GS-11 STRUCTURAL ANALYSIS AND INVESTIGATIONS OF SHEAR-HOSTED GOLD MINERALIZATION IN THE SOUTHERN LYNN LAKE GREENSTONE BELT (PARTS OF NTS 64C/11, /12, /15, /16)

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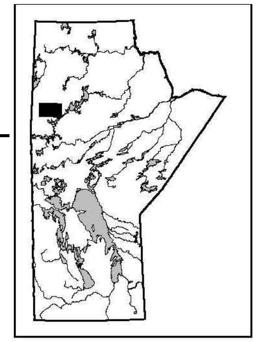

Beaumont-Smith, C.J., Anderson, S.D. and Böhm, Ch.O. 2001: Structural analysis and investigations of shear-hosted gold mineralization in the southern Lynn Lake greenstone belt (parts of NTS 64C/11, /12, /15, /16); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 67-75.

SUMMARY

Continuing structural analysis of the southern Lynn Lake greenstone belt has delineated six generations of ductile to brittle-ductile fabrics. Overprinting relationships among the various generations of fabric suggest that the deformations represent discrete deformation having different kinematic frames. The oldest deformation (D_1) is responsible for the tectonic assembly of Wasekwan Group metavolcanic rocks prior to the intrusion of abundant plutons and the deposition of Sickle Group fluvial-alluvial arenaceous rocks. An intense D_2 transposition-shearing deformation overprints the D_1 geometry, producing the east-west distribution of the greenstone belt. Transposition associated with D_2 is characterized by the development of shallowly plunging, upright, F_2 isoclinal folds. The geometry of F_2 folds suggests a shallow pre-D_2 surface, a geometry most easily explained by D_1 thrust imbrication of the Wasekwan Group. Late-stage D_2 deformation is characterized by the development of regional-scale, D_2 dextral-transpressional shear zones. This is reflected in the development of D_2 shear zones within the greenstone belt, in addition to the previously identified Johnson Shear Zone developed along the southern margin of the belt. The overprinting of the resultant D_1/D_2 geometry by younger deformations does not result in the macroscopic reorientation of the pre-existing geometry.

Gold mineralization in the Lynn Lake greenstone belt is hosted by mafic and felsic metavolcanic rocks affected by D_2 shear zones. The delineation of D_2 shear zones within the greenstone belt significantly increases the amount of underexplored gold-prospective stratigraphy in the Lynn Lake belt beyond the Johnson Shear Zone. Known gold mineralization is accompanied by intense synshear alteration. The alteration assemblages have unique characteristics, controlled by the respective host rocks. Alteration associated with synshear gold mineralization hosted by mafic metavolcanic rocks is characterized by intense silicification, biotitization and carbonatization, and the introduction of finely disseminated pyrite. Synshear gold mineralization hosted by felsic metavolcanic rocks is accompanied by intense silicification, sericitization and the introduction of finely disseminated arsenopyrite. The economic potential of the newly delineated D_2 shear zones is highlighted by the identification of several alteration zones with intensities and assemblages similar to those associated with known gold mineralization.

INTRODUCTION

Structural analysis of the southern Lynn Lake greenstone belt and the companion investigation into shear-hosted gold mineralization represent two components of a regional study into the tectonic and metallogenic history of the north flank of the Kisseynew margin. The geoscientific research in the Lynn Lake–Leaf Rapids area presented in this volume represents collaboration between the Manitoba Geological Survey (MGS) and the Geological Survey of Canada (GSC), in the form of a Targeted Geoscience Initiative (TGI). The goal of the TGI process is to foster research that provides an improved understanding of the mineral potential of the targeted region. Structural analysis and geochronological studies of the Lynn Lake greenstone belt are directed toward a better understanding of the deformational history of the belt and the metallogeny of shear-hosted gold mineralization in the belt.

Fieldwork undertaken in 2001 represents an expansion of the focus of structural analysis beyond the Johnson Shear Zone (JSZ; Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000) to include significant portions of the Lynn Lake greenstone belt. The change in mandate reflects the requirement for a more regional understanding of the deformational history of the greenstone belt, in light of the complex tectonic assembly of the greenstone belt inferred from revised regional geochemistry (Zwanzig et al., 1999) and the identification of multiple high-strain zones within the greenstone belt (Beaumont-Smith, 2000; Ma et al., 2000). This revised approach not only provides context for the shear zone–focused, mineral-deposits research, but also supports the ongoing geochemical work and newly initiated geochronological research. It is hoped that, by adopting a broader focus to the research, including regional geochronology, more direct comparisons with other juvenile arc and back-arc domains can be made, in order to aid the mineral-exploration community and provide a better understanding of the tectonic evolution of the Lynn Lake belt.

GEOLOGICAL SETTING

The Paleoproterozoic Lynn Lake greenstone belt (Fig. GS-11-1) comprises a diverse tectonostratigraphy in the form of two east-trending supracrustal belts of metavolcanic rocks and subordinate metasedimentary rocks, collectively assigned to the Wasekwan Group (Bateman, 1945). The age of the Wasekwan Group is approximately 1910 Ma (Baldwin et al., 1987).

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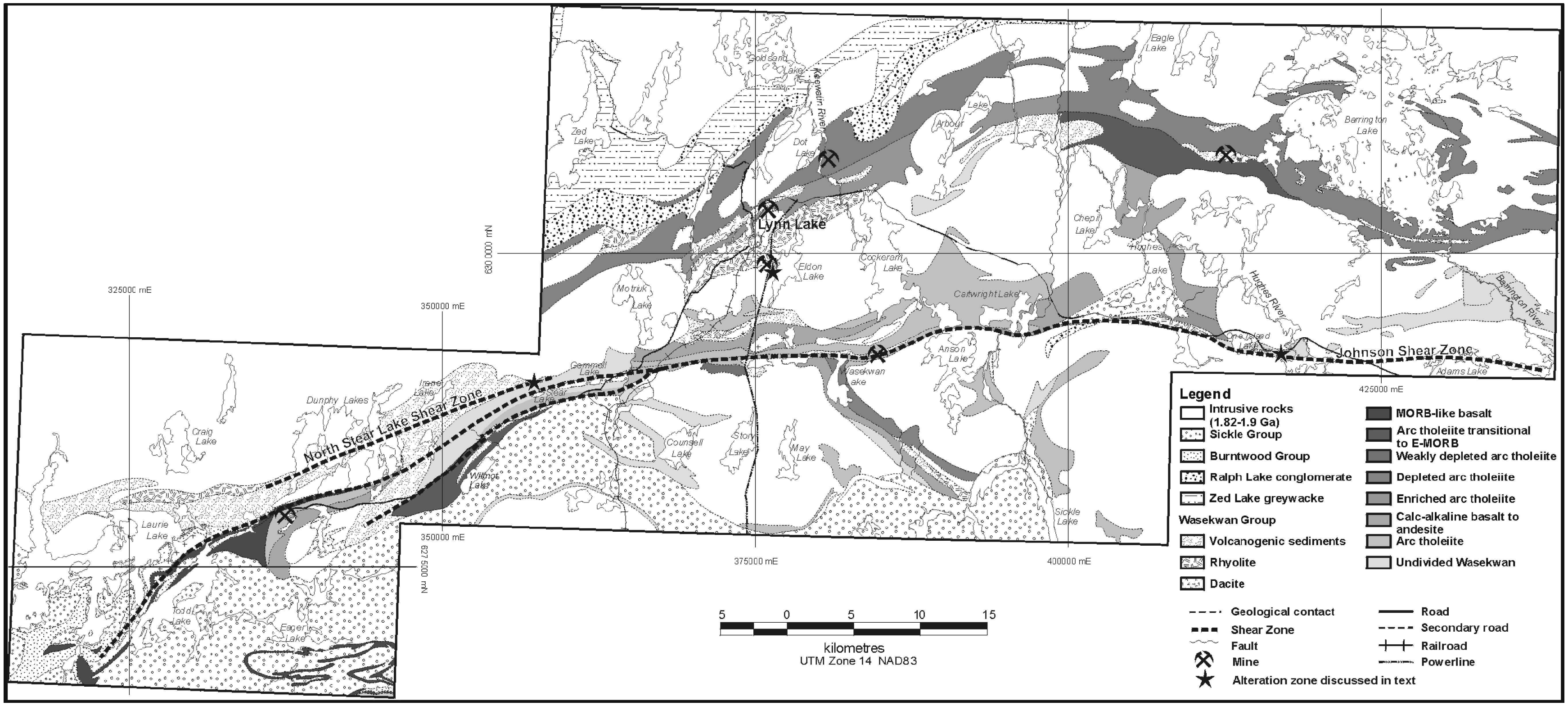


Figure GS-11-1: Geology of the Lynn Lake greenstone belt, highlighting the location of regional D_2 shear zones and alteration zones discussed in the text.

Both belts are characterized by mafic metavolcanic rocks that represent a wide variety of tectonic affinities, suggesting that the assembly of the greenstone belt involved significant tectonic juxtaposition early in its deformational history (*see* Zwanzig et al., 1999). The northern belt is dominated by a variety of submarine, tholeiitic, mafic metavolcanic and metavolcaniclastic rocks that are interpreted to represent an overall north-facing, upright, homoclinal succession. Included in the northern belt is the Agassiz Metallotect (Fedikow and Gale, 1982), a unique tectonostratigraphic succession consisting of ultramafic flows (picrite), banded oxide-facies iron-formation, and associated exhalitive sedimentary rocks. The Agassiz Metallotect represents a relatively narrow stratigraphic-structural unit that has generally persistent strike-continuity along a significant portion of the northern belt (*see* Ma et al., 2000; Ma and Beaumont-Smith, GS-13, this volume). The southern belt is composed of submarine metavolcanic and metavolcaniclastic rocks, with tectonic affinities ranging from tholeiitic to calc-alkaline, and minor amounts of mid-oceanic ridge basalt (MORB) and ocean island basalt (OIB) that contribute to a complex tectonostratigraphy (Zwanzig et al., 1999).

The complex Wasekwan Group tectonostratigraphy was tectonically assembled prior to the intrusion of a variety of plutonic rocks, collectively assigned to the Pool Lake plutonic suite (Manitoba Energy and Mines, 1986). The plutons consist of weakly to moderately foliated gabbro to granite and have a three-fold age distribution: 1876 Ma (Baldwin et al., 1987) to1871 Ma (Turek et al., 2000); 1857 to1853 Ma (Machado, unpublished data); and 1832 Ma (Turek et al., 2000). These recently determined ages are consistent with the subdivision of intrusive rocks into early, middle and late successor-arc plutons, as applied in the Flin Flon Belt (Whalen et al., 1999), and suggest a similar complex magmatic evolution in the Lynn Lake belt.

Unconformably overlying the Wasekwan Group and 1876 to 1853 Ma plutons along the southern margin of the greenstone belt are coarse fluvial-alluvial arenaceous rocks of the Sickle Group (Norman, 1933; Gilbert et al., 1980). The basal Sickle conglomerate contains rounded supracrustal, plutonic and white vein-quartz cobbles, in a fine-grained arkosic to locally pelitic matrix. The conglomerate fines upward into thick-bedded, trough cross-bedded and cross-laminated arkose. The age of the Sickle Group is uncertain, but a preliminary detrital zircon age spectrum (Machado, pers. comm., 2000) and a composition and stratigraphic position similar to that of the 1850 to 1840 Ma McLennan Group in the La Ronge area of Saskatchewan (Ansdell et al., 1999) suggest a similar age for the Sickle Group.

A different clastic sequence, along the northern margin of the belt, consists of the Ralph Lake conglomerate and the Zed Lake greywacke. The sequence has an unknown age and is intruded by undated plutons. In this sequence, conglomerate composed of dominantly plutonic cobbles and minor supracrustal cobbles in an arenaceous matrix is overlain by pelite-poor turbidite. One similarity with the Sickle Group is the high concentration of magnetite within the lowermost conglomerate units.

Regional deformation, reflected in penetrative tectonic foliations, has affected all rocks in the Lynn Lake greenstone belt. The intensity of foliation development is highly variable throughout the belt and there is mesoscopic evidence of at least six phases of ductile and brittle-ductile deformation. The most intense phases of deformation have been overprinted by at least two metamorphic events, resulting in mineral assemblages that increase from upper greenschist facies in the Hughes Lake–Cockeram Lake area to upper amphibolite facies throughout other portions of the belt. The peak of metamorphism postdates the assembly of the greenstone belt and the major transposition–shear zone development event (Beaumont-Smith and Rogge, 1999; Beaumont-Smith, 2000). Accordingly, metamorphic recrystallization has significantly modified many of the fabric elements developed during the major deformations.

STRUCTURAL ANALYSIS

Structural analysis of the Lynn Lake greenstone belt has identified six regionally penetrative, ductile deformation events (D_1–D_6). These are based on differences in their kinematic framework and overprinting relationships. The oldest deformation (D_1) is largely inferred from a stratigraphic architecture in which different tectonic assemblages were juxtaposed to create a complex tectonostratigraphy within the Wasekwan 'Group'. In addition, reversals in pillow tops outline large-scale, east-northeast-trending F_1 folds, such as the McVeigh Lake anticline (Gilbert et al., 1980). These structures are cut by ca. 1876 Ma plutons. Mesoscopic D_1 fabrics are generally rare, due to D_2 transposition and metamorphic recrystallization. Where preserved, mesoscopic D_1 fabric elements consist of slaty cleavage, which is crenulated to form a differentiated S_2 crenulation cleavage, and a shallowly plunging volcanic-clast lineation.

The macroscopic geometry of the Wasekwan Group is the result of the D_2 overprinting of the D_1 geometry. The D_2 deformation postdates the intrusion of plutons and the Sickle Group, so the distribution of these rocks is the result of D_2 deformation alone. Fabric elements of D_2 generally represent the regional mesoscopic fabrics. A steeply north-dipping S_2 schistosity to strongly differentiated foliation is ubiquitous. It is associated with upright, shallowly plunging, tight to isoclinal F_2 folds. The shallow plunge suggests an early subhorizontal enveloping surface, which probably developed with its related fabric elements during D_1 folding and thrusting. This inference not only explains the D_2 geometry, but also provides a mechanism for the D_1 juxtaposition of the various tectonic-geochemical affinities that constitute the Wasekwan Group.

Intense D_2 deformation has produced broad zones of transposition and a composite S_2 fabric (i.e., a differentiated fabric representing the crenulation of an older fabric without the preservation of the older fabric). The D_2 deformation is interpreted to have become more focused with time as regional shear zones developed during its the final stages. The most significant regional D_2 shear zone is the JSZ (Bateman, 1945; Milligan, 1960), which represents a major zone of ductile deformation along the southern margin of the southern Lynn Lake greenstone belt. In the central portion of the greenstone belt, the JSZ forms the boundary between the Wasekwan Group and the Pool Lake plutonic suite, as well as between stratigraphically unrelated belts of Wasekwan Group rocks. In this region, the JSZ has an anastomosing mylonitic core within a 300 m wide zone of intense crenulation cleavage. The occurrence of the JSZ along the supracrustal-plutonic contact probably reflects the localization of regional D_2 shear strain along a primary rheological boundary.

Shear zones in the western portion of the southern greenstone belt are characterized by a series of parallel high-strain zones within the Wasekwan Group. Three subparallel shear zones have been delineated west of Gemmell Lake (Fig. GS-11-1). The southernmost of these appears to be the main strike continuation of the JSZ. A second zone, parallel to the JSZ, has been delineated immediately north of Gemmell Lake and has been traced westward through intermittent outcrop north of Stear Lake. The westward continuation of this shear zone forms the Dunphy Lakes fault system (cf. Beaumont-Smith, 2000). The entire Gemmell–Dunphy Lakes zone represents a splay of the main JSZ, which bifurcates immediately east of Gemmell Lake. A third shear zone has been identified in the northern portion of the southern greenstone belt, approximately 1 km south of the northern greenstone belt margin north of Stear Lake. This shear zone, the North Stear Lake Shear Zone (NSLSZ), forms a prominent topographic linear feature, which trends subparallel to the JSZ, slightly oblique to the regional strike of the greenstone belt. The topographic linear extends south of Irene Lake through to Dunphy Lakes, where it corresponds to a 200 m wide zone of intense deformation involving Wasekwan Group sedimentary rocks and granodiorite. The eastern strike extension of this shear zone is unknown, but it does not appear to represent a JSZ splay.

In the eastern portion of the southern Lynn Lake belt, the JSZ has been traced farther to the east beyond One Island Lake. In this area, it corresponds to a series of topographic linear features, including Wetikoeekan and Adam lakes and the Barrington River north of the Eden Lake Intrusive Complex (Cameron, 1988). Limited outcrop in this area precludes precise positioning of the JSZ, but it appears to follow the supracrustal-intrusive contact and continues east beyond the greenstone belt, affecting the Barrington River megacrystic granite.

The D_2 shear zones developed in the Lynn Lake belt demonstrate very uniform kinematics, further supporting the idea that they developed in response to regional D_2 deformation. The shear zones are characterized by dextral-transcurrent shear-sense indicators on horizontal surfaces and steeply plunging, generally down-dip stretching lineations. Shear zones with similar kinematics are generally interpreted as transpressional shear zones (cf. Lin et al., 1998). Shortening normal to the shear zone is accommodated by peripheral regions, producing steeply plunging stretching lineations, whereas the transcurrent component of the deformation is accommodated by a narrow, highest strain shear-zone core characterized by shallowly plunging stretching lineations. Shallowly plunging stretching lineations have not been documented in the Lynn Lake belt. Variations in the obliquity of stretching lineations within the belt are a function of host rock, with shear zones that affect the Wasekwan Group characterized by generally down-dip (steep) stretching lineations, whereas those that affect Pool Lake suite granitoid rocks have more variable, steep to moderately plunging stretching lineations (Fig. GS-11-2). This suggests that the steep plunge of the stretching lineations may reflect a component of inheritance and incomplete reorientation during shearing of stretching lineations produced during bulk regional shortening that is associated with D_1 and the earlier stages of D_2 transpression, as opposed to their development solely in response to noncoaxial shearing.

There is mounting evidence that D_2 is responsible for the regional development of shear zones in the Lynn Lake greenstone belt. The NSLSZ is an example of a regional-scale shear zone developed in the interior of the greenstone belt, as opposed to along the margin of the belt where regional deformation is concentrated along zones of rheological contrast

Figure GS-11-2: Moderately east-plunging, oblique stretching lineations developed in mylonitized Pool Lake Plutonic suite granodiorite affected by the NSLSZ in the western Dunphy Lakes area; note pen at top of photo for scale.

between the Wasekwan Group and intrusive rocks, resulting in the development of the JSZ. The regional development of D_2 shear zones following transposition may represent a strain softening mechanism, counteracting the strain hardening effects of the continued tightening of F_1 and F_2 folds responsible for regional-scale transposition.

The D_1/D_2 geometry of the Lynn Lake belt is overprinted by a series of structures that formed during less intense phases of deformation. Although these events are penetrative at mesoscopic scale, their effect on the macroscopic geometry (map pattern) is generally minimal. Deformations D_3 and D_4 are manifested by northwest- and northeast-trending crenulation cleavage and open to closed folds, respectively. With the exception of the Boiley Lake–Counsell Lake area (*see* Anderson and Beaumont-Smith, GS-12, this volume) and possibly the complex dome-and-basin geometry developed in the Laurie Lake area (Zwanzig, 2000), these deformation phases been related to the distribution of units in the Lynn Lake belt. Deformation D_5 comprises a north-oriented conjugate cleavage set and open folds associated with the macroscopic warping of the greenstone belt. The final deformation (D_6) represents the brittle-ductile reactivation of D_2 shear zones, producing a variety of open to tight folds and pseudotachylite breccia zones within D_2 shear zones. The D_6 reactivation is thought to be sinistral transcurrent in nature, based on a predominance of sinistral offsets and fold asymmetry.

METAMORPHISM

The metamorphic history of the Lynn Lake belt represents a composite of two metamorphic events. Contact metamorphism, associated with the abundant intrusions of the Pool Lake plutonic suite (M_1), produced narrow upper greenschist facies aureoles that are overprinted by upper greenschist to upper amphibolite facies mineral assemblages produced during regional metamorphism (M_2). In addition to the recrystallization associated with the M_2 regional overprinting, the intense D_2 deformation that followed intrusion of the plutons has largely transposed the M_1 contact metamorphic aureoles, making identification of M_1 assemblages difficult. The M_1 assemblages are generally recognized by the growth of garnet prior to D_2 fabric development. The M_1 garnets either contain S_1 internal foliations discordant with the matrix S_2 foliation or are strongly deformed during D_2, resulting in boudinage of the porphyroblasts or folding of elongated (stretched) porphyroblasts and their pressure shadows. Along the west shore of Eldon Lake, a particularly well exposed granodiorite contact region contains highly deformed calc-silicate, consisting of lime-green siliceous boudins in S_2 within a garnet- and diopside-rich matrix (Fig. GS-11-3).

The regional M_2 metamorphic event has produced widespread, post-D_2 recrystallization and porphyroblast growth. The M_2 porphyroblast growth both overprints and is affected by D_4 fabrics, indicating broadly syn-D_4 timing of the regional metamorphic peak. In the western portion of the greenstone belt, where the metamorphic grade reached middle to upper amphibolite facies, this has resulted in significant modification of D_2 fabric elements. Highly strained and strongly crenulated amphibolite at lower grade becomes mafic tectonite, recognized by the development of very regular differentiated layering.

SHEAR-HOSTED GOLD METALLOGENY

In conjunction with structural analysis, investigations into the origin of shear-hosted gold mineralization are critical to understanding the history of the Lynn Lake greenstone belt and the economic viability of the region. To this end, the identification and delineation of shear zones in the western and eastern portions of the Lynn Lake belt was a major focus of this year’s fieldwork.

Shear-hosted gold mineralization in the southern Lynn Lake belt has been characterized by two distinct mineralization styles, based on host-rock and alteration assemblage (Beaumont-Smith, 2000). Mafic volcanic–hosted gold mineralization is

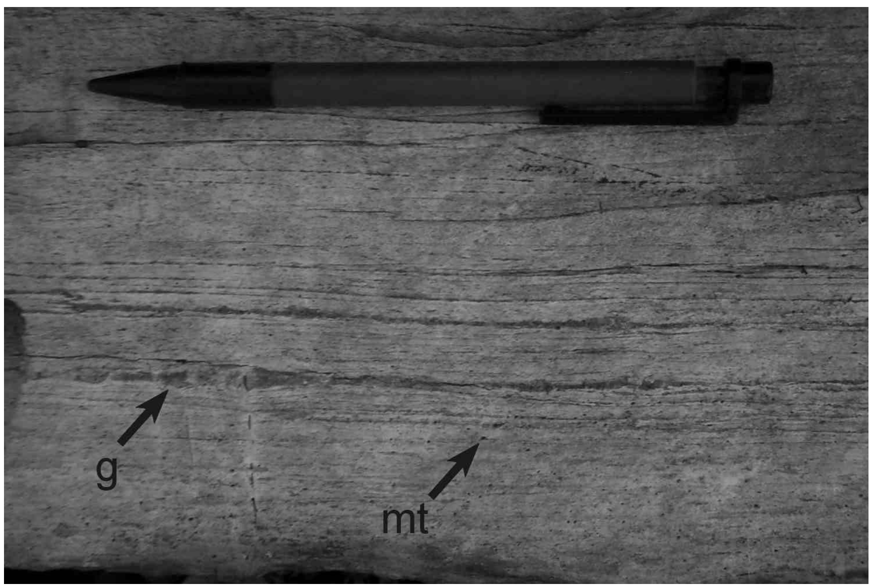
Figure GS-11-3: M_1 garnet-diopside calc-silicate developed in the contact aureole of a Pool Lake suite granodiorite at Eldon Lake.

characterized by intense silicification, biotitization and carbonatization of highly sheared mafic volcanic and volcaniclastic rocks. The alteration is broadly synshear, with gold mineralization associated with the introduction of finely disseminated pyrite in highly silicified alteration zones. Examples of this style of mineralization include the BT deposit (Peck and Eastwood, 1997; Peck et al., 1998; Beaumont-Smith and Rogge, 1999; Jones et al., 2000), which is a broad zone of silicification and alteration in the Wilmot Lake area (Beaumont-Smith, 2000). The second style of gold mineralization is hosted by highly sheared, intensely silicified and altered felsic volcanic rocks west of Gemmell Lake (Beaumont-Smith and Edwards, 2000). The mineralization is associated with very finely disseminated arsenopyrite within zones of silicification. The presence of arsenopyrite is indicated by a burnt reddish coloured bloom on weathered surfaces that has been tentatively identified as arseniosiderite.

The identification and delineation of additional D_2 shear zones in the southern Lynn Lake belt may prove significant in the search for gold mineralization. The eastward continuation of the JSZ includes a broad zone of intense silicification, biotitization and carbonatization of highly sheared mafic volcanic rocks in the Hughes River area, east of Lynn Lake. The NSLSZ represents a regionally significant shear zone, which extends west from Stear Lake to Dunphy Lakes and includes the southern Irene Lake area, an area of confirmed gold mineralization (Ferreira, 1993). The NSLSZ is neither a splay of the JSZ nor directly associated with it, and therefore demonstrates the regional development of D_2 shear zones. This shear zone hosts a zone of intense sericitization, silicification and pyritization of felsic volcanic rocks within a broader garnet-magnetite alteration zone north of Stear Lake (Fig. GS-11-4). Although analyses are pending, the intensity and style of alteration are highly prospective for gold mineralization.

Another significant finding from this summer's fieldwork is a zone of intense alteration along the western shore of Eldon Lake. The alteration is hosted by strongly deformed calc-silicate and biotite-rich, felsic volcaniclastic sedimentary rocks within the contact aureole of the Pool Lake suite granodiorite immediately to the south. The high state of strain in these rocks probably reflects the localization of regional D_2 strain in the volcaniclastic rocks, as opposed to the more competent Lynn

a)



b)

Figure GS-11-4: Felsic phyllonites from the D2 NSLSZ north of Stear Lake: a) weakly altered felsic phyllonite from the footwall of the shear zone, with alteration characterized by the synshear growth of garnet (g) and magnetite (mt); b) intensely sheared and sericitized pyritic phyllonite from a more central portion of the shear zone.

Rhyolite to the north and granodiorite to the south. There is considerable boudinage and intercalation of units within the high-strain zone. The alteration consists of several zones of intense silicification, possibly containing fuchsite, with associated disseminated to semimassive sulphide minerals (Fig. GS-11-5). The broadest alteration zone is approximately 10 m in width. There are multiple sulphide species present, including pyrite, pyrrhotite, chalcopyrite and possibly bornite. No assay results are available, but the amount and intensity of the alteration are of considerable interest.

CONCLUSIONS

Continuing structural analysis of the southern Lynn Lake greenstone belt has provided constraints on the deformational history of the greenstone belt and identified additional prospective areas for shear-hosted gold mineralization. The early deformational history of the greenstone belt probably involved thrust imbrication and upright folding of the Wasekwan Group (D_1), followed by an intense foliation development related to transposition and shearing (D_2). These events are largely responsible for the present distribution of the greenstone rocks and explain the observed juxtaposition of the various tectonic affinities that constitute the Wasekwan Group. The D_2 deformation evolved into transpression during its later stages. Shear zones related to D_2 are more numerous and widespread than earlier thought and represent prospective targets for shear-hosted gold mineralization. Several new zones of shear-hosted alteration have been delineated in the western and eastern portions of the greenstone belt. The zones are characterized by the intense silicification of mafic and felsic volcanic rocks affected by D_2 shear zones.

ACKNOWLEDGMENTS

The authors thank Jerine Thackeray, Shannon Johnston and John Harrison for their enthusiastic assistance. Paul Pawliw and Michael Gareau of Black Hawk Mining Inc. are thanked for their continued support of MGS fieldwork in the Lynn Lake belt. Glenn Prior and the staff of Aur Resources Ltd. are thanked for property access and technical support. The input of Paul

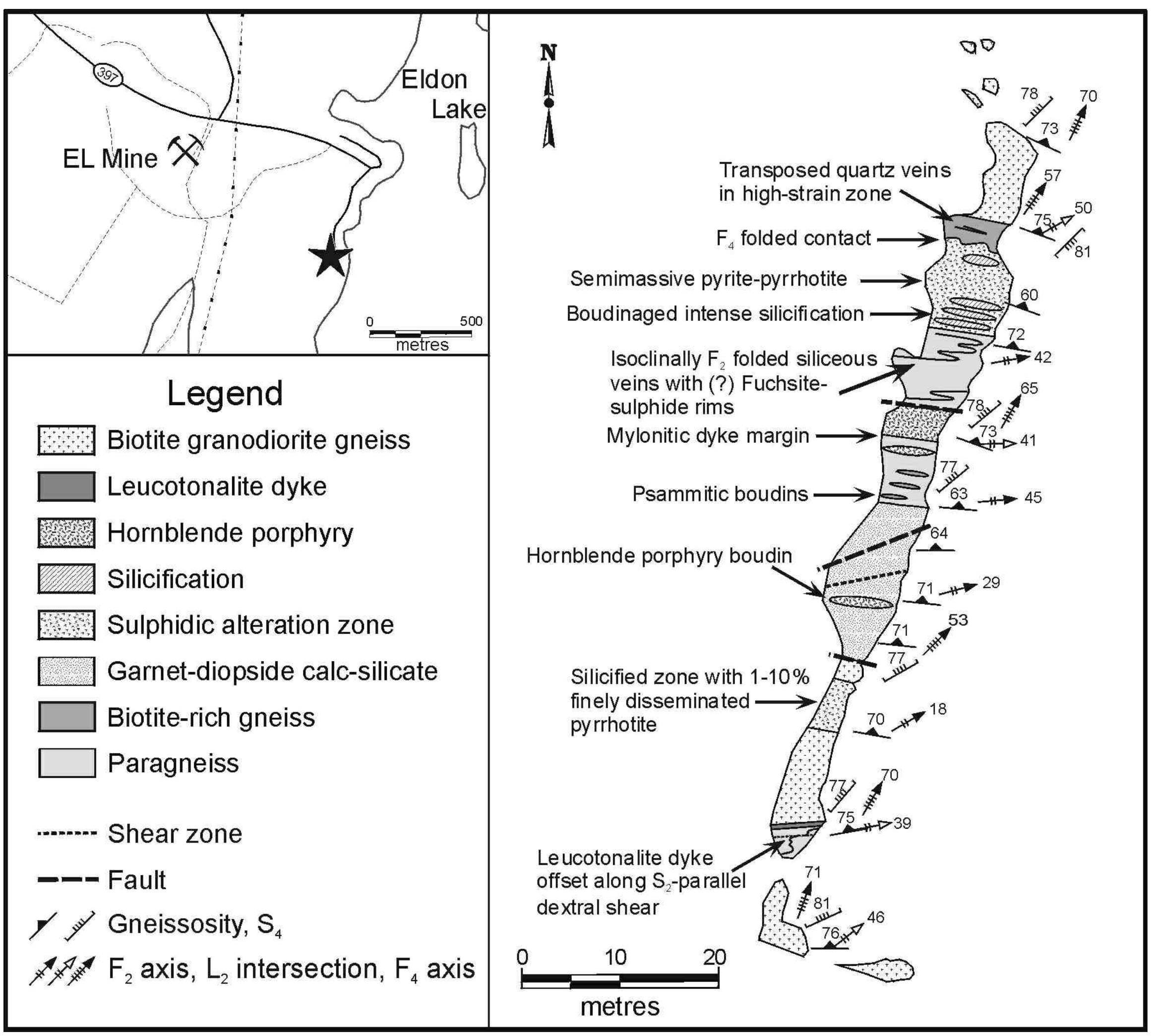


Figure GS-11-5: Sketch map showing the distribution of the intense silicification and sulphidization characterizing the Eldon Lake alteration zone.

Williams, Shoufa Lin, Dahzi Jaing and Bruno LaFrance clarified many issues during the distillation process. Robert Jones held the fort. Earl Simmons and the crew of the Manitoba Conservation warehouse in Lynn Lake provided invaluable assistance. The reviews of Herman Zwanzig greatly improved the manuscript.

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