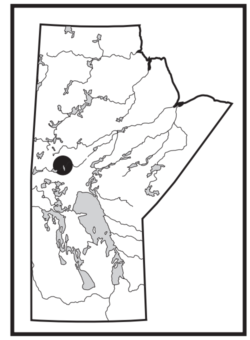
GS-1 Structural geology and gold metallogenesis of the New Britannia mine area, Snow Lake, Manitoba (NTS 63K16)

by C.J. Beaumont-Smith and J. Lavigne[1]



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Summary

Gold mineralization in the Snow Lake area demonstrates a strong spatial association with the hangingwall of the McLeod Road Thrust. This relationship suggests a possible deformational origin for the mineralization, and structural analysis was therefore conducted in the area of the New Britannia mine to determine the extent of structural controls on gold mineralization. The gold mineralization is hosted by a sequence of mafic and felsic volcanic and volcaniclastic rocks, with gold deposits generally located adjacent to lithological contacts, suggesting structural or possibly compositional controls on gold emplacement.

Structural analysis documents the penetrative isoclinal F_1 fold intercalation of volcanic rocks forming the hangingwall of the thrust fault. Associated with F_1 folding is the local development of an S_1 layer-parallel foliation, which is generally restricted to the vicinity of stratigraphic contacts. These D_1 fabric elements are overprinted by a progressive D_2 deformation characterized by S-asymmetric, shallowly inclined F_2 folds and D_2 thrust faulting. The emplacement of quartz-vein–hosted gold mineralization and the associated potassium-carbonate alteration assemblage is also overprinted by F_2 folding, which constrains the age of gold emplacement to pre- to syn-D_2. Many textural relationships suggest that the later stages of D_2 are coincident with gold emplacement, although the gold mineralization is potentially older and was remobilized during D_2.

Introduction

The New Britannia mine horizon consists of a sequence of mafic to felsic volcanic and volcaniclastic rocks that hosts a series of gold deposits in the hangingwall of the McLeod Road Thrust, in the town of Snow Lake. Three deposits within the New Britannia mine horizon are responsible for the production of more than 1.4 million ounces of gold during two periods of mining. During the first period (1949–1958), 610,458 ounces were produced from the Nor-Acme mine. The second period (1995–2005) produced 794,492 ounces from the Nor-Acme (New Britannia) deposit, 25,281 ounces from the No. 3 zone and 2,777 ounces from the Birch zone, for a total of 1,433,008 ounces. The characteristic common to the deposits is the high degree of structural-fabric development and intense carbonatization and silicification of the hostrocks. The exploited deposits—Birch zone, No. 3 zone and Nor-Acme (New Britannia) mine—demonstrate a strong spatial association with stratigraphic contacts. This stratigraphic control represents a possible structural control on the development of the deposits, since stratigraphic contacts act as loci for deformation.

Fieldwork in 2008 focused on the New Britannia mine horizon in the area between the McLeod Road Thrust in the eastern portion of the map area and Squall Lake, with the goal of elucidating the relationship between volcanic stratigraphy, structural development and gold mineralization. The stratigraphic and structural relationships of the study area are presented in Preliminary Map PMAP2008-1 (Beaumont-Smith and Gagné, 2008). This area includes a large number of gold deposits and occurrences, and a complex stratigraphy consisting of fold-repeated packages of mafic and felsic volcanic and volcaniclastic rocks.

Regional geology

The Snow Lake area is situated in the eastern portion of the Flin Flon–Snow Lake greenstone belt in northwestern Manitoba. This greenstone belt is part of the internal or juvenile portion of the Trans-Hudson Orogen (THO). The belt trends east for a distance of more than 250 km and has a width of ~50 km from north to south. It is bounded to the north by the Kisseynew Domain, to the east by the reworked Archean rocks of the THO external zone (Superior Boundary Zone) and to the west by the Wollaston fold belt. The southern portion of the greenstone belt is unconformably overlain by Paleozoic sedimentary rocks.

The eastern segment of the Flon Flon–Snow Lake greenstone belt forms the Snow Lake allochthon of Syme et al. (1996), which represents a tectonic collage composed of ocean-floor and island-arc assemblages (ca. 1.9 Ga) and younger (ca. 1.86–1.84 Ga) metasedimentary rocks of the Kisseynew Domain (Figure GS-1-1). The arc volcanic rocks are part of the Amisk Group and comprise three sequences, each having distinctive characteristics (Bailes and Galley, 1996, 1999, 2007). The lowermost Anderson sequence is a bimodal mafic–felsic succession dominated by flows. The middle sequence, the Chisel sequence, is dominated by volcaniclastic rocks of highly variable composition, and the uppermost Snow Creek

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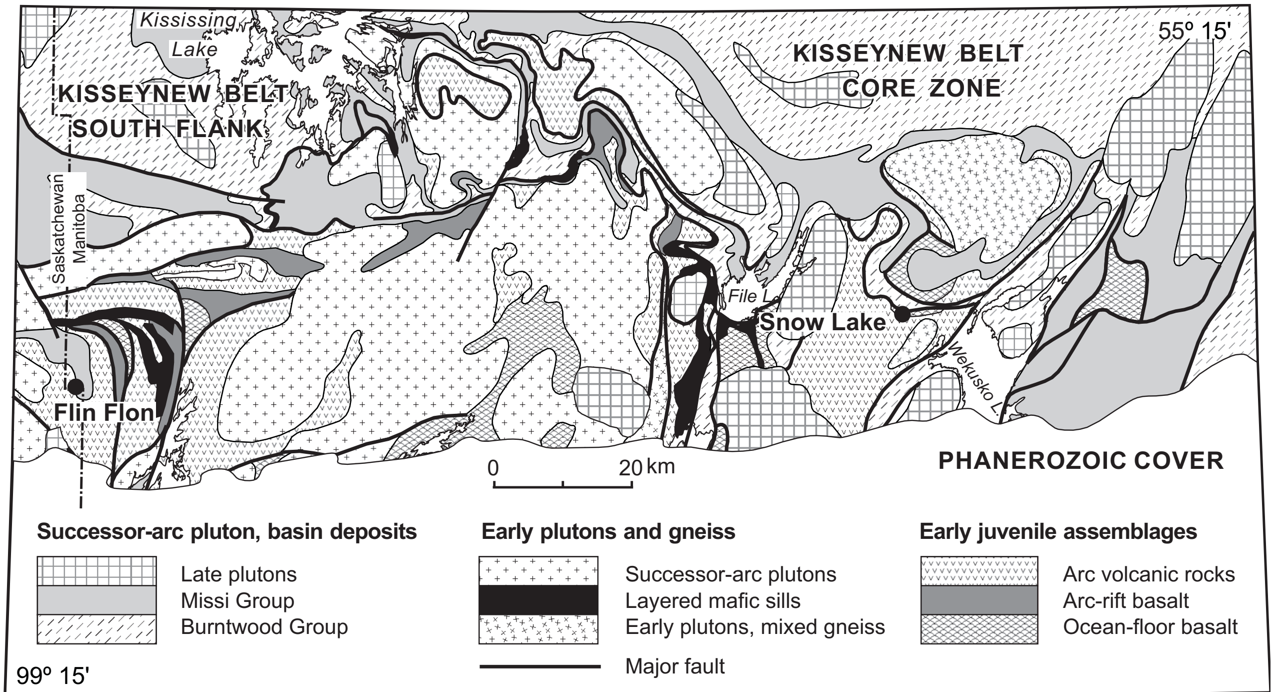

Figure GS-1-1: *Geology of the Flin Flon–Snow Lake greenstone belt.*

sequence is composed almost entirely of pillowed basalt. The three sequences have been interpreted to reflect the evolution of the Snow Lake arc from primitive through evolved to arc rift.

The Kisseynew Domain is an east-trending belt of Paleoproterozoic paragneiss and related granitoid plutons, bounded to the north and south by the Lynn Lake and Flin Flon–Snow Lake greenstone belts, respectively. The margin of the Kisseynew Domain is underlain by fluvial-alluvial sedimentary rocks of the Missi Group (south margin) and Sickle Group (north margin), and filled with Burntwood Group turbidites.

The structural development of the Snow Lake allochthon reflects a thrust-fold–belt style of tectonics (Connors, 1996; Kraus, 1998; Kraus and Williams, 1999; Lucas et al., 1996; Zwanzig, 1999). This is manifested by thrust imbrication of Amisk Group arc-volcanic rocks and Burntwood and Missi group sedimentary rocks prior to D_3 folding. The map pattern in the Snow Lake area is dominated by a series of D_2 thrust faults and the northeast-plunging macroscopic D_3 Threehouse synform.

Metamorphism in the Snow Lake area is manifested as an east-trending metamorphic isograd pattern, which reflects a northward increase in peak-metamorphic temperature from ~500°C to ~700°C with only a minor corresponding increase in pressure from 4 to 6 kbar (Kraus and Menard, 1997). This northward increase is demonstrated by changes in metamorphic mineral assemblages, increasing from chlorite zone in the south, through the staurolite zone (New Brittania mine), to the sillimanite zone near Squall Lake. In the Kisseynew Domain, mineral assemblages vary from sillimanite-garnet-biotite along the margin to garnet–cordierite–K-feldspar migmatite in the central portion of the belt.

Stratigraphy

The New Britannia mine horizon, termed the McLeod Road–Birch Lake allochthon by Bailes and Schledewitz (1998), comprises a moderately north-dipping bimodal sequence of mafic and felsic volcaniclastic and epiclastic rocks, and gabbro (Figure GS-1-2). The McLeod Road Thrust is responsible for the emplacement of ca. 1890 Ma volcanic and volcaniclastic rocks of the Snow Lake arc assemblage (Bailes and Galley, 2007) on top of ca. 1845 Ma Burntwood Group sedimentary rocks. A second thrust fault, the Birch Lake Fault, emplaced ca. 1845 Ma Missi Group sedimentary rocks above the volcanic and volcaniclastic rocks.

Structural analysis conducted this field season has significant implications for understanding the stratigraphic relationships of the mine horizon. Various interpretations of the mine sequence include an isoclinally folded sequence (Galley et al., 1988) and a north-dipping homoclinal sequence (Bailes and Schledewitz, 1998). In the latter model, the sequence was thought to comprise felsic volcanic and volcaniclastic rocks, overlain by pyroxene-porphyritic mafic volcaniclastic and intrusive rocks, and capped by aphyric basalt (Bailes and Schledewitz, 1998). Structural analysis indicates that the mine sequence is significantly more deformed than previously recognized. The repetition of felsic and mafic volcaniclastic rocks that characterizes the mine horizon represents an F_1 fold–repeated sequence (*see* below). Accordingly. the volcanic stratigraphy of the McLeod Road–Birch Lake allochthon

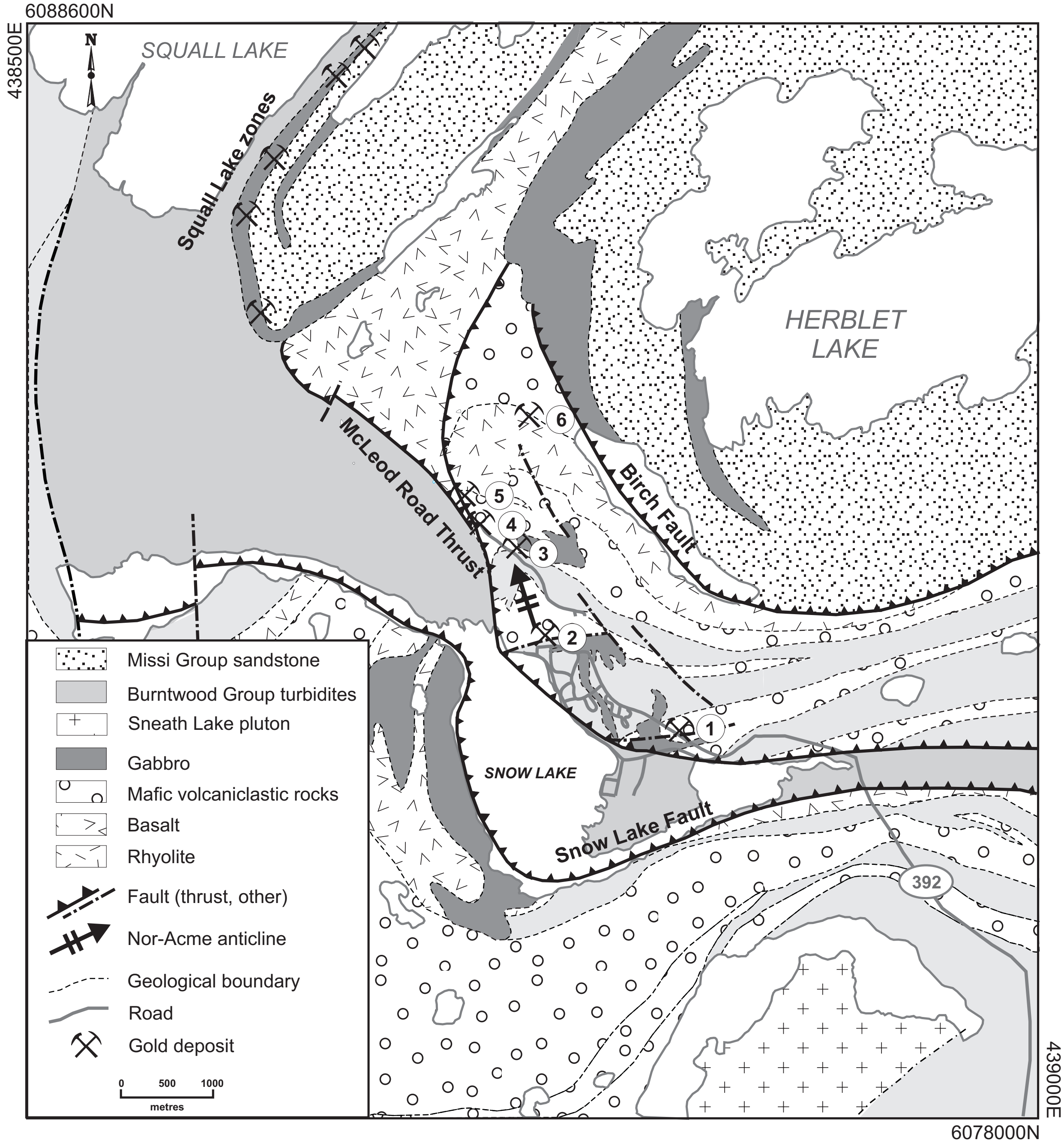

Figure GS-1-2: *Geology of the New Britannia mine area. Gold deposits: 1) Bounter zone, 2) New Britannia mine, 3) Boundary zone, 4) Kim zone, 5) No. 3 zone, 6) Birch zone.*

is presented from south to north, reflecting the structural arrangement of the volcanic and volcaniclastic rocks, followed by the sedimentary stratigraphy.

Felsic volcanic rocks (unit 1)

The felsic volcanic rocks, representing the structurally lowest member of the mine sequence, consist of dacite to rhyodacite flows and volcaniclastic rocks (Figure GS-1-3a). They are generally aphyric to K-feldspar porphyritic, but local quartz- and quartz–K-feldspar–porphyritic varieties are present. This unit appears to have a crude internal stratigraphy. The structurally lowest member is a package of quartz-amygdaloidal dacitic flows. This unit weathers beige to grey and is generally massive, with the exception of 1–3 mm elliptical quartz amygdules and 1–3 cm quartz blebs, which are interpreted as dismembered and deformed flow banding.

The upper members of the felsic volcanic stratigraphy comprise quartz–K-feldspar–porphyritic, K-feldspar–porphyritic and aphyric felsic lapilli tuff and tuff breccia, respectively. Quartz–K-feldspar tuff immediately overlies the amygdaloidal dacite flows. All the tuffaceous

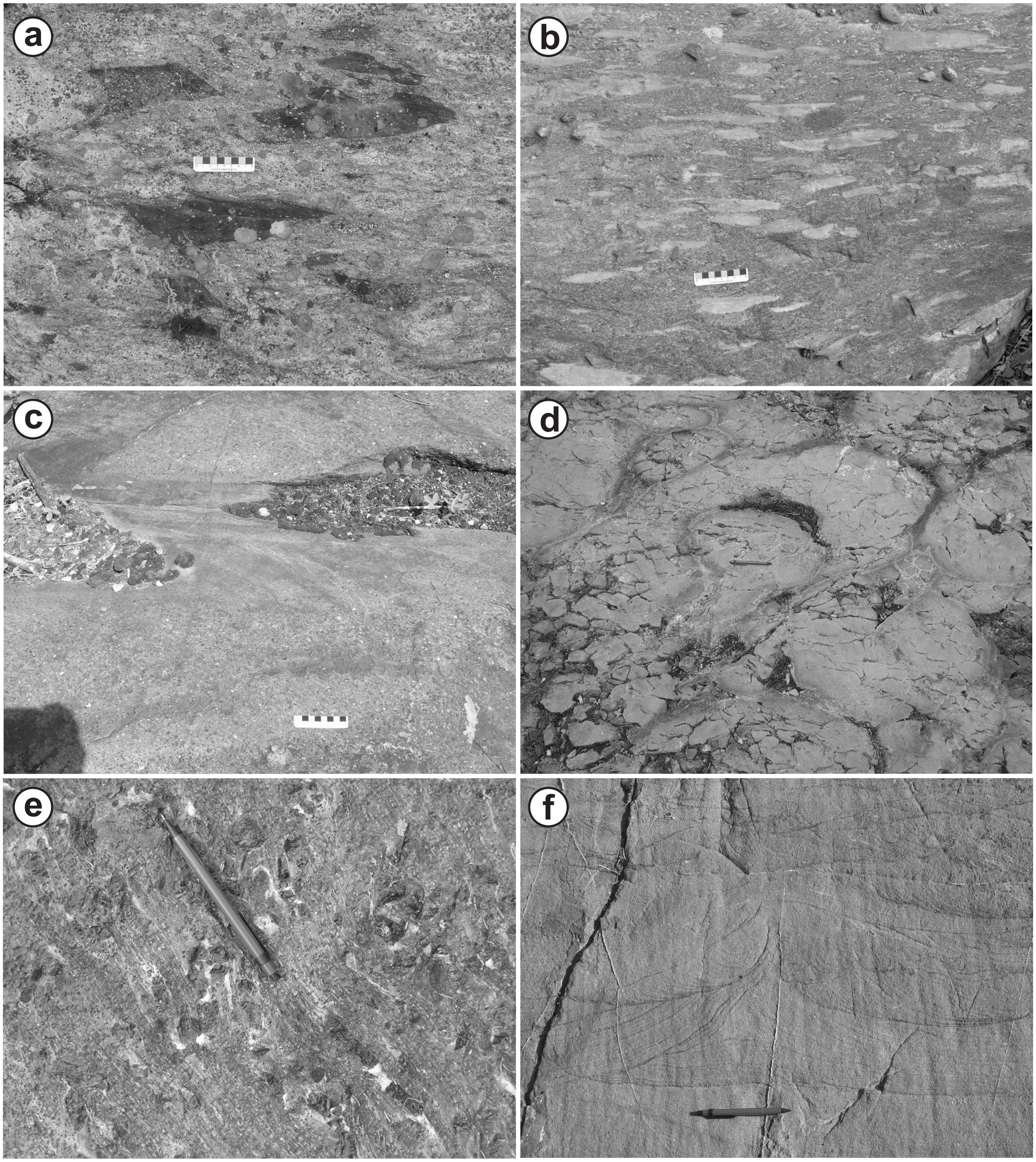

Figure GS-1-3: Volcanic and sedimentary rocks in the Snow Lake area: ***a)*** *heterolithic felsic tuff breccia containing amygdaloidal dacite clasts, east of Snow Lake;* ***b)*** *plagioclase-pyroxene–porphyritic mafic lapilli tuff, No. 3 zone area;* ***c)*** *bedded felsic lapilli tuff in the golf course area;* ***d)*** *pillowed Birch basalt north of No. 3 zone;* ***e)*** *Burntwood Group staurolite-garnet schist from Snow Lake;* ***f)*** *Missi Group trough-crossbedded arenite north of Birch Lake.*

units weather a similar buff-grey colour and contain small (<1 mm) phenocrysts. The lapilli and tuff breccia are matrix supported and contain subangular to subrounded clasts. The rounding of the clasts appears to be a function of deformation, as opposed to primary predepositional rounding. Clast populations generally reflect the matrix composition; rare heterolithic units are present. Delineating a more precise internal stratigraphy is made difficult by rapid lateral facies changes between lapilli tuff and tuff breccia, and isoclinal F_1 folding.

Porphyritic mafic volcanic and volcaniclastic rocks (unit 2)

The porphyritic mafic volcanic and volcaniclastic rocks underlying the map area comprise pyroxene- and pyroxene-plagioclase–porphyritic tuff to tuff breccia and pyroxene-porphyritic basalt that define three map units. The mafic volcaniclastic rocks are highly variable in composition, characterized by rapid lateral facies changes, but appear to have a crude internal stratigraphy. They can be divided into two groups based on their phenocryst populations. Pyroxene-plagioclase–porphyritic crystal tuff, lapilli tuff and rare tuff breccia represent the more volumetrically significant group, with subordinate pyroxene-porphyritic tuff to tuff breccia forming the second volcaniclastic group. The internal stratigraphy of these groups is difficult to define, suggesting rapid lateral volcanic facies changes. The third map unit is a sequence of pyroxene-porphyritic pillowed basalt and flows, which represents a lateral facies of pyroxene-porphyritic tuff.

Plagioclase-pyroxene–porphyritic mafic tuff

Plagioclase-pyroxene–porphyritic crystal tuff is seriate porphyritic with abundant angular phenocryst fragments and rare small lithic clasts. These rocks are generally massive, but bedding is locally recognized. Plagioclase-pyroxene–porphyritic lapilli tuff is characterized by a seriate-porphyritic matrix similar in texture to the crystal tuff, which supports subangular to subrounded lapilli clasts (Figure GS-1-3b). The clast populations vary from monolithic to heterolithic. The monolithic tuff includes clasts with compositions and textures similar to that of the matrix, whereas the heterolithic lapilli tuff includes a mixture of mafic porphyritic and fine-grained aphyric clasts. A potentially mappable unit comprises a matrix-supported lapilli tuff that contains light-coloured, intermediate-composition, aphyric volcanic clasts in a seriate plagioclase-pyroxene–porphyritic matrix. Heterolithic tuff breccia is similar in composition to the lapilli tuff but contains larger clasts.

Pyroxene-porphyritic mafic tuff

Pyroxene-porphyritic mafic tuff represents the upper unit of the mafic volcaniclastic package, and ranges from massive to bedded, seriate-porphyritic crystal tuff, lapilli tuff and tuff breccia. Bedded crystal tuff, exposed in a single location, consists of 20–30 cm thick graded beds (Figure GS-1-3c). Younging is demonstrated by the pronounced grading of phenocrysts, pelitic tops and local basal scour. The strong refraction of S_2 through the beds also indicates younging, denoted by the angle between S_2 and bedding becoming more acute in concert with decreasing grain size. This reflects the partitioning of the D_2 deformation between the coarser base, which experiences pure shear strain, and finer grained top of the bed, which experiences simple shear strain. The lapilli tuff and tuff breccia are characterized by seriate-porphyritic matrix containing subangular to subrounded pyroxene-porphyritic mafic clasts.

Pyroxene-porphyritic mafic volcanic rocks

Pyroxene-porphyritic volcaniclastic rocks grade laterally into pyroxene-porphyritic basalt east of the town of Snow Lake. The basalt sequences generally consist of a series of thick pillowed flows, overlain by massive porphyritic flows and thin pillowed flows. Individual flow units are separated by thin pillow breccia and flow-top breccia. The basalt sequence is generally capped by a thick (<10 m), monolithic to weakly heterolithic, pyroxene-porphyritic lapilli tuff unit.

The pyroxene-porphyritic tuff is remarkably similar in appearance to a series of pyroxene-porphyritic dikes that intrude the pyroxene-plagioclase–porphyritic mafic tuff, gabbro and felsic volcanic rocks. The dikes are generally thin (<1 m) and have no to narrow chilled margins. The margins of the dikes are weakly foliated and the cores appear unfoliated. These dikes are interpreted to be feeder dikes to the pyroxene-porphyritic tuff, which therefore places the pyroxene-porphyritic tuff at the stratigraphic top of the volcanic/volcaniclastic sequence.

Mafic volcanic rocks (unit 3)

Occupying the structural top of the mine sequence are the aphyric basaltic rocks of the Birch basalt (Bailes and Schledewitz, 1998; Figure GS-1-3d). Younging information from mafic sedimentary rocks within this unit suggests that isoclinal F_1 folding significantly affects the internal stratigraphy of the unit. While upward-facing pillowed flows have been documented, significant portions of the unit are overturned. The lower structural contact of the unit is overturned, based on graded bedding in the immediately underlying porphyritic tuff breccia, suggesting that the overall stratigraphy is overturned.

The Birch basalt comprises a sequence of aphyric to locally plagioclase-porphyritic pillowed basalt, massive flows, coarse-grained basalt and mafic-derived sedimentary rocks. The pillowed basalt is light green weathering with thin selvages and minor interpillow hyaloclastite. Pillows contain ubiquitous thermal-contraction cracks, which are generally filled with carbonate and are locally weakly variolitic. Interbedded with the pillowed basalt are units of massive medium-grained basalt, which are interpreted as thick flow units, and finely laminated mafic sedimentary rocks. The sedimentary rocks form an apparent single unit consisting of 2–5 cm thick, finely graded turbidites with thin pelitic tops and local crossbedding. Bedding in this unit is consistently overturned, suggesting macroscopic overturning of the stratigraphy.

Gabbro (unit 4)

A rather irregularly shaped unit of equigranular gabbro intrudes the rhyolite and mafic volcaniclastic rocks in the central portion of the study area. The gabbro has a salt-and-pepper texture, is weakly foliated and has experienced metamorphic recrystallization. The very irregular map pattern suggests minimal deformation, although it locally contains an S_2 foliation. This unit is also intruded by pyroxene-porphyritic mafic dikes; this relationship is interpreted to indicate that the gabbro is a member of the volcanic stratigraphy.

Sedimentary rocks

The ca. 1890 Ma volcanic stratigraphy that forms the Snow Lake arc is stratigraphically overlain by ca. 1845 Ma sedimentary rocks of the Kisseynew basin (Domain). In the Snow Lake area, these rocks consist of fluvial-alluvial conglomerate and arenite of the Missi Group and the turbidites of the Burntwood Group.

Burntwood Group (unit 5)

The Burntwood Group in the Snow Lake area consists of medium- to thick-bedded turbidites. In the Snow Lake area, the Burntwood Group turbidites consist of staurolite-garnet-biotite schist and garnet-biotite-staurolite schist (Figure GS-1-3e). The former is characterized by the growth of large (<1 cm) staurolite porphyroblasts and small (2–3 mm) garnet porphyroblasts, which are included in the staurolite. The latter is a finely porphyroblastic pelite to semipelite, which is tentatively correlated with the Corley Lake member (Bailes, pers. comm., 2008). The Burntwood Group is in structural contact with the volcanic rocks, and occupies the area between the Snow Lake Fault in the south and the McLeod Road Thrust.

Missi Group (unit 6)

The Missi Group represents fluvial-alluvial sedimentary rocks deposited along the margin of the Kisseynew Basin. It occupies the area north of the Birch Fault, with the exception of a small wedge of north-facing mafic volcaniclastic rocks at the western end of Birch Lake (Figure GS-1-2).

In the Snow Lake area, the Missi Group is characterized by thick-bedded, generally trough-crossbedded lithic arenite (Figure GS-1-3f), with local matrix-supported conglomerate and pebbly greywacke. The beds generally contain Bouma A–C horizons and lack significant amounts of pelitic to semipelitic material. The abundant crossbedding results in a high number of lag deposits, and Missi Group arenite is commonly weakly magnetic. It is also characterized by the growth of small, pink, almandine-garnet porphyroblasts.

Mafic dikes are common within the area underlain by Missi Group arenite. These dikes appear to generally intrude parallel to bedding in the arenite, but are locally discordant. They are medium to coarse grained, diabasic textured and characterized by narrow chilled margins.

Structural analysis

The New Britannia mine horizon has been the focus of considerable work in recent years (Galley et al., 1986, 1988; Schledewitz, 1997, 1998; Gale, 1997, 2002; Bailes and Schledewitz, 1998; Fieldhouse, 1999; Fulton, 1999), yet the controls on gold mineralization remain poorly understood. Most deposits exhibit a high degree of structural control, so structural analysis of the area is critical to a more complete understanding of the genesis of the gold mineralization.

The Snow Lake area is affected by four deformations (Kraus, 1998; Kraus and Williams, 1999), and the New Britannia mine horizon demonstrates the development of three generations of fabric elements representing deformations D_1–D_3.

D_1 deformation

The oldest deformation for which fabric elements are preserved in rocks of the Snow Lake area produced upright to moderately inclined isoclinal folds and an associated axial-planar slaty cleavage (Figure GS-1-4a). The presence of F_1 folds is widespread in the Amisk and Burntwood groups, whereas the penetrative development and preservation of S_1 is rare. The isoclinal geometry of F_1 folds results in the development of a layer-parallel foliation, which was either not penetratively developed or was developed but transposed during subsequent deformations. The F_1 folds in the Burntwood Group lack an axial-planar foliation, with S_1 largely transposed into a bedding-oblique, weakly differentiated S_2 foliation. Kraus (1998) and Kraus and Williams (1999) reported the widespread preservation of S_1 as internal foliations in the microlithons of crenulation cleavage in staurolite porphyroblasts, suggesting pervasive S_1 development in the Burntwood Group. In volcanic rocks, S_1 is locally observed as a layer-parallel slaty cleavage in areas adjacent to stratigraphic contacts, perhaps suggesting that S_1 developed in response to flexural slip along stratigraphic contacts during F_1 folding.

In the Burntwood Group, F_1 folds are highly asymmetric, with a consistent S-asymmetry that maintains the overall upright younging direction. The development of D_1 structures in the Burntwood Group constrains the age of D_1 as younger than ca. 1845 Ma. The D_1 deformation affects all rocks in the Snow Lake area and thus postdates the assembly of the Snow Lake greenstone belt. Within the volcanic stratigraphy, reversals in younging direction define macroscopic isoclinal F_1 folds. These folds are largely responsible for the intercalation of felsic volcanic and mafic volcaniclastic rocks in the hangingwall of the McLeod Road Thrust. The plunge of F_1 is poorly constrained but appears to be relatively shallow, based on the steep attitude of the L_1 stretching lineation, which is generally oriented perpendicular to the plunge of the associated folds, assuming the folding is cylindrical. Associated with the development of F_1 folds is a moderately to steeply plunging stretching lineation. This lineation is best observed in volcaniclastic rocks, which are characterized by a well-developed clast lineation. Overprinting relationships in the eastern portion of the study area clearly demonstrate the oblique overprinting of an L_1 clast lineation by S_2 (Figure GS-1-4b).

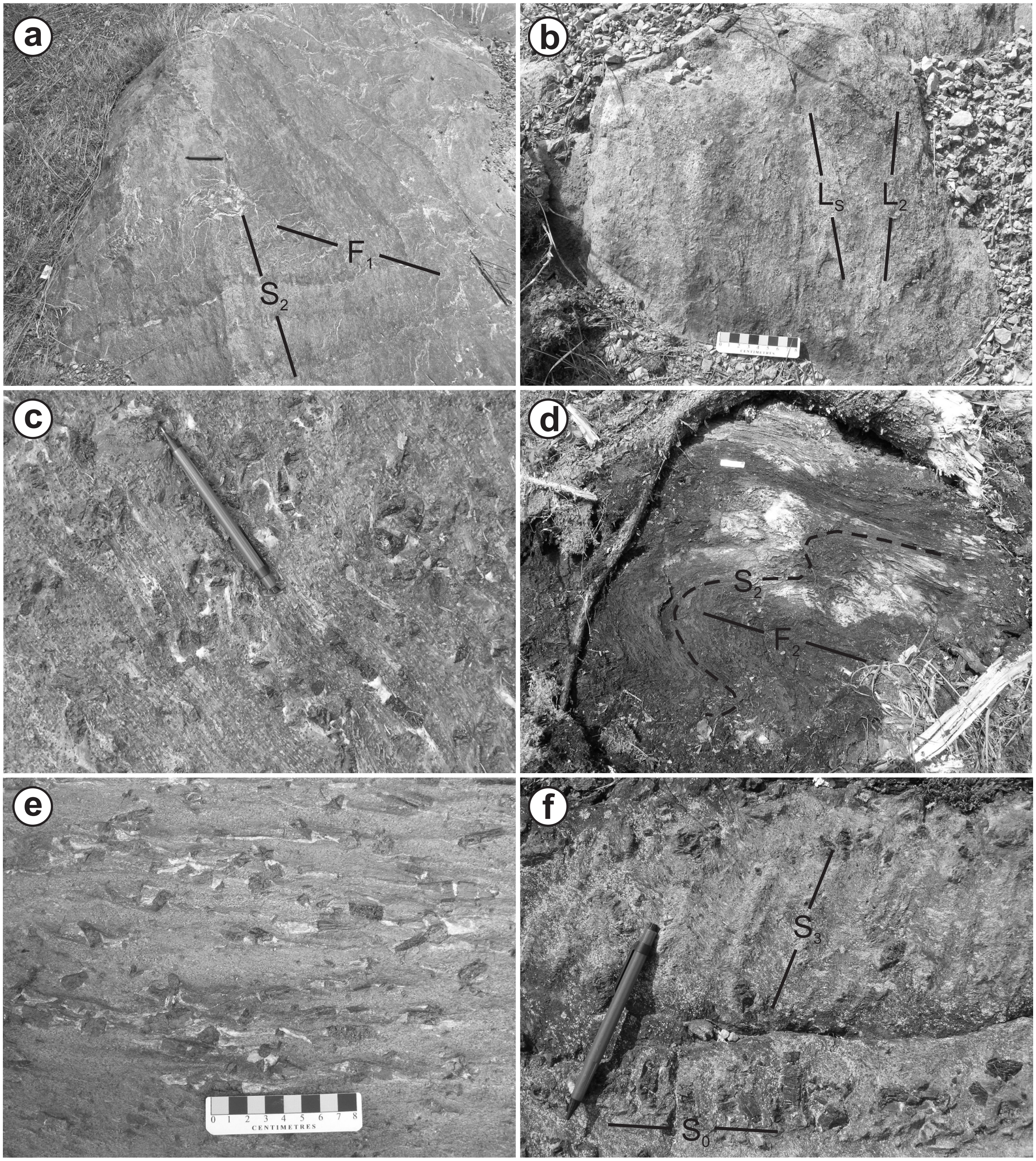

***Figure GS-1-4:** Overprinting relationships between deformational fabric elements in the New Britannia mine area: **a)** S-asymmetric F_1 fold developed in Burntwood Group staurolite schist, overprinted by weakly differentiated S_2 foliation; **b)** overprinting of L_1 stretching lineation (L_S), defined by clasts, and the L_2 intersection lineation; **c)** differentiated S_2 foliation and S_2-parallel staurolite boudinage; **d)** intense S_2 development, denoted by a strong preferred orientation and boudinage of staurolite, along the margin of the McLeod Road Thrust; **e)** F_2 folding of the S_2 mylonitic foliation in the core of the McLeod Road Thrust; **f)** F_3 chevron folds of S_2 developed in the pelitic top of staurolite schist.*

D_2 deformation

The second deformation (D_2) represents a progressive deformation that produced shallowly inclined, open to close folds and a regionally penetrative axial-planar S_2 foliation, and culminated in thrust imbrication of the Snow Lake allochthon.

In the Snow Lake area, S_2 is a moderately north-dipping, consistently layer-oblique foliation that dips more shallowly than bedding and is associated with S-asymmetric, northeast-plunging, shallowly inclined F_2 folds, which results in clockwise S_2-layering/bedding relationships. The S_2 foliation generally represents the oldest foliation preserved in most rocks. In Burntwood Group turbidites, the overprinting of F_1 folds and the transposition of S_1 by S_2 is widespread and results in the lack of S_1 preservation. Consequently, S_2 developed in the Burntwood Group is generally a spaced, weakly differentiated schistosity (Figure GS-1-4c). The graded nature of the turbidites and the oblique orientation of S_2 are reflected in S_2 refraction. Staurolite porphyroblasts have a weak to well-developed, S_2-parallel, preferred dimensional orientation and local S_2-parallel boudinage, consistent with the growth of coarse-grained staurolite porphyroblasts coinciding with D_2.

In volcanic rocks, S_2 is the main mesoscopic foliation except adjacent to lithological contacts, where S_1 is locally developed. The S_2 foliation is a penetrative slaty cleavage to spaced cleavage that is oriented acutely clockwise to bedding. The angle between S_2 and bedding is acute in the eastern portion of the study area and increases to the west as the Nor-Acme anticline (Harrison, 1949) is approached in the vicinity of the No. 3 zone portal, west of the New Britannia mine site. A small area between the portal and the McLeod Road Thrust, which represents the opposing limb of the Nor-Acme anticline, is characterized by anticlockwise relationships between S_2 and bedding.

The McLeod Road Thrust is characterized by a 10–30 m wide zone of intense fabric development. The fault zone dips moderately north to northeast as it is folded about the Threehouse synform. The thrust fault includes a down-dip stretching lineation and sinistral transcurrent shear-sense indicators, suggesting a component of oblique slip. The McLeod Road Thrust is interpreted as a D_2 structure based on the F_3 folding of the thrust fault, which constrains thrusting to pre-D_3, and the thrust truncation of F_1 and F_2 fold axes, which constrain thrusting to post-D_2 folding. The D_2 fabric development in the periphery of the high-strain core of the thrust-fault zone demonstrates synchronous development with the later stages of D_2 fabric development, and accordingly results in the interpretation of thrust faulting as a late-stage D_2 event (cf. Galley at al., 1986; Kraus, 1998; Kraus and Williams, 1999). In the footwall of the thrust, there is a pronounced D_2 strain gradient as the fault zone is approached. The S_2 foliation in the turbidites systematically rotates towards parallelism with the fault, bedding becomes increasingly disrupted and porphyroblasts show evidence of increasing D_2 deformation intensity. In one location, S-asymmetric F_2 folds fold the mylonitic fabric in the high-strain core of the thrust (Figure GS-1-4d). The axial plane of the F_2 folds is parallel to S_2 in adjacent staurolite schist outcrops (Figure GS-1-4e).

The Birch Lake Fault, which forms the boundary between the volcanic and volcaniclastic rocks of the mine sequence and younger Missi Group conglomerate and arenite exhibits many of the structural characteristics of the McLeod Road Thrust. Although it is not stratigraphically required to be a thrust fault, these similarities support its interpretation as one. This may become significant if the underlying volcanic stratigraphy is downward facing. In such a case, one that requires further study, the Birch Lake Fault would represent the boundary between upward-facing sedimentary and mafic volcaniclastic rocks and downward-facing volcanic rocks.

The interpretation of D_2 as a progressive deformation reflects the similar kinematic framework of D_2 folding and foliation development and the later thrust faulting. The shallow dip and shallowly inclined orientation of F_2 fold-axial planes reflects recumbent F_2 folding, possibly related to the nappe emplacement that takes place in the western Flin Flon–Snow Lake greenstone belt margin (*see* Zwanzig, 1999). The progression from folding to thrust faulting can be explained as out-of-sequence thrust faulting that overprints folding developed during the early stages of a thin-skinned deformational event.

The progressive nature of D_2 results in a temporal spectrum of overprinting relationships between D_2 fabric elements, D_2 thrust faults and fabric elements ascribed to other deformations. Thrust imbrication of the stratigraphy clearly predates the regional D_3 Threehouse synform and overprints early-formed D_2 fabric elements. This is best demonstrated west of the New Britannia mine site. In this area, the McLeod Road Thrust truncates the axial plane of the macroscopic F_2 Nor-Acme anticline (Figure GS-1-2).

The shallowly northeast-dipping attitude of S_2, in concert with the steeper dip of bedding/layering, dictates moderate to shallow plunge of F_2. In the eastern portion of the study area, where the effects of F_3 folding are less pronounced, the difference in the orientation of the regional L_1 stretching lineation and the L_2 intersection lineation can be resolved. This provides further evidence for the early D_1 structural timing of the stretching lineation, which experienced reorientation during subsequent deformations.

D_3 deformation

Fabric elements developed during the third deformation (D_3) in the Snow Lake area form large-scale, northeast-trending F_3 folds and a weak to penetrative differentiated S_3 axial-planar foliation. As with other generations of structures, rock type has a major influence on the style of fabric-element development. In the Burntwood Group, D_3 fabric elements consist of chevron folds developed in the more pelitic portions of turbidites (Figure GS-1-4f). These folds generally lack a true axial-planar foliation, but spaced fracture cleavage is locally developed. In volcanic rocks, F_3 folding is rare and S_3 generally forms a spaced differentiated foliation.

This deformation has a major control on the distribution of units throughout the Snow Lake allochthon. In the New Britannia mine area, the most prominent D_3 structure is the macroscopic Threehouse synform, which folds the imbricated Burntwood and Amisk groups about a shallowly northeast-plunging fold axis. The orientation of bedding and S_2 change systematically about the Threehouse synform axis, which highlights a rather enigmatic feature of the structural development in the Snow Lake area. Specifically, there is a pronounced shallowing of the dips of pre-D_3 fabric elements in the core and western limb of the Threehouse synform that results in an apparent coaxial relationship between linear fabric elements. Hence, the relationship between the L_2 and L_3 intersection lineations and the regional stretching lineation is unclear. Previous workers (*see* Kraus, 1998; Kraus and Williams, 1999) noted the coaxial relationship between the L_2 and L_3 intersection lineations and the L_1 regional stretching lineation, all of which plunge moderately to the northeast.

Detailed structural analysis of the New Britannia mine horizon has helped resolve this apparent problem. The recumbent folding and out-of-sequence thrust geometry of the D_2 deformation produced a shallowly inclined attitude of S_2 that generally dips more shallowly than bedding/layering throughout much of the Snow Lake area. This, in concert with a regionally consistent S-asymmetry of F_2, produced northeast-plunging L_2 intersection lineations and F_2 fold axes, which are subparallel to the L_1 stretching lineation. As fabric elements are refolded around a shallowly northeast-plunging F_3 fold axis, it becomes increasing difficult to differentiate between the various lineations, particularly after a high degree of metamorphic recrystallization has overprinted early deformations. As mentioned earlier, the oblique overprinting of an early-formed L_1 stretching lineation by S_2 has been documented. Accordingly, the subparallel relationship between linear structures is simply apparent and does not reflect coaxial deformational events. The only potential genetic relationship reflects the penetrative nature of the stretching lineation exerting a control on the orientation of the developing macroscopic F_3 folds.

Gold mineralization

The understanding of the relationship between gold mineralization and the structural-metamorphic history of the Snow Lake area is a critical factor in the development of a metallogenic model for the development of area's gold deposits. On a regional scale, there is a strong spatial association between gold mineralization and the McLeod Road Thrust. Gold mineralization is located in the hangingwall of the thrust and is hosted by a wide variety of rock types. Two common characteristics are the hosting of mineralization within high-strain zones and the location of gold mineralization along or adjacent to lithological contacts (Figure GS-1-2), a feature that has led to the interpretation of a syngenetic origin for the mineralization (Froese and Moore, 1980). These features indicate that the structural development of the hangingwall to the McLeod Road Thrust may be integral to the development of economic gold mineralization. Accordingly, structural analysis this season focused on elucidating this relationship.

Gold mineralization in the New Britannia mine horizon is hosted by quartz and quartz-carbonate replacements and veins. There appears to be a systematic change in the style of mineralization from east to west. The largest known deposit, the Nor-Acme or New Britannia deposit, is characterized by massive quartz-carbonate replacement of potassium-altered mafic volcaniclastic rocks adjacent to the contact with felsic volcanic rocks. To the west, the deposits become more closely associated with quartz veins. The Boundary zone contains both quartz replacement and quartz-vein–associated gold mineralization focused at the contact of felsic volcanic and mafic volcaniclastic rocks. Farther west, the Kim and No. 3 zones comprise mineralization associated with quartz veins. The Kim zone appears to occupy the contact between two massive mafic crystal tuff units, and the No. 3 zone is located at or near the contact between mafic volcaniclastic rocks and pillowed basalt. The westernmost deposit in the mine horizon is the Birch zone, which consists of a fine quartz stockwork.

Structural analysis identified several important features of the gold mineralization. The most significant in terms of exploration is the fact that large portions of the volcanic stratigraphy are overturned. The intercalation of felsic volcanic and mafic volcaniclastic rocks structurally above the Nor-Acme deposit is the product of isoclinal F_1 folding. This is demonstrated at the Boundary deposit, where the volcaniclastic rocks along the mafic-felsic contact have graded bedding, indicating the overturning of the contact that is subsequently overprinted by S_2 (Figure GS-1-5). Following this contact around the macroscopic F_1 fold eventually leads to the Nor-Acme deposit, suggesting that the two deposits occupy the same stratigraphic position. If there is a syngenetic component to the localization of gold mineralization, fold repetitions of stratigraphy may become an important exploration guide. While unequivocal bedding and younging determinations are relatively rare in the volcanic rocks, similar overturned bedding was observed at the No. 3 zone portal. The delineation of F_1 folds in the volcanic stratigraphy is by no means complete, but the location of overturned volcanic stratigraphy near the structural top of the mafic volcaniclastic unit suggests that the Birch basalt may represent the stratigraphic base of the succession.

Mesoscopic overprinting relationships between gold mineralization and fabric elements constrain gold emplacement to syn-D_2 or older. Quartz veins that accompanied gold emplacement at the Kim and No. 3 zones are both folded by F_2 and locally cut F_2 axial planes. This relationship suggests that gold emplacement coincides with D_2, which would also coincide with the peak of metamorphism. This interpretation represents a minimum relative age for gold mineralization. An older relative age for the gold mineralization is suggested by the correlation between intense S_1 development along lithological contacts and gold emplacement along the same horizons. Although a genetic relationship between

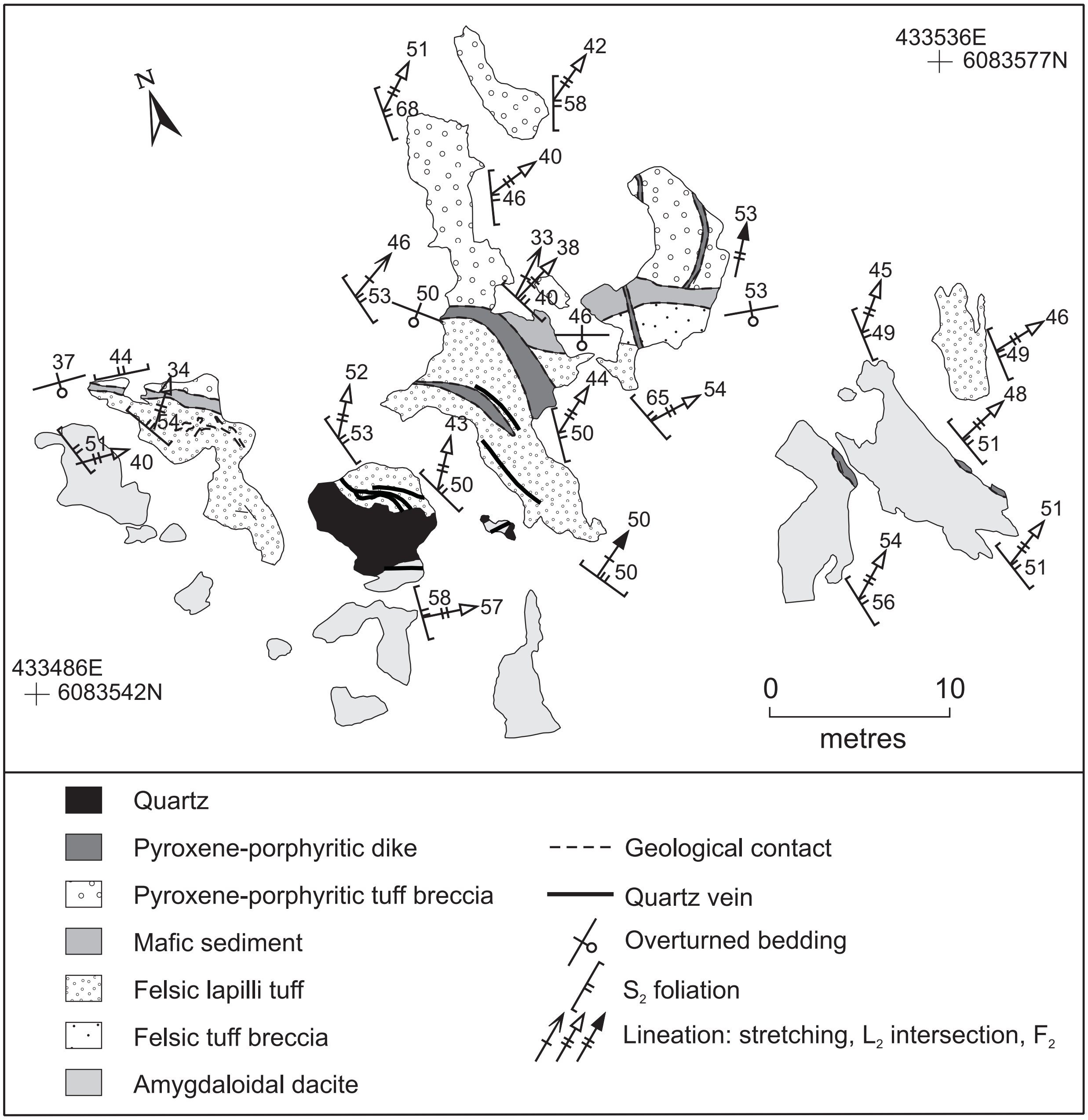

Figure GS-1-5: *Sketch map of the Boundary zone surface exposure, documenting the pre-D$_2$ overturning of the mafic-felsic contact.*

D_1 and gold emplacement remains unresolved, in this scenario, the F_2 folding of auriferous quartz veins would represent a remobilization event, as opposed to primary gold deposition. Further research is required to resolve these two end members.

Economic considerations

A more complete understanding of the relationship between gold mineralization and the tectonometamorphic history of the Snow Lake area will provide important constraints on gold exploration and development. Exploration success, and possible mine development, are dependent on a robust geological model for the genesis of gold mineralization. This model also affects the design and implementation of gold-exploration programs. Fieldwork undertaken this year represents the first stage in a multistage process of refining the geological model for gold genesis in the Snow Lake area. Additional structural analysis is required to further delineate F_1 folding and generate data that will help constrain the timing of gold emplacement.

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