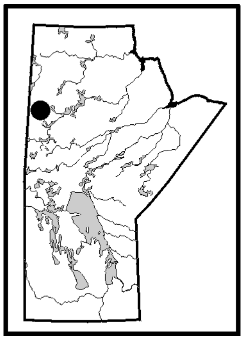
GS-20 STRUCTURE AND STRATIGRAPHY IN THE AGASSIZ METALLOTECT, LYNN LAKE GREENSTONE BELT (NTS 64C14 AND 64C15), MANITOBA

by A.F. Park[1], C.J. Beaumont-Smith and D.R. Lentz[1]



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SUMMARY

Detailed structural analysis of the Agassiz Metallotect in the MacLellan mine area demonstrates that the distribution of the metallotect stratigraphy is a function of D_2 transposition, producing a hybrid tectonite lacking primary lithological characteristics. Locally, D_2 low-strain domains preserve a coherent stratigraphy. The structural geometry of the metallotect is the result of intense noncoaxial D_2 deformation, which produced isoclinal to rootless F_2 folds with a dominant Z-asymmetry and strongly curvilinear hinges. The overall F_2 fold geometry is a shallow plunging sheath, which overprinted shallow dipping (recumbent), isoclinal F_1 folds. The emplacement of gold mineralization and associated alteration appears to be lithology sensitive, with less competent rock types favoured.

GEOLOGICAL BACKGROUND

The Lynn Lake greenstone belt of northern Manitoba (Bateman, 1945) is part of the early Proterozoic Trans-Hudson orogenic belt that crosses the exposed Canadian Shield from northern Quebec and Baffin Island, across Hudson Bay and through the northern and central parts of Manitoba and Saskatchewan (*see* Hoffman, 1990). The Lynn Lake greenstone belt is bounded to the north by the Southern Indian Domain, a mixed metasedimentary and plutonic domain flanked to the north and southeast by the voluminous Wathaman-Chipewyan Batholith. To the south, the Lynn Lake belt is bounded by the Kisseynew metasedimentary domain (Gilbert et al., 1980). Similar greenstone belts occur to the east (Rusty Lake belt) and to the west (La Ronge belt of Saskatchewan).

The supracrustal rocks that constitute the Lynn Lake greenstone belt form the Wasekwan Group, consisting of mafic to felsic volcanic and volcaniclastic rocks and minor mafic intrusions, including a group of metapicrite bodies. The Wasekwan Group is distributed in two east-trending belts, referred to as the northern and southern Lynn Lake belts. The greenstone belt is overlain by two younger supracrustal successions. Along the northern margin of the belt, the Wasekwan Group is overlain by the Ralph Lake conglomerate and Zed Lake greywacke, both containing detritus derived predominantly from the greenstone belt (N. Rainer, pers. comm., 2001). The southern margin of the belt is overlain by younger fluvial-alluvial sedimentary rocks that constitute the Sickle Group. Igneous rocks, from metagabbro to granitoid, intrude some or all the supracrustal sequences. The metagabbro and diorite include the host to the Lynn Lake Cu-Ni-Co deposit, mined between 1958 and 1976, and are probably the earliest intrusive rocks postdating deposition of the Wasekwan Group. Their relationship to the other supracrustal groups is ambiguous, but they are deformed and were probably emplaced early in the deformation history. The granitoid bodies are predominantly later, with some predating deposition of the Sickle Group and others intruding the Sickle Group.

This study has concentrated on the Agassiz Metallotect (Fedikow and Gale, 1982; Fedikow, 1983, 1986, 1992; Fedikow et al., 1986, 1991) between Lynn Lake and the MacLellan mine (Fig. GS-20-1). This Au-Ag metallotect is completely contained within the supracrustal rocks of the Wasekwan Group in the northern Lynn Lake greenstone belt, especially the various mafic and ultramafic volcanic rocks. The Farley Lake and MacLellan gold mines, which are located within the Agassiz Metallotect, exploited mineralization hosted by quartz veins and related alteration in the mafic and ultramafic volcanic rocks.

LITHOLOGICAL UNITS

Eight lithological units are recognized at the 1:10 000 mapping scale of the Agassiz Metallotect in the MacLellan mine area (Fig. GS-20-2).

Metapicrite (unit 1)

These rocks are actinolite-talc-chlorite schist with variable amounts of biotite, magnetite-chromite and carbonate (mainly siderite), and are the equivalent of the 'high Mg-Cr-Ni' basalt of Gagnon (1991). They weather a very

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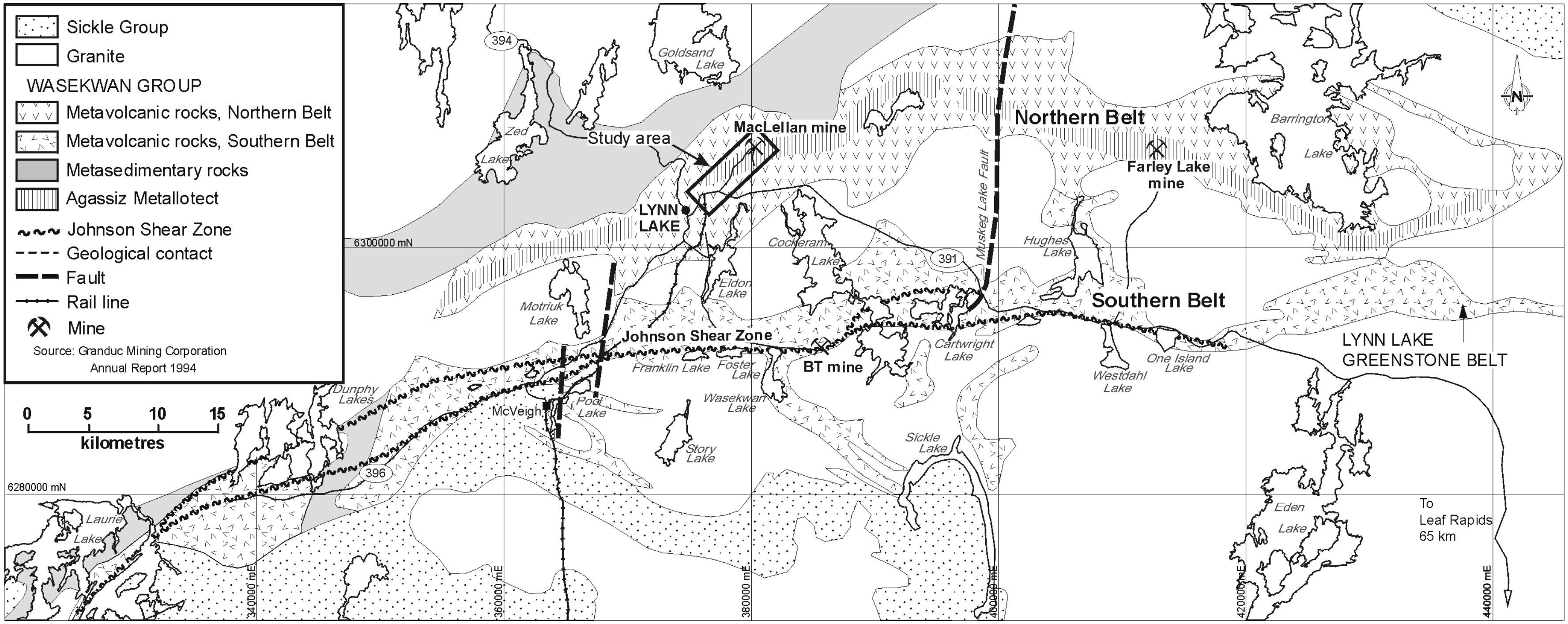

Figure GS-20-1: General geology of the Lynn Lake greenstone belt, showing the location of the Agassiz Metallotect and the study area.

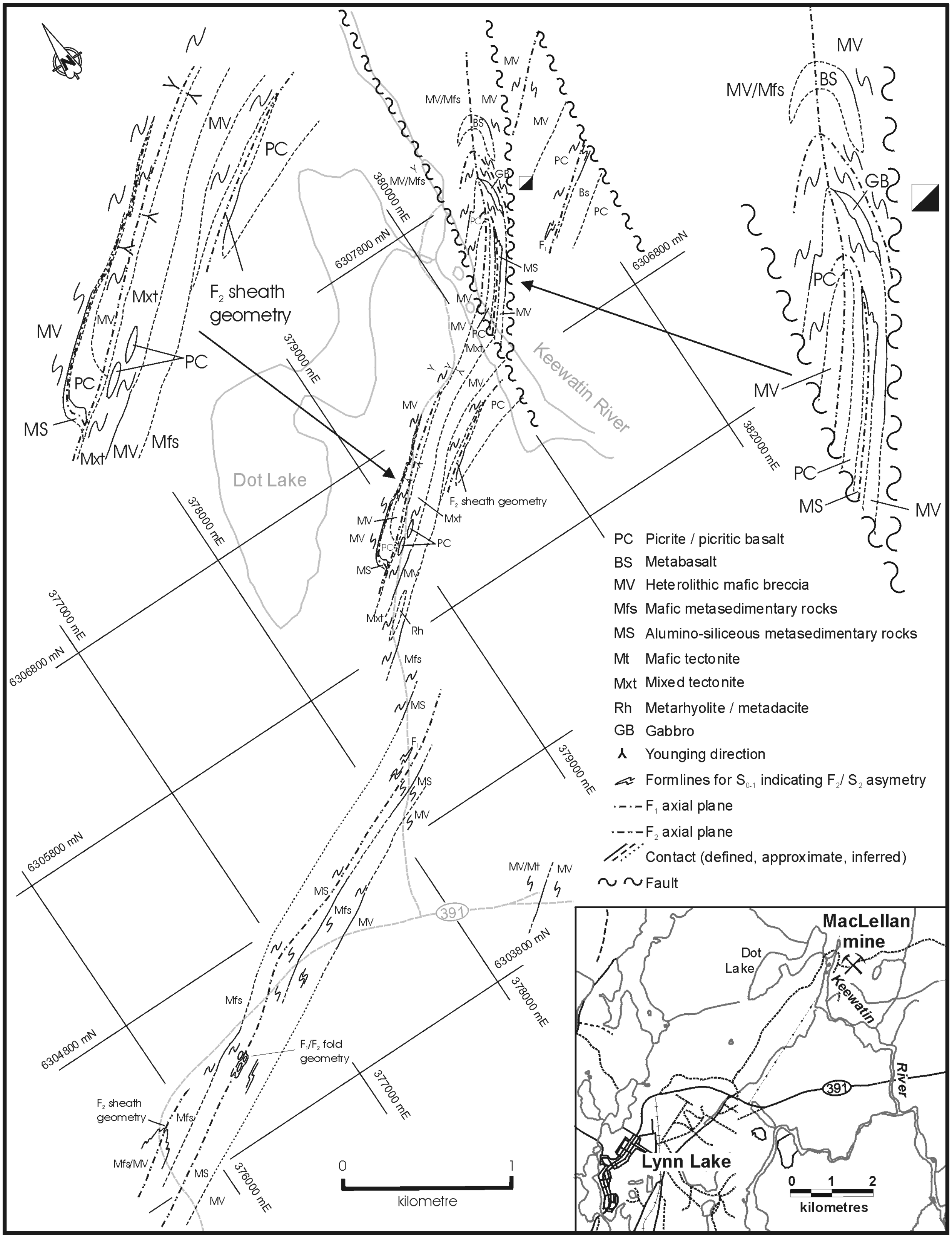

Figure GS-20-2: Detailed geology of the Agassiz Metallotect between the town of Lynn Lake and the MacLellan mine.

distinctive ‘forest green.’ Pillow selvage relicts are locally recognized, but these rocks are tectonite in most localities. Amphibole and talc have reciprocal modal abundances, in that metapicrite at the MacLellan minesite is characterized by 40% or more coarse actinolitic hornblende and accessory talc, whereas 2 km to the southwest at the ‘Rushed zone’, it is talc-chlorite schist (up to 50% modal talc) with minor actinolite.

Metabasalt (unit 2)

Massive metabasalt has been altered to fine-grained amphibolite that weathers a distinctive dark grey to black. Both aphyric and plagioclase-phyric basalt are recognized, and pillow relicts survive. These rocks vary from moderate to well foliated, and are less common than previous studies suggest.

Heterolithic mafic breccia (unit 3)

This is a generally well-foliated amphibolite with abundant relicts of angular to subrounded clasts of aphyric basalt, plagioclase-phyric porphyritic basalt, mafic pillows and pillow fragments. The matrix commonly forms 30 to 50% of the rock, but locally grades up to 100% with outsized clasts absent. This matrix can be aphyric or plagioclase-phyric, and can be mistaken for massive metabasalt when clast poor. This clast-poor material sporadically preserves sedimentary structures, including erosive contacts of coarse, sand-size units on finer silt to mud, crossbedding and channel forms. Every variation from clast-rich, poorly structured units to clast-poor units exists, with many displaying characteristics of turbidity-current deposits.

Overall, this unit accounts for more than 60% of the outcrop exposures between Lynn Lake and the MacLellan mine, representing the southwest end of the Agassiz Metallotect (Fedikow, 1983). Identifying and making use of the way-up indicators present in the more mature mafic volcaniclastic turbidite units has revealed details of the F_1 and F_2 fold relationships previously not documented in this extensive unit.

Mafic metasedimentary rocks – para-amphibolite (unit 4)

Fine- to medium-grained mafic schist alternates with bands of amphibole-rich and amphibole-poor material on the centimetre to decimetre scale. The modal variants seen in this unit consist of variable amounts of garnet, biotite, epidote, plagioclase and chlorite. This lithology is gradational into the more turbiditic components of the heterolithic mafic breccia (unit 3).

Alumino-siliceous metasedimentary rocks (unit 5)

Fine- to medium-grained schist with garnet-amphibole-biotite-plagioclase and quartz shows banding on the centimetre scale. Modal variations in garnet-amphibole and quartz define the bands. This unit interlayers with the mafic metasedimentary rocks, and is locally rich in sulphide minerals, especially along its contacts with mafic metasedimentary rocks and the heterolithic mafic breccia.

Felsic porphyroblastic schist (unit 6)

These are coarsely banded feldspar-mica-quartz-amphibole rocks, with the banding created by modal variations in mica content. These units are generally thin (<5 m thick) but locally persistent along strike (up to 1 km in one case). They are interlayered with mafic metasedimentary rocks and alumino-siliceous metasedimentary rocks, with exposed contacts commonly being rich in sulphide minerals. They appear to represent felsic volcaniclastic rocks.

Massive felsic units / metarhyolite (unit 7)

These are of limited occurrence, only recorded at the MacLellan minesite in any abundance and sporadically to the southwest. They are, however, a major lithology to the south of the Agassiz Metallotect in the ‘Lynn rhyolite’. They are fine-grained, aphyric or porphyritic, quartz-rich rocks with variable amounts of feldspar (this being the phenocryst/porphyroblast species) and white mica. No primary textures have been identified at the MacLellan minesite. Most bodies are tectonized and their relationships to other rocks are obscured, but primary intrusive contacts are preserved in metarhyolite sheets associated with the ‘Rushed zone.’

Ferruginous metasedimentary rocks (unit 8)

Iron-rich metasedimentary rocks do not form mappable units, but consistently occur as distinctive elements of the mineralized zones throughout the metallotect. A quartz-rich, white mica schist with pyrrhotite-pyrite forms a discontinuous layer through the 'Rushed zone' and its extension to the northeast. Similar discontinuous layers occur in the K-2 zone. In both cases, the layer in question is less than 0.5 m thick and traceable for tens of metres, with boudinage being responsible for the discontinuous nature of the layer. A quartz-magnetite iron formation occurs within metasedimentary rocks of units 4 and 5 at the MacLellan mine. It is up to 0.3 m thick but cannot be traced continuously from these outcrops. A pyrrhotite-rich, graphitic black pelite has also been recorded at the MacLellan mine.

Interpretation of the heterolithic mafic breccia

This lithologically diverse unit makes up some 60% of the outcrop between the MacLellan mine and Lynn Lake. As the name implies, the most common rock type is a psephite, which is characterized by angular to subrounded clasts in a finer matrix (original matrix grain size is conjectural, as all of these mafic metasedimentary rocks are recrystallized to amphibolite). Clast size ranges up to boulder (>64 mm) but is more commonly cobble or pebble (Fig. GS-20-3a, b, c). Clast types are all mafic, consisting of aphyric and plagioclase-phyric metabasalt (both amygdaloidal and nonamygdaloidal varieties; Fig. GS-20-3a). Alteration, where present, is represented in the recrystallized material as an abundance of calc-silicate minerals (generally epidote, with some garnet and amphibole). Clasts may be either completely altered or only partly replaced (Fig. GS-20-3d, e), but this alteration terminates at the clast margins. Many clasts appear to be fragments of pillowed flows (Fig. GS-20-3c) or, more rarely, whole pillows, and recrystallized selvages or segments of such selvages are still recognizable.

Clast to matrix proportions vary considerably, from outcrops where only isolated clasts can be identified (in the absence of bedding, such outcrops have been mapped as massive basalt) to outcrops where clasts make up more than 75% of the rock. Even in the clast-dominated material, however, clast-supported breccia is quite rare. Most of the breccia is matrix supported.

The matrix itself shows considerable variation in appearance. Mostly, it is an aphyric, fine- to medium-grained amphibolite, but plagioclase porphyroblasts, possibly after primary grain-clasts, are locally abundant. Where bedding can be identified, grading is evident, from coarse sand-sized material downwards, possibly to material originally as fine-grained as silt (recrystallization precludes a conclusive determination).

Bedding (S_0, usually transposed as S_{0-1} or S_{0-1-2}) is best defined in the fine-grained, clast-poor parts of the heterolithic mafic breccia, and it is in this material that size grading and other way-up indicators are best defined. Crossbeds (Fig. GS-20-3f), channel forms, scours and erosive bases have all been identified, as well as possible rip-up clasts in one example. In these clast-poor units, plagioclase porphyroblasts are generally larger and more abundant in the coarser part of the graded unit, and are either sparsely developed or absent from the finer upper parts. When clasts are rare or absent, these graded units are on the order of a metre thick and are identical to the mafic metasedimentary rocks (para-amphibolite) that form independently mappable units throughout this part of the Lynn Lake belt. This equivalence is reinforced by the present of large breccia clasts near the base of larger graded units within the heterolithic mafic breccia, and the appearance of such units within the mafic metasedimentary rocks.

The morphological range of the bedded units within the heterolithic mafic breccia can be summarized as follows:

1.) **Clast-dominated units:** These show very poorly defined bedding, when they show bedding at all. Individual units are in excess of 3 m thick, and very little grading is evident throughout most of the thickness of these units. Where tops can be defined, a thin drape of sand-sized material is evident, but this is generally less than 10 cm thick. Bases of these units are erosive into underlying units. Clast-supported breccia may be present in the lower parts of these units but is not typical.

2.) **Crudely graded clast-rich units:** These are better organized than the clast-dominated units. Where full thickness can be seen, they are generally 1 to 2 m thick and have 40 to 50% fine-grained (i.e., sand size and finer) material present toward the top. Clast-dominated material is confined to the lower half. Bases are erosive into underlying units and the upper part may contain preserved crossbedding.

3.) **Graded clast-poor units:** These have the best preserved bedding and are generally less than 1 m thick. Where clasts are present, they are confined to the basal portion. Preserved bases are erosive into underlying units and the tops are fine grained. When these units are free of outsized clasts, they are identical to the graded units seen in the mafic metasedimentary rocks and are only differentiated in mapping when they are interlayers within the heterolithic mafic breccia.

It must be emphasized that this three-fold subdivision represents distinct points on a continuous spectrum, and all variations between types 1 and 3 can be found in outcrop. However, this range seems to represent a gradation from poorly organized massive units through material that becomes better organized (graded) as the outsized clasts diminish

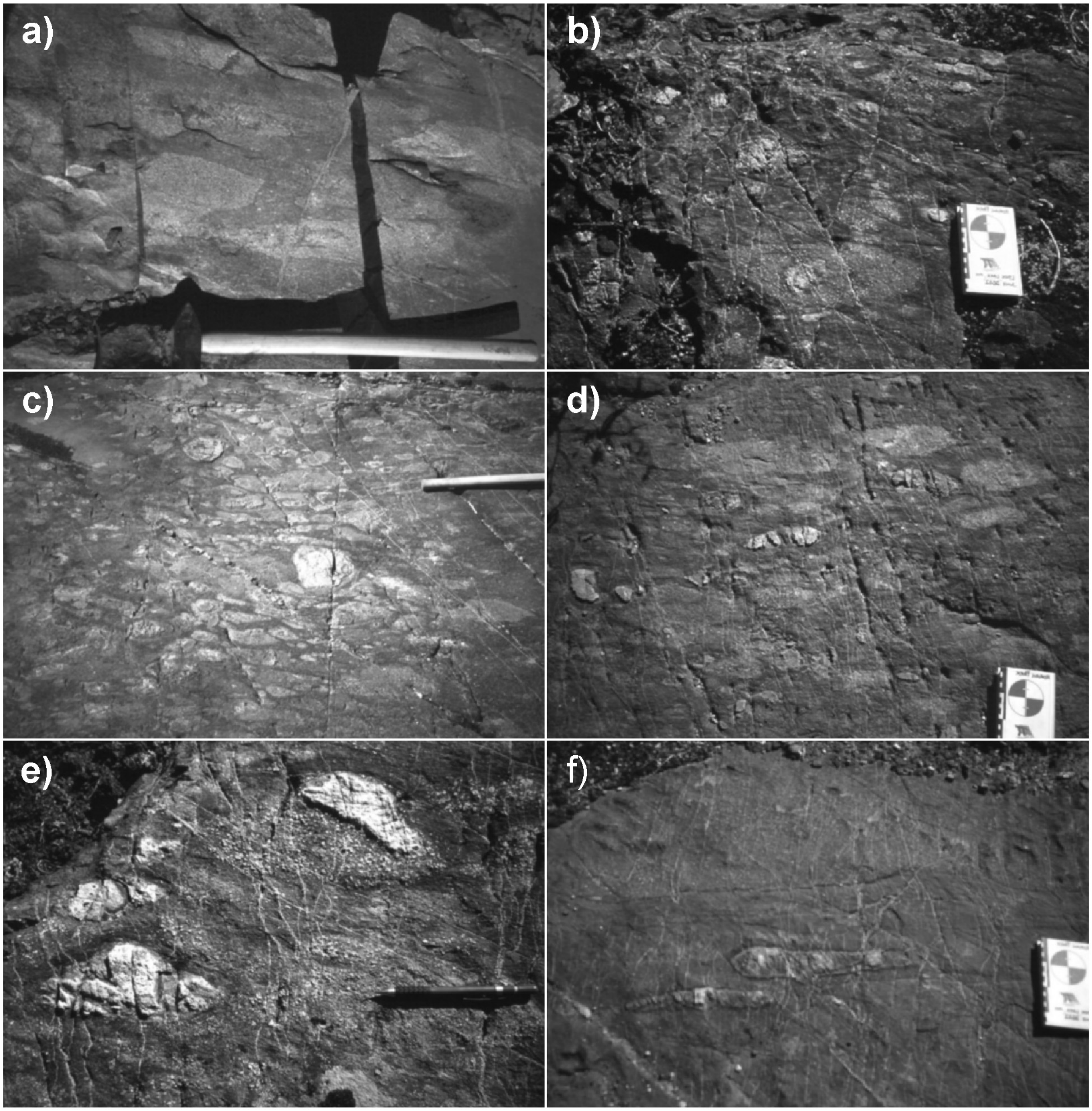

Figure GS-20-3: a) Heterolithic mafic breccia with matrix-supported clasts up to boulder size; both aphyric and porphyritic basalt clasts are present. b) Pebble- to cobble-size clasts in heterolithic breccia; scale on notebook is in centimetres, north toward the top. c) Mixed clast population in heterolithic mafic breccia, including aphyric and porphyritic basalt, and pillowed fragments; large clast in centre was silicified (note different competence) prior to deformation. d) Silicified, nonsilicified and partly silicified basalt clasts in heterolithic mafic breccia. e) Detail from Fig. GS-20-3d, showing partly silicified basalt clasts in heterolithic mafic breccia; silicification is cut off by the clast margin, and therefore predated clast formation. f) Fine-grained unit in heterolithic mafic breccia displaying relict crossbedding; way-up indicates top is toward top of photo (south).

in abundance. This range represents a facies transition from massive debris flows to mafic volcaniclastic turbidites. The debris is generally well mixed. Single units, in the range between types 1 and 2, can therefore contain altered and unaltered, aphyric and porphyritic material, pillows, pillow debris and clasts that are neither. The material being transported consists of a mixture of aphyric and porphyritic mafic flow debris, pillows and pillow fragments. Among the pillow fragments, both complete and incomplete selvages are seen, implying that some of the debris was hyaloclastite. How much of the finer grained (sand size and smaller) was originally tuff cannot be ascertained. Hyaloclastic debris does not seem to form independent units; it is always mixed in with the other clast types.

The interpretation offered here is that the heterolithic mafic breccia is cogenetic with the mafic metasedimentary rocks, and the contrast between them represents a proximal-distal facies relationship. The poorly organized, clast-dominated types are debris flows, which laterally range into better graded turbidites, substantial accumulations of which (minus the outsized clasts) form the mappable mafic metasedimentary units (unit 4). If this interpretation of the heterolithic mafic breccia is appropriate, then it raises a number of important points. Firstly, of the massive basalt and metapicrite units found within the outcrop of the heterolithic mafic breccia (i.e., all those identified between Lynn Lake and the MacLellan mine), only a small number preserve intrusive relationships with the breccia and are clearly hypabyssal intrusions. Even those outcrops that retain pillow selvages (both basalt and picrite pillows are seen at the MacLellan minesite) cannot be unambiguously defined as autochthonous. Recent examples of debris flows from the flanks of island volcanoes are known to contain slumped blocks of massive volcanic material in the 0.5 to 10 km size range (e.g. North Kona landslide, Hawaii; *see* Moore et al., 1995). Secondly, geochemical studies of these volcanic rocks must acknowledge their essentially sedimentary nature. Although volcanic debris may still yield geochemical signatures identifying characteristics of their source, individual debris flow units may contain debris from more than one eruptive centre, or one stage in the evolution of the volcanic edifice. Such sampling should be confined to the coarser clasts, as the finer matrix is more likely to be of mixed provenance.

TECTONO-LITHOSTRATIGRAPHY

Given the degree of deformation and transposition parallel to the S_2 foliation throughout the Agassiz Metallotect, any 'stratigraphy' must be regarded as a preliminary scheme for the purposes of regional mapping. Recognition of way-up criteria in the heterolithic mafic breccia has, however, revealed some relationships of local significance.

Way-up indicators in the heterolithic mafic breccia near contacts with various metasedimentary units, in areas where the D_2 structure opens out in low-strain enclaves, show metasedimentary rocks (units 4 and 5) consistently above breccia. Where both types of metasediment are present, type 4 is always beneath type 5. Mafic breccia is also interlayered with mafic metasedimentary rocks. This is consistent with the mafic metasedimentary rocks being largely or partially a distal facies variation of the heterolithic mafic breccia.

The massive basalt and picrite are either flows or hypabyssal intrusions, or possibly both, given their continuity over tens to hundreds of metres. In those areas where they occur among the heterolithic mafic breccia in D_2 low-strain enclaves, way-up criteria indicate homoclinal panels where both rock types occur within mafic breccia. Most contacts are tectonized, even in low-strain enclaves, but the presence of pillow relicts in both basalt and picrite indicates that some bodies are flows. Caution is necessary, however, in interpreting their stratigraphic relationship to the breccia. Given the interpretation of these breccia units as submarine debris flows slumped from hyaloclastic deltas marginal to volcanic islands, there is the possibility that the basalt and picrite could also be megaclasts.

STRUCTURAL HISTORY

The sequential development of structural elements in the rocks of the Agassiz Metallotect has been discussed by Gilbert et al. (1980) and Beaumont-Smith and Rogge (1999). The reader is also referred to work by Ma et al. (2000), Beaumont-Smith (2000), Beaumont-Smith and Edwards (2000), Jones et al. (2000), Beaumont-Smith et al. (2000), Beaumont-Smith et al. (2001), Anderson and Beaumont-Smith (2001) and Ma and Beaumont-Smith (2001). At least five generations of folds and foliations and their related lineations have been identified, plus faults and fractures. Four generations of these elements have been recognized between Lynn Lake and the MacLellan mine (Fig. GS-20-2).

Structure from Lynn Lake to the MacLellan mine is dominated by D_2 structures and the associated high strain and transposition. The D_2 structures are the primary influence on outcrop pattern–defining lithological packages contained within and lying parallel to the Johnson Shear Zone (Bateman, 1945). The entire outcrop of the 'north belt' of the Lynn Lake greenstone belt between Lynn Lake and the MacLellan mine (i.e., the Agassiz Metallotect) is contained within D_2 structures, and all earlier structural elements are either restricted to low-strain enclaves, seen at scales ranging from less than 1 m on outcrop to zones more than 0.5 km in strike length and approximately 200 m across strike. Most pre-D_2 features are transposed into the S_2 foliation (Ma et al., 2000; Ma and Beaumont-Smith, 2001).

Deformation D_1

The F_1 folds and an axial-planar S_1 foliation are preserved in low-strain enclaves forming complex interference patterns with F_2. The S_1 foliation is a spaced (0.5–2 mm), differentiated foliation defined by modal variations in most rock types, although weakest in the heterolithic mafic breccia. It is always close to, if not actually parallel to, S_0 (primary layering or bedding).

The F_1 folds are isoclinal and generally preserved as rootless, intrafolial relicts transposed in S_2. This makes determination of their original form difficult. Where the S_{0-1} enveloping surface is visible, however, it is commonly within 20° of horizontal, except where F_2 fold hinges are strongly curvilinear. This characteristic, and the general low angle between S_0 and S_1, implies that F_1 folds were isoclinal with shallow-dipping or horizontal axial planes prior to D_2. Locally well-preserved F_1-F_2 interference patterns are consistent with this. Although F_1 folds now have distinctly curvilinear hinges, it is not possible to determine, through the D_2 overprint, whether they were originally sheath folds.

Deformation D_2

These elements dominate the Lynn Lake–MacLellan mine transect, and the progressive, noncoaxial nature of the D_2 structures can be demonstrated at a number of locations on several scales (Fig. GS-20-2, GS-20-4).

The S_2 foliation has a heterogeneous expression with varying degrees of transposition. Some of the best preserved evidence for the development of this fabric is seen in the metapicrite. In low-strain enclaves within metapicrite boudins, S_2 is a well-spaced foliation (1–4 cm), initiated as dark, discontinuous septa on asymmetric Z- and S-microfolds. As strain increases, the S_2 septa become more continuous, and the intervening microlithons narrower (0.5–1 cm) in a well-defined crenulation. Eventually, the form of F_2 microfolds is lost in an S_2 phyllonite containing isolated lithons with S_1 relicts, some of which become S-surfaces in a C-S foliation. These relicts are eventually obscured by S_2-generation C′-shear bands.

The F_2 folds generally have axes plunging between 5° and 40° to the northeast, consistent with the general trend of the L^1_2 lineation (intersection of S_1 and S_2). On the outcrop scale, however, both F_2 axes and this axis-parallel lineation locally define tightly curvilinear fold hinges that are true sheaths (showing rotation through 300° in the axial plane). This pattern is not repeated at larger scales. A second asymmetry is also apparent. Shear sense on S_2 for F_2 minor folds, C-S fabrics, C′-plane shear bands and extension-shortening geometries for deformed veins is predominantly right-lateral (dextral) on horizontal surfaces. Other geometries, such as M- and W-F_2 minor folds, S- and left-lateral shear-sense indicators are few and always associated with visible F_2 closures and low-strain enclaves. On the largest scale, this suggests that F_2 folds are strongly asymmetric structures dominated by their right-lateral limbs and the northeast-plunging sectors of their hinges (Fig. GS-20-2, GS-20-4). They have a sheath geometry, but the complementary left-lateral limbs and southwest-plunging hinge segments are only preserved in low-strain zones (Fig. GS-20-4).

Some of this ambiguity could be clarified if an L_2 stretching lineation could be identified more widely. There is no shortage of lineations on the S_2 foliation, but most of them are intersection lineations or mineral growths following differentiation along these intersections. Aside from the ubiquitous and locally dominant S_4 crenulation of S_2, the following intersection lineations have been noted:

L^1_2: the S_1-S_2 intersection lineation, commonly plunging 5° to 40° northeast, locally defining sheath closures

$L^{c\text{-}s}_2$: the intersection of S-planes with C-planes within S_2 and locally developed from the L^1_2 intersection; it is usually steeply dipping (>70°) to down-dip on S_2

$L^{s\text{-}b}_2$: the intersection of C′-plane shear bands with S_2 C-planes; generally steep (>70°) to down-dip on S_2

Less commonly, an L^s_2 stretching lineation is preserved as a mineral growth with length-parallel pull-apart (usually in coarse amphibole) or as a prolate form to the deformed clasts in the heterolithic mafic breccia. These examples are shallow plunging (<30°) or subhorizontal. This is consistent with an overall sheath geometry for the F_2 folds, but does not demonstrate it.

Deformation D_3

These are structures recognized regionally, including a spaced cleavage (S_3). Too few examples have been noted in the Lynn Lake–MacLellan mine transect to make any conclusions about its overall geometry or significance.

Deformation D_4

These structural elements overprint those of D_2 throughout the area. The F_4 folds are open to tight structures with steeply plunging axes and vertical or near-vertical axial planes. Fold asymmetry on all scales is predominantly right-lateral. The S_4 is a spaced fracture or spaced crenulation cleavage (0.5–2 cm) overprinting S_2 and is locally very strong (obliterating or partly obscuring L_2 lineations). Fractures and small-scale shears parallel to S_4 often carry quartz veins and are locally defined by thin pseudotachylite veinlets. A large-scale F_4 fold, partly modified by later faults, is responsible for the dramatic change in strike of S_2 and the orientation of F_2 axial planes at the MacLellan minesite. This is the only example on this scale of F_4 structure in the Lynn Lake area.

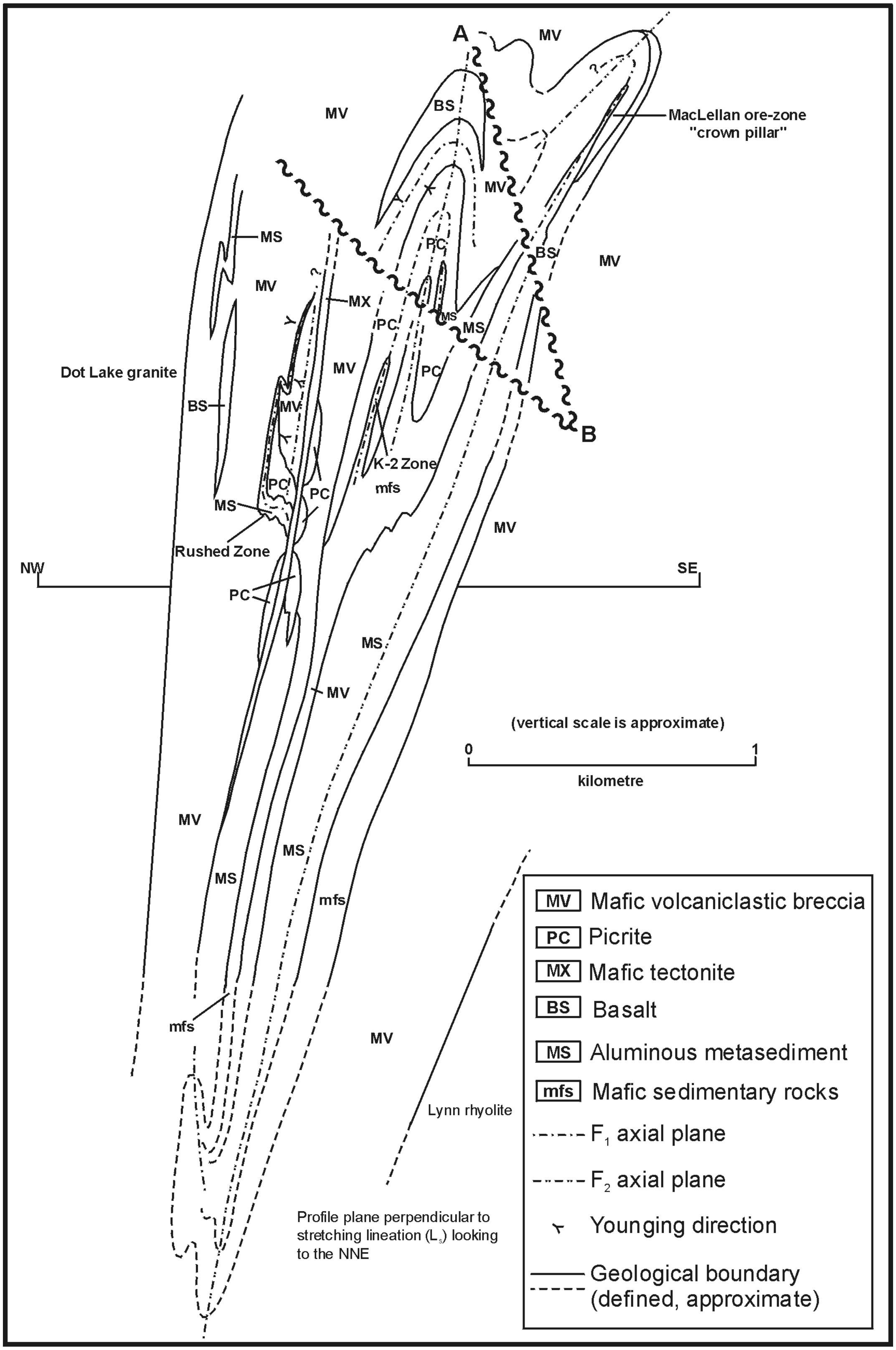

Figure GS-20-4: Structural cross-section through the Agassiz Metallotect between Lynn Lake and the MacLellan mine. Out-of-section details are projected into the profile plane parallel to the L_2 stretching lineation. The profile plane is oriented northwest-southeast about 2 km southwest of the MacLellan mine. Looking north down the plunge of most F_2 folds.

Late faults and fractures

At least three faults, vertical structures trending north to north-northeast, occur near the MacLellan mine. One of these runs parallel to the Keewatin River south of Dot Lake and has the largest displacement. At least two faults that are splays of this structure cross the minesite. No other faults affect the outcrop pattern to this extent. Although the faults themselves are not exposed, outcrops close to their presumed location carry abundant pseudotachylite veins. Indeed, some of these outcrops are effectively pseudotachylite breccia.

LARGE-SCALE STRUCTURE

Based on detailed observations of the vergence of F_2 minor folds, the asymmetry of S_1, S_{0-1} and S_2 relationships, kinematic indicators of shear sense related to S_1 and S_2, and facing of S_0 and S_{0-1} on S_2, some aspects of regional structure in the Agassiz Metallotect can be resolved from this study. From Lynn Lake to the MacLellan mine, the structure is dominated by a large F_2 fold, the core of which is marked by vergence change across a belt of metasedimentary rocks (Fig. GS-20-2). This structure can be traced up to the Keewatin River immediately west of the mine, where it is offset by the fault lying parallel to the river. The continuation across the fault is more speculative, but the interpretation favoured here is that the F_2 closure seen immediately east of the Keewatin River is a mesoscale parasitic F_2 fold, while the main closure runs into the ore zone at the mine itself (Fig. GS-20-2). However, projection of these structures across the second fault (A-B on Fig. GS-20-4) is very provisional. There are schlieren of metasedimentary rocks in the MacLellan orezone, but this enclave could also be an F_1 closure with an F_2 overprint. Extant data cannot resolve this, but small-scale F_1 structures refolded by F_2 are present here.

Viewed in cross-section, the F_2 folds close both up and down in the plane of section because this profile plane is perpendicular to the stretching lineation L_s and they are large-scale sheaths (Fig. GS-20-4). That this is not an F_1-F_2 interference pattern is demonstrated by the few localities where F_1 folds can be traced out. The 'Rushed zone', together with its continuation along the mine road, is one such location. The metasediment enclave hosting the mineralization is an F_1 closure, with sedimentary top directions pointing into the enclave from both sides. When this F_1 fold is traced along the larger F_2 limb, the F_2 minor folds change from S- to Z-asymmetry, whereas the plunge of the minor folds does not change. Sheath geometries can be demonstrated in a similar fashion at the K-2 zone, where F_2 minor folds display strongly curvilinear hinge lines on a single axial plane, and in the road cuts 300 m north of Lynn Lake, where the same features occur and a single stretching lineation (L_s) direction can be observed.

Transposition is a common characteristic throughout the Agassiz Metallotect, but one zone of intense transposition is large enough to be a mappable unit and can be traced for at least 3 km. This is the 'mixed tectonite' unit shown on Figure GS-20-2. The F_2 sheath fold that includes the Rushed zone is related to this structure (it forms the southern limb of the fold). This does not represent a major structural break; it is just an extreme development of the common, stronger transposition on the dextral limbs. Although the F_2 folds are sheath folds, there is a very strong asymmetry, where the longer limbs have dextral shear sense, and the opposing limbs with sinistral shear sense tend to be short and often sheared out. It is this bias that gives the entire zone a predominant right-lateral strike-slip shear sense. Another strong bias comes from the preserved closures. The sheath tips cover relatively small areas. Most outcrop lies on the upward or downward closures away from the tip. As with the strong asymmetric limbs, the northeast-plunging closures are more common than those plunging southwest.

Detailed locality maps

Four locations were mapped at very detailed scales (outcrops gridded at 10 m), as large as 1:200, because they were mineralized and/or showed especially important field relationships between lithological units, veins and alteration, or meso- to macroscopic structure.

1.) MacLellan minesite, 300 m southwest of head frame (Fig. GS-20-5)

Stripped and cleaned outcrops at the MacLellan minesite display relationships between lithostratigraphy and F_2 folds involving iron formation, mafic metasedimentary rocks, alumino-siliceous metasedimentary rocks, metapicrite and metarhyolite. The iron formation is attenuated and discontinuous around an isoclinal fold hinge. The S_1 and S_2 foliations here are nearly parallel and are both parallel to the axial plane in the fold hinge. For this reason, it is impossible to determine whether this is an F_1 or F_2 fold. It may be either an F_2 fold in the closure of the larger structure mapped in the western part of the minesite, or an F_1 fold in the limb of this larger structure.

Metapicrite, interlayered with heterolithic mafic breccia, grades to the southeast into mafic tectonite, with relicts of both rock types observed and with pseudotachylite and cataclasite of two generations evident. The early generation

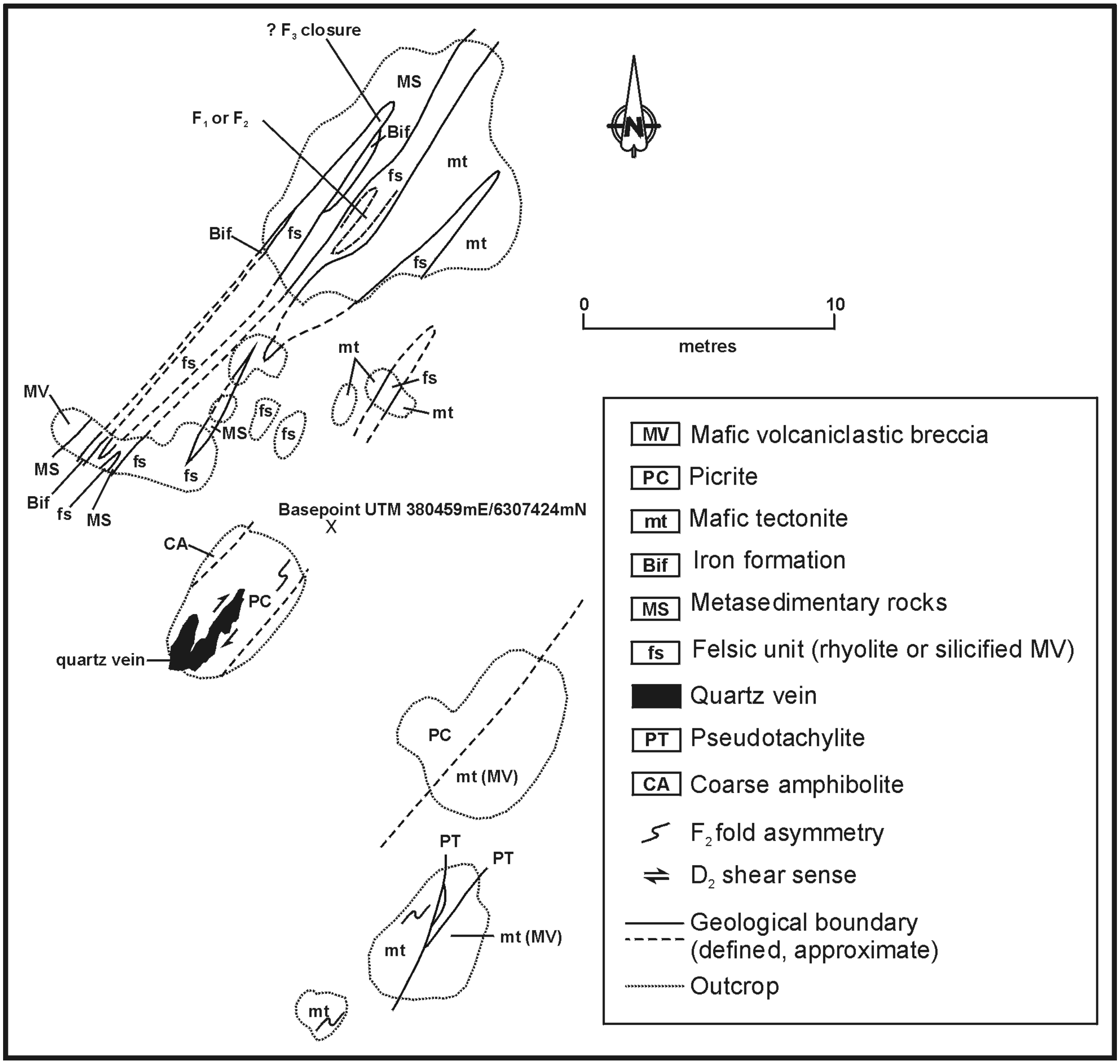

Figure GS-20-5: Detailed outcrop map of cleaned exposures southwest of the MacLellan mine headframe.

is predominantly cataclasite developed parallel to the S_2 foliation, and is widely chloritized and crenulated by S_4. The later phase, with well-preserved pseudotachylite (chilled margins and intrusive veinlets), is partly discordant to S_2 and S_4 and includes blocks with conspicuously rotated S_2 fabrics. These later pseudotachylite units are related to a large fault running immediately southeast of these outcrops.

2.) MacLellan minesite, in the firebreak, 400 m north of the head frame (Fig. GS-20-6)

The bedrock here is heterolithic mafic breccia with a folded enclave of mafic metasedimentary rock (amphibole-garnet schist). One of the large, late faults runs immediately east of this outcrop, and the outcrop is cut by smaller splays of this structure. Both the large fault and its splays run parallel to the S_4 fabric in these rocks.

The metasediment enclave lies parallel to the S_2 foliation; within it, the foliation is a composite of $S_{0\text{-}1\text{-}2}$, picked out by amphibole growth. This composite foliation is intensively crenulated by S_4. The trace of this metasediment layer across these outcrops defines a mesoscale F_4 fold that plunges steeply to the north-northeast.

Pervasive silicification of the heterolithic mafic breccia is seen along both contacts with the metasediment layer; this alteration carries an amphibole and biotite growth, which carries the S_2 fabric in the breccia. Outcrop of the

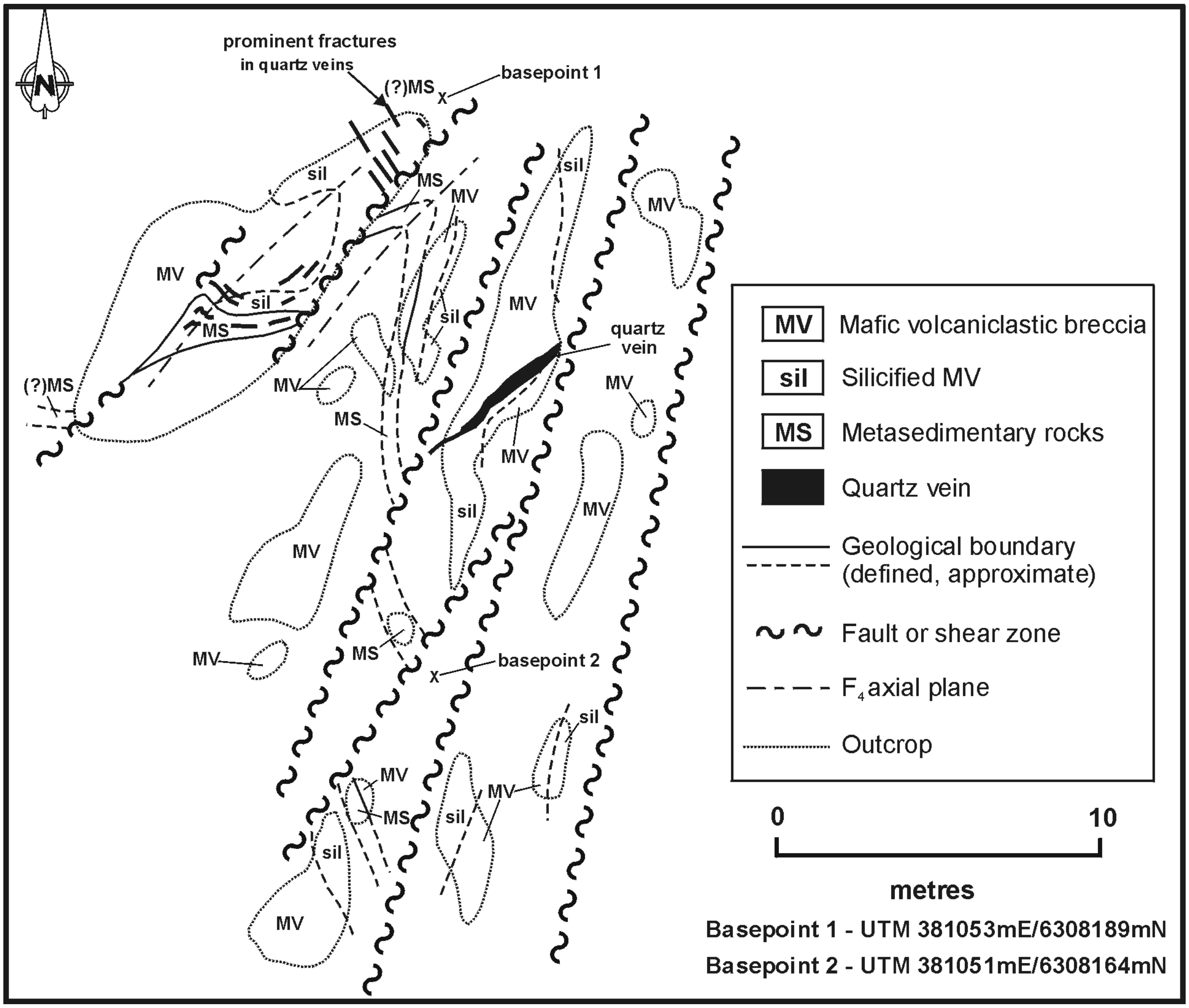

Figure GS-20-6: Detailed outcrop map of the exposure in the fire break north of the MacLellan mine headframe.

metasediment layer picks out an F_4 fold and the metasedimentary rock is strongly crenulated by S_4. This layer is offset along faults parallel to S_4. Silicification overprinting S_2 is found in the wallrocks to these faults. At the northernmost point of these outcrops, a set of quartz veinlets in fractures is conjugate to these faults, and these veinlets are also associated with silicification.

Both S_2 and S_4 show signs of reactivation as fractures when either fabric lies parallel or nearly parallel to the late faults. Quartz veinlets with sulphide mineralization occur on both reactivated planes, and in the late fault conjugates.

3.) **K-2 Zone** (Fig. GS-20-7)

Mineralization here is contained within a ferruginous metasedimentary enclave that defines a southwest-closing F_2 fold with an isoclinal profile. The northern limb can be traced across these outcrops to the northeast. The southern limb persists and then vanishes, possibly around another closure (closing northeast), which is not exposed but is inferred by an F_2 vergence change. The F_2 minor folds at the south end of the trench show highly variable plunges, ranging from approximately 40°NE to 60°SW, that delineate a highly curvilinear hinge for the larger F_2 structure. Quartz stringer zones with silicification and sulphide mineralization run parallel to S_2 in the metapicrite of both footwall and hangingwall, with the metapicrite in the F_2 fold showing extensive silicification up to the metasediment contact.

Some of the larger quartz veins here show wallrock alteration that is sensitive to lithology. The most prominent examples of this are in areas that cross the metasediment-metapicrite contact and die out rapidly in the latter rock type as fractures surrounded by extensive growth of coarse amphibole.

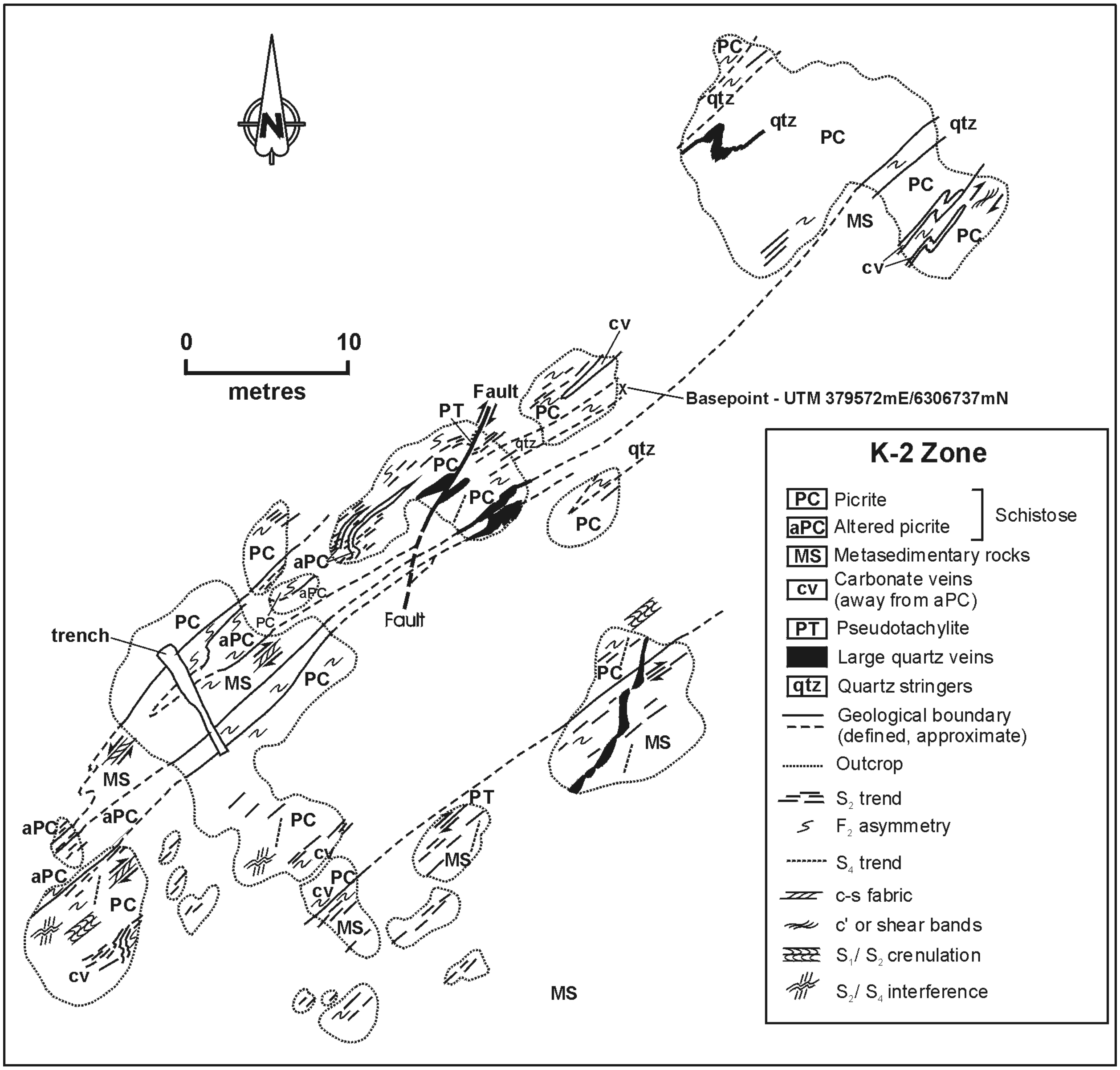

Figure GS-20-7: Detailed outcrop map of the K-2 zone.

4.) "Rushed' zone and its roadside continuation (Fig. GS-20-8)

The 'Rushed zone' and its continuation can be traced in outcrop for nearly 1 km. At the southwest end (the 'Rushed' zone itself), it is contained in a metasedimentary enclave between heterolithic mafic breccia and a metapicrite body. The F_2 minor folds here show S-vergence with a shallow plunge to the northeast. A large F_2 fold closes around the metapicrite body into a mafic tectonite in which schist derived from heterolithic mafic breccia is intimately interlayered with metasediment, and in which all folds show Z-vergence and shear sense is consistently right lateral.

The mineralized zone along the metasediment contact can be traced along strike back to roadside outcrops, at which point the metapicrite pinches out and the metasediment enclave is completely enclosed in heterolithic mafic breccia with mafic metasedimentary layers (the more turbiditic facies of the breccia). Younging indicators in the breccia show top towards the metasedimentary enclave from both sides. However, from the point where the zone meets the road and to the northeast, F_2 fold vergence on the west side of the enclave has changed to Z-vergence. Fold axes throughout the area consistently plunge 15° and 30° to the northeast.

Eventually, the metasedimentary enclave becomes discontinuous as boudins in a distinct shear zone axial to the northeastward F_2 fold closure. Approximately 200 m northeast of the last outcrop of metasediment, Z-verging F_2 minor folds affect metasedimentary rocks in the breccia where facing on S_2 has reversed. This northeast closure of

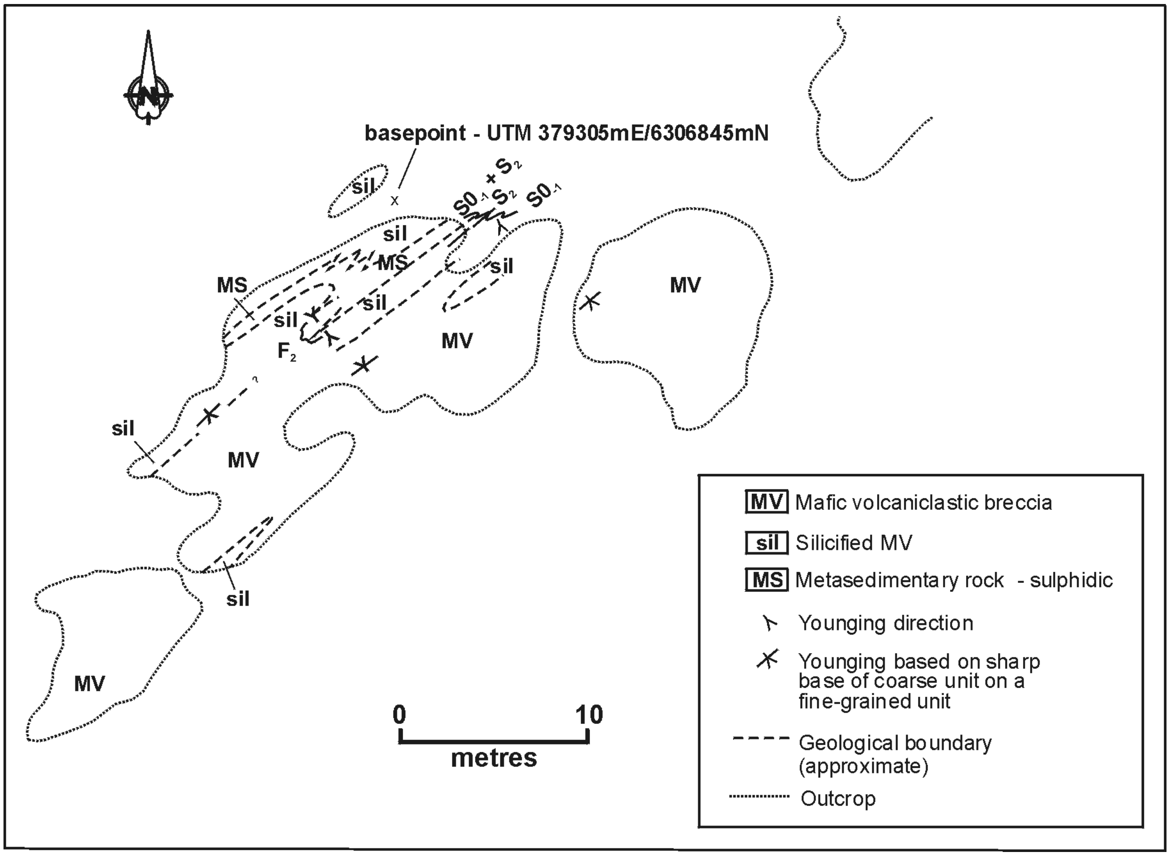

Figure GS-20-8: Detailed outcrop map of part of the 'Rushed' zone and its extension along the MacLellan mine road.

mineralized metasedimentary enclave appears to be an F_1 closure transposed into S_2. There is one locality where an oblique S_0-S_1 relationship is preserved. The larger structure here is an F_2 sheath, characterized by the change in vergence along strike in the same fold limb and the double closing of F_2 folds with the same plunge. The mineralized metasediment enclave forming the 'Rushed zone' extension itself defines an F_1 fold wrapped around the sheath.

CONCLUSIONS

1.) The heterolithic mafic breccia, which dominates this part of the Agassiz Metallotect, is a mafic volcaniclastic debris-flow deposit showing facies variation into more organized sandy-silty turbidite and eventually into mafic turbidite that is gradational into the mafic metasedimentary rocks of unit 4. Within the heterolithic mafic breccia, the more turbiditic rock types preserve way-up criteria based on the sharp and often erosive contacts between sandy and silty units. Detailed mapping of these criteria locally permits recognition of meso- to large-scale F_1 structures through the pervasive D_2 transposition.

2.) Progressive noncoaxial deformation and transposition during D_2, coupled with alteration and the development of pre-D_2 quartz and carbonate veins, has created a series of tectonite units that form mappable entities in their own right. These are hybrid rocks from which all or most primary characteristics have been obliterated. Examples include 1) the mafic tectonite derived from heterolithic mafic breccia, with or without metapicrite enclaves; and 2) mixed tectonite in which heterolithic mafic breccia, metapicrite, metabasalt, mafic metasedimentary rocks and alumino-siliceous metasedimentary rocks can all be identified as schlieren, ranging in scale from less than a metre to larger coherent boudins.

3.) The outcrop pattern of the Agassiz Metallotect between Lynn Lake and the MacLellan mine is dominated by D_2 structures, of which F_2 sheath folds are the most important. The left-lateral shear sense and S-folds associated with the short limbs, and the southwest-plunging F_2 minor folds are poorly represented, giving a strong bias toward right-lateral shear sense with Z-folds, and northeast-plunging F_2 minor folds in this area. This defines a major portion of a right-lateral strike-slip zone splaying northeast from the Johnson Shear Zone and encompassing a substantial portion of the exposed 'north belt' of the Lynn Lake greenstone belt.

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