Structure of a High-Grade, Electrum-Bearing, Quartz-Carbonate Vein Stockwork at the Brucejack Deposit, Northwestern British Columbia (NTS 104B)

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Introduction

One of the most commonly cited mechanisms for the formation of gold deposits invokes transport of gold in aqueous solution through the Earth's crust and localized precipitation due to changes in physical conditions or solution chemistry. Numerous examples of epithermal and orogenic deposits, where gold is contained in hydrothermal vein systems, have been explained by dissolved transport (e.g., Krupp and Seward, 1987; Simmons and Browne, 1990; Mikucki, 1998; Hayashi et al., 2001; Williams-Jones et al., 2009). However, solubility of gold in hydrothermal solutions is low (approximately 1–10 ppb in vapour and 100–1000 ppb in liquid; Heinrich et al., 2004; Williams-Jones et al., 2009; Zezin et al., 2011) and, in deposits where gold concentrations are highly variable and range locally to extremely high grades, it may be worthwhile to search for an alternative mechanism for gold transport and enrichment.

At the Brucejack deposit of Pretium Resources Inc. in northwestern British Columbia, gold is present as electrum, a gold-silver alloy, within epithermal quartz-carbonate veins. These veins locally show extremely high grades of gold (up to 41 500 ppm), occurring as porous or dendritic blebs of visible electrum approximately 0.5–5 cm in size. However, the adjoining wallrock and vein material are typically low grade (<1 ppm Au). The extreme 'nugget effect', or inherent unpredictability, of the spatial statistics of the gold-assay population presents complications for estimating the mineral resource. In order to help with resource estimation and further exploration, controls on gold mineralization, in particular the local enrichment of electrum within the quartz-carbonate veins, must be understood. The extreme concentration gradients of gold seen at Brucejack have led the authors to investigate the possibility that additional transport mechanisms may aid in localizing gold enrichment. One suggested mechanism is the transport of gold in colloidal suspension (e.g., Saunders 1990; Herrington and Wilkinson, 1993; Saunders and Schoenly, 1995; Hough et al., 2011).

The purpose of the study at Brucejack reported herein is to test the potential for colloidal deposition and contextualize the role of colloidal transport within the vein system by examining both quartz and electrum for evidence of relict colloids (cf. Saunders, 1990; Hough et al., 2011; Kirkpatrick et al., 2013; Faber et al., 2014). An essential aspect of the study is to describe and interpret the structural relationships within the faults, extensional veins and stockworks that constitute the vein system, and to understand the roles of hydrofracture, fault slip and static fluid flow in controlling vein-mineral precipitation and gold distribution. The aim of the project is to understand the specific deformational context of the formation of enriched veins, including the differentiation of sites of structural dilation that may have contributed to precipitation of electrum and quartz, and the identification of structural-trapping sites (e.g., vein jogs and intersections) where colloids may have ponded or adhered during hydrothermal flow.

This paper presents preliminary field observations from detailed vein mapping of a surface outcrop and underground intersections of mineralized quartz-carbonate stockwork systems that extend to depth within the Brucejack mineral resource. These observations led the authors to believe that quartz-carbonate stockwork veining is a result of multiple episodes of cyclic fault motion, with vein precipitation occurring between slip/fracture events.

Tectonic Setting

The Brucejack deposit is hosted by rocks of the Early Jurassic lower Hazelton Group, a package of arc-related vol-

Keywords: *Stikinia, Early Jurassic, Hazelton Group, Brucejack, stockwork, veins, quartz-carbonate, gold, electrum*

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cano-sedimentary rocks within Stikinia. Stikinia, along with other Paleozoic–Mesozoic arc and oceanic terranes of the Intermontane Belt, is interpreted to have accreted to ancestral North America by mid-Jurassic time (Monger et al., 1982; Nelson and Colpron, 2007; Gagnon et al., 2012). Following accretion, Stikinia was subjected to at least one major episode of compressional deformation during the mid-Cretaceous formation of the northeast-verging, sinistral-transpressive Skeena fold-and-thrust belt (Evenchick, 1991, 2001). This deformation gave rise to the McTagg anticlinorium (Figure 1; Henderson et al., 1992), where the thickness of the lower Hazelton Group decreases considerably from the east to the west limb. The change in stratigraphic thickness is interpreted by Nelson and Kyba (2014) to represent the presence of a paleostructural highland along the axis of the McTagg anticlinorium and a volcano-sedimentary basin to the east. Hazelton Group deposition within this basin was coeval with displacement along basin-bounding faults. Several large mineral deposits, including the Kerr-Sulphurets-Mitchell (KSM) copper-gold porphyries and the epithermal Brucejack gold vein-stockwork system, are located along a narrow south-southeast trend just west of the McTagg anticlinorium and are interpreted to relate to Jurassic magmatic and hydrothermal systems controlled by the basin-bounding faults (Nelson and Kyba, 2014; Febbo et al., 2015).

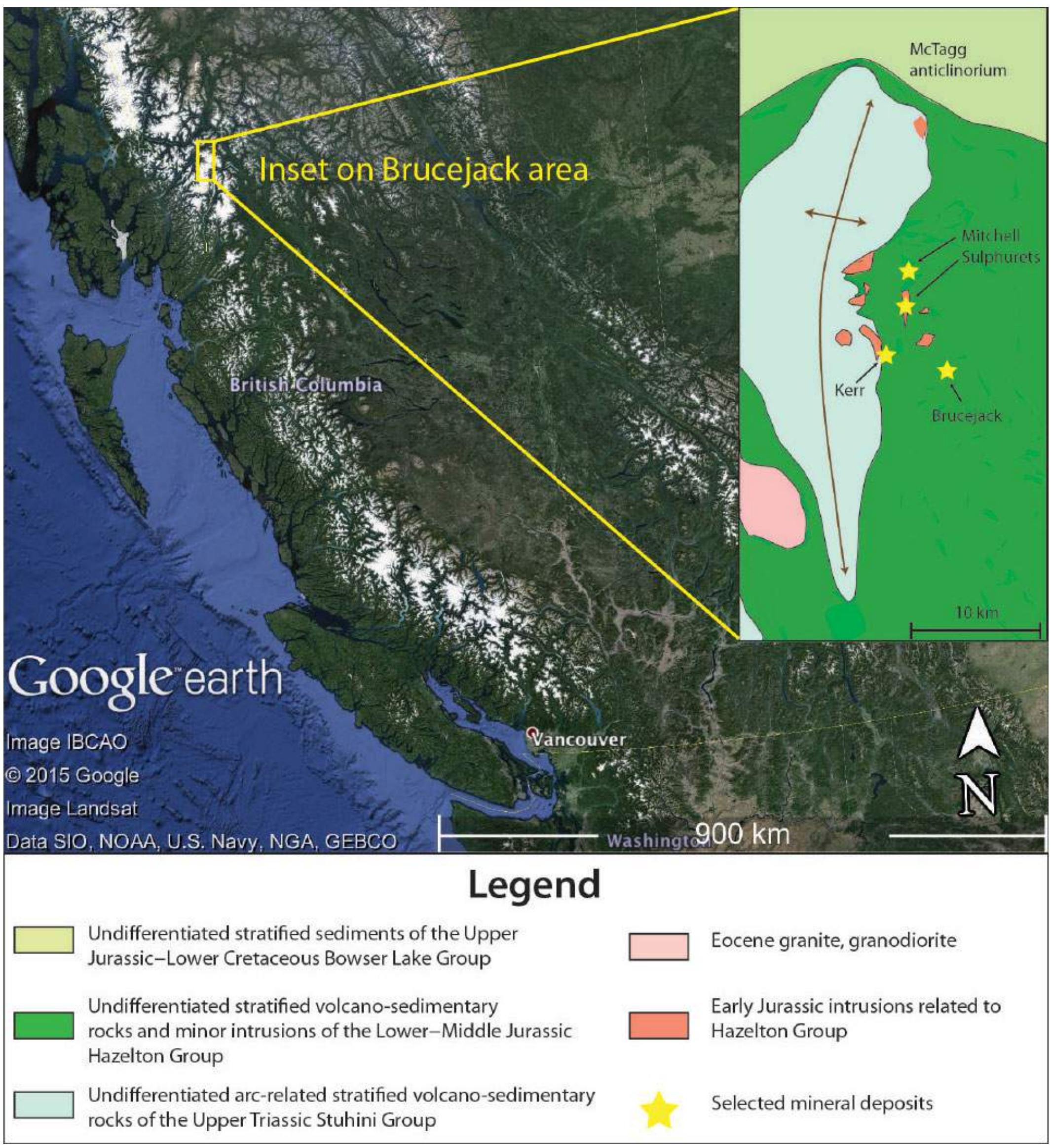

Figure 1. Google Earth™ image of the location of the Brucejack deposit in northwestern British Columbia. Inset on the left shows a simplified regional geology map with the location of the McTagg anticlinorium. The stars show the locations of three major copper-gold porphyry deposits, as well as the Brucejack gold-silver epithermal deposit. Geology contacts from Erdmer and Cui (2009) and legend modified from Nelson and Kyba (2014).

Deposit Geology

Quartz-carbonate stockwork veining in the Brucejack deposit hosts the majority of a total mine reserve of 7.3 million oz. gold and 35.3 million oz. silver (proven and probable reserves; Jones, 2013). Previous work at Brucejack has documented electrum-bearing quartz-carbonate vein networks that crosscut latite lavas and breccias, and associated immature volcaniclastic rocks (Board and McNaughton, 2013; Jones, 2013). The mineralized veins are found within a band of quartz-sericite-pyrite (QSP) alteration that follows the outline of broad easterly plunging folds. These fold axes are folded by a north-trending syncline, suggesting that polyphase deformation has occurred (Board and McNaughton, 2013; Jones, 2013). This coincides with polyphase-deformation interference patterns recorded in mid-Jurassic to early Cretaceous clastic sequences within the Bowser Basin that overlies Hazelton Group strata (Evenchick, 2001), and three phases of deformation recorded within the nearby Mitchell copper-gold porphyry deposit (Febbo et al., 2015). Peak metamorphism, up to lower-greenschist facies, within the Brucejack deposit coincided with the beginning of the formation of the Skeena fold-and-thrust belt at 110 Ma (Kirkham and Margolis, 1995; Evenchick, 2001). This later deformation has affected all of the early Jurassic mineralized-vein generations at Brucejack (Kirkham and Margolis 1995; Board and McNaughton, 2013; Jones, 2013). Lenses of silicified conglomerate have been correlated as a marker horizon that outlines the stratigraphy within the band of QSP alteration. Stockwork-vein systems follow an east-northeast trend and dip subvertically, subparallel to hostrock foliation, however, this foliation is believed to postdate vein formation (Kirkham, 1992; Davies et al., 1994; Board and McNaughton, 2013; Jones, 2013). Within stockwork zones, veins may occur in many different orientations. Although mineralization is hosted within veins, higher grades are not clearly correlated with vein intensity because diffuse stockwork zones with a smaller percentage of vein material may contain significant electrum.

Several generations of veining have been documented in the Brucejack deposit (Board and McNaughton, 2013; Jones, 2013; Tombe, 2015); pyrite veins that are suggested to be associated with early QSP alteration are crosscut by electrum-bearing quartz-carbonate veins. These quartz-carbonate veins exist as dense stockwork and stockwork breccia, and as parallel, decimetre- to metre-spaced, layered vein sets. They, in turn, are cut by quartz-carbonate veins containing base-metal sulphide (sphalerite, galena, chalcopyrite), electrum and silver sulphide mineralization. A third generation of manganoan carbonate-quartz veins contains local high-grade electrum mineralization. Quartz-chlorite fibrous slicken veins and tension gashes associated with later (probably Skeena fold-and-thrust belt) shortening crosscut all earlier vein systems. They contain limited chalcopyrite and no reported electrum.

Fluid-inclusion thermobarometry completed by Tombe (2015) yielded mineralized vein formation temperatures of approximately 160°C and co-trapping of liquid and vapour inclusions, indicating that boiling probably occurred during quartz precipitation. Rhenium-osmium dates on molybdenite suggest some of the initial veining occurred at 188 Ma (Tombe, 2015), and crosscutting relationships between an electrum-bearing generation of veins and 182.7 Ma, late syn- to postmineralization monzonite dikes suggest that the latest electrum-mineralizing event may have occurred at approximately this time (Pretium Resources Inc., 2013). Volcanic rocks on the property range in age from 196 to 182 Ma (U-Pb zircon; Pretium Resources Inc., 2013), and porphyritic intrusions related to copper-gold mineralization at the nearby KSM deposit have yielded U-Pb zircon ages of 197–189.9 Ma (Bridge, 1993; Febbo et al., 2015). If the deposits are related to the same magmatic activity, these dates suggest a long-lived magmatic-hydrothermal system lasting up to 15 million years.

Observations

In order to document the scale and geometry of the vein system at Brucejack, detailed maps were prepared of individual and composite vein orientations, lithology and patterns of alteration, at a scale of tens of metres, on surface exposures of major vein systems. These were then linked, in part using drillhole intersections, to structural measurements underground, where the same vein systems were intersected by active workings. Aerial photographs were acquired using a lightweight drone (DJI Phantom3 Advanced). Low-altitude airphotos were used to construct a three-dimensional surface model from which a detailed georeferenced orthophoto was extracted (methods described in Johnson et al., 2014). The orthophotos have a scale of approximately 1–2 pixels/cm, depending on the size of the outcrop. Veins were then mapped directly onto these orthophotos using a tablet, with locations of structural measurements and vein descriptions denoted by station names. Rock types were mapped directly onto paper printouts of the outcrop orthophotos. Three outcrop map areas (one shown in Figure 2) were chosen to get a good representation of the stockwork systems at Brucejack. Each of these areas is located around stockwork systems of different size and orientation, and within different hostrocks or alteration assemblages. The first location (Figure 3a, map area 1) was also chosen because this vein system may be correlative with ‘Domain 20’, an important gold-bearing vein system that is well exposed in the underground workings of the Brucejack mine. The focus of this preliminary paper is on observations of this vein system from surface and underground mapping.

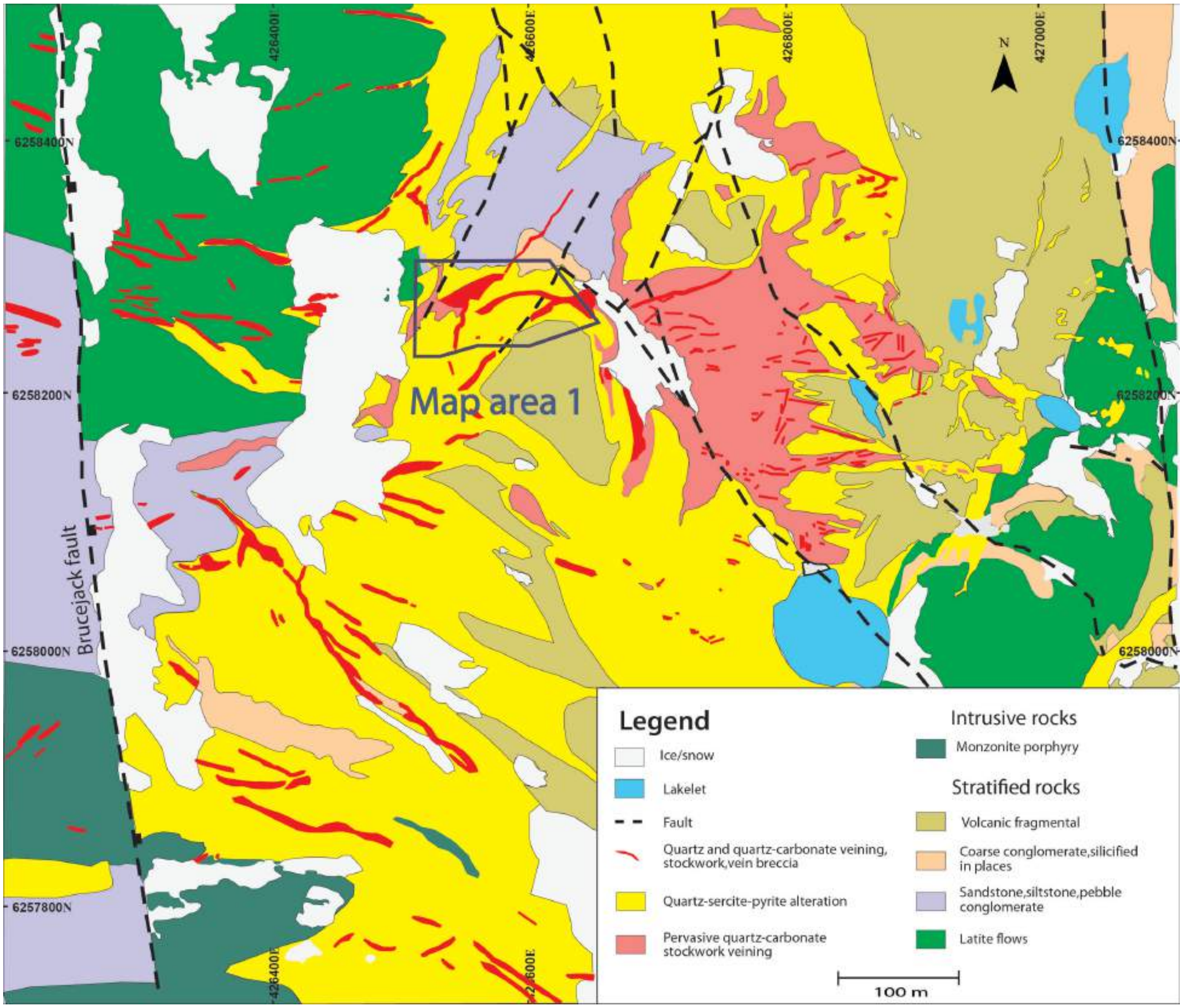

Figure 2. Simplified deposit geology of the Brucejack gold-silver deposit (modified from Pretium Resources Inc., unpublished data, 2015), with schematic representation of quartz-carbonate veining, stockwork and breccia (true thickness of veins approximately 0.5–10 m). Detail of map area 1 is shown in Figure 3. Stockwork system shown in map area 1 extends to the southeast as a broad zone of stockwork with both southeast- and east-striking veins.

Figure 3a presents the detailed outcrop geology of map area 1 (location shown in Figure 2). This outcrop is part of a large, steeply south-dipping stockwork system that strikes east-southeast to the west of the map area. Directly east of map area 1, Figure 2 shows northeast- to east-trending veins that are part of an area of pervasive quartz-carbonate stockwork that extends east and southeast for several hundred metres. This system may be linked to Domain 20 (see discussion), a stockwork zone that drillcore and underground workings show extends underground for 400 m along strike (east-southeast) and at least 400 m vertically (steeply south dipping; Pretium Resources Inc., unpublished data, 2015). Previous detailed surface mapping (Figure 2) shows that the stockwork system in map area 1 may actually consist of several large, en échelon stockwork zones (Pretium Resources, unpublished data, 2015). Figure 3a depicts one of these large zones and subsidiary stockwork.

Figure 3a shows that map area 1 contains several composite quartz veins, the largest of which is up to 10 m wide and strikes ~240° for at least 60 m. The boundaries of the smaller individual veins that form the composite 10 m wide zone can be distinguished only on the weathered surface of outcrop. Some of these individual veins are subhorizontal, creating a cap with less susceptibility to erosion that may enhance the strong positive relief of the vein in outcrop. On the southern edge of the intensely veined zone is 10–20 m of less intense stockwork and vein networks cutting intact wallrock, where several additional parallel stockwork zones, up to 4 m in width, were mapped. At the eastern edge of the mapped area, there is a 2–3 m wide stockwork zone

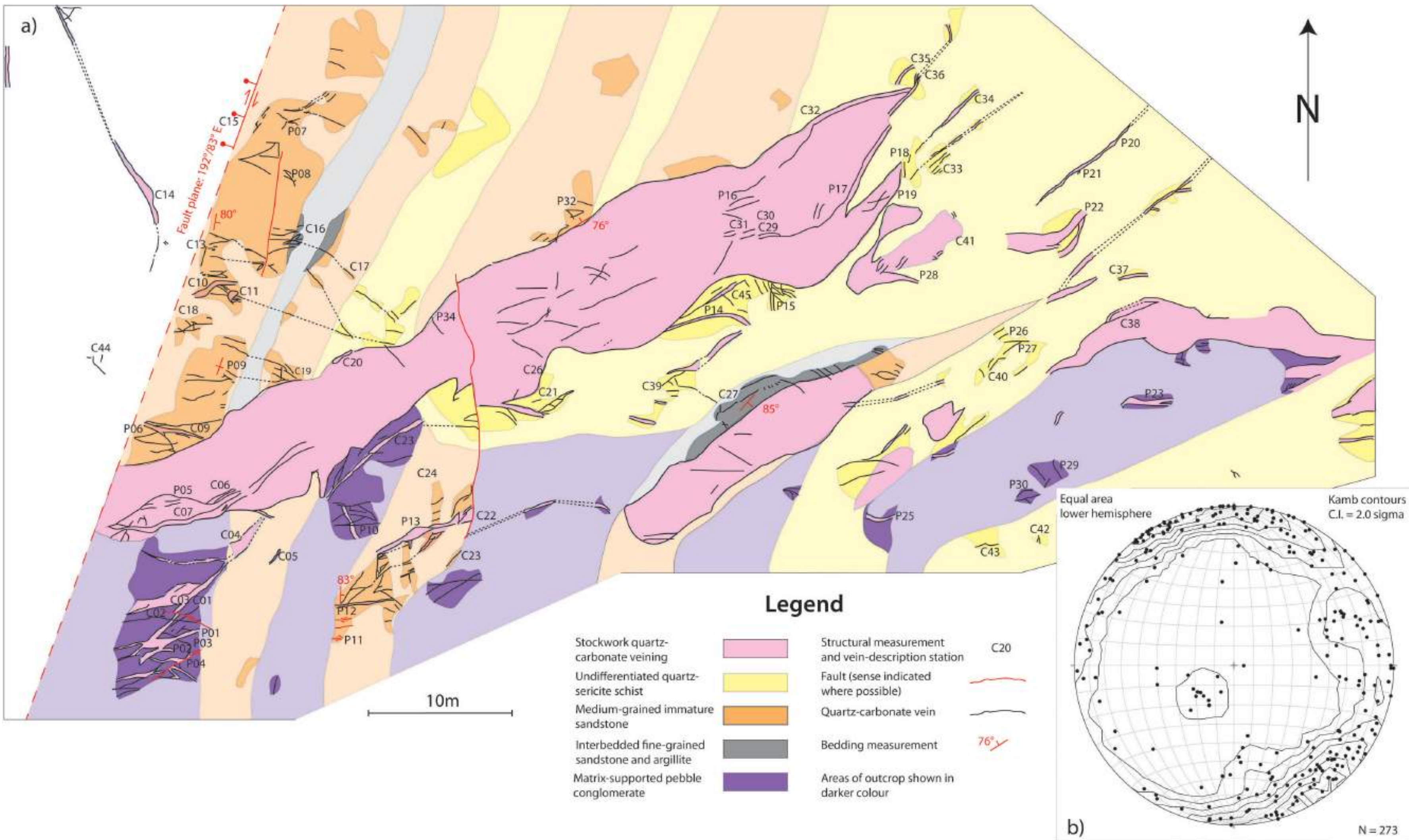

Figure 3. **a)** Lithology, stockwork quartz-carbonate veining and faults in map area 1 of the Brucejack gold-silver deposit (see Figure 2 for location). **b)** Equal-area projection of poles to vein orientations measured at stations indicated in (a); Kamb contours indicate concentration of poles. See text for further description.

that strikes east. At the western edge of the main stockwork zone, a 2 m wide fault zone offsets veining by reverse right-lateral motion (Figure 3a, station C15). To the north of the main stockwork zone, there are several veins that join with the main stockwork zone. These east-southeast-trending veins can be up to a metre wide. The surrounding zone of stockwork is typically not symmetric about the core (Figure 3a) and may consist of subsidiary zones of dense stockwork veining ~1 m wide. Along strike to the northeast from the largest stockwork zone, several continuous quartz-carbonate veins up to 1 m in width continue out of the map area at the same 060° azimuth as the main zone (station C34).

In total, 273 vein orientations were measured at indicated stations throughout the map area (Figure 3a, b). Mapping and equal-area projection plots of these veins indicate at least three sets of orientations: 1) continuous, east- to northeast-striking veins, up to 1 m wide, that are parallel with the main (en échelon) stockwork zones; 2) discontinuous, north-trending veins and veinlets (many below map scale on Figure 3a) located mainly in the eastern half of the map area; and 3) centimetre-scale, subhorizontal veins associated with dense stockwork zones. Many of the quartz-carbonate veins throughout the area of surface outcrop change orientation near intersections with other veins. Intersections where several veins coalesce are common, with each vein bending or following a previous fracture or vein toward a single intersection (Figure 4a). This geometry is evidence that at least some of the veins were open fractures when subsequent veins formed, acting as free surfaces to reorient the local stress field during crack propagation.

Lithological mapping is difficult due to the intensity of the QSP alteration around the stockwork veining, which serves to obliterate diagnostic rock textures. The rock type close to the intense veining is predominantly undifferentiated quartz sericite schist. However, there are areas with mappable units of immature medium-grained sandstone, interbedded finer grained sandstone and argillite, and matrix-supported pebble conglomerate. To the north of the main stockwork zone, there are regular 3–10 m wide beds of coarse sandstone, interbedded sandstone and undifferentiated quartz-sericite schist. To the south, there are irregular beds of pebble conglomerate. This juxtaposition of dissimilar rock sequences across the stockwork zone suggests that it coincides with a fault. Measurements and contact traces indicate that stratigraphy is steeply dipping and strikes north-northeast to northeast. Northeast-striking units are situated proximally southeast of the main stockwork zone and may trend closer to north farther along strike to the southwest, away from the large stockwork zone. To the north and southwest of the main stockwork zone, the unit contacts strike north-northeast. This pattern may indicate dextral drag of bedding along the southern contact of the stockwork zone, suggesting shear along the vein system.

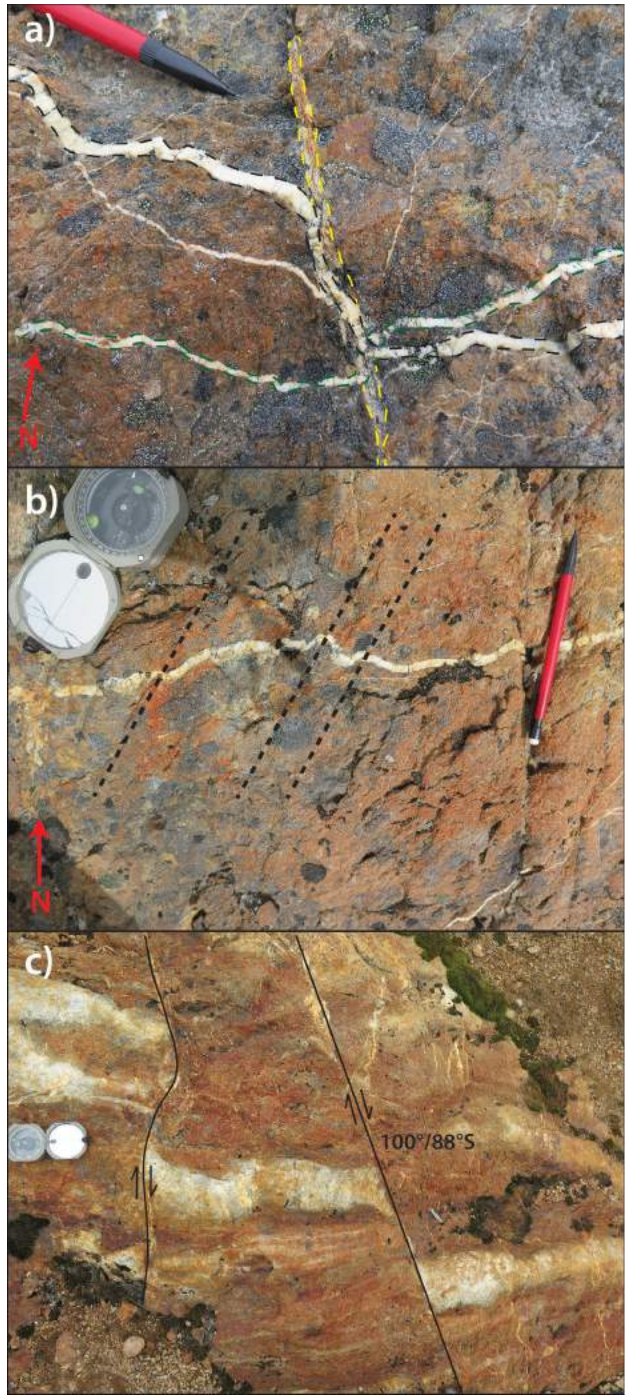

Figure 4. Photographs showing textures and geometry of veins and faults in map area 1 of the Brucejack gold-silver deposit: **a)** syntaxial quartz-carbonate veins bending and coalescing (green and black) along the surface of an earlier vein (yellow), station P10 (Figure 3a); **b)** disharmonic folding of a quartz-carbonate vein, the axial planes of the folds trending approximately 035°, station P10 (Figure 3a); **c)** two subvertical faults showing approximately 20 cm of apparent dextral offset of sandstone beds, station P11 (Figure 3a).

Minor faults mapped to the south of the main stockwork zone show minor left- and right-lateral apparent offset on the 10–50 cm scale. Only 12 exposed fault planes were measured in map area 1, which is not enough to construct a kinematic analysis, but a distinct set of faults was observed that is parallel to the large fault cutting the main stockwork zone on the western side of the map area. These faults strike east-southeast and dip steeply to the east. A few steeply dipping faults subparallel to the main stockwork are also exposed. They show both right-lateral (Figure 4b) and left-lateral apparent offset (Figure 3a, stations P01, P04, P11). Several veins were deformed into disharmonic folds (Figure 4c). The axial plane of these folds strikes ~35° with approximately subvertical dip, indicating some southeast-directed shortening that postdates vein formation.

Veins in map area 1 (Figure 3a) are predominantly quartz with minor calcite, although a small stockwork zone with 0.5–1 m thick, grey-weathering blocky calcite was mapped directly southeast of the main stockwork (Figure 3a, station C31). These carbonate veins show multiple phases of mineralization, with quartz layers in the centre and along the wallrock, as well as along fractures within the grey calcite. Quartz in this area displays a bladed crystal habit similar to that of calcite, suggesting that it pseudomorphed after calcite. Within the main stockwork zone, multiple phases of veining crosscut one another and are locally brecciated. Similarly, large bull quartz veins were observed in the underground workings crosscutting early-silicified wallrock and breccia, as well as early veins of banded colloform quartz with local cores of cryptocrystalline silica. Quartz growth in most veins, where it can be observed, is syntaxial, with symmetric crystal growth away from the wallrock toward the centre of the vein (e.g., Bons et al., 2012). Similar euhedral to blocky quartz is also found as rims on many of the breccia clasts, with radial quartz growth occurring from clast boundaries into pore space. Both of these textures suggest there was open-space growth of quartz.

Electrum mineralization is not observed in the outcrop of map area 1 due to weathering and gossan formation on the surface. However, it can be seen in multiple locations underground (Figure 5). It is located in predominantly quartz-carbonate vein breccia within or proximal to the main stockwork zones (Figure 5c). Electrum can be present in reworked quartz-carbonate vein clasts within vein stockwork (Figure 5c), as well as in more continuous veins and sheeted veins. At least one location shows electrum crosscut by a later syntaxial quartz vein, indicating that stockwork formation occurred for some time after some electrum precipitation or deposition. Base metal–sulphide (galena, sphalerite, chalcopyrite) quartz-carbonate veins are visible underground. They contain silver sulphosalts and silver-rich electrum, and can be tabular and continuous over tens of metres.

Where the tentatively related stockwork system (named ‘Domain 20’ by Pretium Resources Inc.) is exposed in the walls of underground workings down-dip from map area 1, patterns similar to those observed on surface emerge (Figure 5a). However, with a much smaller number of measurements underground, the clustering is less clear in equal-area projections (Figure 5b), and the measured vein orientations do not belong to the same population shown in Figure 3b. The thickest veins may dominate the pattern seen in outcrop, which makes it visible in outcrop but obscured on the equal-area projection that includes all vein measurements. Underground, a distinct set of vertical veins parallel to and south of the main stockwork can be seen. Sigmoidal tension gashes that crosscut steep veins can be seen in the footwall of a significant reverse fault. However, these definitive fault-related veins are the latest stage of veining seen in Figure 4a and do not appear to be related to the stockwork veining in Domain 20.

Discussion

The vein systems seen in map area 1 and in the underground workings of the Brucejack deposit show a textural relationship. Both show a (5–10 m wide) core zone with intense stockwork consisting of several generations of quartz-carbonate veins whose contacts are difficult to discern. Away from this core zone, vein intensity diminishes, and a sharper boundary is observed on the north contact (footwall) of the core stockwork. To the south, large, steeply dipping veins with associated stockwork are spaced centimetres to decimetres apart within a region up to 20 m away from the core, in the hangingwall of the stockwork system. These large parallel veins can be seen close to the south contact (hangingwall) of the core zone in both the ~80 m long (strike-parallel) surface map and the ~15 m long (dip-parallel) underground exposure. Measured vein orientations underground and on surface, however, are different (Figures 3b, 5b), with the underground veins showing a distinct southeast trend compared to the east-northeast trend of those in map area 1. Also, a direct projection of the Domain 20 stockwork system to surface (Pretium Resources Inc., unpublished data, 2015), using both drillhole intercepts and underground measurements, would lie 100 m to the south of map area 1. There is a distinct possibility that the two sites do not expose the same continuous vein system; they may be linked, however, via one of the following three scenarios:

- The Domain 20 system could branch updip, meaning that the stockwork seen in map area 1 may represent a northern branch of Domain 20 (Figure 6a).
- To the east of map area 1, an extensive stockwork zone that extends both east and southeast (Figure 2) contains en échelon east-trending veins (Figure 2). This type of en échelon pattern may also extend downdip from map

area 1, causing the stockwork system to step south downdip (Figure 6b).

- The stockwork has been displaced along one or more north-verging thrust faults (Figure 6c). Figure 4a shows a steeply south-dipping reverse fault cutting the main stockwork zone of Domain 20 underground. Motion is deduced from tension gashes and offsets on tension gashes along a conjugate fault below the main through-going fault plane. Late north-verging thrust faults that could be related to formation of the Skeena fold-and-thrust belt have been mapped elsewhere in underground workings, on surface and using drillholes (Board and McNaughton, 2013; Jones, 2013). Combined northward heave on several of these faults between the outcrop and the exposures in the underground workings may result in an offset between the projected location of Domain 20 and the outcrop in map area 1 (Figure 6c).

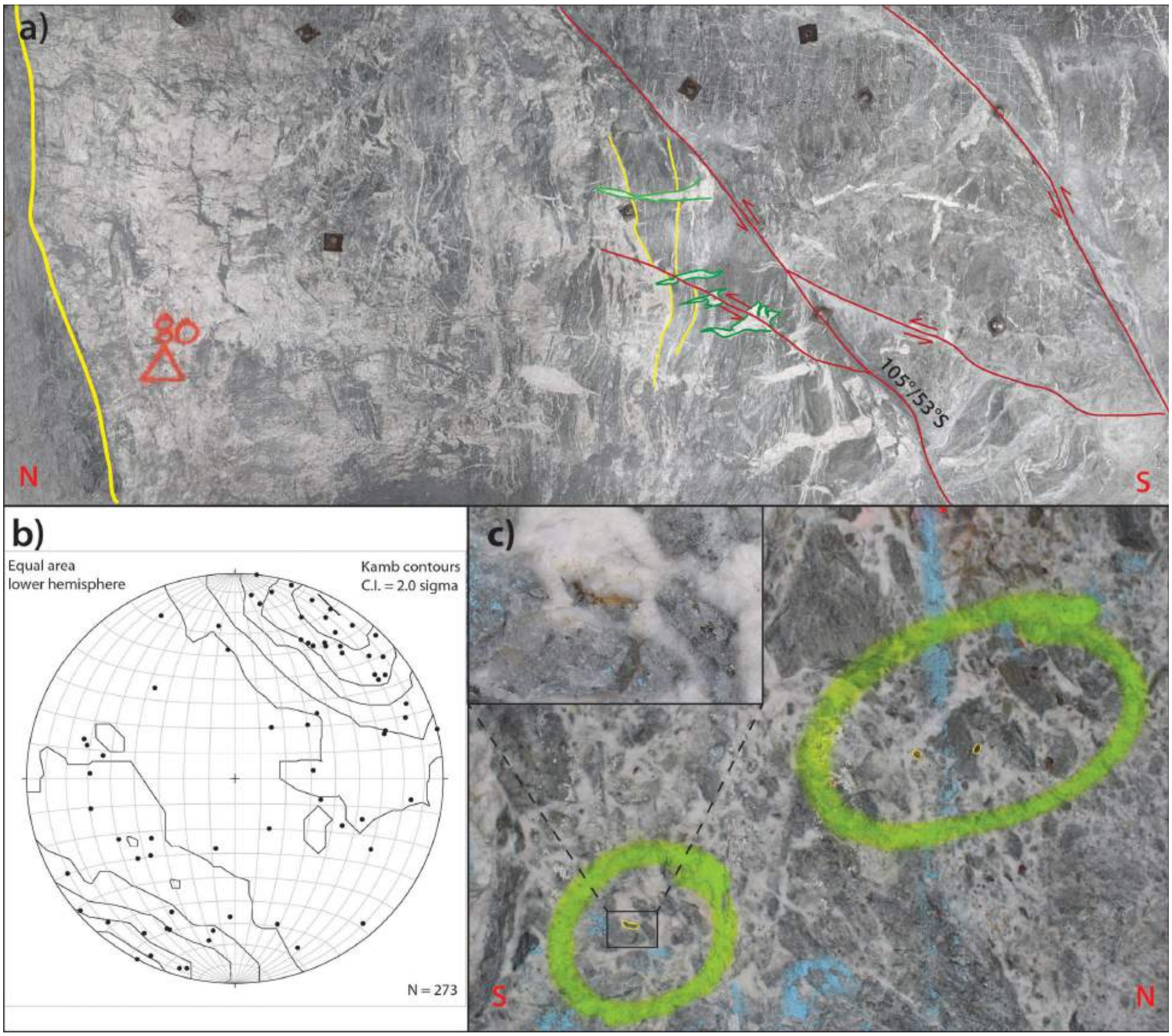

Figure 5. Photographs and measurements of stockwork exposure in the underground workings at the Brucejack gold-silver deposit: **a)** Domain 20 exposure in the east wall of a crosscut; view of vertical wall is approximately 8 m wide and faces east; yellow lines indicate subvertical veining and the sharp northern contact of the core stockwork zone of Domain 20; location of the subvertical veins highlighted in yellow on the south side shows where there is a transition from the core stockwork zone to less intense quartz-carbonate veining; red lines show late faults with associated tension-gash veins that crosscut subvertical veins highlighted in green; **b)** equal-area projection shows poles to 71 veins; Kamb contour interval is 2σ; measurements were taken from both the east and west walls of the photographed crosscut, as well as both the east and west walls of another exposure updip (85 m vertically above photo); **c)** quartz-carbonate breccia along the north (footwall contact) of Domain 20; small yellow circles indicate electrum-quartz vein fragments that form clasts in the breccia; circle spray-painted green in bottom left of photo is approximately 15 cm in diameter; inset in top left corner shows electrum within a clast of older grey quartz surrounded by younger white quartz that forms cement within the breccia.

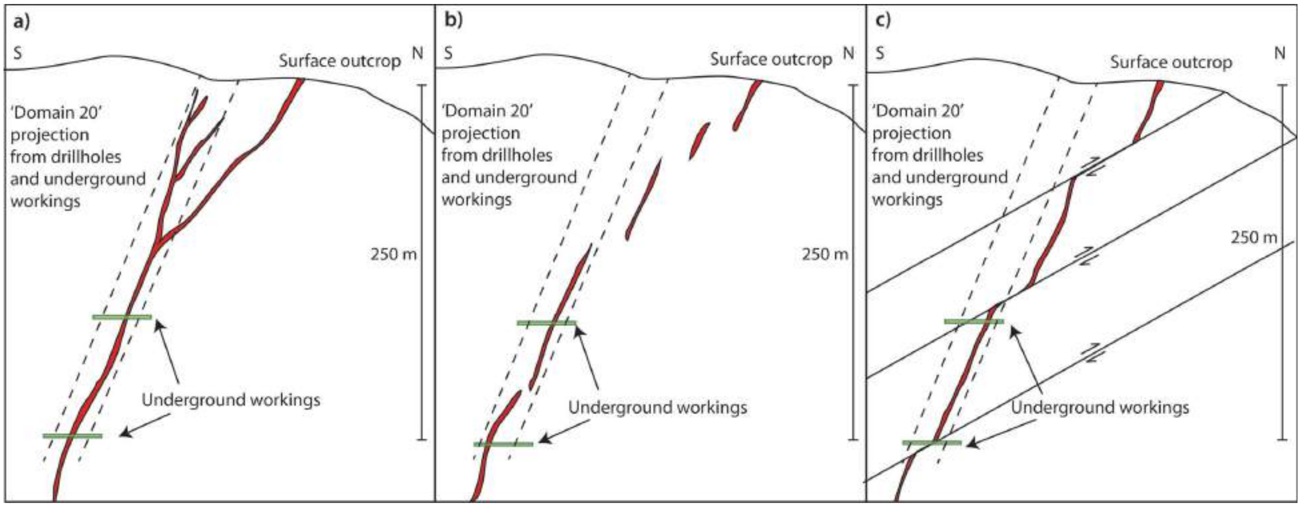

Figure 6. Schematic representation of the projection of Domain 20 from underground workings, drillhole intercepts and surface outcrop of stockwork to the north (map area 1), being offset by **a)** branching stockwork geometry, **b)** en échelon stockwork veining, or **c)** north-verging thrust faults.

However, these scenarios do not explain the differing orientations of veins between map area 1 and the underground exposure (Figures 3b, 5b).

A number of observations suggest that the stockworks of map area 1 and Domain 20 occupy fault/shear zones. The offset in rock units across the stockwork zone, and the similarities in geometry of the stockwork and surrounding zone of veining to fault-zone cores and damage zones described in the literature (e.g., Chester and Logan, 1986; Smith et al., 1990; Forster et al., 1991; Caine et al., 1996), indicate that these types of stockwork features (which include Domain 20) formed along fault zones. In the case of the mapped outcrop, the massive composite quartz vein is the fault core and the surrounding steep veining is the damage zone, with veins appearing to follow fracture sets with Andersonian fault geometry (e.g., Caine et al., 2010). Figure 3a shows several areas (stations C03, C09, P10) where sets of steeply dipping conjugate veins may exist. Equal-area projection plots of poles to vein orientation from both the underground workings and the surface outcrop show predominantly steep veining, and the range in strike of these veins reflects varied damage-zone fracture geometry. At least one of the exposures of the Domain 20 stockwork system in the underground workings shows an abrupt contact between stockwork and wallrock on the north contact (the footwall) of the main stockwork zone. On the south (hangingwall) contact, there is an extensive zone of less intense stockwork veining. Similarly, the north contact on the surface map displays a significant drop in stockwork-vein intensity (Figure 3a). Here, several large veins are mapped, but vein size and intensity are less than to the south, where 10–20 m of less intense stockwork veining is mapped.

These outcrop patterns show an asymmetry in veining about the core stockwork zone. Asymmetry in damage zones around faults due to asymmetric strain distribution can be a result of lithological or structural contrast across a fault zone (e.g., Aydin and Johnson, 1978; Antonellini and Aydin, 1995; Nelson et al., 1999; Mitra and Ismat, 2001; Clausen et al., 2003; Doughty, 2003; Berg and Skar, 2005). Mapped rock units in Figure 3a show a pronounced bend near the southern contact of the core stockwork zone. This may be due to drag folding of strata during apparent dextral fault motion. Exposures in the underground workings show areas of brecciation along the contacts of the core stockwork zone (Figure 5a, c) that could also be a result of faulting. Clasts within this breccia include quartz-carbonate vein and wallrock, indicating that the fault zone was active during the formation of stockwork vein systems such as Domain 20.

Although the overall geometry of the stockwork in map area 1 is suggestive of shear offset, many of the veins within the stockwork do not show measurable offset across them and are interpreted as opening-mode veins. Syntaxial quartz growth indicates open-space quartz crystallization, which may be evidence of supra-lithostatic fluid pressure (Wilson, 1994; Bons et al., 2012). This syntaxial texture is seen in all orientations of veins, including subhorizontal veins, further supporting the suggestion of extremely high pore pressure. As most of the quartz is syntaxial and euhedral, and there is a lack of consistent offset across veins, the authors deduce that quartz-crystal growth did not occur during periods of major slip along faults. Much of the quartz precipitation occurred during periods of static high fluid pressure between slip and fracturing events, or within pressurized fracture networks in the damage zone of the fault. However, cryptocrystalline quartz within some vein cores may also indicate that rapid silica precipitation occurred during changes in temperature or pressure caused by seismic events. As there are many crosscutting relationships between isolated veins, large composite veins and vein breccias containing clasts of quartz-carbonate vein material (including electrum-mineralized veins), it can also be deduced that the formation of stockwork veining occurred during multiple seismic events. These seismic events must predate later Cretaceous transpression during emplacement of the Skeena fold-and-thrust belt.

Examination of the electrum mineralization in the Domain 20 stockwork system underground does not show that it occurs at any preferred structural traps. This may be due to the fact that electrum is locally observed in clasts and vein fragments within the core stockwork zone, and so was inherited from older vein systems that have been reworked into the present vein geometry. Consequently, deducing the original location of electrum precipitation when it occurs as a clast may be difficult. Instances of electrum mineralization being crosscut by later syntaxial quartz-carbonate veining indicate that the mineralization was not an isolated later event. Instead, the electrum mineralization is considered to have formed both early in the development of the stockwork and coeval with the stockwork development.

Conclusions

Vein mapping and observations on selected large quartz-carbonate stockwork zones in outcrop and underground workings (e.g., Domain 20) show similarities in vein texture and geometry, indicating that they may be part of the same stockwork system. However, the surface projection of Domain 20 is approximately 100 m south of the outcrop investigated in map area 1. This offset could be due to branching stockwork veining, an en échelon stockwork vein network or previously mapped north-verging thrust faults. Previously described fault-zone geometry has similarities to mapped stockworks at the Brucejack deposit, and offset of lithological units across the main stockwork in map area 1 suggests shear offset. This leads the authors to believe that the described stockwork formed within a fault zone. Quartz-vein formation occurred within open space in fractures where the static fluid pressure was above that of lithostatic pressure. Multiple slip events have caused several generations of fractures, with quartz growth within veins occurring mainly between fracturing events (i.e., earthquake slip) and lesser cryptocrystalline quartz precipitation occurring during seismic slip. The fault core consists of recycled vein material, which also indicates that cyclic seismicity occurred during vein formation. This seismicity must predate later Cretaceous polyphase deformation during emplacement of the Skeena fold-and-thrust belt. Electrum occurring within recycled clasts of quartz-carbonate veining, and electrum occurrences that are cut by syntaxial quartz-carbonate veining, show that at least one of the mineralizing event(s) at Brucejack was early to coeval with stockwork emplacement.

Future Work

Further investigation of field data and analysis of samples is required to achieve the ultimate goal of investigating the role of colloidal transport in the formation of high-grade quartz-carbonate veins. The structural setting of electrum occurrence is still not fully understood. The pattern of displacement across faults and veins will be further analyzed to constrain stress orientation during fault-zone and vein formation within the mapped stockwork systems. Maps and structural data for the two other outcrop locations will be compared to the information presented here in order to generalize stockwork geometries on the deposit scale. The structural setting in which electrum mineralization occurs within Domain 20 is difficult to determine due to complexity of the stockwork and the existence of electrum within clasts. Electrum occurrences elsewhere in the underground workings at the Brucejack deposit have been documented within smaller continuous veins where the structural setting may be more easily deduced. Several of these locations were described in the field in August 2015 and will be further analyzed to determine if electrum mineralization at Brucejack occurs in a preferred structural setting. Additionally, millimetre- to micrometre-scale analysis of both electrum and vein quartz will be used to investigate whether relict colloid textures exist, which might confirm colloidal transport and deposition.

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