and arsenic (Fig. 6b) with $r^2 = 0.1369$. Arsenic values range from a high of 73.5 ppm to <0.05 ppm. The higher arsenic values >10 ppm are commonly associated with millimetre to centimetre-scale quartz veining in the core (Fig. 4) and not the chlorite-altered sections. The mean arsenic assay for all three holes (Fig. 4) is 4 ppm.

DISCUSSION AND CONCLUSIONS

Gold-bearing mesothermal veins in the Klondike Schist are controlled by post-metamorphic compressional structures and infill local extensional sites associated with a variety of pre-existing structures (MacKenzie *et al.*, in press). The veins are typically white milky quartz with some open-space cavities infilled with clear euhedral quartz crystals. Some veins contain breccia fragments of host schist that are silicified and impregnated with finely disseminated sulphide minerals (mainly pyrite). Local sericitic alteration affects some schist fragments and may extend into wall rock. This alteration and local silicification is generally not extensive however, and is confined to a few millimetres adjacent to vein margins. Metre-scale alteration in the form of disseminated sulphide minerals (mainly millimetre-scale euhedral cubes of pyrite) is associated with the gold-bearing veins and host chloritic schist at King Solomon Dome, and the mineralized veins and deformed mica schist at Lone Star ridge. This

disseminated pyrite alteration forms an otherwise subtle alteration halo around the quartz veins in these areas.

The spotty chlorite and disseminated pyrite alteration intersected in drill core at Lone Star ridge is easier to distinguish than that described above and is not associated with quartz veins. Gold grades >1 ppm are associated with this alteration in mineralized schist at Lone Star ridge (Fig. 4). In spotty chlorite-altered mineralized schist, gold is consistently elevated on a centimetre-scale throughout the altered zone (Fig. 5). No visible gold was noted in these sections but there was a crude association with gold and the amount of finely disseminated pyrite. Hence the gold in these altered sections may be locked in pyrite and other trace sulphide minerals. The mineralogical distribution of gold is the focus of ongoing research.

High gold values in the spotty chlorite altered sections are not directly correlated with high arsenic (Fig. 6 a, c), whereas in the veined sections of core, there is a weak correlation between the two elements (Fig. 6b). In general where quartz veins are logged, there is a crude association between gold and arsenic, but where there are no quartz veins only background levels of arsenic are observed. This relationship between arsenic and gold distinguishes the Klondike Schist from other comparable mineralized metamorphic belts like the Otago Schist, New Zealand. Gold deposits in Otago are characterized by high arsenic (up to 10 000 pm), where veins and mineralized schist commonly contain arsenopyrite (< 5%). Typical arsenic values in mineralized Otago Schist range from 1000 to 2000 ppm (Craw *et al.*, 2007) compared with 1 to 100 ppm in mineralized Klondike Schist samples (Fig. 7). Background arsenic values in unmineralized Otago Schist are much higher as well and range from 10

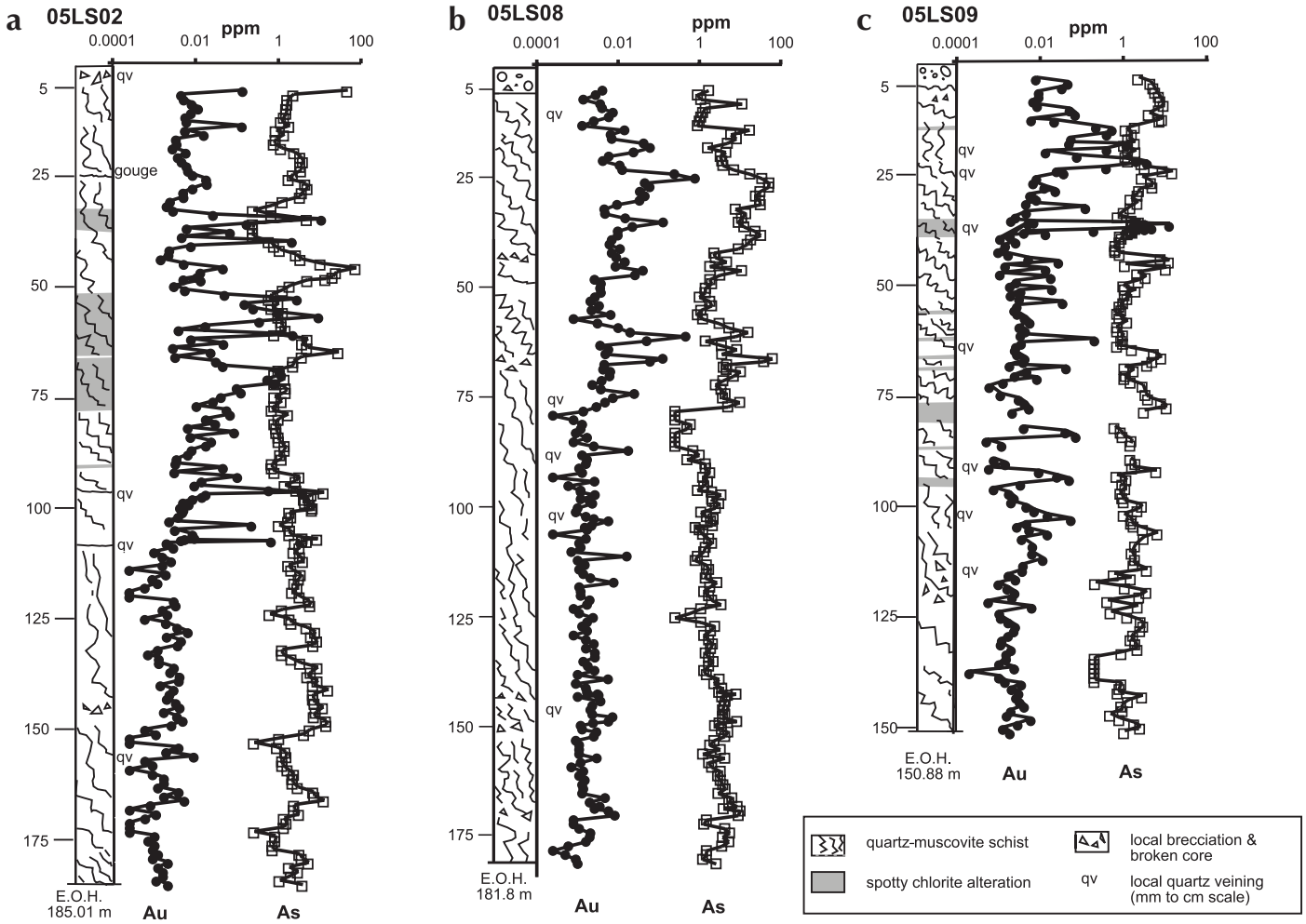

Figure 4. *Sketches of three diamond drillholes from Lone Star ridge showing variation of gold and arsenic assays with depth.* ***(a)*** *05LS02 (dip -70°).* ***(b)*** *05LS08 (dip -70°).* ***(c)*** *05LS09(dip -50°).*

to 20 ppm compared with 0.1 to 2 ppm for unmineralized Klondike Schist.

Higher arsenic levels in the Otago Schist may be the result of relatively enriched host rocks that released arsenic into mineralizing fluid reservoirs during greenschist facies metamorphism. This arsenic was then remobilized and deposited as arsenopyrite along with gold in late-metamorphic shear zones and post-metamorphic quartz veins. It is possible that Klondike host rocks did not have much arsenic in them and thus there was less arsenic available for later remobilization.

The importance of disseminated mineralization in Otago gold deposits has only recently been recognized. Prior to the late 1990s, with the opening of the currently active Macraes mine, exploration was directed solely at gold-bearing quartz veins. Mineralized schist with disseminated sulphide minerals forms the bulk of the material mined now at Macraes. Higher grade quartz veins are mined locally but these form a volumetrically small proportion of the ore. Ore-grade material is composed primarily of mineralized host schist.

Disseminated gold mineralization in the Otago Schist is interpreted to be epigenetic in origin. This may also be the case for disseminated gold described here from within the Klondike Schist, especially that contained within mafic schist hosts adjacent to gold-bearing quartz veins in the King Solomon Dome area. An alternative interpretation for disseminated gold contained within felsic schist in the Lone Star ridge area, however, is that at least some of it might be syngenetic in origin. Felsic schist on Lone Star ridge was derived from pyritic, submarine felsic tuff. Narrow bands of disseminated to semi-massive pyrite with minor galena, sphalerite and rare chalcopyrite have been recognized within schist on Lone Star ridge and in similar host rocks in several other localities in the Klondike. These sulphide bands are interpreted to represent small volcanogenic massive-sulphide (VMS) occurrences on the basis of both their geological setting and Pb isotopic

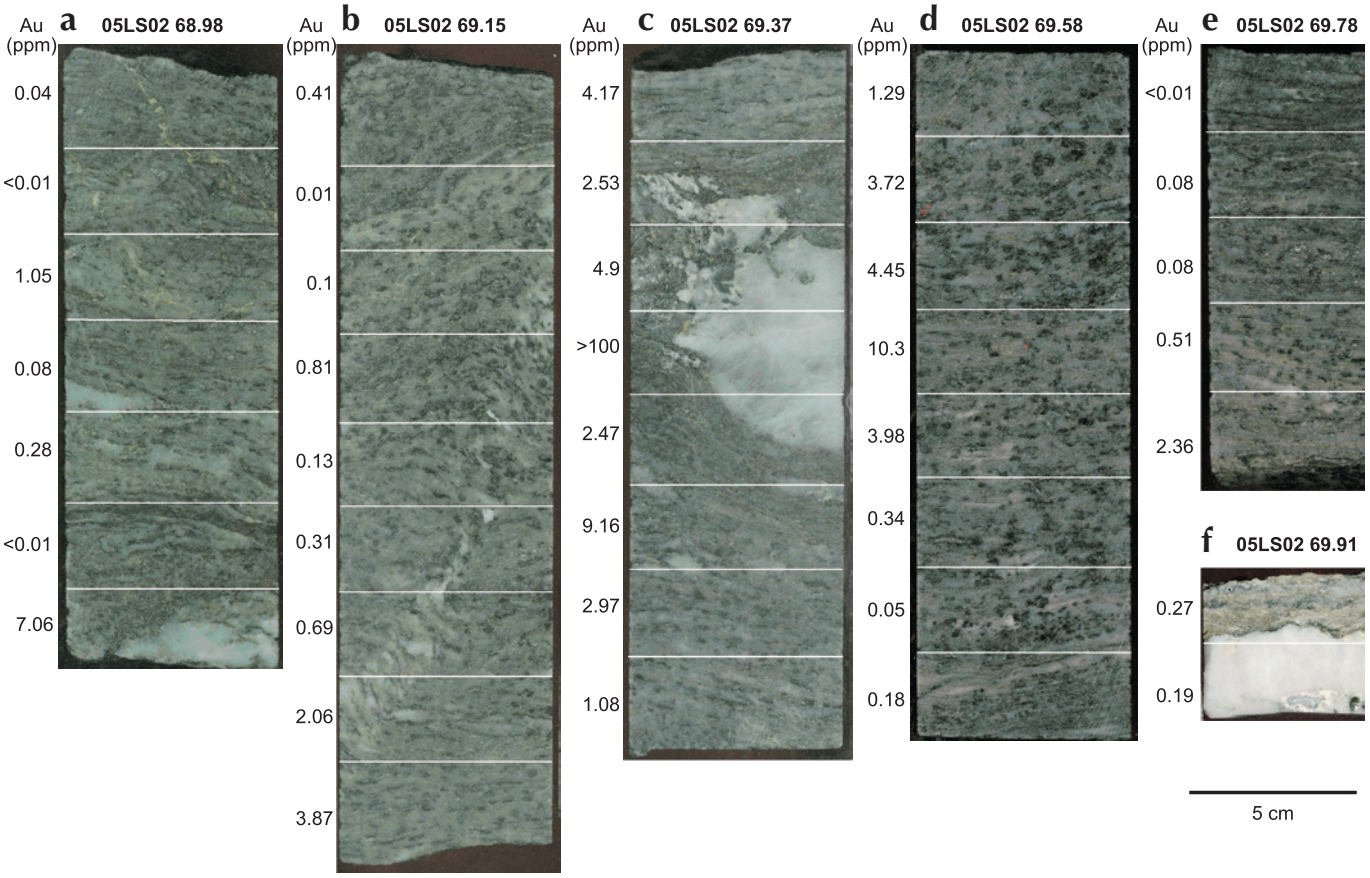

Figure 5. *A 1-m interval (69 to 70 m) of diamond drill core from hole 05LS02 on Lone Star ridge. This interval was sampled in detail and white lines delineate the boundaries between individual samples. Gold content in ppm is indicated to the left of each sample.*

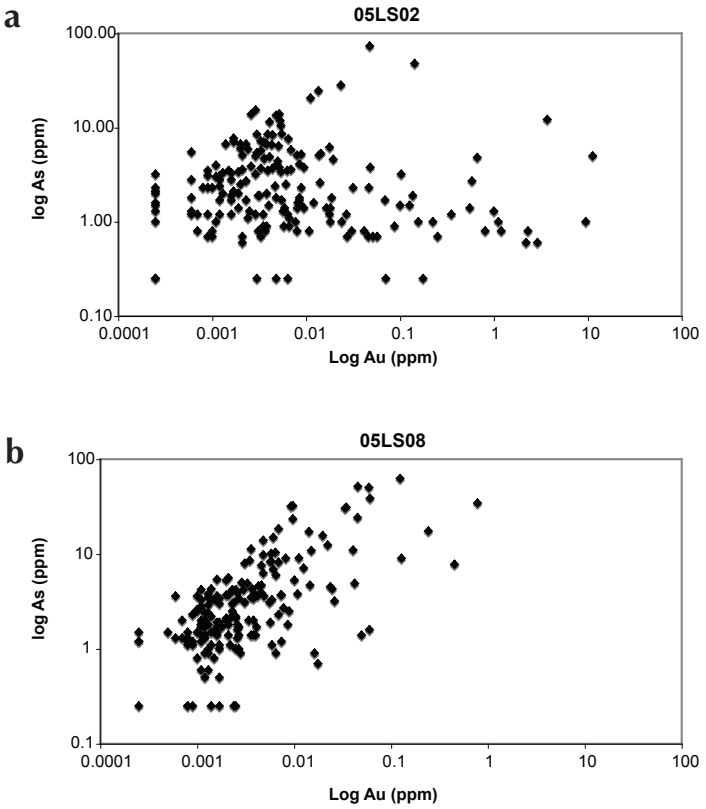

Figure 6. *Plots of log arsenic versus log gold for Lone Star ridge drillholes in Figure 4:* ***(a)*** *05LS02,* ***(b)*** *05LS08,* ***(c)*** *05LS09.*

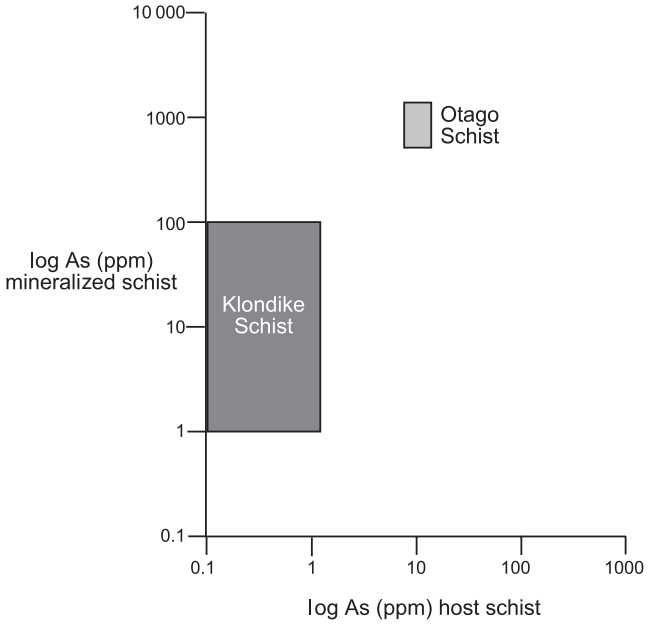

Figure 7. *The range of typical log arsenic values in mineralized schist plotted against log arsenic in umineralized schist to compare the Klondike Schist with the Otago Schist, New Zealand.*

compositions (Mortensen *et al.*, 2006). Thus gold-bearing quartz veins in the Lone Star ridge area are hosted by felsic metavolcanic rocks that at least locally contain elevated primary base and possibly precious metal values. We are still investigating possible linkages between the scattered syngenetic base metal occurrences and the disseminated gold (and gold-bearing quartz vein) mineralization.

Due to many similarities with the Otago Schist, the Klondike Schist is considered very prospective for disseminated mineralization. Recent drilling shows there is a strong association of gold with disseminated sulphide minerals without quartz veins at Lone Star ridge. The recognition of disseminated mineralization in Klondike Schist is encouraging and has expanded the exploration target and potential mineable width of gold-bearing quartz veins in this area.

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