

**PRELIMINARY OBSERVATIONS ON THE GEOLOGY AND
GEOCHEMISTRY OF QUARTZ VEINS IN THE
KLONDIKE DISTRICT, WEST-CENTRAL YUKON**

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ABSTRACT

Four main styles of quartz veining are recognized in the Klondike District. These include foliaform and discordant mesothermal quartz veins in schistose metamorphic rocks, quartz-carbonate veins in altered ultramafic rocks and greenstones, epithermal chalcedony veins cutting Eocene igneous and sedimentary rocks, and low-temperature epithermal veins associated with intensely altered Plio-Pleistocene White Channel Gravel deposits. Foliaform mesothermal quartz veins are invariably barren; however discordant mesothermal veins locally contain visible gold. Both styles of epithermal veins in the Klondike contain at least geochemically anomalous levels of gold. The complex history of hydrothermal activity in the Klondike has led to considerable confusion about the nature of veining in this area. The results of this study provide a preliminary framework within which to evaluate the various prevailing theories regarding the major sources of gold in the Klondike placer deposits.

RÉSUMÉ

Quatre principaux types de veines de quartz sont reconnus dans le district du Klondike; ce sont des veines de quartz mésothermal foliiformes et discordantes dans les roches métamorphiques schisteuses, des veines de quartz et carbonate dans les roches ultramafiques altérées et les roches vertes, des veines de calcédoine épithérmale recoupant des roches ignées et sédimentaires de l'Éocène et enfin des veines épithérmale formées à basse température associées aux dépôts plio-pléistocènes de graviers de White Channel intensément altérés. Les veines de quartz mésothermal foliiformes sont invariablement stériles; cependant les veines mésothermales discordantes renferment par endroits de l'or visible. Au Klondike, les deux types de veines épithérmale renferment au moins des concentrations géochimiquement anormales d'or. L'histoire complexe de l'activité hydrothermale au Klondike a suscité une confusion considérable quant à la nature de la formation des veines dans cette région. Les résultats de cette étude assurent un cadre préliminaire pour l'évaluation des diverses théories prédominantes concernant les sources majeures d'or dans des dépôts alluvionnaires au Klondike.

INTRODUCTION

Exploration for lode gold mineralization in the Klondike District began immediately after the discovery of rich placer gold deposits in the area in 1896. Although many quartz veins, some containing visible gold, were discovered early in the development of the Klondike District (e.g. McConnell, 1905), they have received little detailed study. In this paper we summarize preliminary results of an on-going investigation of the field relationships, genesis and composition of the different vein systems, and discuss the implications of this work for the origin of placer gold deposits in the area.

GEOLOGY OF THE KLONDIKE DISTRICT

The bedrock geology of the Klondike District is shown in Figure 1 (from Mortensen, 1990). Bedrock units can be divided into four main groups; (1) schistose metamorphic rocks, (2) greenstones and ultramafic rocks, (3) undeformed intrusive rocks, and (4) young volcanic and sedimentary rocks. The schistose metamorphic rocks include a variety of metaplutonic, metavolcanic, and metasedimentary rocks which range in age from pre-Late Devonian to mid-Permian. These rocks display a penetrative foliation which generally parallels compositional layering, and formed during the first main deformation event in the area (F1). Metamorphism associated with the F1 event was at middle greenschist facies (chlorite-biotite grade) throughout most of the area, but reached garnet grade along the southwest margin of the study area, and sillimanite grade along lower Dominion Creek adjacent to the granitic orthogneiss which underlies Mt Burnham (Fig. 1).

A younger deformation event (F2) produced macroscopic scale folds in the Bonanza Creek and Eldorado Creek areas, and one or more crenulation cleavages over much of the Klondike area. Metamorphism associated with F2 was at lower greenschist facies, and is usually seen only as a retrogression of F1 mineral assemblages.

The schistose metamorphic rocks in the Klondike have been imbricated by regional scale thrust faults along which bodies of massive greenstone and altered ultramafic rocks (including serpentized harzburgite, serpentinite, and quartz-carbonate-Cr mica rocks) were emplaced. The greenstones and ultramafic rocks were not affected by F1 deformation, and field observations suggest that the F2 event approximately coincided with the thrust faulting (Mortensen, 1990).

K-Ar and Rb-Sr ages for metamorphic muscovite and hornblende in the Klondike range from Middle Jurassic to earliest Cretaceous, probably reflecting very prolonged cooling after the F1 event.

Two distinct suites of undeformed and unmetamorphosed intrusive rocks which post-date thrust faulting have been recognized in the Klondike. These are: (1) hornblende-biotite granodiorite which forms a small plug along middle Hunker Creek (Fig. 1) and yields a latest Cretaceous K-Ar hornblende age (R.L. Debicki, pers. comm., 1984), and (2) a widespread bimodal suite of quartz-feldspar porphyry and diabase and plagioclase-phyric mafic porphyry which occur as dykes and

as a large stock between lower Hunker Creek and the Klondike River (Eocene K-Ar whole-rock age, R.L. Debicki, pers. comm., 1984; Mortensen, 1990) (Fig. 1).

Unmetamorphosed andesite flows which are interlayered with clastic sediments along Last Chance Creek (Fig. 1) are undated, but, closely resemble similar sequences south of Indian River that have given latest Cretaceous isotopic ages (Lowey et al., 1986). An undated sequence of felsic lapilli tuff and volcanic breccia interlayered with immature clastic rocks near the mouth of Germaine Creek (Fig. 1) is composed of quartz-feldspar porphyry identical to the Eocene felsic porphyry intrusions and is considered to be their extrusive equivalent.

Despite the close proximity of the Klondike District to the Tintina Fault, there is surprisingly little evidence for large-scale steep faults in the area (Mortensen, 1990).

The Klondike District is unglaciated and three main unconsolidated units in the area are known to contain gold. These are: (1) White Channel Gravels of Plio-Pleistocene age that rest on high level terraces, (2) gravels that occupy the beds of present streams, and (3) colluvium which mantles hillslopes (e.g. McConnell, 1905; Morison, 1987).

VEIN SYSTEMS IN KLONDIKE DISTRICT

Four main styles of veining are recognized in the Klondike District. These are: (1) mesothermal quartz veins in schistose metamorphic rocks; (2) quartz-carbonate veins cutting greenstones and ultramafic rocks; (3) Fluorite and chalcedony veins cutting igneous and sedimentary rocks of Eocene age; and (4) Quaternary, low-temperature epithermal veins.

Veins of the first type are by far the most widespread and abundant, and form the main focus of this paper.

MESOTHERMAL VEINS IN SCHISTOSE METAMORPHIC ROCKS

Quartz vein material makes up a significant proportion of the schists and gneisses that underlie most of the Klondike District. Two main types of veins can be distinguished based mainly on their structural setting. Foliaform veins form typically lensoid bodies oriented along F1 foliation planes. Discordant veins form tabular bodies that crosscut the main foliation in the wall rocks. The main characteristics of these two types of veins are briefly summarized below.

Foliaform veins.

These veins range up to 3 m in thickness, but are typically discontinuous. They are present in all metamorphic rock units in the area, and are particularly abundant in the mica-rich lithologies (i.e. felsic schist, chloritic schist, and carbonaceous schist), where they locally comprise up to 10% of the rock volume. Structurally, the foliaform veins have been little affected by the F2 deformation, but locally occupy F2 fold hinges (see description of the PORTLAND occurrence

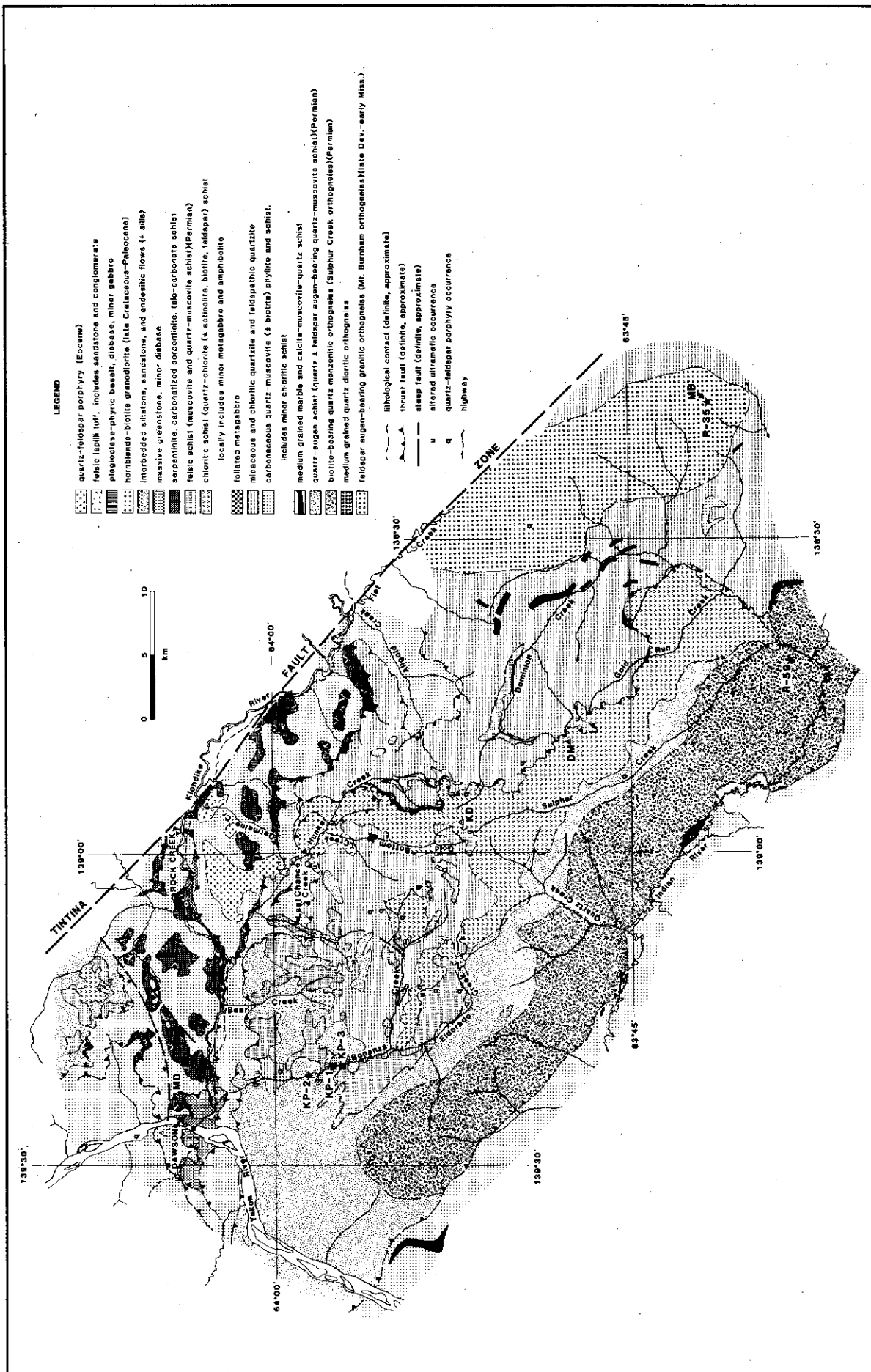


Figure 1. Geological map of Klondike District. Solid stars show locations for geochronological samples discussed by Mortensen (1990). MD = Midnight Dome; KD = King Solomon Dome; DM = Dominion Mountain; MB = Mt Burnham.

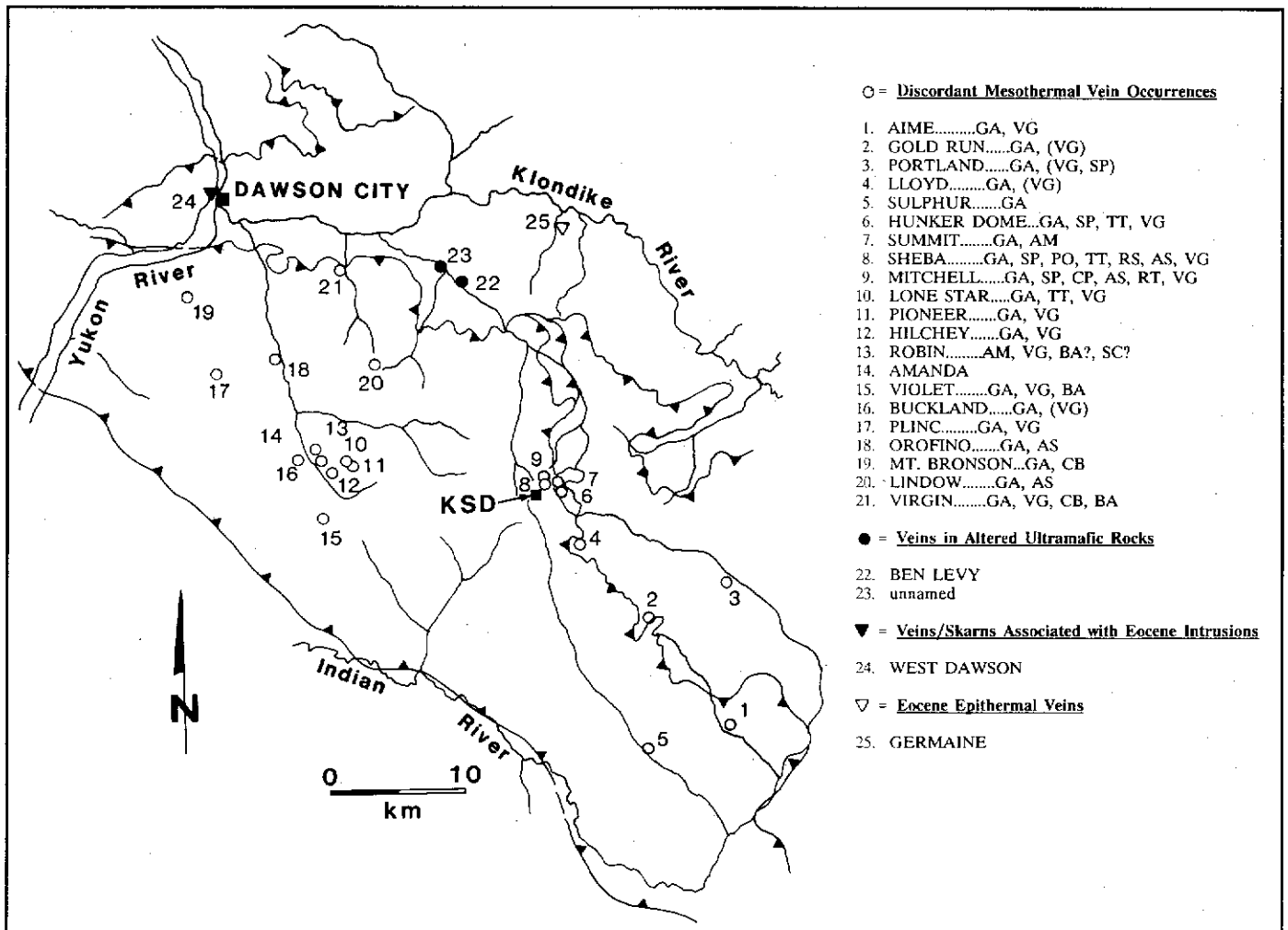


Figure 2. Sketch map of the Klondike District showing locations of the mineralized discordant vein occurrences as well as other occurrences referred to in the text. Also shown are the occurrence name (in capital letters) and minerals present other than quartz and pyrite (minerals in parentheses reported to be present but not confirmed). GA = galena, SP = sphalerite, AS = arsenopyrite, PO = pyrrhotite, TT = tetrahedrite, VG = visible gold, RS = pyrargyrite, AM = amethyst, CB = carbonate, BA = barite, SC = scheelite, RT = rutile. Includes data from Debicki (1984), Friedrich and Hoymann (1989), and Yukon Minfile (1991). KSD refers to King Solomon's Dome.

(MINFILE 1150 064) in Maclean, 1914, p. 101-102 for an example), suggesting formation late in the F2 event.

Foliaform veins consist almost entirely of milky to clear, coarse grained quartz with locally abundant calcic to ferroan carbonate. Small masses of muscovite and/or chlorite are present in some of the foliaform veins, but it is uncertain whether these minerals form part of the vein assemblage or are small screens of mica-rich wall rock. Pink K-feldspar occurs in small amounts in foliaform veins within the quartz-augen schist unit and the Sulphur Creek orthogneiss, both along Bear Creek and in areas of somewhat higher metamorphic grade in the southwestern part of the district. Vuggy cavities appear locally in the foliaform veins.

The foliaform veins appear to contain no visible sulphides or gold and no evidence of alteration is visible in adjacent wallrocks.

Discordant veins.

Discordant veins occur sporadically throughout the Klondike, although they are most abundant in the central and southern parts of the district. The abundance of discordant veins appears to decrease rapidly north of the Klondike River, northeast of Hunker and Dominion Creeks, and south of Indian River. The locations of some of the better known and explored veins and vein sets are shown in Figure 2. Discordant veins are usually less than 1 m thick; however examples up to 3 m thick are present at some localities (e.g. AMANDA occurrence on Eldorado Creek, (MINFILE 1150 051). In some instances single veins can be traced up to 800 m along strike. Most of the veins occupy steeply dipping extensional structures, which locally appear to form en echelon arrays. An example of such an array includes the

MITCHELL-SHEBA-HUNKER DOME occurrences (MINFILE 1150 068 and 1150 067) north and east of King Solomon Dome, where the largest and most continuous veins present form a north-south trending, left-stepping en echelon array. There is no obvious geometric relationship, however, between the orientation of these veins and any of the presently recognized regional deformation events.

Discordant veins crosscut, and are therefore younger than, foliaform veins at a number of localities in the Klondike District. In two instances, however, clearly discordant quartz veins appear to merge with foliaform veins, suggesting a possible partial overlap in age between the two types of veins.

Small vuggy cavities lined by clear quartz (and rare carbonate) crystals are abundant in some discordant veins. Ribbed veins are very rare; most veins appear to represent simple, single-stage, open space filling. Ribbed vein material appears in float at the south end of the vein system at the HUNKER DOME occurrence (MINFILE 1150 067), and on the dump at the AIME occurrence (MINFILE 1150 061)(Fig. 2). Angular wall rock fragments to 25 cm in longest dimension appear in discordant veins at the LLOYD (MINFILE 1150 066) and SHEBA (MINFILE 1150 068b) occurrences (Fig. 2). There is no evidence for faulting synchronous with vein formation, although post-vein faults produce minor (up to several metres) offset on veins in the Lone Star mine area (MINFILE 1150 072) and zones of crush breccia along vein margins at the MITCHELL-SHEBA occurrence (MINFILE 1150 068)(Fig. 2).

Like the foliaform veins, discordant veins consist mainly of milky white to locally clear, coarse grained quartz. Coarse grained amethyst crystals line a vuggy cavity in a discordant vein near the north end of the HUNKER DOME occurrence (Fig. 2). A greater range of vein minerals is generally present in the discordant veins than in the foliaform veins. Barite, calcite, ferroan carbonate and rare rutile and feldspar occur locally as gangue in some of the veins. Scheelite appears in placer concentrates from most drainages in the Klondike (Gleeson, 1970), and coarse scheelite and barite grains have also been recovered from colluvial deposits in an area with abundant discordant veins near the ROBIN occurrence (MINFILE 1150 148) on Oro Grande Gulch (Fig. 2). Although scheelite has not been found in outcrop, it is most likely derived mainly from the discordant veins.

The discordant veins typically display very low sulphide concentrations. Pyrite is usually present in at least trace amounts, mainly as discontinuous selvages along vein walls or as irregular disseminations in vein interiors. Galena also commonly occurs in trace amounts, typically as disseminated grains and grain aggregates associated with pyrite in vein interiors. In relatively sulphide-rich portions of the discordant veins, other sulphides and sulphosalts including sphalerite, chalcopyrite, tetrahedrite, and rare pyrrotite, arsenopyrite and pyrrargyrite have also been noted.

Visible gold is present in a number of discordant veins in the Klondike District (Fig. 2). It is typically associated with sulphide (especially pyrite) concentrations, and occurs both in pyritic selvages and as disseminations in vein interiors. The

gold occurs as flakes and irregular inclusions up to 5 mm in diameter in pyrite (and in masses of limonite after pyrite) and as free grains of similar size in quartz. Crystalline gold has been reported from discordant veins at the LONE STAR occurrence (Tyrrell, 1912). Zones of relatively high gold grades appear locally in some veins; for example, assays of up to 857 g/t (25 opt) have been reported for handpicked specimens of vein material from the HUNKER DOME occurrence (Fig. 2) (Yukon Minfile, 1991). Pyrite-rich discordant veins in the vicinity of the Lone Star mine locally contain abundant visible gold. Such veins include narrow, shallowly dipping quartz-pyrite and pyrite veins and stringers in the open cut at the Lone Star mine itself (Fig. 2) and a very pyrite-rich vein (now largely altered to limonite) near the ROBIN occurrence on Oro Grande Gulch (Fig. 2). There appears to be an empirical correlation between the gold and pyrite contents of discordant veins, although it is also possible that the pyrite-rich veins described above represent a different (possibly younger) discordant vein event.

Mineralized discordant vein systems in the Klondike District produce irregular zones of weakly to moderately anomalous gold and arsenic values in soil which are locally associated with sporadic anomalous Pb, Zn and Cu values (Yukon Minfile, 1991).

The nature and extent of alteration around discordant veins is controlled to some extent by the mineralogy and bulk composition of the wall rocks. Felsic wall rocks are generally visually unaltered, but the more mafic lithologies, especially the chloritic schist unit, commonly display discernible alteration up to 3 m from the margins of discordant veins. The alteration consists mainly of introduction of ferroan carbonate into the wall rocks where it imparts a distinctive brownish weathering character to the otherwise green-weathering chloritic schist. The carbonate alteration is particularly well developed in an area of bulldozer trenching along the MITCHELL vein (MINFILE 1150 068)(Fig. 2). Pyritization and sericitization also occur locally in narrow zones adjacent to discordant veins in the chloritic schist. At the MITCHELL occurrence (MINFILE 1150 068)(Fig. 2), narrow zones of fine to coarse euhedral pyrite grains locally comprise up to 40% of the wall rock by volume within 1-4 cm of the vein walls. At least some of the pyrite is formed from the sulphidization of magnetite porphyroblasts that are abundant in some bands in the chloritic schist unit in this area. The remainder of the schist in these zones is strongly bleached and altered to a muscovite-quartz assemblage. R.J. Cathro reported that samples of pyritic bleached schist adjacent to the MITCHELL vein assayed between 3.4 and 39.7 g/t gold (Yukon Minfile, 1991). The gold content of the alteration halo significantly increases the potential for proving up mineable tonnages of ore from relatively narrow discordant vein systems.

VEINS IN GREENSTONES AND ULTRAMAFIC ROCKS

Quartz and quartz-carbonate veins occur in massive greenstone and altered serpentinite in the northern and central

parts of the Klondike District. Greenstone-hosted veins are exposed in new road cuts on the Midnight Dome access road and along the Klondike Highway east of Rock Creek (Fig. 1). They are typically quartz-rich, and are superficially similar to the discordant veins described above, but contain no sulphides and tend to be more irregular and discontinuous than the discordant veins in schistose wall rocks. Ferroan carbonate-rich veins occur within silica-carbonate altered serpentinite ("listwanite") in two areas on lower Hunker Creek. These include the BEN LEVY occurrence (MINFILE 116B 157) and a new occurrence exposed by bulldozer stripping approximately 2.5 km to the northwest (MINFILE 116B 167)(Fig. 2). The BEN LEVY occurrence consists of a vein at least 5 m thick which has been explored by limited underground development and by recent reverse circulation and core drilling by United Keno Hill Mines Ltd. It appears to dip moderately northeast and consists of 1-5 mm bands of comb-structured ferroan carbonate with rare interbands of clear fine grained quartz. Vuggy cavities, usually lined by drusy quartz crystals, appear locally, and angular fragments of strongly carbonatized serpentinite (and minor carbonaceous schist) occur within the vein. No sulphides are present in the vein or in adjacent wall rocks, and only trace levels of gold were detected (A.J. McFaul, pers. comm., 1988).

The second occurrence consists of irregular, coarse grained, apparently discontinuous ferroan carbonate-quartz veins and vein breccias up to 0.5 m wide. Disseminated rutile needles and blebs of galena, chalcopyrite, and pyrite are locally present. No assay information is presently available for this occurrence.

VEINS IN EOCENE IGNEOUS AND SEDIMENTARY ROCKS

Two distinct types of veins are included in this category. Medium grained quartz-calcite-epidote-tremolite-sulphide veinlets up to 2.5 cm wide occur in mafic porphyry dykes of inferred Eocene age on the west side of the Yukon River across from Dawson. This occurrence lies less than 300 m west of the WEST DAWSON occurrence (MINFILE 116B 015)(Fig. 2), a Cu-Pb-Ag skarn developed in calcareous bands within the graphitic schist unit. Sulphides present in the veinlets include chalcopyrite, pyrite and galena. Wall rocks appear to be weakly carbonatized. The identical mineralogy and Pb isotopic signature of the veins and skarn mineralization suggest a close genetic relationship.

Veining is also associated with high-level quartz-feldspar porphyry intrusions, felsic tuffs and coarse clastic rocks of Eocene age in the northern and eastern portions of the Klondike District. The felsic igneous rocks typically contain high levels of fluorine (W.D. Sinclair and S.B. Ballantyne, pers. comm., 1988), and fluorite is present as both disseminations and narrow discontinuous stringers at several localities along lower Hunker Creek (MINFILE 116B 006)(Fig. 2). This mineralization was probably produced during late or post-magmatic volatile streaming. Chalcedony

veins to 10 cm wide and zones of chalcedonic breccia up to 1 m in diameter cut felsic lapilli tuff, volcanic breccia, and underlying pebble and cobble conglomerate and altered serpentinite between the mouths of Germaine and Goring creeks (MINFILE 116B 004)(Fig. 2). The chalcedonic material includes structureless, medium grey to resinous reddish brown open space fillings, and delicately laminated grey to very pale blue veinlets and crustifications. The veining is associated with intense kaolinization and silicification of wall rocks, and breccia fragments enclosed by veins are similarly altered. No sulphide mineralization has been found immediately adjacent to the chalcedony veins, although clay-altered felsic and mafic dykes of the Eocene suite locally contain up to 2% pyrite elsewhere in the Klondike. The veins and associated alteration are variably anomalous in As, Hg, Sb and Tl, but available analyses indicate only rare anomalous precious metal values (S.B. Ballantyne, pers. comm., 1988). The style of veining and associated alteration, and the nature of its geochemical signature are typical of volcanic-hosted epithermal systems elsewhere in the Cordillera.

QUATERNARY VEINING

Plio-Pleistocene White Channel Gravel deposits have been intensely altered in several areas of the northern Klondike district (e.g. MINFILE 116B 159)(Tempelman-Kluit, 1982; Dufresne, 1986; Dufresne et al., 1986). Narrow quartz-chalcedony veins are observed cutting both metamorphic rocks and diabase dykes of probable Eocene age beneath these altered zones. These veins are generally less than 2-3 cm thick, and range from vuggy, banded and crustiform quartz (plus minor siderite) to thinly banded quartz and chalcedony veins. Both the veins and the associated alteration zones are geochemically anomalous for S, Ba, As, Sb, and Au, and are considered to be the products of an epithermal mineralizing system of Quaternary age (Dufresne, 1986; Dufresne et al., 1986, 1987).

FLUID INCLUSION STUDIES

Doubly polished chips for fluid inclusion studies were prepared from more than 100 samples of vein quartz from the Klondike District in order to define the temperature and salinity of vein fluids, and gain information on the paleopressures under which the veins formed. Data discussed here pertain to primary inclusions which are thought to represent the main phase of each vein formation event.

Epithermal Veins

Ten of the chips represent Eocene epithermal veins in the Germaine Creek area. The samples include chalcedonic vein quartz cutting Eocene quartz-feldspar porphyry, and vuggy quartz veins in the underlying brecciated serpentinite. No useable inclusions were found in these samples.

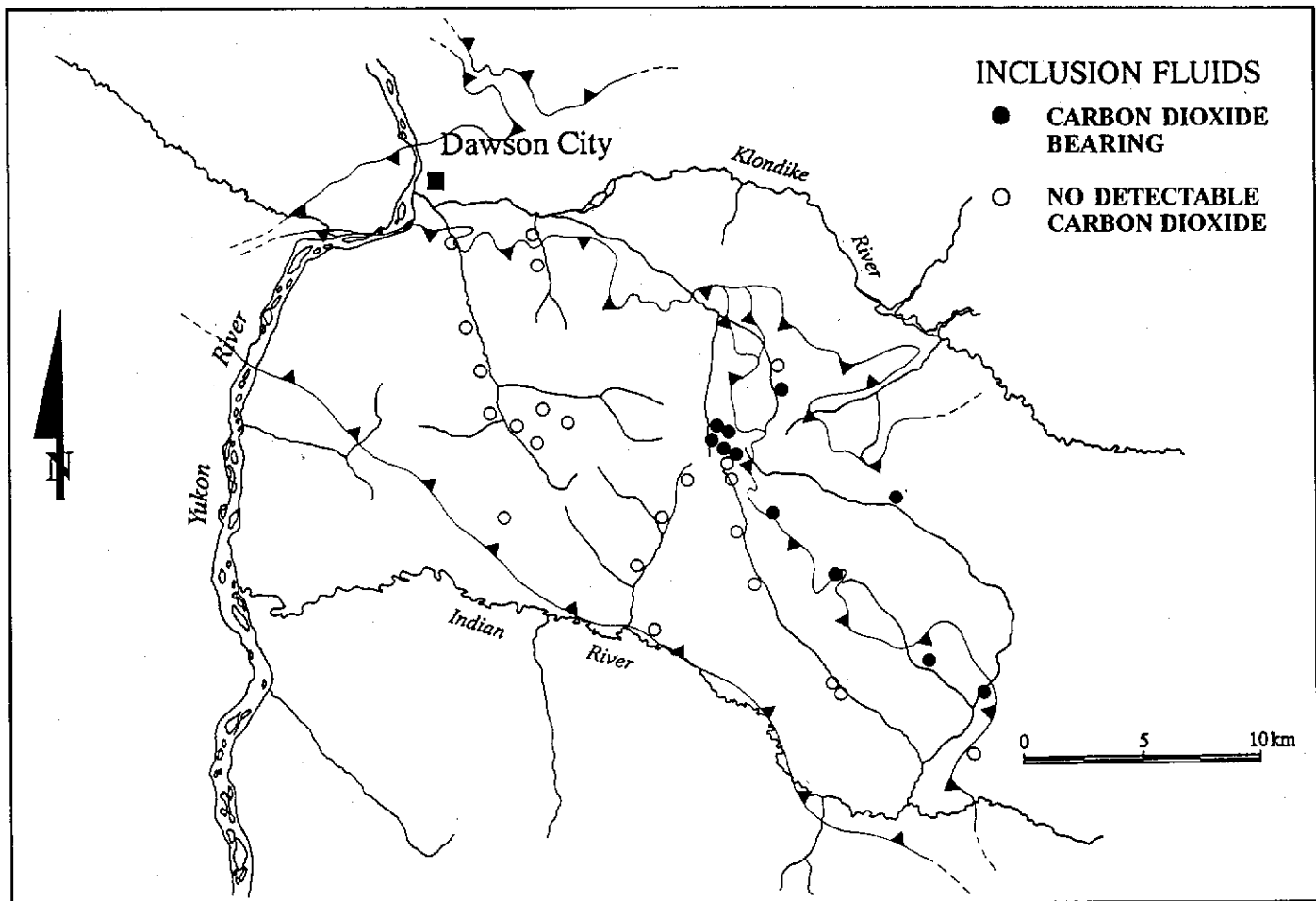


Figure 3. Map showing the distribution of samples analyzed for fluid inclusions and the occurrence of carbon dioxide in inclusion fluids. KSD refers to King Solomon Dome.

Mesothermal Veins

In contrast to the epithermal veins, excellent fluid inclusions were found in nearly all of the 80 chips prepared from mesothermal quartz vein samples. Both foliaform and discordant veins from a number of localities were examined.

Nesbitt et al. (1990) define mesothermal lode gold deposits as those formed at temperatures of 250-350°C and pressures greater than 600 bars. By averaging only those samples which gave results above 250°C, it is evident that the foliaform veins have a higher average homogenization temperature than the discordant population (Table 1). There is a suggestion that homogenization temperatures for both types of veins increase from north to south in the Klondike area, although further data are needed to confirm this.

Inclusion fluid salinities, determined from freezing experiments, are similar for both vein types, although the foliaform veins show a slightly larger range (Table 1). Detectable CO₂ in inclusion fluids is confined to veins in the east-central and southeastern parts of the study area (Fig. 3), and occurs predominantly in discordant veins. CO₂ homogenization temperatures range from approximately 20-

29°C and appear to decrease toward the south, possibly indicating an increase in paleopressure in this direction.

The apparent increase in homogenization temperatures toward the south-southeast approximately parallels the increase in metamorphic grade in that direction (Mortensen, 1990). The difference in average homogenization temperatures between the foliaform and discordant veins may reflect the slight difference in their relative ages. If, as field observations suggest, the foliaform veins are older than the discordant veins, they probably formed slightly earlier in the cooling history of the area, and therefore at slightly higher temperatures.

The occurrence of CO₂ in fluid inclusions appears to be confined to veins in the central and southeastern parts of the Klondike. This may also be due to the increase in metamorphic grade. Elevated paleopressures in these regions may have prevented the loss of CO₂ by effervescence from the vein-forming fluid during its passage through the host rocks. The presence of CO₂ in the mineralizing fluids may also explain the common occurrence of wallrock carbonatization around discordant veins in the King Solomon Dome area.

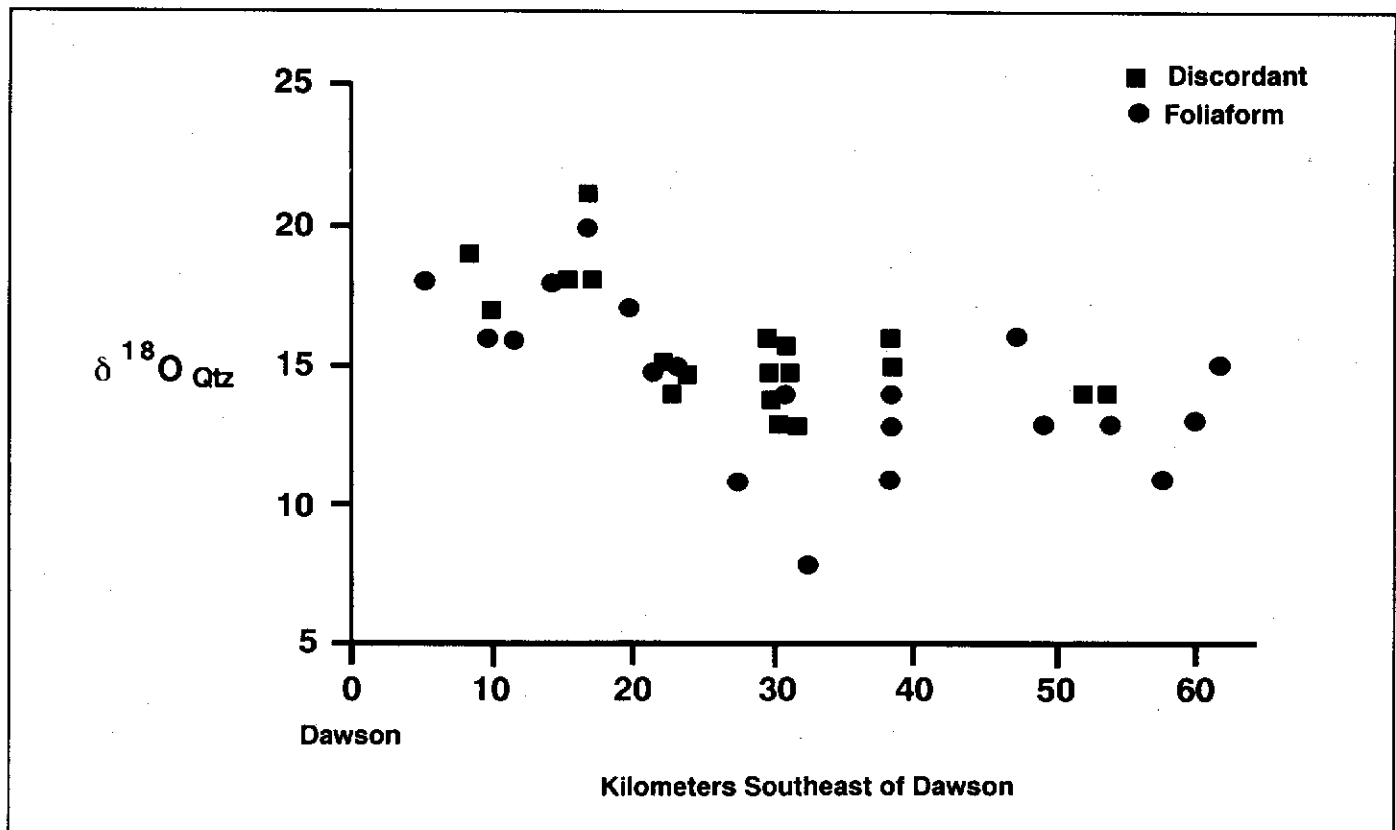


Figure 4. Projection of $\delta^{18}\text{O}$ values for discordant and foliaform mesothermal veins to a northwest-southeast reference line through the Klondike District (see Fig. 3).

Quaternary veins

Fluid inclusion studies by Dufresne (1986) and Dufresne et al. (1987) indicate that veins associated with intense alteration of White Channel Gravel deposits in the northern Klondike District formed at relatively low temperatures ($\approx 125^\circ\text{C}$) and were of low salinity (≤ 2 wt % NaCl equivalent).

LIGHT STABLE ISOTOPES

The principal objective of light stable isotope studies of the quartz (\pm carbonate) veins in the Klondike District is to document the origin and chemical evolution of fluids responsible for the formation of mineralized and barren mesothermal veins in the area. In addition, these studies are useful for evaluating the relationships between foliaform and discordant vein systems, as well as documenting any regional trends in isotopic patterns which might relate to the distribution of Au-bearing mesothermal veins.

Numerous samples were collected from vein systems which have been reported to yield high gold assay values. A number of samples were also taken from apparently barren veins throughout the Klondike. Quartz and carbonate from the veins were analysed for $^{18}\text{O}/^{16}\text{O}$ ratios. Carbonate and fluid inclusion CO_2 were analysed for ^{13}C , and δD analyses were

conducted on fluids extracted from fluid inclusions.

$\delta^{18}\text{O}$ values for mesothermal vein quartz range from +8 to +21‰ with most of the data in the +13 to 17‰ range. Where carbonate coexists with quartz in the mesothermal veins, the carbonate $\delta^{18}\text{O}$ is 1 to 4‰ lower than the $\delta^{18}\text{O}$ value for the quartz.

In Figure 4, $\delta^{18}\text{O}$ values for vein quartz are projected onto a line which runs between Dawson and the Gold Run-Dominion Creek junction. The data show a northwest to southeast regional control on the distribution of $\delta^{18}\text{O}$ in vein quartz. Near Dawson, the $\delta^{18}\text{O}$ values tend to be enriched in ^{18}O , ranging from +21 to +16‰. To the southeast, the $\delta^{18}\text{O}$ values decrease to the +13 to +16‰ range for LONE STAR (MINFILE 1150 072) and LLOYD (MINFILE 1150 066) veins and occurrences in the King Solomon Dome area, to +11 to +15‰ further southeast.

A comparison of $\delta^{18}\text{O}$ values for foliaform versus discordant veins (Fig. 4) does not reveal any consistent pattern of enrichment or depletion of ^{18}O between the two morphological types of veins, i.e. based on the stable isotope data the two vein types are indistinguishable. In addition, the results from areas of known mineralization and those from apparently barren veins in the same area are statistically identical.

Only six of the sampled veins contain carbonate. Results of ^{13}C analyses of these vein carbonates vary from -1 to -

11‰. Analyses of CO₂ from fluid inclusions produced a similar large spread of δ¹³C values varying from -5 to -17‰. The results from analyses of both inclusion CO₂ and carbonates are too limited at this stage to be of use in defining regional trends or comparisons between discordant or foliaform vein systems.

Approximately 20 samples of inclusion fluids have been analyzed for D/H ratios. The data cover a very wide range of values from -31 to -167‰ and appear to possess a regional zonation pattern similar to that observed in the δ¹⁸O study. Near Dawson, veins typically have relatively low δD values of -15‰ or lower. Areas of known mineralization near King Solomon Dome and at the LONE STAR (MINFILE 1150 072) and LLOYD (MINFILE 1150 066) occurrences typically have values in the -140 to -160‰ range. Farther southeast, δD values increase somewhat and are generally in the range -130 to 100‰. Additional work is needed to verify the apparent trend; however, there is a general indication that vein-forming fluids in the southeast part of the Klondike incorporated significantly higher proportions of D in the fluids. Similar to the results from the δ¹⁸O study there do not appear to be any distinct differences in D/H ratios between foliaform and discordant veins or between mineralized and apparently barren veins.

The results of the δ¹⁸O and δD studies, in addition to geological relationships and fluid inclusion studies, suggest that the depth of erosion in the Klondike increases from northwest to southeast, so that veins exposed in the southeast were formed at deeper levels than those in the northwest. Consequently, the vein systems of the Klondike offer an opportunity to observe the progressive evolution of a mesothermal vein system from deeper (southeast) to shallower (northwest) levels of exposure.

The regional trend recognized in the oxygen isotope results for vein quartz could either reflect increasing temperatures of vein formation toward the southeast or decreasing δ¹⁸O values in the vein-forming fluids. At present neither possibility can be excluded but based on the observation that the metamorphic grade in the Klondike increases to the southeast, it appears likely that the temperature of vein formation is higher in the southeast part of the area. Assuming a temperature of 350°C for vein formation in the southeast part of the region (see Fluid Inclusion section) and an average δ¹⁸O value of 14 ± 2‰ for vein quartz, calculations indicate the vein fluids had a δ¹⁸O value 9 ± 2‰. Farther north the estimated δ¹⁸O value of the vein-forming fluid is 7 ± 2‰. Considering the approximations incorporated into these estimates, these results show there is no significant difference between veins in the two areas in terms of δ¹⁸O.

The low δD values obtained from inclusion fluids in quartz veins near Dawson indicate that the major component of the vein-forming fluid was meteoric water. This result coupled with the relatively heavy δ¹⁸O values determined for the fluids indicates the vein-forming fluids consisted of deeply convected, isotopically evolved meteoric water (Nesbitt and Muehlenbachs, 1989). The increased δD values toward the

southeast can be explained either as the result of isotopic interaction of meteoric water with the wallrock at very low water/rock ratios (<0.1) or as a result of mixing meteoric and metamorphic devolatilization fluids with convecting meteoric water. Given the increase in metamorphic grade in the area, the second explanation involving mixing of meteoric and metamorphic fluids seems more likely.

The isotopic results show no significant distinctions between mineralized and unmineralized vein systems. However, in the area of known mineralization around the LONE STAR (MINFILE 1150 072), LLOYD (MINFILE 1150 066), and King Solomon Dome occurrences (MINFILE 1150 067,68), δ¹⁸O values begin to increase. This suggests that gold deposition was influenced by the vertical zonation of the fluid regime and that gold may have been preferentially deposited at a specific level in the system. Gold mineralization in the southeast part of the area may have been lost to erosion and in the northwest part of the area, the mineralized level may not yet be exposed.

Dufresne (1986) and Dufresne et al. (1987) report average δ¹⁸O values of +4‰ for epithermal veins of Quaternary age in the northern Klondike District. These values correspond to a calculated δ¹⁸O of -15‰ for the vein-forming fluids, indicating that these fluids were mainly meteoric water which had not interacted extensively with the host rocks.

LEAD ISOTOPE STUDIES

The lead isotopic composition of sulphide minerals, particularly galena, can provide important information about the ultimate source of metals in vein systems. More than 40 Pb isotopic analyses have been carried out at the Geological Survey of Canada on galena from the Klondike District. Most of these samples are from discordant mesothermal quartz veins. The results for the discordant vein samples fall in a broad range with ²⁰⁸Pb/²⁰⁴Pb = 38.8-39.5; ²⁰⁷Pb/²⁰⁴Pb = 15.67-15.78; and ²⁰⁶Pb/²⁰⁴Pb = 19.0-19.9. These relatively radiogenic compositions appear to preclude derivation of the Pb (and, by inference, the Au) in the veins from altered ultramafic rocks, as was suggested by Mortensen (1984). The data are interpreted to indicate mixing of Pb derived from a number of isotopically diverse sources, and the data therefore cannot be used directly to obtain information on the age of the mineralization.

Galena from veins cutting Eocene diabase dykes near the WEST DAWSON (MINFILE 116B 015) occurrences (Fig. 2) yields exactly the same restricted range of Pb isotopic compositions as Cu-Pb-Ag skarn mineralization in adjacent schist (²⁰⁸Pb/²⁰⁴Pb = 39.3; ²⁰⁷Pb/²⁰⁴Pb = 15.7; ²⁰⁶Pb/²⁰⁴Pb = 19.3). These compositions indicate that the two styles of mineralization are closely related, and are consistent with an Eocene age for the mineralization.

DISCUSSION

The preliminary results reported here indicate that several very different types of quartz veins occur in the Klondike

District. Both mesothermal and epithermal veins are represented, and at least three distinct ages of veining (middle or late Mesozoic, Eocene, and Quaternary) have been distinguished. Vein-forming fluids included meteoric water, metamorphic fluids, and, for at least some of the Eocene veins, magmatic fluids. This complex history of hydrothermal activity and vein formation has led to considerable confusion about which quartz veins are potentially gold-bearing. For example, much of the early hard-rock surface exploration in the Klondike was focused on foliaform mesothermal veins which can easily be identified in the field, and which are now known to be invariably barren. It is hoped that the results of this study will help constrain future lode gold exploration models for the area.

IMPLICATIONS FOR THE ORIGIN OF PLACER GOLD DEPOSITS

At least three of the styles of quartz vein described in this report contain anomalous levels of gold. Discordant mesothermal veins locally contain visible gold, some of which is quite coarse. Epithermal chalcedony veins of Eocene age yield sporadic anomalous Au values. Finally, Quaternary epithermal veins are moderately to strongly anomalous in Au. An important consideration regarding the source of gold in Klondike placer deposits, however, is that only relatively coarse gold had been recovered by historical (and present) placer mining methods. Gold in either of the two epithermal vein systems is likely to be too fine grained to have been recovered from the placers. Three possible candidates therefore remain for the ultimate source of the placer gold. These are (1) gold-bearing, discordant mesothermal veins, (2) coarse-grained gold originally deposited at a high level in Eocene epithermal vein systems, but now completely removed by erosion, and (3) coarse gold grown which grew within White Channel sediments during Quaternary epithermal

activity. Additional investigations are now in progress to attempt to determine from which source (or combination of sources) the bulk of the placer gold was derived.

CONCLUSIONS

Four main styles of quartz veining have been recognized in the Klondike District. Included are mesothermal quartz veins in metamorphic rocks, quartz-carbonate veins in altered ultramafic rocks and greenstones, epithermal chalcedonic quartz veins of Eocene age, and low-temperature epithermal veins of Quaternary age. These vein styles are sufficiently different that they can generally be distinguished in the field. Discordant mesothermal veins and Eocene and Quaternary epithermal veins are all known to contain at least geochemically anomalous levels of gold, although only the discordant mesothermal veins contain visible gold. Further investigations are required to determine the relative importance of these three styles of mineralization as the ultimate source(s) of the Klondike placer gold deposits.

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Table 1. Summary of fluid inclusion homogenization temperature and salinity data for Au-bearing discordant and barren foliaform mesothermal quartz veins.

	Discordant Veins	Foliaform Veins
T_{hom} (°C)	310 ± 30	330 ± 43
Salinity (wt-% NaCl equivalent)	4.3 ± 2.2	4.8 ± 2.9