GS-12 **Preliminary results of geological mapping and structural analysis of the Bird River greenstone belt, southeastern Manitoba (NTS 52L5 and 6)**

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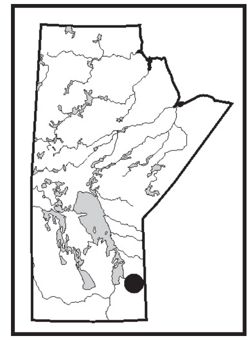

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Summary

The Bird River greenstone belt of the Superior craton is situated between the English River subprovince to the north and the Winnipeg River subprovince to the south. During the summer of 2005, field investigations showed that the Bird River greenstone belt has experienced polyphase ductile deformation. The first event consisted of a south-side-up shearing that affected all units. A subsequent polyphase strike-slip tectonic event resulted in strike-slip movements with dextral and sinistral shear sense in the eastern and western portions of the belt, respectively.

Introduction

The Bird River greenstone belt is located in southeastern Manitoba, about 150 km northeast of Winnipeg. It is a significant ore-deposit district that has been explored since 1920, hosting the Tanco rare element pegmatite deposit, the Maskwa Fe–Ni–Cu–platinum group element (PGE) deposit and the Dumbarton Ni-Cu-Zn-PGE deposit. Few regional maps are available (Davies, 1956; Trueman, 1980; Cerny et al., 1981), and those that are available display numerous inconsistencies.

Three collaborative geological mapping projects were initiated in 2005 by the Manitoba Geological Survey and the University of Waterloo, with financial support from Gossan Resources Limited (together with North American Palladium Ltd.), Mustang Minerals Corp. and Tantalum Mining Corporation of Canada Ltd. (Tanco). The objective of these projects is to improve the understanding of the stratigraphic, structural and tectonic framework of the greenstone belt, in order to establish the setting of the various mineral deposits that occur within the belt. This three-year, multidisciplinary project involves targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology. The ten-week field program conducted by the author in 2005 involved geological mapping and a related kinematic study. This paper presents the results of this fieldwork, as well as a preliminary tectonic interpretation of the evolution of the greenstone belt.

General geology

The Bird River greenstone belt is situated within the Superior craton, between the English River subprovince to the north and the Winnipeg River subprovince to the south. Available geochronological data indicate that the supracrustal rocks are ca. 2.78–2.73 Ga in age (Timmins et al., 1985; Wang, 1993). The most recent geological mapping of the Bird River greenstone belt, by Trueman (1980), subdivided the supracrustal rocks into six formations (Figure GS-12-1):

- The Eaglenest Lake Formation is composed of volcaniclastic sedimentary rocks and mafic lavas.
- The Lamprey Falls Formation consists of pillowed basalt with intercalated tuff and iron formation in fault contact with the Eaglenest Lake Formation and the Bird River Sill.
- The Peterson Creek Formation contains rhyolite flows, pyroclastic breccia, lapillistone tuff and volcanic sandstone.
- The Bernic Lake Formation is composed of basalt, andesite, dacite, rhyolite, iron formation, conglomerate and sandstone. All these rocks are extensively metamorphosed and deformed in the amphibolite facies.
- The Flanders Lake Formation, which is composed of polymictic conglomerate (with pebbles derived from the Bernic Lake Formation) and metamorphosed lithic arenite, is in shear zone contact with the Peterson Creek, Booster Lake and Bernic Lake formations.
- The Booster Lake Formation is composed mainly of greywacke-mudstone turbidites. Interbedded conglomerate and iron formation have been observed in the western part of this formation (Cerny et al., 1981). According to Trueman (1980), this sequence is a south-facing, south-dipping monoclinal one, but a synclinorial structure has been mapped at Booster Lake in the eastern part of the formation by Gilbert (GS-13, this volume).

The individual formations described above are generally bounded by east-trending faults, except for the Bernic Lake and Peterson Creek formations. All stratigraphic formations have been subjected to regional metamorphism up to amphibolite-facies grade, with

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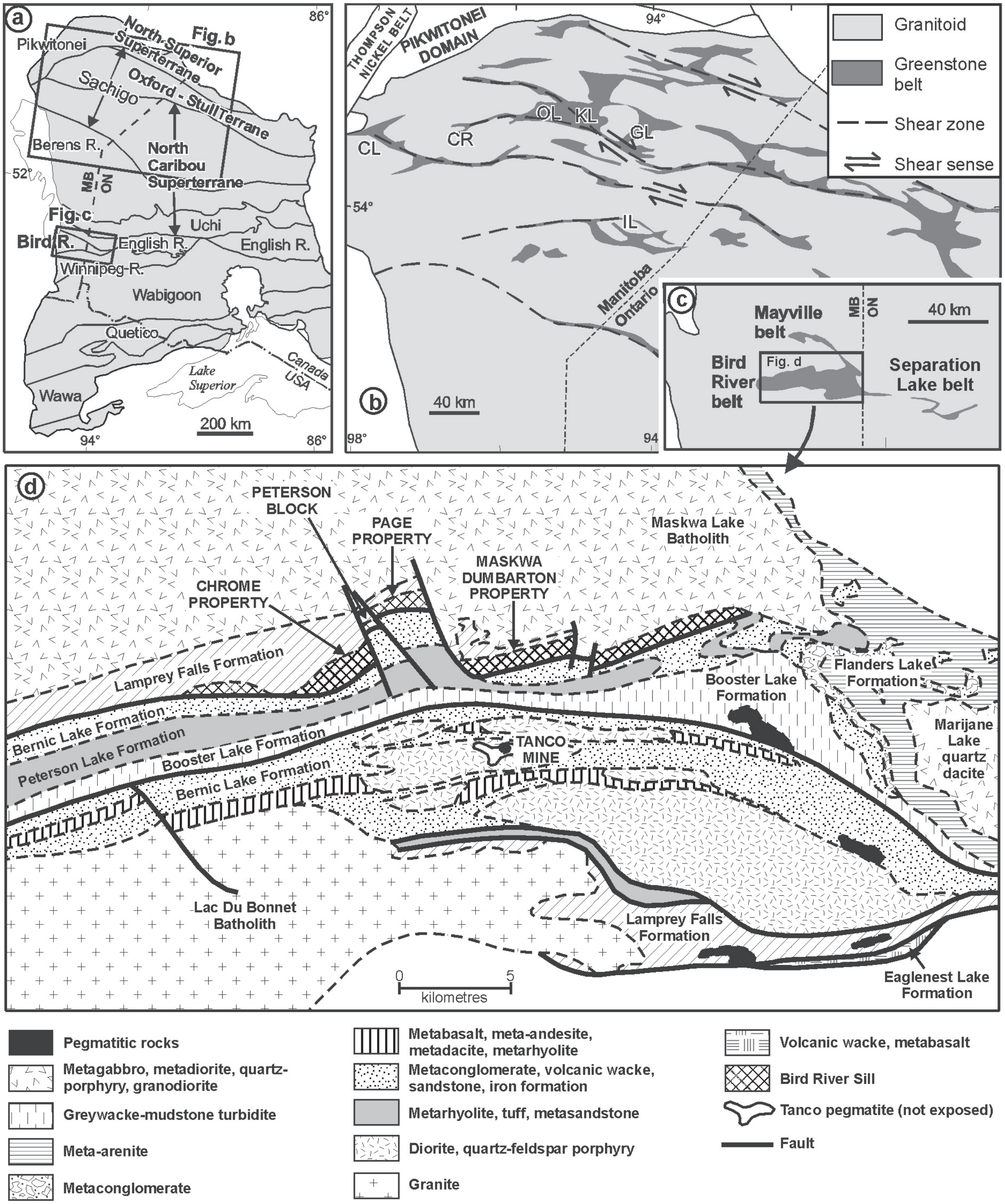

Figure GS-12-1: a) *Tectonic framework of the western Superior craton, showing the location of the Bird River subprovince (Bird R.).* ***b)*** *Generalized geology of the northwestern Superior craton, showing the distribution of greenstone belts and granitoid rocks, and the general dome-and-keel geometry of the area. Abbreviations: CL, Cross Lake; CR, Carrot River; GL, Gods Lake; IL, Island Lake; KL, Knee Lake; OL, Oxford Lake.* ***c)*** *Location of the Bird River greenstone belt.* ***d)*** *Simplified geology of the Bird River greenstone belt (*simplified from *Trueman, 1980).*

subsequent greenschist-facies retrogression (Trueman, 1980).

Available geochronological data indicate that the supracrustal rocks are ca. 2.78–2.73 Ga in age (Timmins et al., 1985).

Trueman (1980) assigned individual map units to formations solely on the basis of lithology and facies type; in the authors' opinion, this has led to misunderstandings and confusion. For example, the Bernic Lake Formation occurs both north and south of the Booster Lake Formation; this also applies to the Lamprey Falls Formation. Moreover, the nature of some contacts between different formations remains unclear. For example, Trueman (1980) stated that the Peterson Creek Formation is both in erosional and in fault contact with the Bernic Lake Formation. The lack of definitive geochemical information for volcanic rocks, as well as uncertainties of some contact relationships due to the lack of structural data, has precluded a rational tectonostratigraphic subdivision of the supracrustal rocks.

The mapping conducted by the senior author in the summer of 2005 has resulted in changes to the existing geological map of Cerny et al. (1981). These changes concern mainly the structural relationships within and between various map units. For example, the 2005 fieldwork shows that the Booster Lake Formation has been subjected to repeated deformation and tectonic disruption, and is not a continuous unit as shown on the map of Cerny et al. (1981). The turbidites of the Booster Lake Formation, which are intensively sheared and folded, disappear in the area immediately west of the Tanco mine road but reappear farther west, in the vicinity of the Bird River. The Bernic Lake Formation to the south is therefore contiguous with the Peterson Creek Formation to the north, along an inferred tectonic contact.

Field investigations elsewhere, in the vicinity of Tanco mine, have shown that basalt within the Bernic Lake Formation is in direct tectonic contact with turbidites of the Booster Lake Formation. No conglomerate or greywacke has been found in the area between these two formations, contrary to the information shown on the map of Cerny et al. (1981).

Structural geology and deformation history

The Bird River greenstone belt has undergone at least three episodes of deformation. The D_1 deformation was coeval with a south-side-up shearing that affected rocks throughout the greenstone belt and resulted in south-side-up tectonic transport and structural juxtaposition of the Bernic Lake (uppermost), Booster Lake and Peterson Creek formations. Following the D_1 tectonic event, D_2 deformation occurred in a dextral-transpressive tectonic setting. In contrast, sinistral shearing during subsequent D_3 deformation is documented by well-preserved structures in turbidites in the western part of the Booster Lake Formation and also in basaltic rocks of the Bernic Lake Formation on the south shore of Bernic Lake. The relative ages of the dextral and sinistral shearing events cannot be confirmed, however, because no definitive overprinting relationships have been observed.

D_1 south-side-up shearing

In the field, the D_1 event is characterized by the development of a pervasive foliation (S_1) that trends southeast in the Booster Lake area, and east to southeast in the central part of the area (Figure GS-12-2). Westward, the foliation trends change to east to northeast. The foliation mostly dips steeply south, except in the Flanders Lake area due to F_2 folding. This foliation bears a mineral and stretching lineation (L_1), oriented southwest to southwest with steep pitch. Some isoclinal folds have axes parallel to the stretching lineation. In section parallel to the stretching lineation and perpendicular to the foliation, some shear-sense indicators are present and indicate a south-side-up shearing. The most spectacular shear criteria observed were asymmetric strain shadows around tonalitic pebbles in the Flanders Lake conglomerate (Figure GS-12-3) and asymmetric boudinage of centimetre-scale pegmatitic dikes in the Booster Lake Formation (Figure GS-12-4). This south-side-up shearing has also been recognized in conglomerate and basalt of the Bernic Lake Formation. The D_1 event is coeval with a regional metamorphic episode that attains amphibolite-facies grade in the Bernic Lake area. In the area immediately north of the Tanco mine, garnet amphibolite characteristic of amphibolite-facies metamorphic grade extends along the contact between the Bernic Lake and Booster Lake formations. Northward from this contact, the Booster Lake Formation is affected by a lower pressure metamorphism. This lower grade metamorphism, characterized by the crystallization of porphyroblasts of andalusite and cordierite in turbidites and volcaniclastic rocks, could be interpreted as contact metamorphism.

In the Peterson Creek Formation, the metamorphic grade seems to be similar to that of the Bernic Lake Formation (amphibolite-facies grade), since some rocks (of suitable chemical composition) have been metamorphosed to garnet-biotite mica schist. At the sample scale, no porphyroblasts of andalusite or cordierite have been found in this mica schist.

Thus, the D_1 event is responsible for the south-side-up shearing and the juxtaposition of the Bernic Lake Formation above the Booster Lake Formation, which itself overlies the Peterson Creek Formation.

D_2 dextral strike-slip shearing

Evidence of the D_2 event has been well documented in the eastern part of Bird River belt at Booster Lake. In this area, the D_2 event is coeval with the emplacement

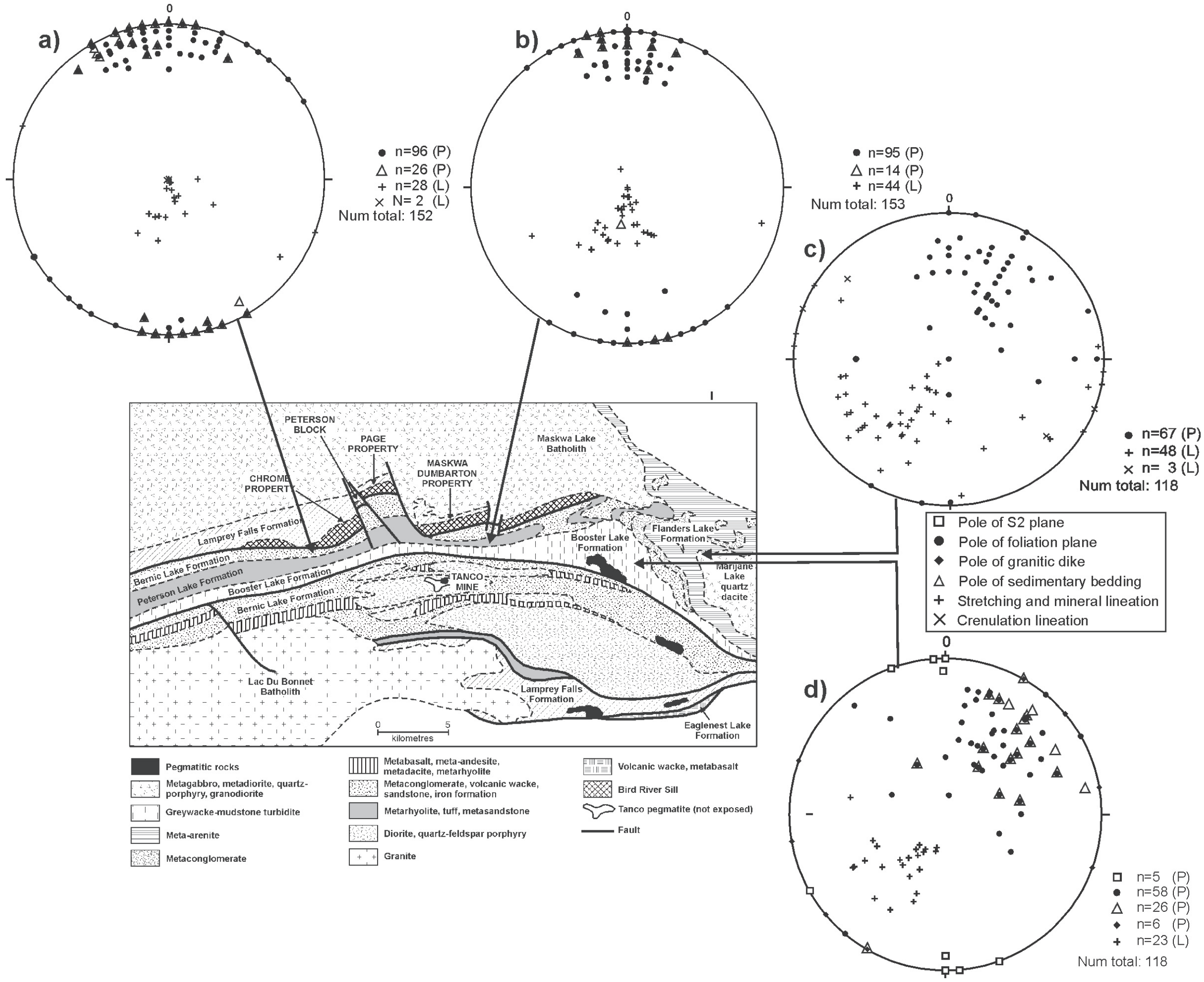

Figure GS-12-2: *Lower-hemisphere stereographic plots of structural data (Schmidt projection); the stereograms are derived from data within various localities shown on the map of the Bird River greenstone belt.*

Figure GS-12-3: *Conglomerate of the Flanders Lake Formation, showing asymmetric strain shadows around tonalitic cobbles; shear sense deduced from these shearing criteria is south side up; pencil for scale.*

Figure GS-12-4: *Asymmetrically deformed pegmatite dike in turbidite of the Booster Lake Formation; shear sense indicated by this deformation is south side up; scale indicated by 4 cm wide leaves in foliage at base of photograph.*

of pegmatitic granite bodies because synkinematic porphyroblasts of cordierite related to contact metamorphism display asymmetric strain shadows that indicate a dextral shear sense (Figure GS-12-5). An east-trending foliation (S_2), oblique to the earlier southeast-trending S_0-S_1 plane, is also well represented in the pelitic layers. The earlier S_0-S_1 plane is reactivated by the dextral shearing, which induces new foliation in metapelitic layer. The consistency of dextral shearing throughout the entire area leads the authors to reject schistosity refraction due to folding as a possible interpretation. The dips of the two sets of foliation vary between 30° and 90°, with an average of around 50°. Major F_2 folds are delineated by a variety of sedimentary features that indicate stratigraphic tops throughout the Booster Lake Formation turbidites (Gilbert, GS-13, this volume). It is likely that the dextral shearing described above was coincident with the F_2 folding. In the Flanders Lake area, immediately east of Booster Lake, Flanders Lake Formation conglomerate contiguous with the Booster Lake Formation displays asymmetric drag folds that are also consistent with dextral shearing (Figure GS-12-6). Furthermore, previous mapping (Trueman, 1980) has shown that the Booster Lake–Flanders Lake Formation contact has also been deformed by tectonic stress consistent with dextral movement parallel to the regional S_0-S_1 trend. These structures could correspond to the last increments of the dextral shear deformation. In turbidites, due to the lack of a vertical plane of observation, the geometry of these folds (i.e., drag folds or upright folds) is not as obvious as in the Flanders Lake area.

The Flanders Lake area is affected by southeast-trending, upright F_2 folds that refold the locally mylonitic S_1 foliation. These folds are defined by variations in the dip of the S_1 foliation. The most important structure related to this folding is a major antiform with an east- to southeast-trending axial trace, located northeast of Booster Lake (Trueman, 1980). The trend and pitch of the early

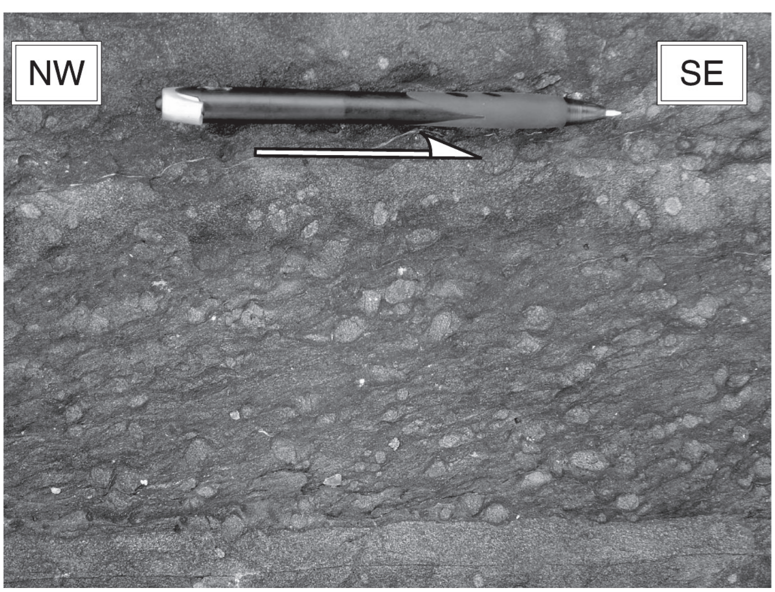

Figure GS-12-5: *Turbidites of the Booster Lake Formation, Booster Lake area; pelitic layers contain abundant synkinematic cordierite porphyroblasts that show a dextral sense of rotation; S_2 foliation is oblique to the earlier S_0-S_1 plane.*

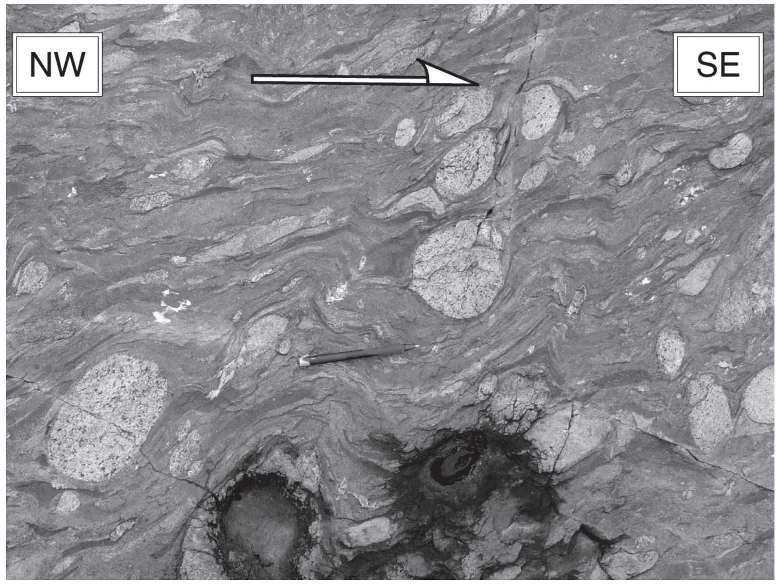

Figure GS-12-6: *Asymmetric drag folds indicate a dextral shear sense, with associated rotation of clasts in metaconglomerate of the Flanders Lake Formation, Booster Lake area.*

stretching lineations within the S_1 plane change from one limb to the other of the F_2 antiform. On the south limb, these lineations have a northeast trend with steep pitch, whereas the lineations on the north limb pitch at shallower angles and trend east to southeast. These lineations are probably related to the D_1 shearing because they are associated with south-side-up shear fabrics. On the north limb of the major F_2 antiform, rare fabrics indicative of dextral shear are possibly coeval with some, at least, of the early (L_1) stretching lineations. Elsewhere, in the Bird Lake area, sporadic occurrences of dextral asymmetric boudinage were observed in granitic dykes, which are particularly abundant in this area and were, in many cases, emplaced parallel to the southeast-trending axial planes of the F_2 folds. In summary, the above-described observations are consistent with an age equivalence between the upright F_2 folds and a dextral shearing event.

Westward, evidence of dextral shearing has been also observed. This deformation occurs as kilometre-scale drag folds that rework the previous D_1 foliation and mylonitic contact between different units. The most remarkable example of such a structure is located within the Peterson Creek Formation, 0.8 km south of Provincial Road 315. At that locality, an F_2 fold is associated with S_2 crenulation cleavage that trends east-northeast (060–080°; Figure GS-12-7); the fold axis plunges steeply west at 80–90°.

D_3 sinistral strike-slip shearing

Evidence of sinistral shearing has been observed at two localities: southern Bernic Lake and the Tanco mine road junction. At the south shore of Bernic Lake, a north-trending stretching lineation occurs within the plane of the S_1 foliation, which trends east and dips steeply north at 75–90º. The stretching lineation is associated with south-side-up shear fabrics, such as garnet porphyroblasts with asymmetric strain shadows that are discernible on planar

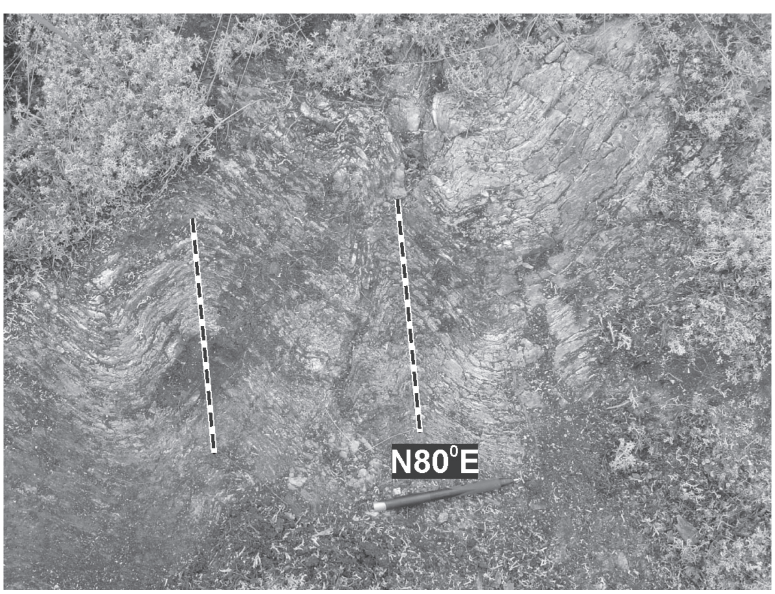

Figure GS-12-7: *Hinge area of the kilometre-scale dextral drag folds in the Peterson Creek Formation; the folds display a vertical axial plane.*

surfaces normal to S_1. This S_1 foliation is deformed by sinistral shear bands that are locally veined by quartz. The shear planes strike approximately 260° and dip north at 60–70°. Minor north-side-up faulting occurs parallel to the shear bands.

Sinistral shearing is particularly well displayed by turbidites of the Booster Lake Formation at the intersection between the Tanco mine road and Provincial Road 315. A hectometre-scale drag fold that resulted from sinistral shear occurs at this locality. The new fabric (cleavage-schistosity) induced by the sinistral shearing is oriented southeast. A variety of shear-sense indicators occurs in the vicinity of the road junction, including asymmetric quartz rods, faults in greywacke layering (Figure GS-12-8) and asymmetric tension gashes.

Conclusions and future work

Fieldwork in 2005 produced new information that was necessary to outline the structural history and kinematic pattern of a part of the Bird River greenstone belt. The belt was previously affected by vertical movements with a south-side-up shearing in the investigated area. An interesting feature of this tectonic event is the juxtaposition of units metamorphosed under amphibolite facies (the Bernic Lake Formation) upon units of a lower metamorphic grade (turbidites of the Booster Lake Formation). This characteristic strongly suggests thrusting-type tectonics at low angle before the steepening of the different units due to strike-slip tectonics. The strike-slip shearing shows contrasting shear sense according to the area. Despite the presence of clear shear criteria, few or no horizontal stretching lineations are associated with the dextral or sinistral shearing.

Further investigations will focus on the following points:

- Does the D_1 top-to-north event correspond to thrusting tectonics or sagduction-type tectonics? For this purpose, it is necessary to explore the southern part of the belt, especially in the Winnipeg River area, in order to examine the structural and kinematic pattern. The study of thin sections should bring supplementary data to test the different hypotheses.
- Considerable basalt and diorite attributed to the Lamprey Falls Formation crop out in this area. Some geochemical samples will need to be taken to decipher the exact nature of these series and for comparison with the basalt that is situated north of the Bird River Sill and also attributed to the Lamprey Falls Formation.
- Fieldwork will be conducted to determine the nature of the contact between the Peterson Creek Formation and the Bernic Lake Formation to the north.
- The structural relationship and timing between the dextral and sinistral shearing events, interpreted provisionally as D_2 and D_3 respectively, remain unsolved. A few samples of pegmatite and granite emplaced during the dextral shearing in the Booster Lake area have been collected for dating. Further geochronological studies will deal with the postkinematic Lac du Bonnet batholith to the west, as well as the Maskwa batholith, situated north of the Bird River greenstone belt.
- An understanding of the metamorphic events and their timing in relation to the deformation history is necessary in order to provide a clear scheme for the tectonic evolution of the Bird River greenstone belt. The metamorphic investigation will focus on rock types (such as metapelite and amphibolite) that are of favourable composition for the development of metamorphic indicator minerals.

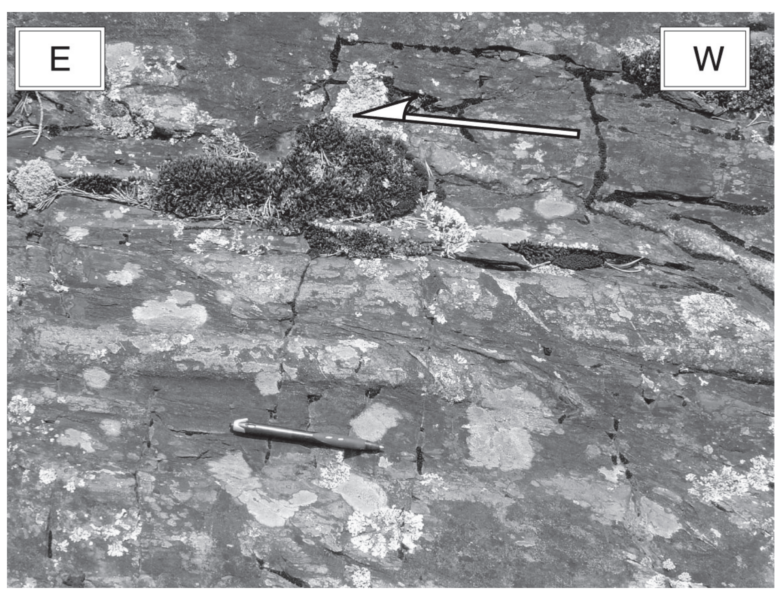

Figure GS-12-8: *Bedding in greywacke turbidite (Booster Lake Formation) north of the Tanco mine road is disrupted and faulted due to the sinistral shearing.*

Economic considerations

The Bird River greenstone belt has been extensively explored for ore deposits since 1920, when Ni-Cu sulphide deposits were discovered in the Cat Creek–Maskwa River area (McCann, 1921). At present, economic interest is focused on mineralization allied to three known ore deposits:

- the Tanco rare-element pegmatite
- the Maskwa Fe-Ni-Cu-PGE deposit
- the Dumbarton Ni-Cu-Zn-PGE deposit

The Tanco mine at Bernic Lake has produced tantalum, cesium and lithium since 1969. The Maskwa and Dumbarton deposits were mined from 1974 to 1976 and from 1969 to 1973, respectively; renewed production at Maskwa is planned as a result of the recent discovery of additional ore reserves (Mustang Minerals Corp., 2005). In the area north of Bernic Lake, Ni-Cu-PGE mineralization is spatially associated with the mafic-ultramafic Bird River Sill.

At the present time, the Bird River greenstone belt is being extensively explored by Tanco for rare element–bearing pegmatite deposits, and by Gossan Resources Limited, Mustang Minerals Corp. and North American Palladium Ltd. for Ni-Cu-Zn-PGE mineralization. The geological setting of the different ore-deposit types remains poorly understood. Mapping, structural and kinematic analysis, and geochronological investigations are necessary in order to better understand both the evolution of the Bird River greenstone belt and the setting of the various ore-deposit types, with a view to supporting the current exploration programs that are underway in the area.

Acknowledgments

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