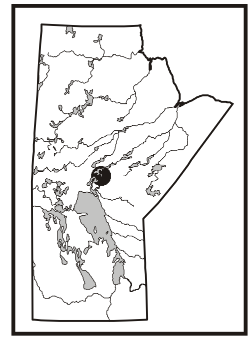
GS-24 KINEMATICS OF THE NORTH AND SOUTH PIPESTONE LAKE SHEAR ZONES IN THE CROSS LAKE GREENSTONE BELT, NORTHWESTERN SUPERIOR PROVINCE



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SUMMARY

The Pipestone Lake area of the Cross Lake greenstone belt is transected by the east-southeast-trending north and south Pipestone Lake shear zones (NPLSZ and SPLSZ, respectively). Both the NPLSZ and the SPLSZ underwent two major generations (G_1 and G_2) of shear deformation, under amphibolite- and greenschist-grade conditions, respectively. The G_1 deformation in the SPLSZ was associated with south-side-up movement, but the kinematics of G_1 in the NPLSZ are not yet clear. The G_2 deformation in both shear zones was associated with subhorizontal dextral shear. Based on tracing of marker horizons and variation in bedding-foliation relationships and younging directions, a macro-scale tight fold was defined in the Cross Lake Group. The observation that massive anorthosite of the Pipestone Lake Anorthosite Complex cuts tectonic foliation in the mafic volcanic rocks of the Pipestone Lake Group indicates that the latter is significantly older than the anorthosite and that the two units are not comagmatic, as previously interpreted.

INTRODUCTION

A main focus of this project is to establish the structural framework of the Pipestone Lake area in the Cross Lake greenstone belt, with emphasis on the kinematic history of the north and south Pipestone Lake shear zones (NPLSZ and SPLSZ, respectively), two major east-southeast-trending structures that dissect the southeast arm of the greenstone belt. These shear zones are potentially part of a large-scale, east-trending shear zone system that extends from Manitoba to Ontario. The kinematic history and structural relationships established here will help to develop a regional tectonic model for the northwestern Superior Province.

Fieldwork in 2000 focused on 1:20 000 scale and detailed mapping of the area around Pipestone Lake. Stratigraphy and geological history of the area have been previously outlined by Rousell (1965), Corkery (1983, 1985), Corkery et al. (1988), Corkery and Lenton (1989) and Corkery et al. (1992). The Pipestone Lake Anorthosite Complex has been studied in detail by Cameron (1984, 1985), Peck et al. (1994) and Jobin-Bevans et al. (1995). Breedveld (1988) undertook a reconnaissance tectonometamorphic pilot study of the Cross Lake greenstone belt.

GEOLOGICAL SETTING

The Cross Lake greenstone belt is flanked to the northwest by the high-grade metamorphic Pikwitonei and metaplutonic God's Lake domains, and to the south by the metaplutonic Molson Lake Domain. Two major structural trends dominate the area: one, to the northeast, extends the length of Cross Lake and the other, to the east-southeast, follows the Nelson River system from west of the Whiskey Jack channel past the southeast corner of Pipestone Lake. Both the SPLSZ and the NPLSZ follow the east-southeast structural trend. Supracrustal rocks in the greenstone belt have been assigned to three main stratigraphic entities, the Pipestone Lake Group, Gunpoint Group and Cross Lake Group (Fig. GS-24-1; Corkery et al., 1992).

The Pipestone Lake Group (ca. (?)2760 Ma) includes predominantly metavolcanic and minor metasedimentary rocks, mainly extensive, weakly to strongly deformed pillowed basalt, minor massive basaltic flows, and thin ultramafic packages. It outcrops on both the north and south shores of Pipestone Lake. These two volcanic packages may not be genetically related and are hereafter referred to as the north and south Pipestone Lake groups, respectively. The north Pipestone Lake Group exhibits well preserved primary volcanic features and is only affected by the NPLSZ along its southern margin. It is bounded to the north by the Cross Lake Batholith. The entire south Pipestone Lake Group has been affected by the SPLSZ. It is bounded to the south by the Whiskey Jack gneiss complex and intruded by the Pipestone Lake Anorthosite Complex (PLAC), a layered complex of melagabbro, leucogabbro and megacrystic anorthosite. The PLAC is host to a major titanium deposit. The PLAC occurs between the south Pipestone Lake Group and the south Pipestone Lake granodiorite along the south shore of Pipestone Lake. Continuing west of Pipestone Lake, it curves to the southwest and follows the northeast structural trend along the southern extension of the Whiskey Jack channel.

The Gunpoint Group (ca. 2744–2728 Ma) unconformably overlies the Pipestone Lake Group and consists of fining-upward successions of metasedimentary rocks with interbedded felsic volcaniclastic rocks. A thin sliver of the Gunpoint Group outcrops along the south shore of Pipestone Lake and is bounded on both sides by Pipestone Lake Group volcanic rocks.

The Cross Lake Group (ca. 2713–2695 Ma), a generally fining-upward fluvial sequence, unconformably overlies both the Pipestone Lake and Gunpoint groups. Shoshonitic basalt and shoshonite-derived sediments were deposited with sediments of the upper Cross Lake Group. The Cross Lake Group is bounded to the north and south by Pipestone Lake Group volcanic rocks. These boundaries are defined by the SPLSZ and the NPLSZ.

SOUTH PIPESTONE LAKE SHEAR ZONE (SPLSZ)

The SPLSZ trends east-southeast. Its width varies from approximately 850 m at the Whiskey Jack channel to less than 100 m in the southeast corner of Pipestone Lake (Fig. GS-24-1). It affects the entire south Pipestone Lake Group, the Gunpoint Group, the northern margin of the south Pipestone Lake granodiorite, the southern margin of the Cross Lake Group, and the eastern part of the Pipestone Lake Anorthosite Complex. Evidence for deformation at both greenschist- and amphibolite-grade has been recognized, and two major generations (G_1 and G_2) of shear-zone deformation have been distinguished.

The G_1 deformation is associated with major shear movement under amphibolite-grade conditions. It is centred on the south Pipestone Lake Group, extending to its northern and southern contacts with the Cross Lake Group and the Whiskey Jack gneiss complex, respectively. Very strong deformation occurred in the southern part of the shear zone where mylonite is well developed. Mylonitic foliations dip moderately to the north along the Nelson River between the Whiskey Jack channel and Pipestone Lake, and steeply north or south along the southern shore of Pipestone Lake. Lineations plunge steeply downdip, both within and outside the mylonite zone. Layers of moderately to strongly sheared and epidotized pillowed basalt parallel the contact between the Pipestone Lake Group and the southern granodiorite. They are traceable along the

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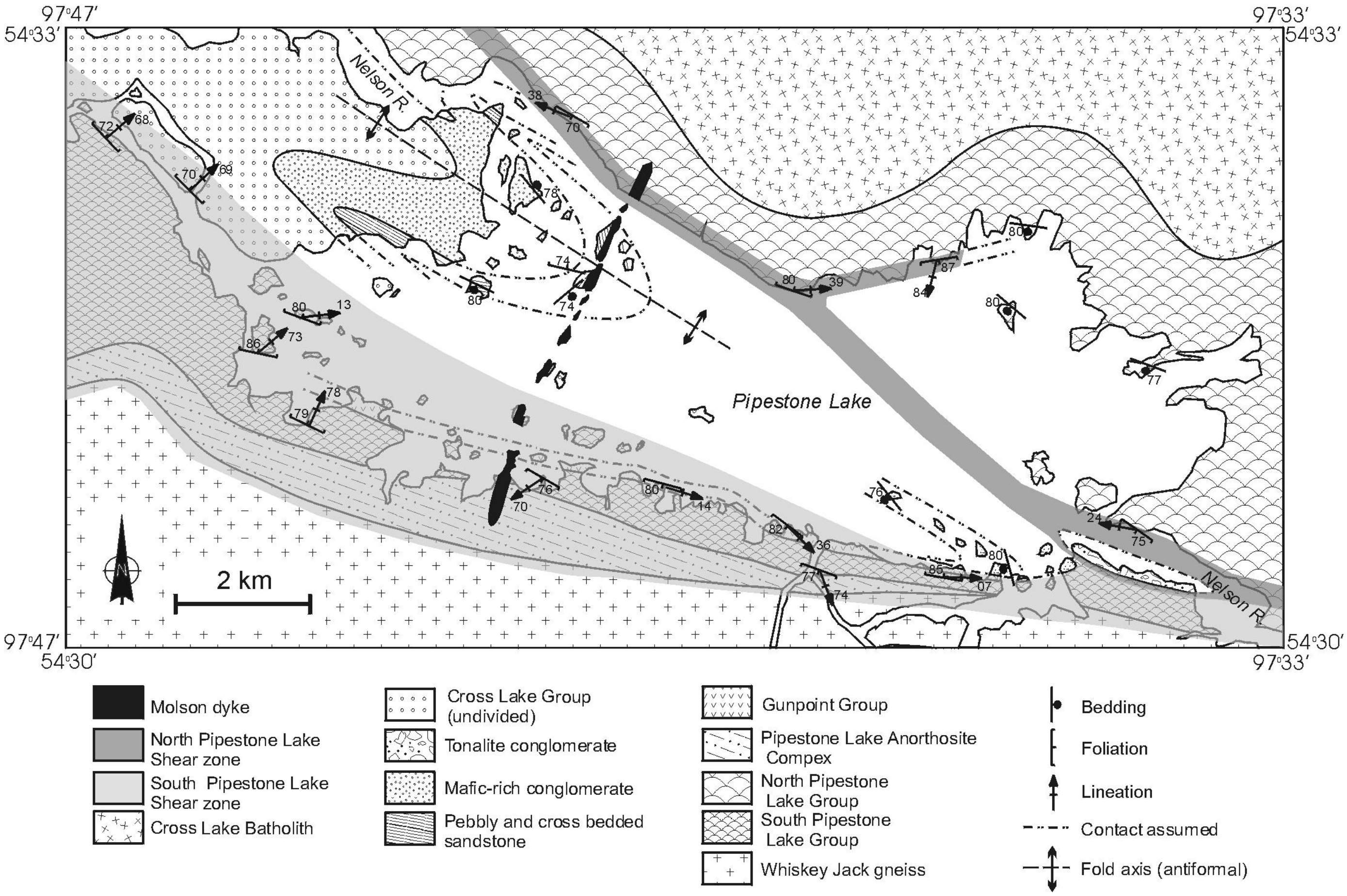

Figure GS-24-1: Simplified geological map of the Pipestone Lake area.

entire length of the SPLSZ and exhibit asymmetrical boudinage features. They indicate vertical south-side-up relative movement and dextral asymmetrical boudinage oblique to lineation (Fig. GS-24-2).

The G_2 deformation is associated with greenschist-grade, thin (<10 m wide) shear zones that overprint G_1 structures and are developed subparallel to the G_1 shear zone. The G_2 mylonitic foliations dip steeply north or south. Lineations are shallow to subhorizontal (east-plunging), approaching horizontal at the contact between the Pipestone Lake and Cross Lake groups in the southeast corner of Pipestone Lake. Abundant dextral shear-sense indicators are observed. These include asymmetrically boudinaged quartz veins in mylonitized basalt and S-C' structures in thin (<3m wide) chlorite-talc schist layers (Fig. GS-24-3).

In the southeast corner of Pipestone Lake, a layer of Cross Lake Group pebbly sandstone and conglomerate is sheared into the SPLSZ. Bedding strike in the layer varies from east-southeast to north, and younging direction changes from south-facing to west-facing toward the shear zone. Bedding-cleavage relationships indicate that this is related to an asymmetrical fold with its southern limb assimilating into the SPLSZ, consistent with dextral shear. At the shear contact, greenschist-grade mylonitization has obliterated any primary depositional features in the sedimentary rocks.

Quartz-carbonate mineralization is a characteristic feature of

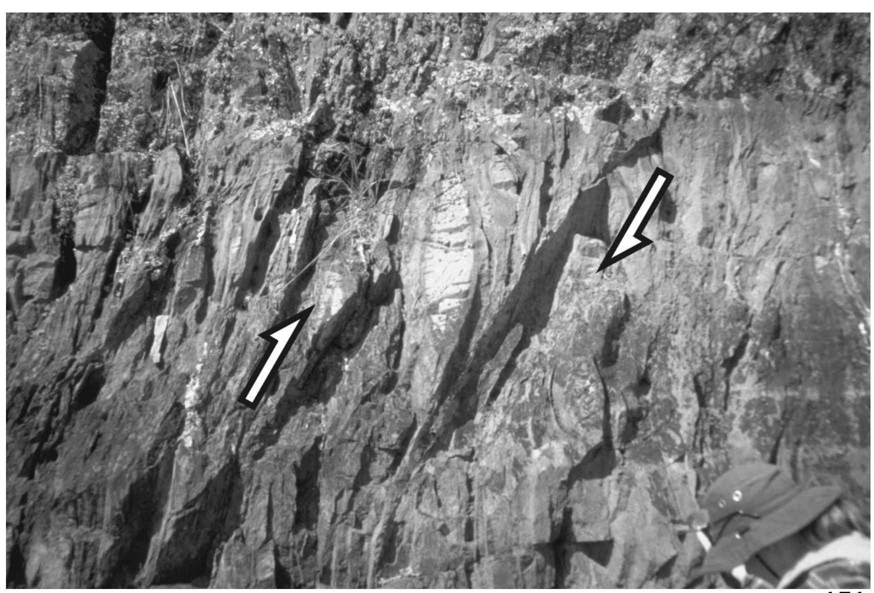

Figure GS-24-2: Boudinaged epidotized pillow indicating south-over-north movement in the South Pipestone Lake Shear Zone (looking west).

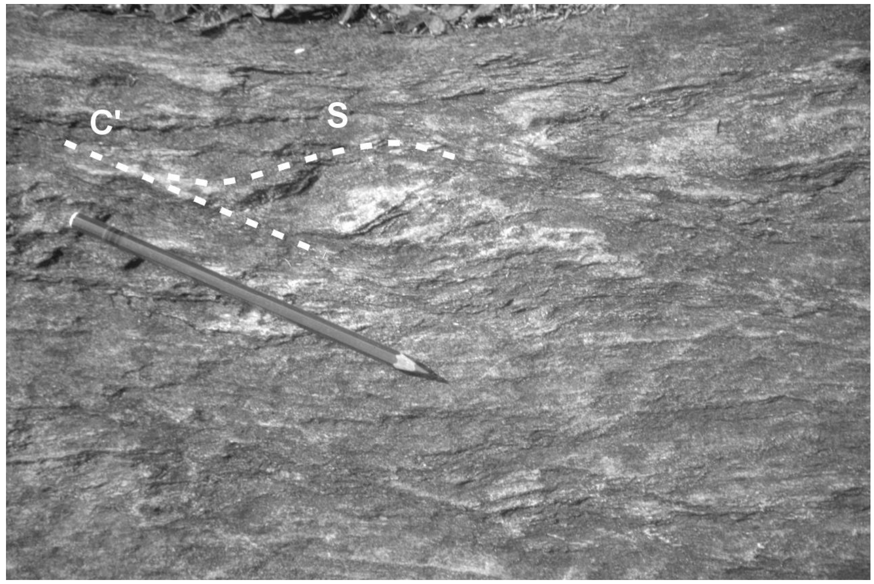

Figure GS-24-3: Chlorite-talc-schist in the South Pipestone Lake Shear Zone with S-C' structures indicating dextral movement.

greenschist-facies deformation in the SPLSZ. The quartz-carbonate occurs in mylonitized Pipestone Lake Group volcanic rocks, both within and adjacent to G_2 deformation zones. This may suggest a genetic link between carbonate-rich fluids and the G_2 shear event. Quartz-carbonate mineralization is most abundant through the centre of the SPLSZ, following the general distribution of the Gunpoint Group. Here, lenses of a distinctly black, carbonate-rich unit can be traced along the entire length of the SPLSZ. The distribution of this unit outlines macro-scale, steeply to shallowly plunging, s- and z-shaped, folded contacts between the Gunpoint and Pipestone Lake groups.

In the southeastern corner of Pipestone Lake, narrow (<40 cm wide), intermittent dextral shear zones deform a gneissic foliation in the southern granodiorite. Our preliminary interpretation links these minor shears with the G_2 deformation event because they have the same shear sense and the same metamorphic grade.

NORTH PIPESTONE LAKE SHEAR ZONE (NPLSZ)

The NPLSZ is developed in the north Pipestone Lake Group and exposed along the northern shore of Pipestone Lake and the southeastern extension of the Nelson River (Fig. GS-24-1). The exposed width of the shear zone varies from approximately 50 to 60 m. The true width of the NPLSZ is unknown because its southern boundary is not exposed. Coincident with the distribution of the NPLSZ are a thin (<4 m wide), discontinuous ultramafic layer and at least two generations of quartz-feldspar porphyry (QFP) dykes. As in the SPLSZ, evidence for both greenschist- and amphibolite-grade deformation has been recognized and two major generations (G_1 and G_2) of deformation have been distinguished.

The G_1 deformation is associated with vertical shear movement under amphibolite-grade conditions. Strong deformation produced a central 5 to 10 m wide mylonite zone. The mylonitic foliation trends east-southeast and dips steeply to the north or south along the north shore at the west end of Pipestone Lake. It curves toward the east-northeast and roughly parallels the north-central Pipestone Lake shoreline, where it is exposed for several hundred metres before being covered by water. Mineral lineations are steep in a downdip direction. Kinematics of the G_1 deformation are unclear due to the effects of the G_2 deformation.

The G_2 deformation is associated with a 20 to 30 m wide, greenschist-grade shear zone that trends east-southeast from northwestern Pipestone Lake to the Nelson River in the southeast. The G_2 mylonitic foliations dip steeply south and lineations plunge shallowly to subhorizontally toward the west. The S-C’ structures in the ultramafic unit and boudinaged sedimentary clasts indicate dextral shear (Fig. GS-24-4).

Toward the southeast, the NPLSZ splits into two zones surrounding a thin wedge of conglomerate rich in tonalite clasts. This conglomerate only outcrops along the north shore of the southeastern extension of the Nelson River channel. It is very poorly sorted and dominantly clast

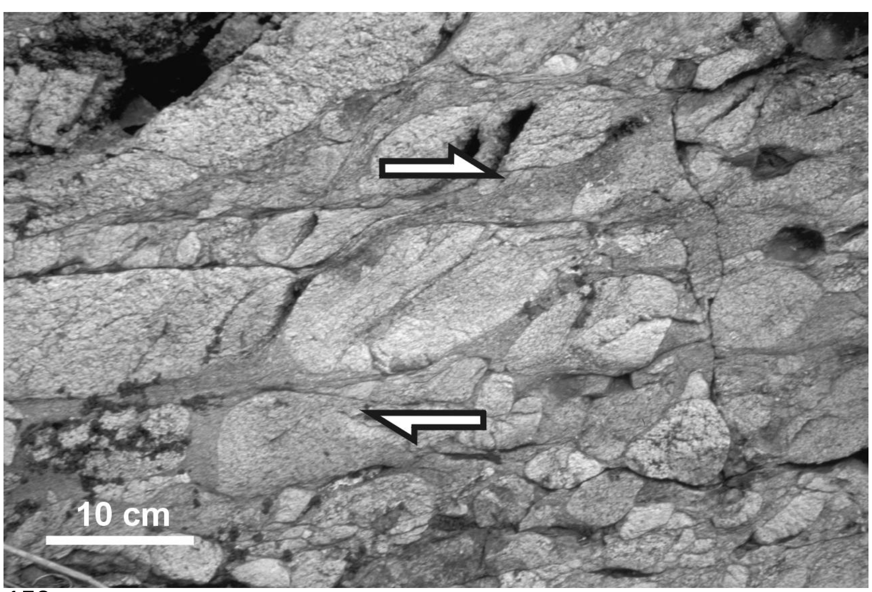

Figure GS-24-4: Dextrally sheared tonalite clast in the North Pipestone Lake Shear Zone, southeast Pipestone Lake.

supported, with approximately 80% tonalite clasts and 20% assorted granitoid and minor argillite clasts. Clasts range in shape from subrounded to angular and may exceed 1 m in diameter. The matrix is rich in medium- to coarse-grained subangular quartz with minor fine-grained mafic constituents. Toward the south contact with the NPLSZ, argillite is the dominant matrix constituent. This conglomerate is very different from any other sedimentary unit on Pipestone Lake. It most closely resembles a tonalitic conglomerate unconformably overlying the Town Tonalite (ca. 2719 Ma), approximately 20 km to the northwest. If these two conglomerates are correlative, it implies that a significant amount of movement occurred along the NPLSZ.

Primary volcanic features are well preserved in the Pipestone Lake Group in the northeast corner of Pipestone Lake. Flow-top indicators are abundant, indicating generally southward younging. Two distinct packages of volcanic strata can be traced with confidence over several kilometres (Fig. GS-24-1). They are defined by continuous layers of pillowed and massive basalt, amoeboid pillows, flow-top breccia, and characteristic plagioclase-phyric massive basalt. Dominantly prolate deformation occurred in these volcanic rocks, with localized L-tectonite development. The relationship between the structural development in this area and the kinematics of the NPLSZ will be a focus of further study.

STRUCTURES IN THE CROSS LAKE GROUP

Cross Lake Group metasedimentary rocks dominate west and central Pipestone Lake. While the north and south contacts of the group are sheared, most of the metasedimentary package contains well preserved primary sedimentary features. These features, including crossbedding and channel-fill structures, are excellent younging direction indicators and are useful, along with bedding-foliation relationships, in outlining a large-scale fold structure in the Cross Lake Group. It is a tight, steeply inclined, east-plunging fold with a variably developed east-southeast-trending axial-planar cleavage. The fold is best outlined by the contact between a clast-supported, mafic clast–rich conglomerate and an overlying pebbly sandstone unit (Fig. GS-24-1). The pebbly sandstone is gradational into a variably sorted, crossbedded sandstone that outcrops adjacent to a dyke belonging to the Molson Dyke Swarm in west-central Pipestone Lake, where the fold closure is located. On the north limb of the fold, the bedding strikes east-southeast and foliation is counter-clockwise to bedding. On the south limb, the bedding strikes east-southeast and foliation is clockwise to bedding. In the hinge area, the foliation is at a high angle to bedding. Bedding tops vary from north-younging on the north fold limb, to east-younging in the fold hinge and south-younging on the south fold limb.

Southward toward the SPLSZ, upper Cross Lake Group sedimentary rocks, including argillite-rich conglomerate, shoshonitic basalt, shoshonite-derived sedimentary rocks and turbidites, are generally south-facing but their relationship with this large-scale fold structure is still unclear. A meso-scale dextral drag-fold structure (Fig. GS-24-5) is developed in strongly foliated turbidites in the southwest corner of Pipestone Lake. The geometry is similar to that developed in sedimentary rocks at the southeastern contact with the SPLSZ. The relationship between deformation structures in the Cross Lake Group and the SPLSZ will be a focus of further study.

RELATIONSHIP BETWEEN THE PIPESTONE LAKE GROUP AND THE PIPESTONE LAKE ANORTHOSITE COMPLEX (PLAC)

The south Pipestone Lake Group and the PLAC have previously been interpreted to be comagmatic (Phinney et al., 1988; Corkery et al., 1992). This interpretation allows that the age of the PLAC (ca. 2760 Ma; Corkery et al., 1992) also represents the age of the south Pipestone Lake Group volcanism. Our detailed field observations do not support this interpretation. At two localities where the contact between the two units is exposed, massive megacrystic anorthosite cuts a strong tectonic foliation in a mafic unit of the south Pipestone Lake Group (Fig. GS-24-6). The observed geometry makes it impossible that the relationship is due to competency contrast. Elsewhere in the PLAC, similar megacrystic anorthosite has undergone variable amounts of deformation. This observation indicates that emplacement of the south Pipestone Lake Group volcanic rocks significantly pre-dated the PLAC and therefore must have taken place prior to 2760 Ma. It is possible that deformation in the south Pipestone Lake Group volcanic rocks at the contact with the PLAC, and elsewhere within the PLAC, are related to the G_1 deformation in the SPLSZ. If correct, this implies that the intrusion of the PLAC took place during G_1. These observations and interpretations should be considered in genetic modelling of the titanium deposit hosted by the PLAC.

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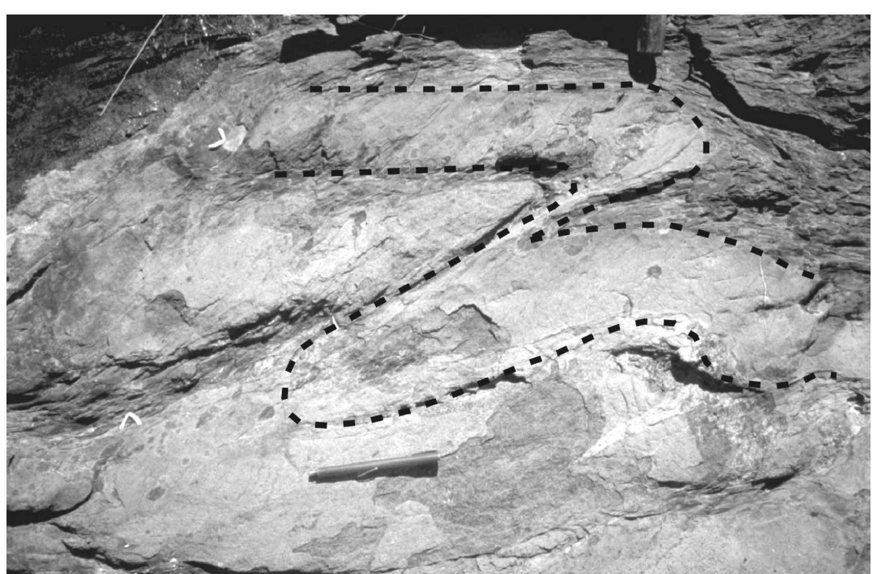

Figure GS-24-5: A Z-shaped drag-fold in Cross Lake Group turbidites, southwest Pipestone Lake.

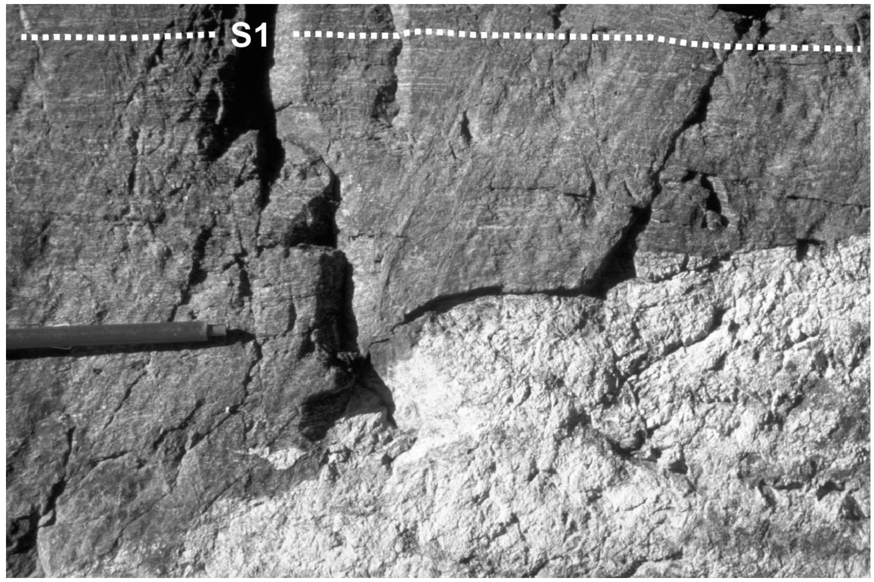

Figure GS-24-6: Massive megacrystic anorthosite crosscutting a tectonic fabric developed in a south Pipestone Lake Group mafic volcanic unit.

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