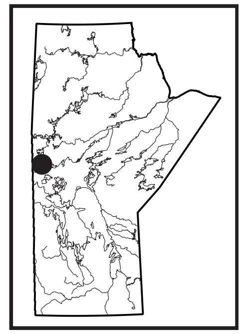
GS-9 **Characteristics and controls of gold mineralization in the Brunne Lake area of the Flin Flon belt, west-central Manitoba (parts of NTS 63K11, 14)**

by J.A. Dunn[1] and S. Gagné



Dunn, J.A. and Gagné, S. 2014: Characteristics and controls of gold mineralization in the Brunne Lake area of the Flin Flon belt, west-central Manitoba (parts of NTS 63K11, 14); *in* Report of Activities 2014, Manitoba Mineral Resources, Manitoba Geological Survey, p. 116–124.

Summary

In July of 2014, fieldwork was undertaken as part of an M.Sc. research project to examine and characterize gold mineralization in drillcores from the Gossan Hill prospect, located along the Gurney Mine shear zone (GMSZ) in the Brunne Lake area of the Flin Flon belt. The geological investigation focused on detailed examination of carefully selected drillcores from the 2010–2011 drilling programs of Callinex Mines Inc. Special attention was given to the documentation of mineralized veins, alteration and deformation fabrics, and their overprinting relationships. Six distinct generations of veins were identified and their relationships to associated alteration and sulphide assemblages were established to reconstruct the potential sequence of mineralization and deformation in the GMSZ. Five phases of deformation were identified, of which the D_4 phase accompanied intense silicification of the shear zone and wallrock, and deposition of gold in association with coarse pyrite and chalcopyrite.

Introduction

The GMSZ is located within the Brunne Lake belt (Gagné, 2012a), a small arcuate package of dominantly mafic supracrustal rocks that is part of the Paleoproterozoic Flin Flon greenstone belt (Figure GS-9-1). The GMSZ is host to the historical Gurney mine (formerly Dominion mine) and the Gossan Hill prospect (Figure GS-9-2). During production (1937–1939), the Gurney mine produced more than 872.28 kg (28,045 oz.) of gold from nearly 94 650 tonnes of ore milled (Richardson and

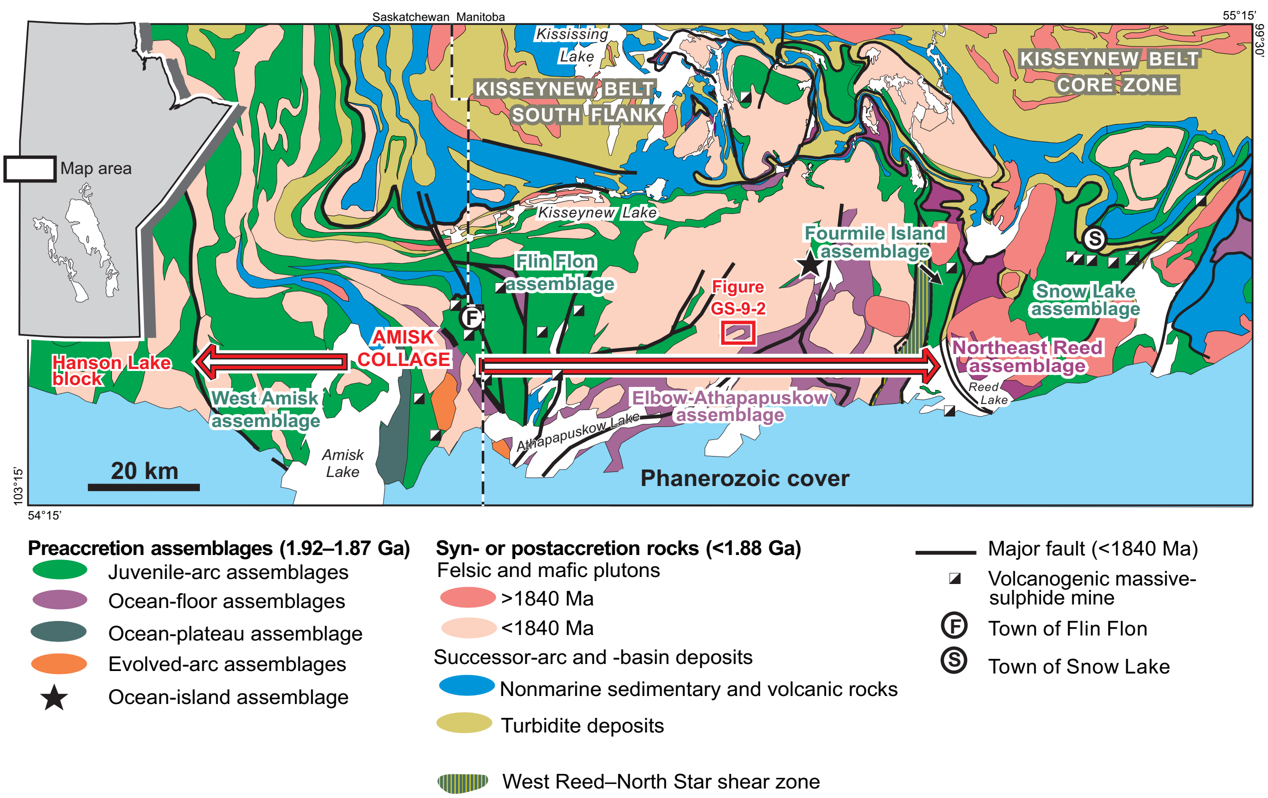


***Figure GS-9-1:** Geology of the Flin Flon–Snow Lake greenstone belt in west-central Manitoba, showing the location of Figure GS-9-2 (modified from Syme et al., 1998).*

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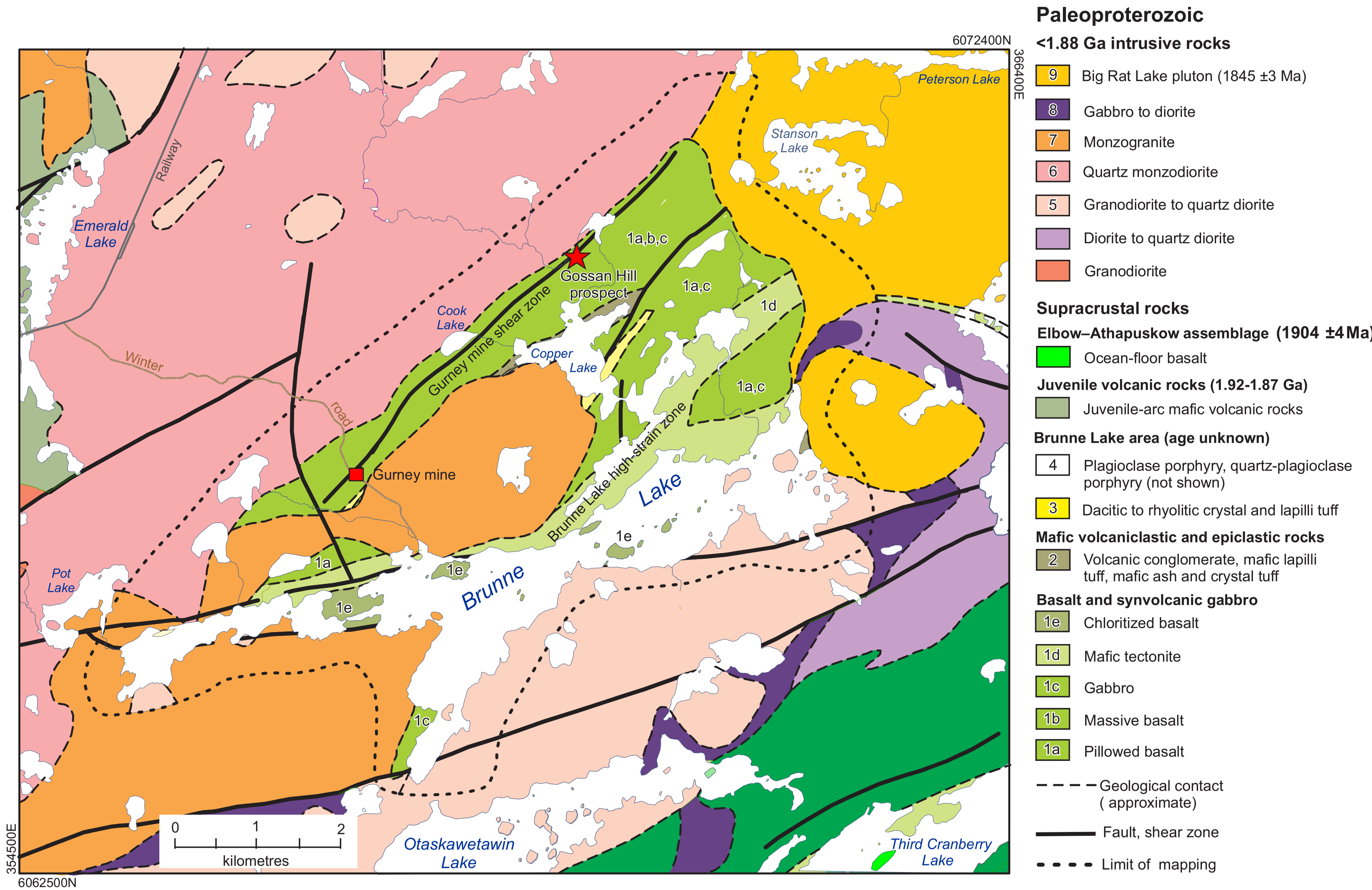

Figure GS-9-2: *Simplified geology of the Brunne Lake area, west-central Manitoba. Unit numbers correspond to those on Preliminary Map PMAP2012-6 (Gagné, 2012b).*

Ostry, 1996). The Brunne Lake area was recently mapped by Gagné (2012a, b), who demonstrated that the GMSZ could be traced continuously from the Gurney mine to the Gossan Hill prospect to the east (Figure GS-9-2). Field investigation of surface showings identified a pervasive silica-replacement style of alteration that is commonly associated with gossans. Examples of both massive and composite quartz-carbonate shear-type veins were recognized in the GMSZ and other shear zones of the Brunne Lake area. The wallrocks vary from weakly or intensely silicified to epidote±chlorite altered, suggesting multiple hydrothermal events. The relationship between gold mineralization and the various alteration types had not been resolved, necessitating further detailed studies.

An M.Sc. research project has been designed to better understand the characteristics and controls of the gold mineralization along the GMSZ. The study was completed at University College Cork in the Republic of Ireland by the senior author in co-operation with the Manitoba Geological Survey and Callinex Mines Inc. The scope of the investigation focuses entirely on the Gossan Hill prospect and makes use of drillcores provided by Callinex Mines Inc. The primary objective of the study was to document the vein generations, alteration and deformation structures to improve the understanding of the timing and controls on gold mineralization along the GMSZ. Preliminary results from the drillcore examination are presented in this report. Further details can be found in the thesis (Dunn, 2014).

Geology of the Brunne Lake belt

The geology of the Brunne Lake area consists of a narrow, arcuate tract of supracrustal rocks dominated by pillowed basalt, synvolcanic gabbro dikes and sills, minor amounts of mafic volcaniclastic and epiclastic rocks, and felsic volcaniclastic rocks. Diverse hypabyssal porphyry intrusions crosscut the supracrustal rocks and both are intruded by diverse plutonic rocks. Mafic volcanic rocks of the Brunne Lake belt display geochemical characteristics of both mid-ocean–ridge and back-arc–basin environments (Gagné, 2012a), a geochemical signature very similar to that of the McDougalls Point basalt (Syme and Whalen, 2012) at Elbow Lake. On the basis of similar geochemistry and geology, the Brunne Lake belt is interpreted to be part of the regionally extensive Elbow-Athapapuskow ocean-floor assemblage (Stern et al., 1995).

Mineralization at both the Gurney mine and the Gossan Hill prospect consists of auriferous quartz-vein systems associated with a major shear zone, the GMSZ, that trends along the northwestern flank of the Brunne Lake belt. The GMSZ is hosted by a sequence of massive and pillowed mafic volcanic rocks and synvolcanic gabbro sills. Several other small gold occurrences and gossans in the Brunne Lake area also show a spatial relationship with shear zones, which typically display a strong subvertical foliation and massive to composite quartz-carbonate shear-type veins.

Geology of rocks hosting the Gossan Hill prospect

The main rock types present in the drillcores are basalt and medium-grained equigranular gabbro, with subordinate diorite and fine-grained volcaniclastic rocks. Although rocks in the vicinity of the Gossan Hill prospect have been regionally metamorphosed to greenschist facies, as is evident in thin section by the presence of a chlorite-epidote-actinolite-biotite assemblage, the prefix 'meta' has been omitted from the rock names for the sake of brevity.

Basalt is the most abundant lithology encountered in the drillcore and accounts for nearly 60% of the supracrustal rocks (Figure GS-9-3a). The basalt is massive and nonamygdaloidal with an aphyric texture, although rare phenocrysts occur locally. It is typically medium grey but weathers to medium to light green-grey in more altered zones. The sequence is intruded by synvolcanic diorite dikes (Gagné, 2012a), ranging from 0.2 to 0.4 m in thickness, that are generally located in or adjacent to high-strain zones or along the margins of shear zones. The basalt is massive to moderately foliated (Figure GS-9-3d), except in high-strain and shear zones where the foliation, referred to as the S_1 fabric, is better developed.

Gabbro varies from light to medium grey to darker grey-green with increasing alteration. It is medium grained (2–4 mm) and equigranular, and displays a granoblastic texture (Figure GS-9- 3b). It ranges from weakly foliated away from the main shear zones to well foliated adjacent to sheared zones. The gabbro shows evidence of a more brittle response to deformation (Figure GS-9-3e) and is host to shear-related feldspathic and quartz veins, with the latter filling brittle fractures along reactivated early veins. The gabbro is intruded by a second, later generation of diorite dikes up to 0.3 m in thickness. The diorite dikes are rare except at the margins of shear zones, where they become more frequent, crosscut the S_1 foliation and are overprinted by later brittle deformation structures.

Mafic volcaniclastic units (Figure GS-9-3c) are interbedded with basalt and gabbro throughout the drill core, and represent 10–15% of the studied sequence. They form horizons that reach up to 40 m in thickness but are more typically 4–10 m thick. They consist of thinly laminated (1–2 mm), fine-grained tuff. These horizons have a moderate to well-developed foliation in high-strain and shear zones. The volcaniclastic rocks are generally medium to dark grey but can be dark grey to black in alteration zones.

Description of shear zones

Shear zones documented in the drillcore are typically concentrated at the contact between gabbro and basalt or volcaniclastic horizons. This is interpreted to result from

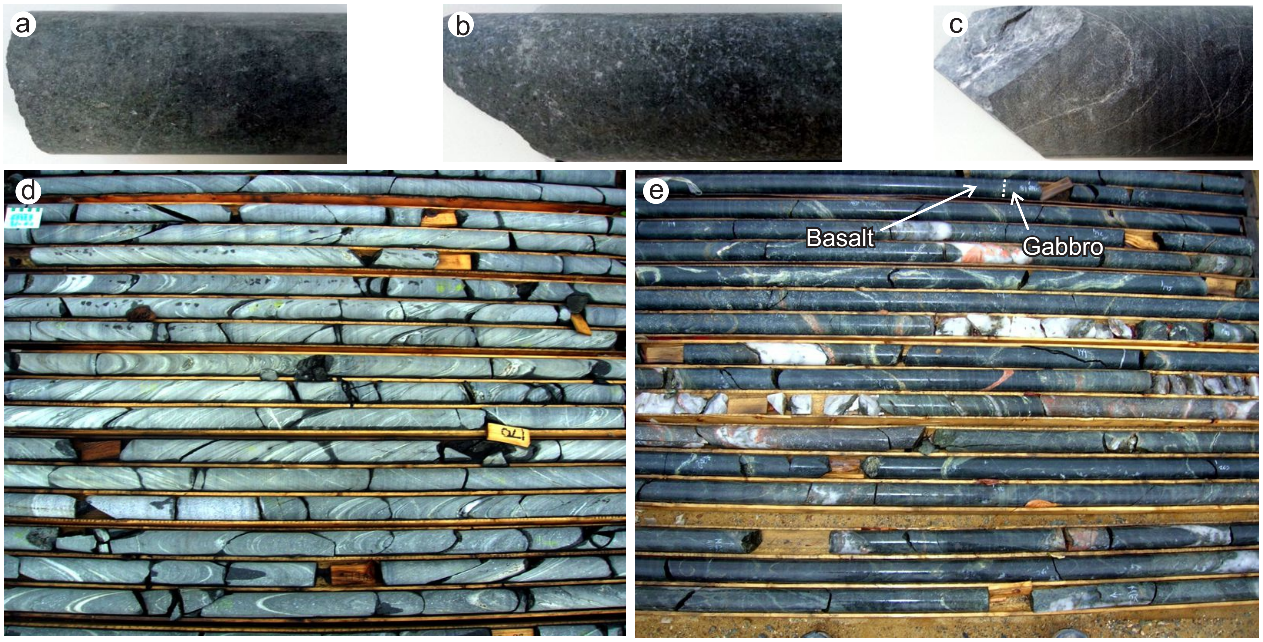

Figure GS-9-3: *Photos of the main rock types and deformation styles encountered at the Gossan Hill prospect:* ***a)*** *medium grey-green massive aphyric basalt (GOS11, 167.68 m);* ***b)*** *medium-grained gabbro (GOS25, 253.05 m);* ***c)*** *fine-grained, laminated mafic volcaniclastic rocks (GOS25, 217.62 m);* ***d)*** *well-developed S_1 foliation in ductile high-strain zone (GOS28, 36.05 m; photo is 1.4 m in width);* ***e)*** *example of brittle deformation in gabbro, manifested by multiple vein generations, in contrast to the basalt at the extreme top of the photo (GOS28, 188.0 m; photo is 1.4 m in width). Drillhole identifier and downhole depth (in metres) are indicated in parentheses.*

the rheological contrast between different rock types (Figure GS-9-3a, b), where basalt and volcaniclastic rocks deformed in a more ductile manner, whereas the gabbro accommodated strain in a more brittle manner.

The shear zones are filled by massive, milky quartz veins (Figure GS-9-4a) with an apparent thickness of up to 9 m in the drillholes studied. They are laterally extensive and appear to correlate between drillholes across the Gossan Hill prospect over hundreds of metres. Adjacent to the shear zones, veins often show evidence of being deformed or reactivated during later deformation. Wall-rock at the shear zone margins contains patchy to intense alteration, with potassic and propylitic alterations overprinted by a later intense silicification.

A pervasive S_1 foliation is weakly to moderately well developed throughout the sequence. Bedrock mapping conducted by Gagné (2012a) showed that the orientation of this fabric is generally consistent, striking approximately 040° with subvertical dip. Localized high-strain zones are commonly observed within all rock types proximal to the main shear zones and exhibit a more intensely developed foliation. These high-strain zones, which are several metres thick, are often overprinted by later brittle deformation.

These features suggest that the supracrustal rocks in the GMSZ have undergone a complex history of deformation and hydrothermal alteration that has controlled the emplacement and distribution of veins and gold mineralization.

Vein generations, alteration and sulphide assemblages

Six principal vein types have been identified in the Gossan Hill prospect (Table GS-9-1). This section provides a description of each vein generation, including mineralogy and associated alteration and sulphide assemblages.

The earliest veins are the V_1 feldspathic veins (Figure GS-9-4b), which are typically up to 0.5 cm in thickness and dominated by alkali feldspar and quartz. They are generally folded and boudinaged in the penetrative S_1 fabric. A narrow feldspathic alteration halo, 1–2 cm in width and defined by a patchy alteration texture along the vein margins, is associated with V_1 veins. These veins do not appear to host any sulphides but are often reactivated by later V_4 milky quartz veins with a more brittle-ductile deformation style (Figure GS-9-4e).

The second generation of veins (V_2) comprises sets of narrow veinlets oriented parallel to the S_1 foliation. They are typically on the order of 0.1–0.2 cm in thickness and occur most frequently in localized high-strain zones or within the main shear zones in the basalt and volcanic sequences. The V_2 veins are associated with chlorite-epidote-actinolite-biotite alteration assemblages. This is the most commonly encountered alteration type observed in the drillcore and is present in varying abundances in

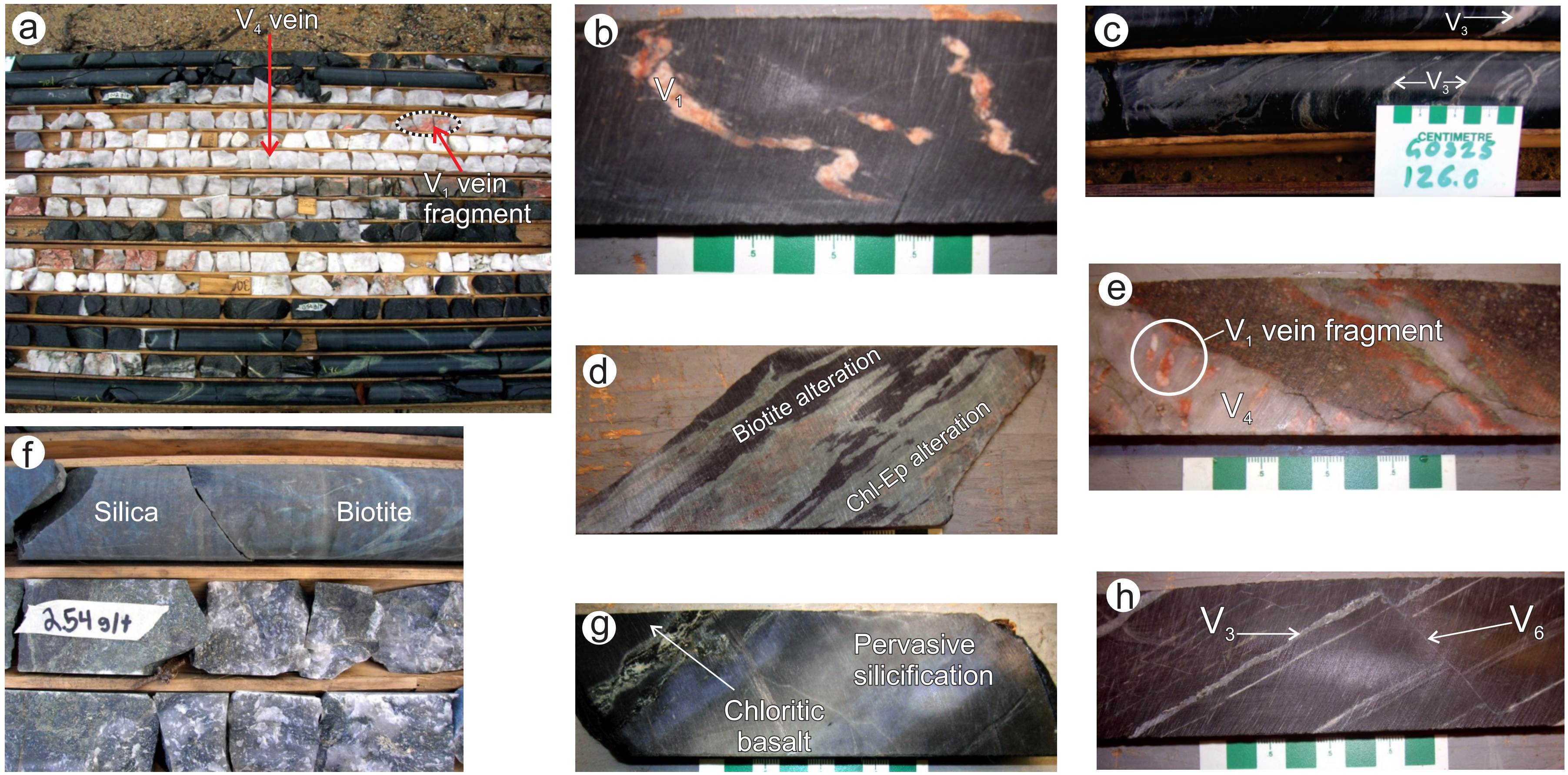

Figure GS-9-4: *Photos of main shear zone and vein generations identified in drillcore from the Gossan Hill prospect:* ***a)*** *massive quartz veins (V_4) in a shear zone; note the pink, angular clasts of V_1 feldspathic vein material (GOS11, 76.5–98.0 m, photo is 1.4 m across);* ***b)*** *folded and boudinaged V_1 feldspathic veins (GOS25, 19.2 m);* ***c)*** *V_3 generation of quartz and quartz-carbonate veins (GOS25, 126.0 m);* ***d)*** *fracture-controlled chlorite-epidote alteration and associated V_3 veins (GOS25, 147.57 m);* ***e)*** *V_4 quartz veins along same orientation as the V_1 veins with alkali feldspar fragments (GOS25, 202.35 m);* ***f)*** *example of silica alteration associated with V_5 veins overprinting milky quartz in a mineralized zone, with gold grades shown for the adjacent sample (GOS25, 212.05 m);* ***g)*** *patchy silicification (light smoky grey) overprinting a medium grey-green chlorite-epidote–altered basalt (GOS25, 93.0 m);* ***h)*** *late brittle quartz veins (V_6) crosscutting the V_3 vein set in split drillcore (GOS11, 27.55 m).*

Table GS-9-1: Summary of the main characteristics of the various types of veins observed in drillcores from the Gossan Hill prospect.

Vein generation	Composition	Associated Alteration	Width of alteration halo	Sulphide assemblage	Gold grade	Deformation
V_1	Alkali feldspar-quartz	Minor feldspathic alteration	N/A	N/A		Folded and boudinaged by S_1
V_2	Quartz	Minor chlorite-epidote-actinolite-biotite	1–2 cm	Minor, fine disseminated pyrite-chalcopyrite		Parallel to S_1, deformed by later shearing
V_3	(V_{3i}) Quartz	Patchy to pervasive chlorite-epidote-actinolite-biotite	2–4 cm	Patchy, semimassive pyrite-chalcopyrite		Oblique to S_1, deformed by later shearing
	(V_{3ii}) Quartz-carbonate	Patchy to pervasive chlorite-epidote-actinolite-biotite	2–4 cm	Patchy, semimassive pyrite-chalcopyrite		Oblique to S_1, deformed by later shearing
V_4	Quartz	Biotite-muscovite-epidote	3–5 m	Very low sulphide content	<1 g/t	Oblique to S_1, reactivates V_1 vein set
V_5	Quartz	Silica	2–5 m	Pyrite-chalcopyrite	0.02–35 g/t	Oblique to S_1, crosscuts all earlier vein sets
V_6	Quartz-carbonate	N/A	N/A	Pyrite-galena		Late brittle veins, cross-cuts all earlier vein sets

all rock types. The alteration assemblage shows a well-developed S-fabric in thin section, suggesting that the chlorite-epidote alteration is associated with the development of the pervasive S_1 foliation during peak regional metamorphism in the Brunne Lake area.

The third generation of veins is subdivided into V_{3i} and V_{3ii} veins (Figure GS-9-4c). No definite crosscutting relationships were observed, but a subset of vein generations is distinguishable on the basis of its composition and orientation relative to the S_1 foliation. The V_{3i} veins are composed mainly of quartz with an associated alteration assemblage of epidote-chlorite (Figure GS-9-4d) and a low sulphide content that consists of fine-grained pyrite and chalcopyrite. The V_{3ii} veins differ in composition (mainly quartz-carbonate) but are associated with the same epidote-chlorite alteration, and pyrite and chalcopyrite.

The fine-grained, disseminated pyrite-chalcopyrite assemblage is encountered throughout the supracrustal horizons and appears to show a spatial relationship with chlorite alteration (Figure GS-9-5a). In thin section, the finer pyrite grains show the same foliation as the chlorite, suggesting that precipitation of the fine sulphides was associated with the peak regional metamorphic fluid phase.

The fourth generation of veins (V_4) principally comprises massive, milky quartz veins (Figure GS-9-4a) that form the main vein type in the principal shear zones, as well as within brittle fractures in gabbro. These massive quartz veins reach up to 9 m in apparent thickness and occur in shear zones at lithological boundaries where there is an apparent competency contrast between two different rock types. Where the V_4 veins fill brittle fractures, they have the same orientation as the V_1 veins and often contain angular clasts of feldspathic material (Figure GS-9-4e).

The V_4 veins are associated with pervasive and generally fine-grained potassic (biotite-muscovite-epidote) alteration. This alteration occurs in both high- and low-grade mineralized shear zones and is most intense at the margins of the massive V_4 quartz veins, where it forms alteration haloes up to 3–5 m thick on either side of the shear zone. Sulphide content in the V_4 veins is very low except where overprinted by later silicification associated with V_5 veins (see below).

The V_5 generation of veins (Figure GS-9-4f) is generally irregular and forms a complex network of anastomosing veins and veinlets through the shear zones where they crosscut the V_4 veins (Figure GS-9-5b). The V_5 veins are associated with patchy to intense and pervasive silica alteration of the wallrock, which in some cases renders the protolith unrecognizable (Figure GS-9-4g).

Intimately associated with the silica alteration and the V_5 veins is a coarser pyrite±chalcopyrite assemblage (Figure GS-9-5a). Coarse euhedral pyrite cubes with fine, brassy chalcopyrite inclusions overprint earlier chlorite-epidote and biotite alteration. Based on field observations and scanning electron microscope (SEM) images of sulphides and gold in thin section (Figure GS-9-5c, d), gold is hosted by euhedral to cubic pyrite, particularly along the margins of pyrite grains. No free gold was observed under the SEM.

The youngest vein generation (V_6) in the drillcore from the Gossan Hill prospect consists of brittle quartz veinlets (Figure GS-9-4h) that crosscut all earlier veins. These veinlets are 1–2 mm thick and typically composed

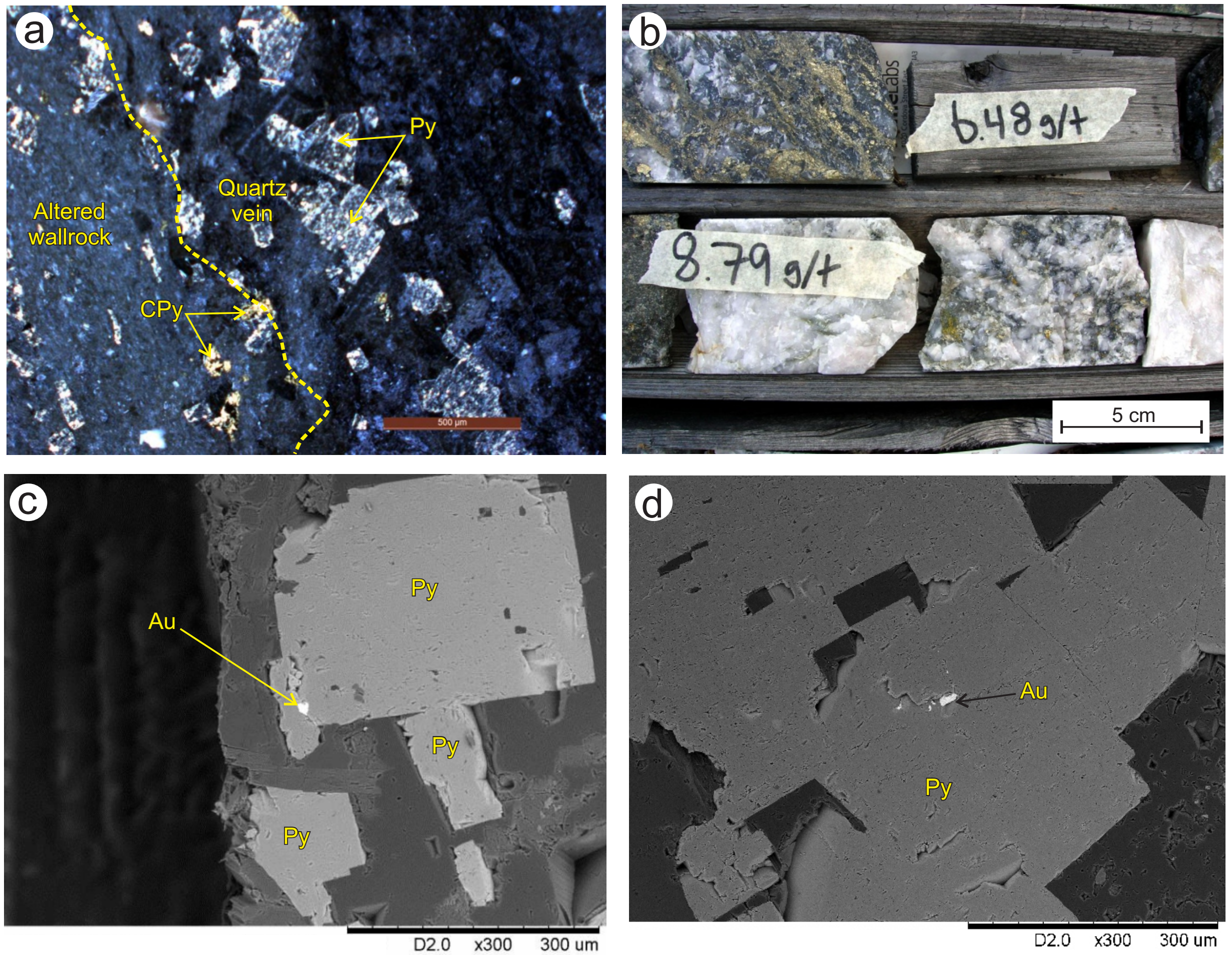

Figure GS-9-5: *Photos of alteration and sulphide assemblages identified in drillcore:* ***a)*** *digital image in plane-polarized light of late, coarse, euhedral pyrite-chalcopyrite overprinting the foliated chlorite-epidote alteration assemblage and associated disseminated, fine pyrite-chalcopyrite. (GOS11, 196.2 m);* ***b)*** *example of dark, smoky silica alteration overprinting milky quartz in mineralized shear zones with reported gold grades shown for the adjacent sample interval (GOS28, 287.9 m);* ***c), d)*** *scanning electron microscope (SEM) images of gold hosted by pyrite±chalcopyrite grains; gold appears as bright, high-reflectance grains at the margins of the pyrite crystals (GOS25, 219.8 m).*

of quartz-carbonate with an associated pyrite±galena assemblage. Where the drillcore has fractured along the orientation of the V_6 veins, the fracture planes are typically coated in pyrite, with minor galena, indicating a sulphide precipitation event in the later stages of deformation along the GMSZ.

Pyrite is the most abundant sulphide mineral in this late assemblage and occurs as fracture coatings and within quartz-carbonate veinlets. Galena is less abundant and is usually observed in V_6 veins within the shear zones, where they crosscut the V_4 quartz veins and wallrock fragments within the shear zones. No evidence of remobilized gold was observed to be associated with the V_6 veinlets.

Deformation history of the Gurney Mine shear zone

Based on the fieldwork undertaken during this study, the deformation history of the GMSZ is interpreted to consist of five main events: D_1–D_5 (Table GS-9-2). The structures associated with these deformation events show a transition from early ductile-dominated deformation (D_1, D_2) through brittle-ductile (D_3, D_4) and finally brittle deformation (D_5).

D_1 deformation

The D_1 deformation is thought to record the onset of shearing and the opening of dilational sites within subsidiary shear zones, followed by the filling of dilational sites with the V_1 feldspar veins. It is proposed that the earliest shearing predates development of the main penetrative foliation (S_1), as the V_1 veins are typically boudinaged and folded by the S_1 fabric (Figure GS-9-3b).

D_2 deformation

The D_2 deformation is recorded by the S_1 foliation, resulting from ductile compression. The S_1 foliation is

Table GS-9-2: Deformation episodes in the Gurney Mine shear zone, and their associated geological features and apparent timing.

Episode	Deformation style	Mineralization	Structures	Metamorphism	Vein generations
D_1	Ductile		Early shearing and opening of shear zone space	None	V_1
D_2	Ductile		Development of S_1 foliation fabric	Regional greenschist	V_2
D_3	Brittle-ductile		Brittle-ductile reactivation of earlier shear zones	Regional greenschist	V_{3i} & V_{3ii}
D_4	Brittle-ductile	Main gold mineralization event	Reactivation of brittle-ductile shear zones	None	V_4 & V_5
D_5	Brittle		Brittle fractures and veinlets	None	V_6

present throughout the study area and is better developed in localized high-strain zones and within shear zones concentrated along lithological contacts. It is proposed that regional metamorphism of the rocks in the Brunne Lake area commenced early during D_2 and continued during D_3. In thin section, the chlorite-epidote-actinolite-biotite regional greenschist metamorphic assemblage defines a well-developed foliation that is broadly parallel to S_1. The second generation of veins (V_2) is interpreted to have been emplaced parallel to the S_1 foliation during D_2 deformation.

D_3 deformation

The D_3 deformation is recorded by the V_3 vein generation, reflecting a change in deformation style from ductile to brittle-ductile. These veins crosscut the S_1 foliation and V_2 veins, indicating post-D_2 emplacement. They are associated with the peak regional metamorphic assemblage (chlorite-epidote-actinolite-biotite), suggesting that peak metamorphic conditions were maintained through the D_2 and D_3 phases of deformation.

D_4 deformation

The D_4 deformation represents the main brittle-ductile shearing event within the Gurney Mine shear zone. The main structural feature of this phase of deformation is the massive quartz veins (V_4) in shear zones (Figure GS-9-4a), which are the main host to gold mineralization. Later during the D_4 event, a second silica-fluid phase (V_5 veins) was introduced into the system and was associated with precipitation of gold-bearing sulphides in the Gossan Hill prospect.

D_5 deformation

Late deformation in the shear zone is represented by the brittle vein set (V_6) emplaced during the D_5 deformation event. This event is interpreted to represent late brittle deformation associated with uplift and cooling of the supracrustal rock package.

Controls on gold mineralization

Gold mineralization at the Gossan Hill prospect is spatially related to subsidiary shear zones that occur along the main GMSZ. In addition to the strong structural control on gold mineralization, it is proposed that gold is associated with V_5 veins that were emplaced during the D_4 deformation event. The pyrite-chalcopyrite assemblage, which has been shown to host gold in the Gossan Hill prospect, is associated with pervasive silica alteration coincident with the emplacement of V_5 veins.

To summarize, the gold mineralization at Gossan Hill

- is hosted by quartz-filled shear zones at lithological contacts within mafic supracrustal sequences where there is a strong competency contrast between different rock types;
- is associated with V_5 smoky quartz veins and patchy to pervasive silicification of the adjacent wallrock; and
- occurs as inclusions in pyrite and chalcopyrite, which are intimately associated with the V_5 veins and silicification of the wallrock.

Economic considerations

The Brunne Lake area is host to the past-producing Gurney mine, as well as the Gossan Hill prospect. Gold mineralization in the area shows a strong spatial association with shear zones subsidiary to the GMSZ, and the distribution of mineralization is considered to be structurally controlled. A strong association exists between gold occurrences and pervasive silica alteration that overprints earlier shear-hosted quartz veins. Within these altered zones at the Gossan Hill prospect, gold is hosted by disseminated to semimassive pyrite and chalcopyrite.

By identifying the main geological features associated with mineralization within the shear zones at the Gossan Hill prospect, new exploration targets and sampling strategies can be developed to further exploration along the 6 km strike of the GMSZ.

Acknowledgments

The authors thank Callinex Mines Inc. for providing drillhole data and permission to examine and sample drillcore from the 2010–2011 drilling programs at the Gossan Hill prospect. E. Anderson and N. Brandson are thanked for their logistical support. We also acknowledge the assistance of R. Green during the core-logging work and for his help around the camp.

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