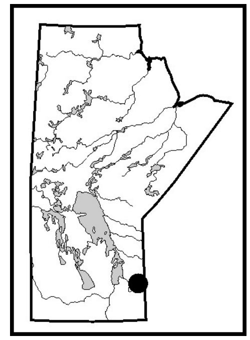
GS-18 Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement

by P.D. Kremer[1] and S. Lin[1]



Kremer, P.D. and Lin, S. 2006: Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 206–213.

Summary

In June of 2005, a two-year M.Sc. project was initiated to examine the structural geology of the Bernic Lake Formation and provide constraints on the emplacement of rare element pegmatite bodies that occur within it. The study is being completed at the University of Waterloo in co-operation with the Manitoba Geological Survey and the Tantalum Mining Corporation of Canada Ltd. (Tanco). Field components of the study included regional geological mapping (1:10 000 scale) of the Bernic Lake Formation around the Tanco mine, detailed geological mapping of exposed pegmatite occurrences within the Bernic Lake pegmatite group, examination of both production and exploration diamond-drill core from the Tanco mine, and underground geological mapping of the Tanco pegmatite.

Preliminary data from Bernic Lake suggest that pegmatite emplacement occurred in the late stages of D_1 deformation, a north-south compressive event manifested by large-scale isoclinal folding and a south-side-up sense of displacement in the area. Pegmatites of the Bernic Lake group show a clear spatial relationship to a thick high-strain zone that runs along the north shore of Bernic Lake and marks the axial plane of a synclinal structure. Where exposed, pegmatites east of the lake are intruded into metavolcanic and volcaniclastic rocks, are oriented either parallel or slightly oblique and crosscutting to regional deformation fabrics, and are locally deformed in a ductile manner (folded and/or boudinaged depending on their orientation relative the principle stresses). The Tanco pegmatite, hosted primarily in a polyphase, synvolcanic gabbro intrusion on the western margin of Bernic Lake, was emplaced along a subhorizontal conjugate fracture set.

Introduction

The Bird River greenstone belt is located in the Archean Superior Province of the Canadian Shield in southeastern Manitoba, approximately 100 km northeast of Winnipeg. It comprises metavolcanic and metasedimentary rocks and associated synvolcanic intrusions, which are bounded to the north by the English River Domain and to the south by the Winnipeg River Domain. Trueman (1980) subdivided the Bird River greenstone belt into six lithostratigraphic formations, termed the Eaglenest Lake Formation, Lamprey Falls Formation, Peterson Creek Formation, Bernic Lake Formation, Flanders Lake Formation and Booster Lake Formation. Detailed descriptions of each formation can be found in Trueman (1980), Cerny et al. (1981), Duguet et al. (GS-16, this volume) and Gilbert (GS-17, this volume).

The Bird River greenstone belt is also host, in part, to the Cat Lake and Winnipeg River pegmatite districts. Within the Winnipeg River district, the pegmatites have been separated into eight groups of spatially, mineralogically and geochemically related bodies. The Bernic Lake pegmatite group is clustered around Bernic Lake and includes the highly fractionated, rare element–bearing Tanco pegmatite, which is currently being mined for tantalum, cesium and lithium.

Results

General geology

An area of approximately 40 km^2, extending from the southern shoreline of Bernic Lake northward to the faulted contact of the Bernic Lake Formation and the Booster Lake Formation, was mapped at a scale of 1:10 000 during the summers of 2005 (Kremer, 2005a, b) and 2006 (Figure GS-18-1; Kremer and Lin, 2006).

Mafic volcanic rocks (basalt-andesite) form the most extensive unit in the map area. They occur primarily as pillowed and massive flows, reaching many tens to hundreds of metres in thickness. The basalt weathers dark greyish green to black and is generally very fine grained and aphyric, although feldspar-phyric occurrences are observed. Quartz±feldspar amygdules up to 3 cm across and epidote alteration are common in pillowed flows. A moderately to very well developed schistosity occurs in all varieties of basalt. Primary features and pillow selvages are occasionally well preserved and, in places, suitable for determination of younging direction, although they often display a very high degree of stretching (aspect ratios up to 100:1) or are completely obliterated by the effects of deformation and recrystallization, with only minor amounts of recognizable relict selvage material (Figure GS-18-2).

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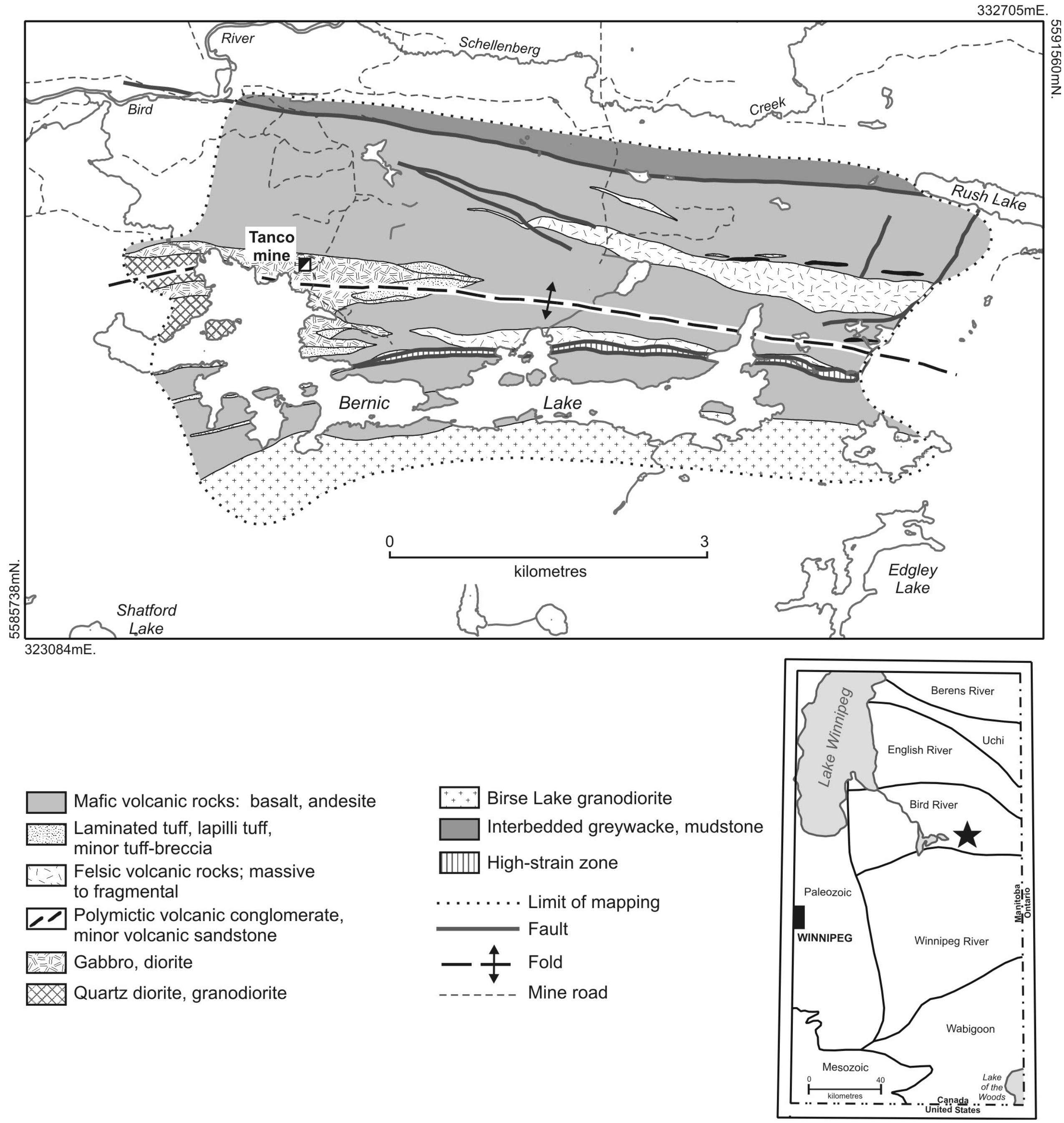

***Figure GS-18-1:** Preliminary map of the Bernic Lake area around the Tanco mine, Bird River greenstone belt, southeastern Manitoba PMAP2006-9 (Kremer and Lin, 2006).*

Massive to fragmental, quartz- and feldspar-phyric dacite defines a map unit that is thickest to the northeast of Bernic Lake and thins toward the west. The dacite typically weathers buff grey to white and contains up to 15% euhedral to subhedral quartz and feldspar phenocrysts. Schistosity is weakly to moderately developed in the dacite unit. Clasts in the fragmental variety show flattening on horizontal outcrop surfaces and display a prominent down-dip stretching lineation on vertical outcrop surfaces.

Thin lenses of volcanic conglomerate, volcanic sandstone, tuff and lapilli tuff, with minor tuff-breccia, occur sporadically throughout the volcanic pile. These rocks, which range up to approximately 50 m in thickness, are not laterally extensive and can rarely be traced along strike for more than a few hundred metres. Primary bedding features are identified in some locations and are consistent with top determinations derived from pillow basalt flows (Figure GS-18-3). The volcanic conglomerate consists predominantly of moderately sorted clasts

__Figure GS-18-2:__ Strongly recrystallized pillow basalt, east of Bernic Lake.

__Figure GS-18-3:__ Normal-graded beds in volcanic sandstone, indicating tops to the north (magnet for scale points north), east of the Tanco mine.

of felsic volcanic rock (dacite) within a fine-grained, typically mafic, schistose matrix; fragments of basalt are rare (Figure GS-18-4).

A medium- to coarse-grained, polyphase, synvolcanic intrusion occurs on the western portion of Bernic Lake around the Tanco minesite. The intrusion is composed of gabbro, diorite, quartz diorite and granodiorite. Contact relationships with the host volcanic rocks are sharp and, for the most part, parallel with the subvertical, east trend of major lithological contacts, although some crosscutting relationships occur. Evidence of intrusion brecciation of early phases (gabbro-diorite) is observed in many locations on Bernic Lake, in locations where weakly to moderately resorbed inclusions of gabbro-diorite are hosted within a granodioritic matrix (Figure GS-18-5). On the southern margin of the intrusion, however, these relationships become spurious, and evidence would suggest that the mafic and felsic phases are comagmatic. The three-dimensional expression of this body is poorly constrained; the deepest vertical diamond-drill holes from the Tanco mine failed to pierce the lower contact.

The southern portion of Bernic Lake is underlain by a large intrusion, known as the Birse Lake granodiorite, that extends southward to the Winnipeg River. It is very homogeneous in shoreline outcrops on Bernic Lake and contains abundant feldspar phenocrysts up to 3 cm in length. Large xenoliths of basalt country rock, up to 5 m across, occur near the margins.

Hostrock structural geology and kinematics

The prominent structural feature within the Bird River greenstone belt is a large synform located in the northeastern portion of the belt. Map units in the area around Bernic Lake trend west to west-northwest, dip subvertically, and define, in part, the southern flank of this

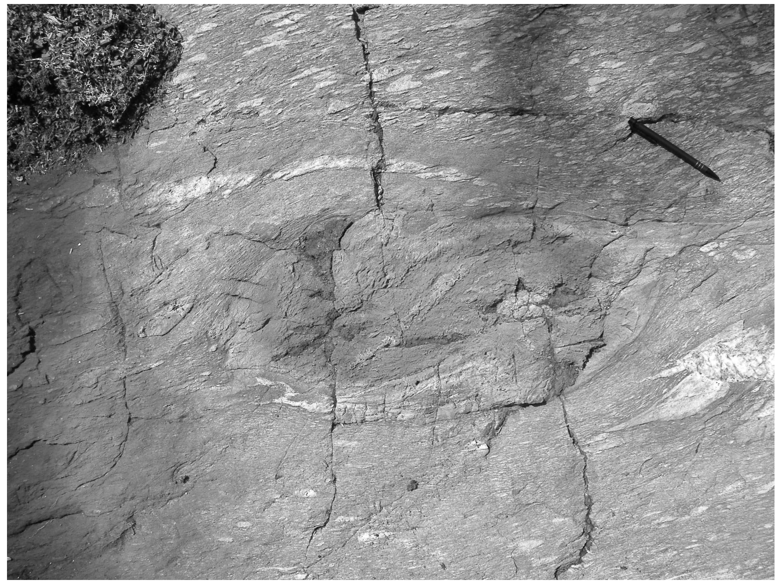

Figure GS-18-4: *Large basalt clast in bedded volcanic conglomerate, northeast of Bernic Lake. Asymmetric tails on clast indicate dextral shear.*

Figure GS-18-5: *Igneous intrusion breccia, western Bernic Lake.*

large fold structure. Mapping has identified three distinct generations of deformation in the Bernic Lake Formation, which are discussed below.

D_1 deformation

Structures associated with the first phase of deformation are ubiquitous throughout the entire map area. This deformation is manifested as a pervasive, closely spaced, layer-parallel, biotite-amphibole±chlorite schistosity (S_1) that is present to varying degrees in all rock types (with the exception of certain intrusive bodies). The S_1 schistosity trends between 80 and 120° and generally dips steeply to the south (Figure GS-18-6). A strong down-dip stretching lineation is defined by elongate fragments in dacite and volcanic conglomerate. Locally, a hornblende mineral lineation is parallel to the stretching lineation. Bedrock outcrops around Bernic Lake define an anticline-syncline pair, which is interpreted to be associated with this deformation. The identification of these folds is difficult owing to poor outcrop exposure along their axial traces and the fact that drag and parasitic folds are virtually absent within the stratigraphy. Nevertheless, consistent reversals in younging criteria across the map area, as well as a general unit repetition, support this interpretation. Where good exposure does exist, very tight to isoclinal, moderately to steeply west- to west-southwest-plunging folds are observed (Figure GS-18-7). The hinge of the synclinal structure lies within and is completely overprinted by a high-strain zone along the northern shore of Bernic Lake.

High-strain and shear zones belonging to the D_1 deformation occur throughout the map area parallel to the S_1 schistosity. Shear zones range from discreet zones no more than 5 cm in width to major structures, the most prominent of which is a high-strain zone observed along the northern shoreline of Bernic Lake and ranges

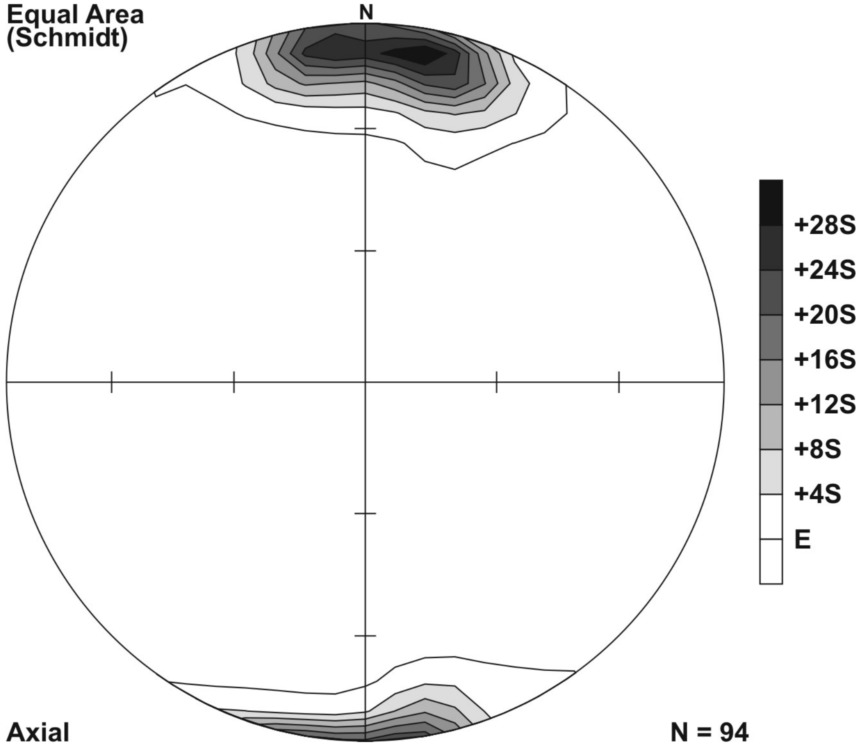

Figure GS-18-6: *Equal-area, lower-hemisphere stereographic projection of D_1 structural elements in the Bernic Lake Formation.*

Figure GS-18-7: *Partially attenuated m-fold along axial trace of F_1 anticlinal structure, power line north of Bernic Lake.*

between 100 and 200 m thick. Primary features are rarely preserved, although the available evidence suggests that the zone represents the tectonized contact between basalt to the south and volcaniclastic rocks to the north. Narrow zones of protomylonite are common throughout the Birse Lake granodiorite, especially near the northern contact. Sense-of-shear criteria are abundant and include asymmetric boudins, asymmetric flattened clasts and asymmetric tails around garnet porphyroblasts. Shear criteria, when viewed in vertical outcrop surfaces parallel to the stretching lineation, consistently show a south-side-up sense of displacement. Minor dextral strike-slip displacement is seen in small-scale z-asymmetric dragfolds and asymmetric tails on horizontal surfaces (Figure GS-18-8).

D_2 deformation

Structures of the D_2 deformation observed in the Bernic Lake area consist of a locally developed, spaced

Figure GS-18-8: *Small-scale, z-asymmetrically folded quartz vein in D_1 high-strain zone, east of Bernic Lake.*

fracture cleavage that is most evident towards the southern portion of the map area, where it is consistently oriented 15 to 30° counter-clockwise to the S_1 schistosity. Opposing vergence was not noted, although this structural feature was not found on the south-facing limb of the anticline-syncline pair. This cleavage is axial planar to small, upright, gentle to open folds that are visible on vertical outcrop surfaces and affect narrow quartzofeldspathic veins that crosscut S_1. Numerous narrow gabbroic dikes are intruded parallel to this feature (Figure GS-18-9). It is likely that reactivation of D_1 structures during D_2 is responsible for some overprinting sinistral strike-slip movement observed along D_1 structural planes.

D_3 deformation

This late, brittle event is manifested by large north- or northeast-trending lineaments that cut across the map area. Displacement across these large-scale structures was never noted. On subsidiary parallel structures, however, a component of sinistral strike-slip movement exists. At least two conjugate fracture sets are present within the entire stratigraphy, and are tentatively associated with this late event. In some instances, intense silicification, albitization and potassium alteration are present along these fracture sets, possibly owing to degassing from buried pegmatites. Structural measurements of brittle fractures, taken over the course of fieldwork, have various orientations; stereographic analysis is underway.

Pegmatite structure

Pegmatites within the map area typically have very limited surficial expression and occur primarily within two areas. Around the Tanco mine, pegmatites are hosted

Figure GS-18-9: *Fine-grained composite dike intruding pillow basalt, northeast of Bernic Lake. Pillows are stretched 110° (S_1) and dike is oriented parallel to overprinting cleavage (S_2) and trends 85°.*

in gabbro-diorite or in metavolcanic rocks. These pegmatites have very sharp, straight contacts with the hostrocks and are generally tabular bodies with shallow to moderate dips. Where well exposed, they are oriented slightly oblique to, and crosscut, the pervasive schistosity within the volcanic rocks. The Tanco pegmatite is hosted largely within gabbro-diorite and is a doubly dipping body that was emplaced along a prominent conjugate fracture set.

Numerous pegmatites that occur east of Bernic Lake show a strong spatial association with the high-strain zone north of the lake. These pegmatites are deformed in a ductile manner within a north-south compressive regime (Figure GS-18-10). Folds and boudins are common, although the pegmatites retain many features of passive crystallization. These pegmatites are interpreted to be emplaced in dilatant zones during the late stages of D_1 deformation. Many of the other pegmatite groups and pegmatitic granite bodies within the Bird River greenstone belt are also emplaced along similar structures, and it is likely that large fault zones acted as conduits through which the late-stage granitic magma ascended.

Discussion

Pegmatites east of Bernic Lake show evidence of ductile deformation that has not been described in the Tanco pegmatite, although mineralogical and geochemical studies indicate that they are genetically related (Cerny and Trueman, 1977; Lenton, 1979; Cerny et al., 1981). Geochronological samples from representative pegmatites in each location were collected and are awaiting analysis to further constrain the relationship between deformed and undeformed pegmatites within the Bernic Lake Formation. Two possibilities seem feasible:

- Multiple generations of pegmatite emplacement may have occurred, whereby late D_1 pegmatite emplacement into ductile dilatant zones was followed by the emplacement of shallowly dipping tabular pegmatites (Tanco, Buck) along late fracture sets associated with D_3 deformation.
- If the analytical data indicate identical ages for pegmatites with different structural characteristics, then it may be a function of rheological contrasts between respective hostrocks (gabbro-diorite versus sheared metavolcanic rocks) that are responsible for the different emplacement styles and mechanisms.

Geochemical and geochronological analyses of the volcanic stratigraphy are currently underway and data are pending. Furthermore, the emplacement history of certain pegmatite occurrences will be further examined by U-Pb geochronology and by Ar-Ar dating of various minerals, extending from the pegmatite into the wallrock. The former will determine whether all pegmatites of the Bernic Lake group are of identical age, while the latter should help to constrain the P-T conditions at the time of emplacement. Microstructural analysis on numerous oriented thin sections is still underway, as is detailed stereographic analysis of late brittle fractures.

Economic considerations

The Tanco pegmatite is a world-class ore deposit that is currently being mined for tantalum, cesium and lithium. Exploration drillholes focused around geochemical anomalies in soil have identified numerous occurrences of rare element pegmatites, although none of them have the dimensions of the Tanco body (approximately 1400 m long by 600 m wide by 100 m deep). The tendency of pegmatites within the Bernic Lake Formation to be spatially associated with a large shear zone suggests that the shear zone may have acted as a plane of weakness within the stratigraphy, along which magma ascended through the crust. If the fracture-hosted, highly fractionated Tanco pegmatite is shown to be coeval with deformed

Figure GS-18-10: *Pegmatite displaying ductile deformation, east of Bernic Lake.*

pegmatites east of the lake that record the final increments of D_1 strain, then large-scale dilatant zones associated with this structure become of interest with regards to potential locations for the accumulation and crystallization of rare element–bearing pegmatitic fluids.

Acknowledgments

The author would like to thank B. Foster, K. Lewis and L. Osadchuk for their capable and enthusiastic assistance throughout the course of the field season, as well as M. Duguet and C. Mealin for sharing insights from their respective projects. C. Galeschuk, P. Vanstone and S. Moran from the Tanco mine are thanked for their support throughout the summer and for sharing their time, opinions and ideas. The project would not be possible without the continued logistical support, assistance and encouragement of the Manitoba Geological Survey.

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