GS-26 DEFORMATION HISTORY OF THE NORTHWESTERN CROSS LAKE GREENSTONE BELT (NTS 63I12), NORTHWESTERN SUPERIOR PROVINCE, MANITOBA

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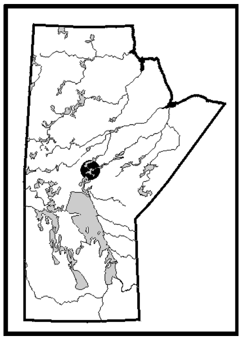

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SUMMARY

This paper reports on a structural study of a portion of the Cross Lake greenstone belt, northwest of the community of Cross Lake, as a continuation of an integrated mapping, geochronological, metamorphic and structural study of the central and southern parts of the belt (Dai et al., 2001). This year's field program revealed that

1) there were two generations of deformation in the Cross Lake Group prior to the deformation associated with the Central Cross Lake Shear Zone;
2) the contact between the main part (sandstone) of the Cross Lake Group and the underlying units is tectonic, likely a low-angle fault formed during the first generation of deformation and folded by the second generation of deformation;
3) the structural framework at the map scale is largely due to the second generation of deformation, which produced the northwest Cross Lake folds and the north Cross Lake anticlinorium in the northwestern Cross Lake area;
4) northeast-trending high-strain zones were produced during the second generation of deformation as a result of progressive strain localization; and
5) the central Cross Lake high-strain zone is the latest feature that overprints all structural elements in the area.

The recognition of this sequence of deformation may help explain the kinematic history of the Cross Lake greenstone belt.

INTRODUCTION

The Cross Lake greenstone belt, in the northwestern Superior Province in Manitoba, extends from the western end of the Gods Lake Domain westward into the Pikwitonei Granulite Domain. Two sets of high-strain zones stand out in the area, one trending east-southeast and the other trending northeast. They control the configuration of the supracrustal belt as well as the topographic pattern (Fig. GS-26-1). Previous studies in this area have focused on stratigraphy, geochronology and metamorphic history (Corkery, 1983, 1989; Corkery et al., 1988; Corkery and Lenton, 1989; Corkery et al., 1992). A thermotectonic pilot study of the Cross Lake greenstone belt was conducted by Breedveld (1989).

To unravel the tectonic history of the supracrustal belt, a structural study was initiated in the central Cross Lake area in the summer of 2001. In the first phase, a structural analysis of the Central Cross Lake Shear Zone (CCLSZ), a major east-southeast-trending shear zone (Fig. GS-26-1) near the southern margin of the greenstone belt, was carried out. The deformation history of that shear zone was outlined in Dai et al. (2001). Four generations of deformation were identified in the zone. The main fabric is a transposed foliation that is observed to cut all other recognized fabric elements of the Cross Lake greenstone belt, including the northeast-trending high-strain zones. Therefore, the main deformation of the CCLSZ is the latest event in the belt. What is the kinematic history prior to the CCLSZ deformation? How were pre-CCLSZ structures modified and overprinted by the CCLSZ? Answers to these questions are essential, not only to elucidate the tectonic history of the Cross Lake greenstone belt but also to understand the structures observed within the CCLSZ. During the past field season, structural analysis was conducted outside the CCLSZ, concentrating on the northwestern part of the greenstone belt where abundant clean shoreline exposures exist. The 2002 study area extends from the north shore of Cross Island about 6 km north and northwest to Eves Rapids (Fig. GS-26-1). This report is a preliminary synthesis of the structural framework of the Cross Lake greenstone belt.

LITHOLOGICAL UNITS

Supracrustal units

The Cross Lake greenstone belt consists of three groups of supracrustal rocks (Corkery et al., 1992):

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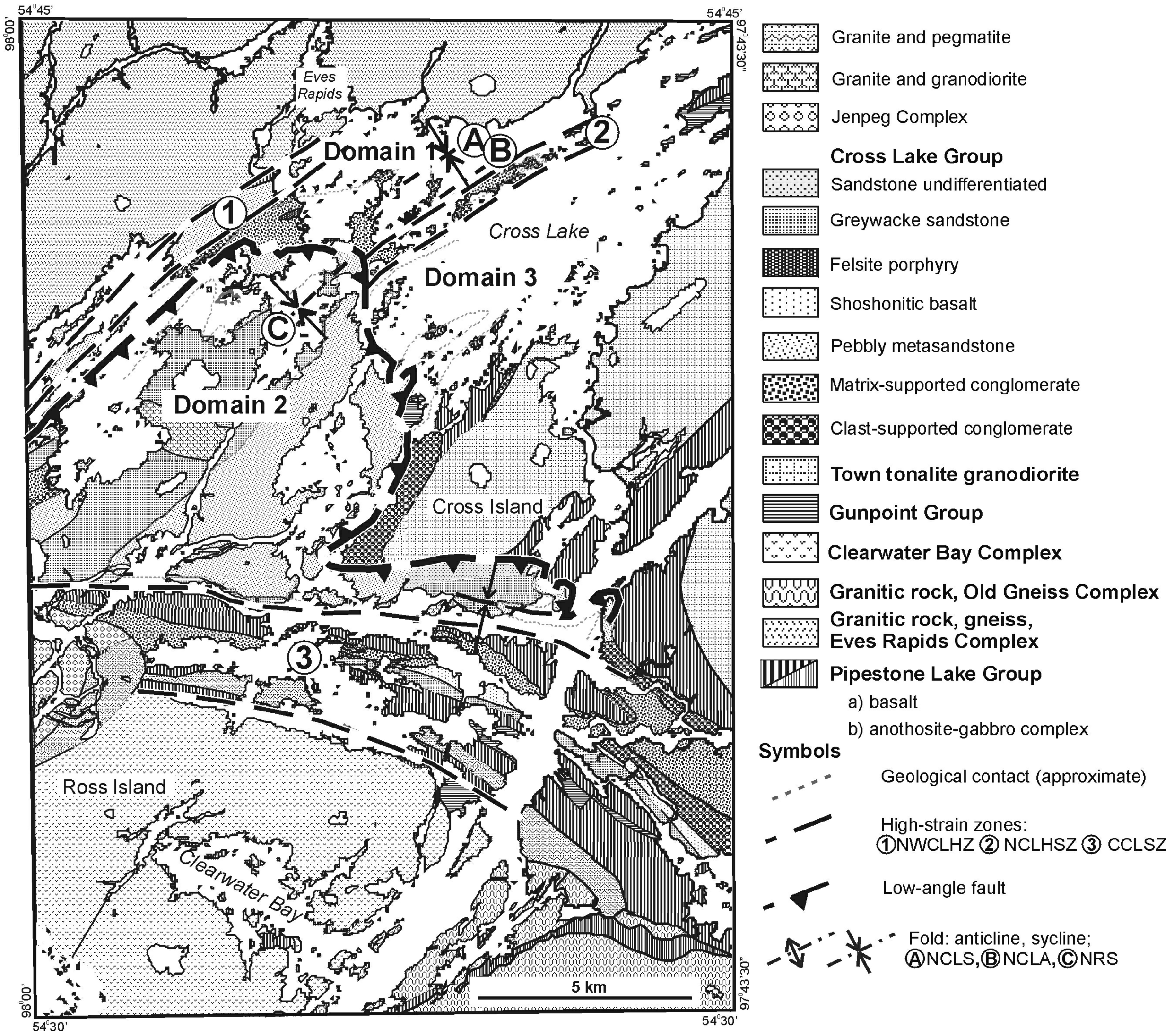

Figure GS-26-1: Geological map of the northwestern Cross Lake area.

1) the Pipestone Lake Group (2760 Ma), a sequence of metavolcanic and subordinate metasedimentary rocks, consisting of weakly to strongly deformed pillowed and massive basalt flows, and related gabbro sills and dikes with minor iron formation;

2) the Gunpoint Group (2730 Ma), a fining-upward clastic sedimentary sequence with interbedded felsic volcanic rocks; and

3) the Cross Lake Group (<2710 Ma), a sequence of fluvial-marine clastic sedimentary rocks with shoshonitic volcanic rocks near the top.

Although the contacts between these three groups are interpreted to be unconformable, they are all tectonic in places where the contacts are observed in the study area. The metamorphic grade of the Cross Lake greenstone belt increases from upper greenschist facies in the Pipestone Lake area to hypersthene granulite grade in the gneissic terrane northwest of Cross Lake (Breedveld, 1989).

Intrusive rocks

Early intrusive rocks within the greenstone belt are either contemporaneous with or postdate the Pipestone Lake Group, but predate the Cross Lake Group. The Pipestone Lake anorthosite complex (2760 Ma), a north-facing layered intrusion dominated by megacrystic anorthosite and melagabbro that is interpreted to be contemporaneous with the Pipestone Lake Group (Corkery et al., 1992), pinches out to the east along a sheared contact in the southeast corner of

Pipestone Lake, and to the west along the southeast shore of Whiskey Jack bay[2] (Parmenter, 2002). The Eves Rapids Complex, which consists of hornblende and biotite tonalite and granodiorite, forms the northern boundary of the greenstone belt along the north shore of Cross Lake. The Whiskey Jack Complex (2734 Ma), dominated by medium- to coarse-grained orthogneiss, intrudes the Pipestone Lake Group along the southeast side of Whiskey Jack bay and is interpreted to be the northern margin of the Molson Lake Domain (Lenton et. al., 1986). The Town tonalite intrusion (2719 Ma), around which the supracrustal belt bifurcates in central Cross Lake, is unconformably overlain by conglomerate of the Cross Lake Group northwest of the town of Cross Lake.

Late intrusive rocks, which postdate all of the supracrustal rocks, include the Clearwater Bay Batholith (2691 Ma), a biotite granodiorite southwest of Whiskey Jack bay, and the Playgreen Complex granite and megacrystic granite, in the southwest near Jenpeg. Both of these intrude Cross Lake Group conglomerate on the south side of the supracrustal belt. A series of simple pegmatite dikes intrudes the Cross Lake Group sandstone at the west end of the belt (Corkery et al., 1992). As well, two series of rare element–enriched (2656 Ma) pegmatites are the latest intrusive rocks recognized in the area.

STRUCTURAL ANALYSIS

The map area is divided into three structural domains (Fig. GS-26-1). Domain I is bounded to the north by the Eves Rapids Complex. Its northwest and southeast boundaries are, respectively, the northwest Cross Lake high-strain zone (NWCLHZ) and the north Cross Lake high-strain zone (NCLHSZ), both trending approximately 040°. The southern limit of domain I is the contact between the Cross Lake Group conglomerate and sandstone. The northern boundary of the CCLSZ and the contact between the Cross Lake Group sandstone and underlying units enclose domain II. Domain III is on the east side of the NCLHSZ, and extends eastwards to the Town tonalite. The contact between the Gunpoint Group conglomerate and the overlying Cross Lake Group forms the west and south boundaries of domain III. Two generations of deformation were identified during this year's mapping in the Cross Lake Group supracrustal rocks in domains I and II. The structure of domain III is an anticlinorium, detailed fieldwork on which will be completed next year.

Deformation D_1

Foliations

Bedding (S_0) is generally recognizable on most outcrops outside of the northeast-trending high-strain zones. Primary structures such as crossbedding and graded bedding are preserved in the Cross Lake Group conglomerate and sandstone (Fig. GS-26-2). They both serve as markers and indicators of the younging direction where they are not strongly deformed.

There is a cleavage (S_1) axial planar to F_1 folds, defined by a preferred alignment of hornblende and biotite in the supracrustal rocks, and flattened clasts and pebbles. This cleavage is usually subparallel to S_0, but may be inclined close to the hinge areas of F_1 folds (Fig. GS-26-3). This relationship is best preserved in the crossbedded conglomerate and pebbly sandstone (Fig. GS-26-2). The S_0-S_1 geometry relationship indicates the overall Z-asymmetry of F_1 folds.

Bedding is generally transposed, due to isoclinal folding and boudinage (Fig. GS-26-4), to form a composite foliation S_T, which dips steeply to subvertically. Where the transposition is significant, S_0 and S_1 cannot be distinguished.

Lineations

There are three types of L_1 lineation, defined by 1) preferred alignment of hornblende and biotite minerals

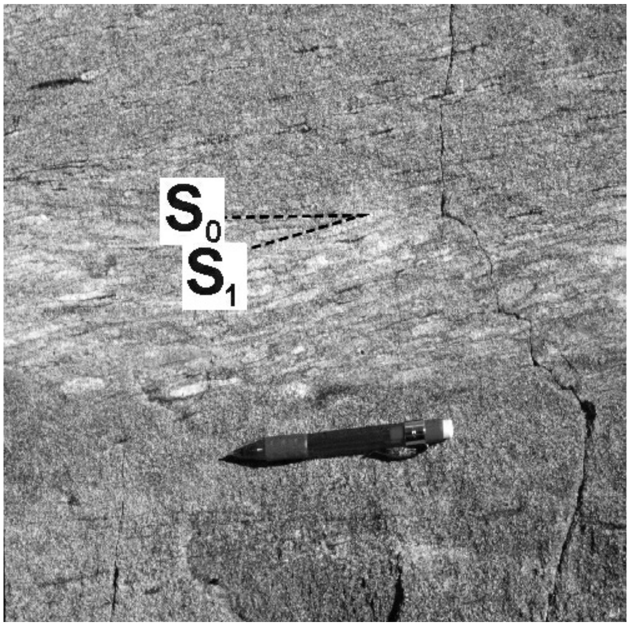

Figure GS-26-2: S_0-S_1 relationship in Cross Lake Group crossbedded pebbly sandstone, northern Cross Island. Pencil oriented towards 060°.

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[2] unofficial name

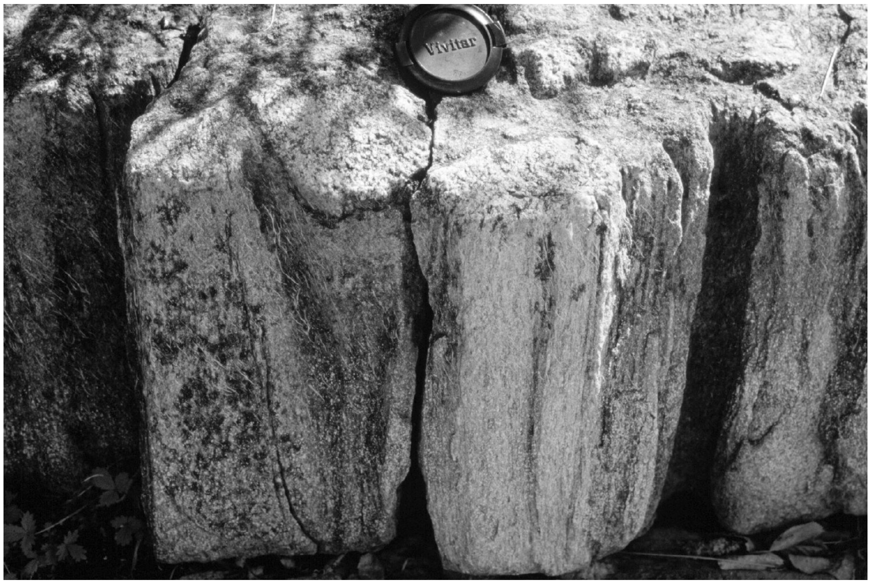

Figure GS-26-3: L_1 lineation defined by vertically stretched clasts (looking south), northern Cross Lake.

on S_0 and S_1 (Fig. GS-26-5a); 2) stretched clasts and pebbles (Fig. GS-26-5b); and 3) the intersection of S_1 and S_0 with the F_1 fold axes. In domains I and III, all three types are parallel to each other, and plunge steeply to subvertically (Fig. GS-26-5a, c). In domain II, lineations defined by F_1 fold axes show significant variation (from subhorizontal to subvertical), but they define a common great circle parallel to the attitude of the northeast-trending high-strain zones (Fig. GS-26-5b), suggesting that fold axes have been rotated significantly (*see* discussion below).

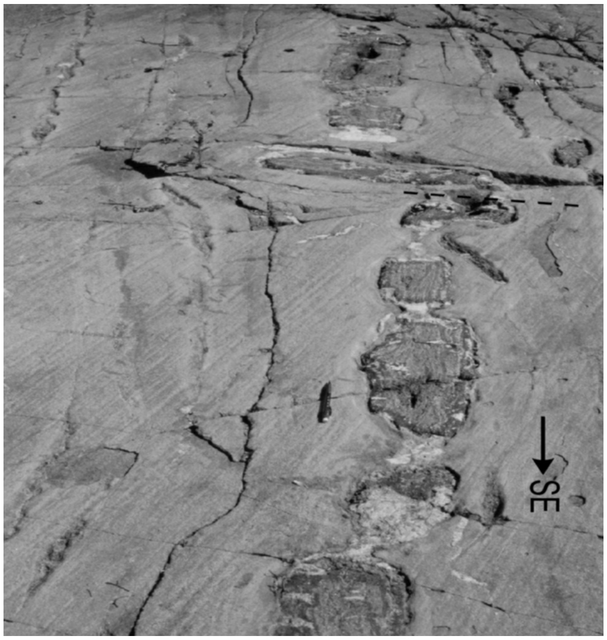

Figure GS-26-4: Boudinaged calc-silicate layer in the Cross Lake sandstone, overprinted by an F_2 fold (looking southeast), northwestern Cross Lake.

Folds

Tight to isoclinal folds are often observed on outcrops, and can have S- or Z-asymmetry. Sheath folds are observed in some places (Fig. GS-26-6). The axes of F_1 folds were only measured in domain II. In that area, F_1 fold axes plunge variably, suggesting strong rotation of F_1 folds (Fig. GS-26-5b) by a later deformation.

No map-scale F_1 folds were recognized. The repetition of stratigraphy in the Cross Lake Group conglomerate at the northeast tip of domain I is interpreted as an F_1 fold closure (Fig. GS-26-1). However, since it is within the NCLHSZ and the facing of the conglomerate beds could not be determined, this interpretation could not be confirmed. If this interpretation is correct, then the map-scale structure of domain I is an F_1 fold refolded by F_2 (*see* 'Deformation D_2' section, below).

Boudinage

Boudin structures were observed, at scales varying from centimetres to metres, in pegmatite and amphibolite layers. The separation of boudins can sometimes be greater than their long dimension, as seen on outcrop, but the layer from which a chain of boudins was derived can usually be recognized. The boudinage is a D_1 structure, and is evidently overprinted by later deformation: the boudinaged layers are commonly shortened and folded, as shown in Figure GS-26-4.

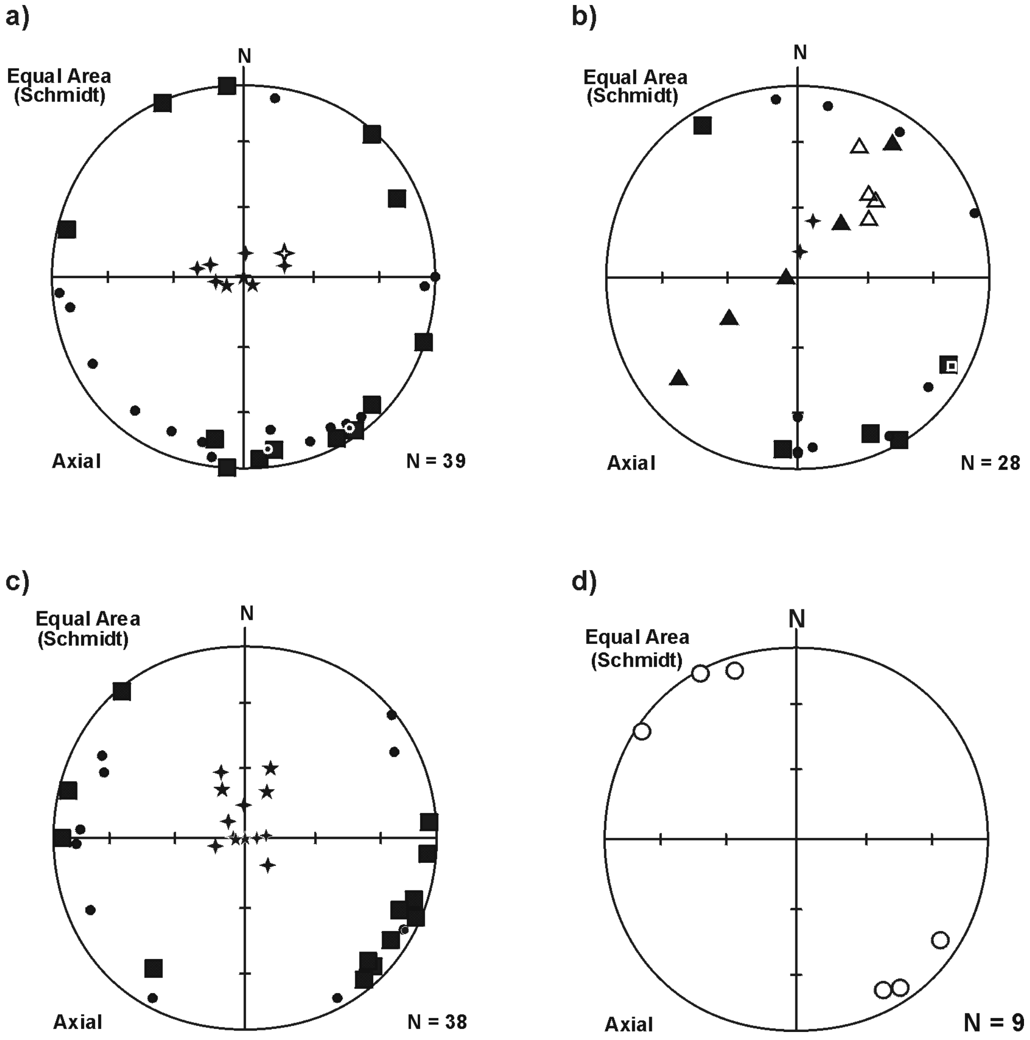

Figure GS-26-5: Equal area lower hemisphere plot of bedding S_0 (dot), S_1 (square), S_2 (circle), L_1 (triangle), F_1 (solid triangle), L_2 (star) and F_2 (cross) for: a) domain I, b) domain II, c) domain III, and d) north Cross Lake high-strain zone (NCLHSZ). Note the similarity of structures in domains I and III, and their contrast with those of domain II (see text for detail).

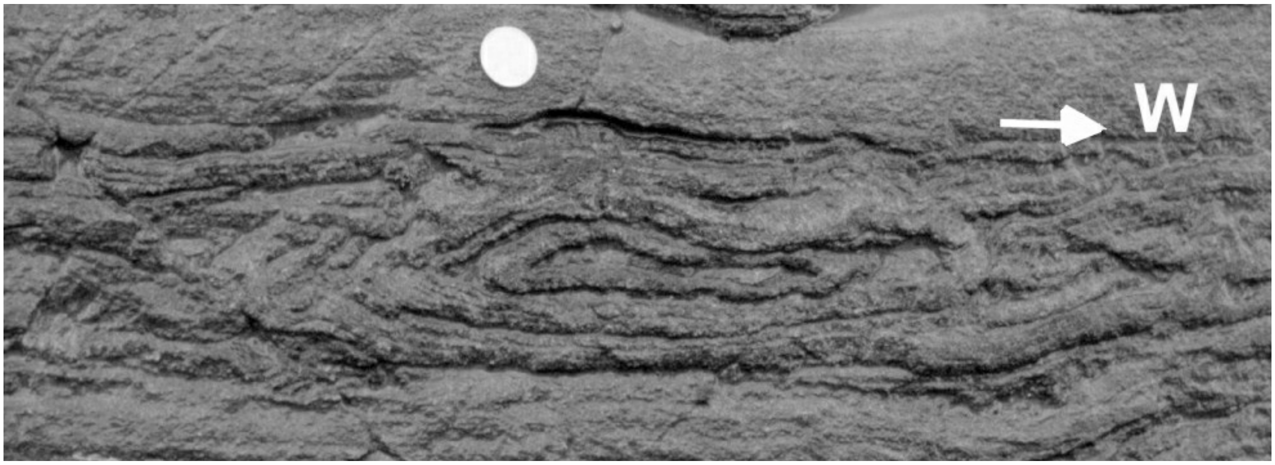

Figure GS-26-6: F_1 sheath fold in Cross Lake Group sandstone, northern Cross Lake.

Deformation D_2

The D_2 deformation overprints S_0, S_1 and S_T, and produces macroscopic F_2 folds in addition to small-scale F_2 folds observable on outcrops. The map-scale structural framework of the north Cross Lake greenstone belt is largely due to D_2 deformation.

Foliations and lineations

The S_2 foliation occurs as a crenulation cleavage overprinting S_T throughout the map area. In the long limb of F_2 folds, it appears as extensional 'shear bands' (Fig. GS-26-7), whereas it occurs as 'kink bands' in the short limbs. The S_2 foliation strikes approximately northeast and dips subvertically.

The L_2 lineation is recognizable if it occurs on S_2 as a mineral lineation. This lineation is also defined by F_2 fold axes. Lineations by stretched clasts are difficult to distinguish from L_1, since L_1 and L_2 are sometimes parallel due to the overprinting of D_2 deformation. The L_2 lineation plunges steeply to subvertically (Fig. GS-26-3).

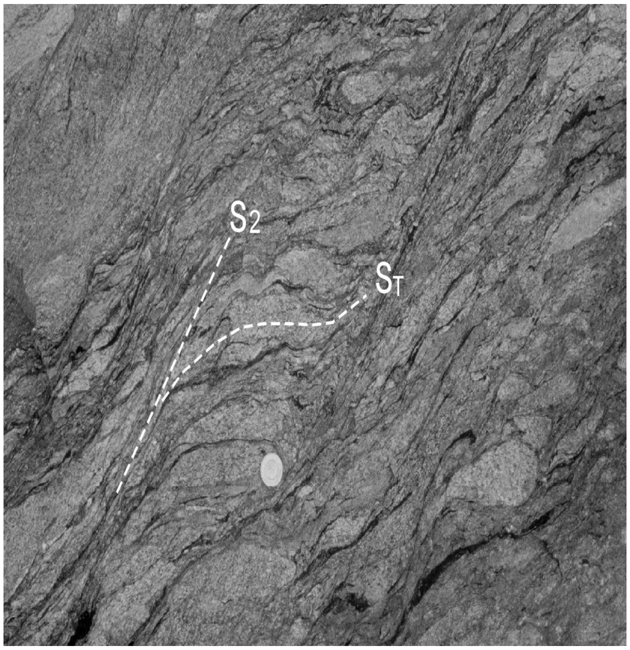

Figure GS-26-7: Crenulation cleavage in Cross Lake Group conglomerate (looking south), northern Cross Lake.

Folds

At outcrop scale, F_2 folds are open to tight asymmetric Z- and S-folds. The macroscopic F_2 folds are recognized based on the overprinting relationship between S_2 and S_T, and the consistent younging direction of Cross Lake Group rocks in open F_2 folds. Macroscopic F_2 folds include a syncline and anticline in domain I, and a syncline in domain II. In domain I, the syncline and anticline are referred to as the northwest Cross Lake syncline (NCLS) and the northwest Cross Lake anticline (NCLA; Fig. GS-26-1). The NCLS plunges steeply towards the northeast, and is defined by the Cross Lake Group clast-supported conglomerate and overlying matrix-supported conglomerate. Bedding is north facing on the north limb and east facing near the hinge. The NCLA is a tight, northeast-plunging anticline. If the interpretation of an F_1 fold closure in the long limb of the NCLA is correct, the Cross Lake Group on the southeast side of the NCLHSZ should all be facing southeast, and there should exist macroscopic, southeast-facing F_2 folds beneath domain II. Unfortunately it was not possible to confirm this interpretation because the high strain in the NCLHSZ has obscured the facing of the rocks. Both the NCLS and NCLA form a map-scale F_2 Z-fold. The syncline in domain II is referred to as the Nelson River syncline (NRS). It plunges towards northeast, and is defined by the contact between trough-crossbedded pebbly sandstone and thinly bedded sandstone and siltstone of the Cross Lake Group (Fig. GS-26-1). The facing of the limbs is hard to identify due to significant transposition by later, high-strain deformation.

The structure in domain III is an anticlinorium, the core of which consists of the Gunpoint and Pipestone Lake groups (Fig. GS-26-5c). Mafic flows of the Pipestone Lake Group outcrop as a structural window within the anticlinorium. Since detailed fieldwork has not yet been carried out in domain III, next summer's fieldwork will be concentrated here.

Northeast-trending high-strain zone deformation

The northeast-trending high strains result from progressive strain localization of D_2 deformation. This is based on the observation that structures in the high-strain zones show similar geometric and kinematic characteristics to those outside the high-strain zones, except that the intensity of deformation is much stronger in the high-strain zones. In the NCLHSZ, bedding cannot be identified at the outcrop scale due strong transposition. The dominant fabric of the NCLHSZ is an S_2 foliation, which is a composite foliation parallel to the high-strain zone. This foliation dips steeply to subvertically towards northeast (Fig. GS-26-5d).

DISCUSSION

Contact between the Cross Lake Group sandstone and underlying units

In the map area, the Cross Lake Group sandstone is the most widespread and continuous unit. It is in angular contact with the Cross Lake Group conglomerate (the boundary between domains I and II); in angular and direct contact with the north Cross Lake anticlinorium in domain III, where the Cross Lake Group conglomerate is missing; and in contact with Cross Lake Group conglomerate on southern Cross Island. Corkery et al. (1992) interpreted the Cross Lake clast-supported conglomerate to be the basal conglomerate marking the angular unconformity between the entire Cross Lake Group and the underlying units. The authors do not dispute this interpretation, but note that the distribution of conglomerate is isolated and discontinuous, in strong contrast to that of the sandstone. If this feature is primary, then the initial contact between the sandstone and the underlying units must represent a transgressive unconformity. An alternative interpretation is that the contact was a low-angle fault (thrust or detachment fault) formed during D_1 deformation. Regardless of the initial nature of the contact, it now marks a major structural boundary across which the style of post-D_1 deformation varies considerably. Below the contact in domains I and III, structural geometries are similar: S_0 and S_1 dip subvertically everywhere, L_1 and L_2 lineations are parallel and subvertical, and F_2 folds plunge steeply to subvertically (Fig. GS-26-5a, c). Above the contact in domain II, F_1 folds plunge variably from subhorizontally to subvertically, whereas F_2 folds plunge steeply to subvertically (Fig. GS-26-5b). Below the contact, in the domain III anticlinorium, the Pipestone Lake Group outcrops as a tectonic window (Fig. GS-26-1).

Kinematics and deformation history of the Cross Lake Group supracrustal rocks

Based on the observations outlined above, the authors conclude that D_1 is a major crustal shortening event that resulted in isoclinal folding and transposition of S_0 in the Cross Lake Group and possibly the development of a low-angle thrust fault. Although it is difficult to infer the kinematics of D_1 due to later overprinting, it is possible that the D_1 and D_2 deformations represent continuous progressive deformation. The D_2 deformation is a pure-shear–dominated (northwest-southeast shortening) transpression. The overall Z-asymmetry of F_2 folds suggests that there is a dextral transcurrent component. Strong vertical stretch during D_2 as a result of the pure shear component of transpression leads to the rotation of all L_1 lineations to the vertical orientation. Therefore, all L_1 lineations except some F_1 fold axes in domain II are also stretching lineations. The contact between Cross Lake sandstone and the underlying units serves as a mechanical boundary (like a décollement) during D_2 deformation. Above the contact, the rotation of F_1 fold axes is less significant than that below the contact. It is the D_2 deformation that contributes to the overall structural framework of the north Cross Lake greenstone belt. Progressive strain localization of D_2 deformation leads to the formation of the northeast-trending high-strain zones. All the deformation structures described above are cut by the CCLSZ (Dai et al., 2001). Thus, the work of the past two field seasons has documented the deformation sequence since the deposition of the Cross Lake Group. Deformation of the Cross Lake greenstone belt prior to this will constitute the focus of next year's work.

The fieldwork carried out in 2002 helps to explain the pre-CCLSZ deformation of the Cross Lake greenstone belt, which was not well studied last year. The F_1 isoclinal folds in the CCLSZ, which were described in Dai et al. (2001), are possibly inherited here from the F_1 and F_2 described above. The hypothesis of the low-angle thrust fault may give some indication of possible early horizontal movement in the Archean Cross Lake greenstone belt.

ACKNOWLEDGMENTS

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