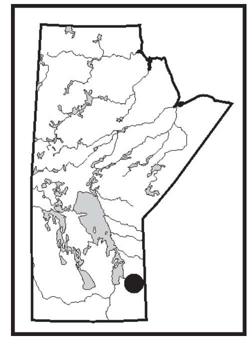
GS-13 Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6N) by H.P. Gilbert



Gilbert, H.P. 2005: Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6N); *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 125–139.

Summary

The Neoarchean Bird River greenstone belt in southeastern Manitoba is the focus of a new regional Manitoba Geological Survey mapping project. A short field program in 2005 included both reconnaissance and detailed mapping at selected localities. In the west part of the Bird River belt, mid-ocean ridge basalt (MORB)–like basalt (Lamprey Falls Formation) at the north margin is structurally overlain by arc-type mafic to felsic volcanic rocks and sedimentary deposits (Peterson Creek and Bernic Lake formations). In the east part of the belt, a turbidite sequence (Booster Lake Formation) is deformed by northwest- to west-trending, major F_1 folds. The hinge line of an F_2 antiform in contiguous fluvial sedimentary rocks (Flanders Lake Formation) is subparallel to the F_1 axial traces. The D_3 deformation resulted in regional warping of the earlier structures by a northeast-trending open fold, whereas D_4 resulted in brittle fracturing and faulting at high angles to the trends of S_0 and regional S_1.

Introduction

A new Manitoba Geological Survey (MGS) mapping project was started this year in the Neoarchean Bird River greenstone belt of southeastern Manitoba (Figure GS-13-1). This initiative is intended primarily to provide an up-to-date, detailed geological map of an area that is currently the focus of base-metal and platinum group element (PGE) exploration by four companies. The Bird River project is also part of ongoing remapping by MGS to upgrade geological data in areas where the existing maps are outdated. Mapping in the Bird River belt will complement recent detailed mapping in the Rice Lake belt to the north (Anderson, 2002, 2003a, 2003b, 2004), as well as several geological research projects, also initiated this summer, based at the universities of Manitoba and Waterloo (Duguet et al., GS-12, this volume; Kremer, GS-14, this volume; Mealin, GS-15, this volume; Murphy and Theyer, GS-17, this volume). The Bird River project will include new 1:20 000-scale geological mapping, together with detailed structural and stratigraphic investigations of the main tectonic components and geochemical documentation of all volcanic rock units. Uranium-lead radiometric dating is planned to supplement the existing geochronological database in the region.

Exploration and geological investigations in the Bird River area span the past century, dating from the pioneering work of Tyrrell (1900). Economic interest in the region was initially focused on the potential of sporadically occurring, Mo-bearing pegmatites, as well as the discovery of Ni-Cu ore at Cat Lake in the area north of Bird Lake (Figure GS-13-2). Subsequent exploration was targeted on rare-earth– and Sn-bearing pegmatites at Shatford and Bernic lakes, as well as chromitiferous layers in the mafic-ultramafic Bird River Sill. The Tanco mine at Bernic Lake produced Sn and Ta ore for a brief interval in 1929 and later, in the 1950s, was a source of Li; the mine became fully operational as a Ta producer in 1969. Minor amounts of Cs,

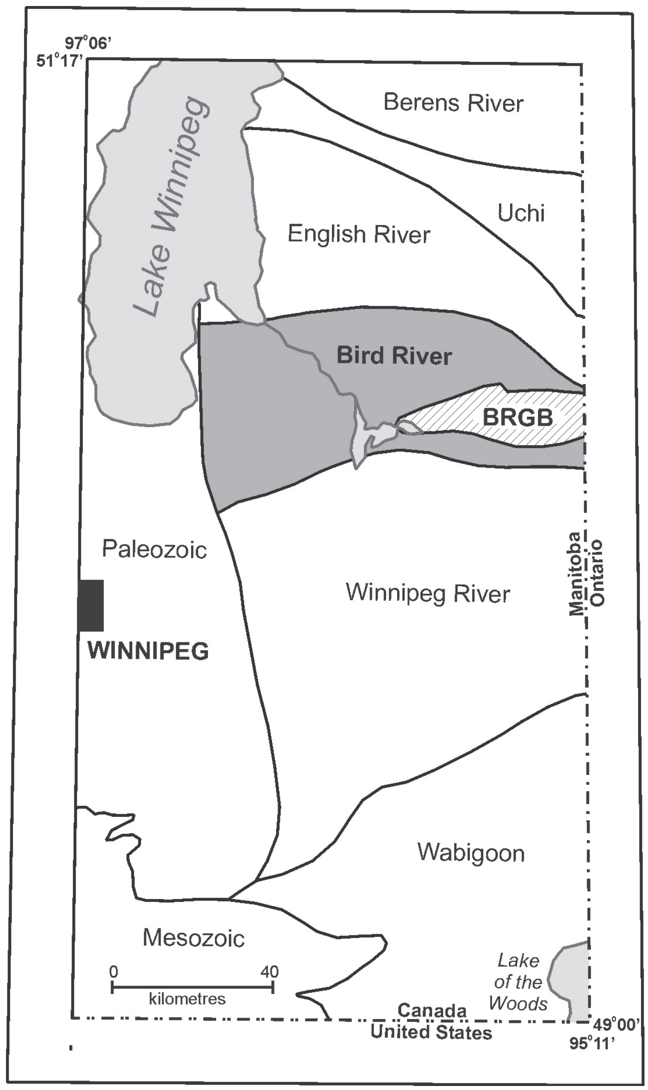


Figure GS-13-1: Regional map of southeastern Manitoba showing geological subprovinces and the location of the Bird River greenstone belt (BRGB).

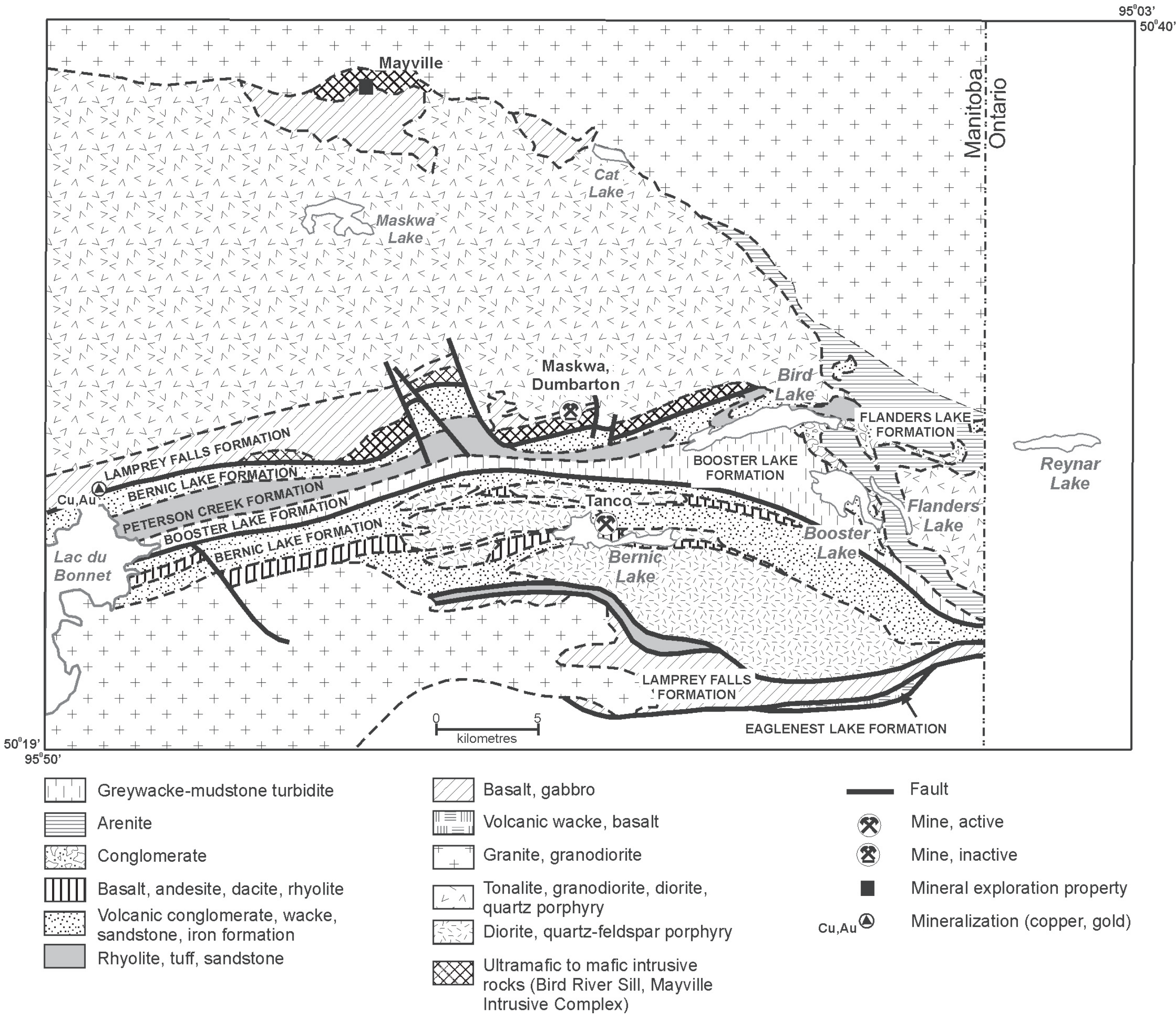


Figure GS-13-2: *Generalized geology of the Bird River greenstone belt, showing the main formations as defined by Cerny et al. (1981).*

Be and Rb have also been recovered from the ore at Bernic Lake. In the central part of the Bird River belt, Cu and Ni were produced for a decade until the mid-1970s from the Dumbarton (and subsequently the Maskwa) orebodies, located just a few kilometres north of Bernic Lake. Renewed production at Maskwa is planned following the recent delineation of additional Ni-Cu ore reserves by Mustang Minerals Corp. (Mustang Minerals Corp., 2005). Current exploration in the Bird River belt is focused on PGE, base metals and prospects for new sources of rare earth elements.

The first systematic geological mapping of the Bird River belt was undertaken in the 1950s (Springer, 1948, 1949, 1950; Davies, 1952, 1955a, 1955b, 1956, 1957). Geological investigations were subsequently carried out by D.L. Trueman, who produced a study of the Bird River Sill (Trueman, 1971); the sill has also been the subject of geological investigations by P. Theyer (Theyer, 1981, 1983, 1991, 2002) and R.F.J. Scoates (Scoates, 1983, 1988; Scoates et al., 1987, 1989). The Bird River greenstone belt was mapped by Trueman as a Ph.D. thesis (Trueman, 1980). Cerny at al. (1981) provided a comprehensive study of the abundant pegmatite intrusions of the region, as well as a synthesis and interpretation of the regional geology. A 1:250 000-scale geological map (Manitoba Energy and Mines, 1987) represents the most recent compilation of the geology of the area.

The Bird River belt, located between the English River subprovince to the north and the Winnipeg River subprovince to the south (Figure GS-13-1), has been interpreted as a collage of various tectonostratigraphic components that are deformed in a major synclinorial structure (Cerny et al., 1981). Along the north margin of the belt, the oldest rocks are relatively homogeneous, subaqueous mafic volcanic flows (Lamprey Falls Formation), structurally overlain by the volcanosedimentary Bernic Lake Formation and felsic volcanic Peterson Creek Formation (Cerny et al., 1981; Figure GS-13-2; Table GS-13-1). The mafic-ultramafic Bird River Sill extends along the south side of the Lamprey Falls Formation;

Table GS-13-1: Table of formations from Cerny et al. (1981).

Intrusive and metasomatic rocks, syn- to late-tectonic
Pegmatite, granite
Intrusive and metasomatic rocks, early- to syn-tectonic
Quartz diorite
Metasedimentary rocks
BOOSTER LAKE FORMATION
Greywacke-siltstone, mudstone, conglomerate
~~ *Unconformity* ~~~~~~~~~~~~~~~~~~~~~~
FLANDERS LAKE FORMATION
Lithic arenite, polymictic conglomerate
~~ *Unconformity* ~~~~~~~~~~~~~~~~~~~~~~
Intrusive rocks, synvolcanic
Gabbro, diorite, quartz-feldspar porphyry, granodiorite
Metavolcanic and metasedimentary rocks
BERNIC LAKE FORMATION
Basalt, andesite, dacite, rhyolite, quartz porphyry, conglomerate (polymictic to oligomictic), schist (cordierite-anthophyllite-garnet-biotite–bearing)
~~ *Unconformity* ~~~~~~~~~~~~~~~~~~~~~~
PETERSON CREEK FORMATION
Rhyolite (massive to fragmental), lapilli tuff, volcanic sandstone
Intrusive rocks, synvolcanic
BIRD RIVER SILL
Dunite, peridotite, picrite, anorthosite and gabbro
Metavolcanic and metasedimentary rocks
LAMPREY FALLS FORMATION
Basalt (aphyric to plagioclase-phyric; locally pillowed, amygdaloidal or megacrystic), related volcanic breccia
EAGLENEST LAKE FORMATION
Volcanic wacke, pebbly wacke

available U-Pb zircon dates (Wang, 1993) are consistent with a slightly younger age for the Peterson Creek Formation (2740 ±4 Ma) relative to the Bird River Sill, which is synvolcanic in age (2745 ±5 Ma). The Peterson Creek Formation and the Bird River Sill are unconformably overlain by polymictic conglomerate of the Bernic Lake Formation (Cerny et al., 1981), which also contains mafic to felsic volcanic rocks and porphyroblastic schist. In the basal part of the sequence at the south margin of the Bird River belt, volcanic-derived epiclastic rocks and iron formation of the Eaglenest Lake Formation are in fault contact with Lamprey Falls Formation basalt. Two episodes of sedimentation are assumed to postdate the volcanic rocks: the fluvial-alluvial Flanders Lake Formation and the greywacke-siltstone turbidite Booster Lake Formation (Cerny et al., 1981). The contact between these two formations has not been observed, hence their stratigraphic relationship and relative ages are not known. In the map of Cerny et al. (1981), these formations are in fault contact. The Booster Lake turbidites extend throughout the length of the Bird River belt, whereas the Flanders Lake sedimentary rocks are confined to the east part of the belt and extend beyond the provincial boundary to the area east of Reynar Lake in Ontario.

Stratigraphy

Bird River belt, west part

Lamprey Falls, Bernic Lake and Peterson Creek formations

At the west end of the Bird River belt (Figure GS-13-2), the Lamprey Falls basalt at the north margin of the supracrustal section is a monotonous, massive to pillowed flow sequence, except for a mineralized, pyrite-bearing zone close to the south (inferred upper) margin of the formation. This rusty-weathering, 16 m wide zone contains minor Cu (0.12%) and traces of Zn, Ni and Au (29 ppb). The basalt is geochemically akin to modern back-arc basin basalt (BABB); the extended-element plot (Figure GS-13-3a) is almost flat, with rare earth element values similar to those of MORB, except for slightly enriched Th. South of the basalt, the shoreline section in

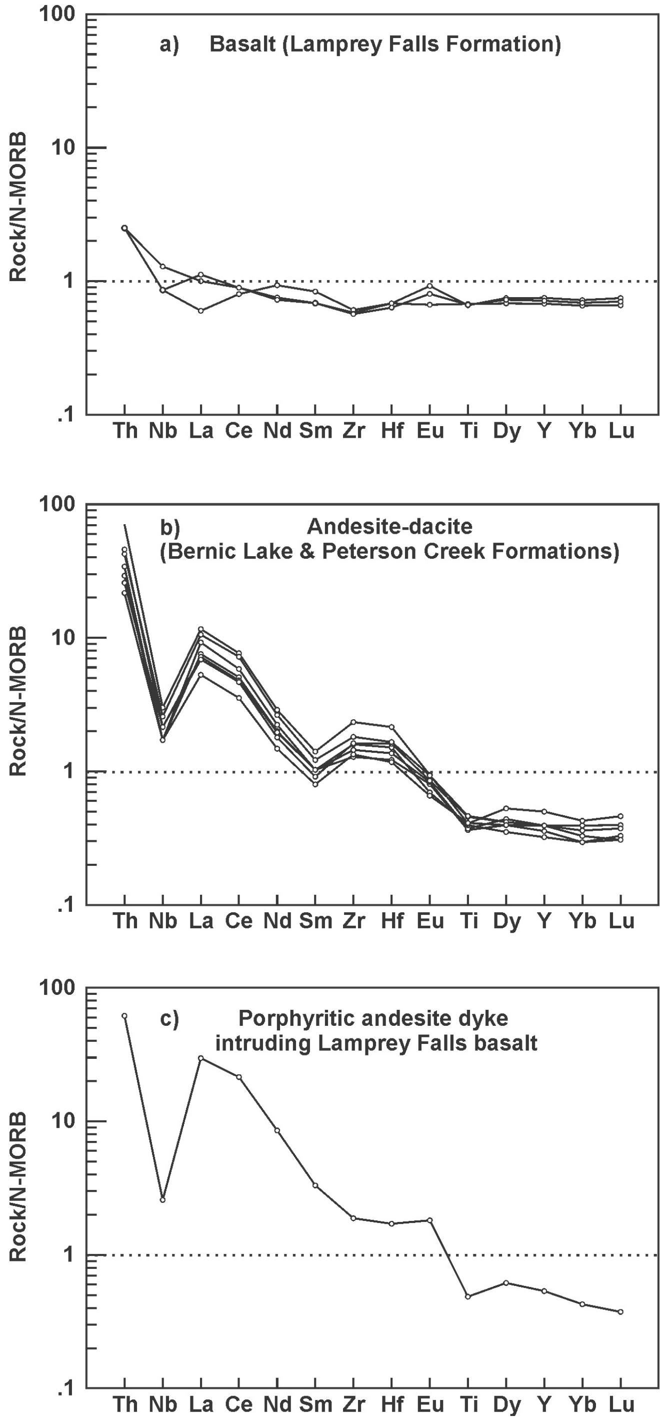


Figure GS-13-3: *Extended-element plots of* ***a)*** *MORB-like Lamprey Falls Formation basalt;* ***b)*** *structurally overlying arc-type andesite and dacite (Bernic Lake and Peterson Creek formations); and* ***c)*** *porphyritic andesite of juvenile-arc affinity, emplaced within Lamprey Falls basalt. Analyzed rocks are from a north-south stratigraphic section in the west part of the Bird River belt. Normalizing values are after Sun and McDonough (1989).*

the northeast part of Lac du Bonnet contains predominantly intermediate to felsic volcanic rocks and breccia (Bernic Lake and Peterson Creek formations) that are compositionally similar to modern juvenile-arc volcanic rocks (Figure GS-13-3b). The contact between the Lamprey Falls and Bernic Lake formations is abrupt and interpreted as a fault; a relatively younger age is inferred for the structurally overlying rocks to the south. This interpretation is supported by the occurrence of a plagioclase-pyroxene–phyric intermediate dike of arc affinity that is emplaced within basalt of the Lamprey Falls Formation (Fig GS-13-3c). The dike is compositionally akin and possibly genetically related to Bernic Lake Formation andesite, suggesting that the latter rocks postdate the Lamprey Falls Formation. The Bernic Lake Formation has been shown to postdate the Bird River Sill, because detritus derived from the intrusion occurs in polymictic conglomerate within the Bernic Lake Formation (Cerny et al., 1981).

Bird River belt, east part

Flanders Lake Formation

Close to the east end of the Bird River belt, fluvial sandstone, conglomerate and derived paragneiss of the Flanders Lake Formation extend along the northeast margin of the Booster Lake turbidite sequence (Figure GS-13-2). The arenaceous component is arkosic and characterized by widespread crossbedding and pebbly horizons, locally associated with graded bedding and scour-and-fill structures (Figure GS-13-4). These primary features are of limited use for indicating stratigraphic tops, in part as a result of metamorphic recrystallization. Nevertheless, the pattern of intercalated conglomerate and sandstone map units, together with sporadic top indicators, suggests that the Flanders Lake Formation is deformed in a major, northwest- to west-trending antiform that refolds earlier F_1 folds, consistent with the interpretation of Cerny et al. (1981). The polymictic Flanders Lake conglomerate contains a variety of volcanic, sedimentary and granitoid cobbles and sporadic boulders, some of which display pre-incorporation gneissosity (Figure GS-13-5).

A fluvial-alluvial sedimentary environment is suggested by the lithological types and depositional features within the Flanders Lake Formation. Posehn (1976), however, has interpreted this formation as a turbidite sequence subsequently reworked in a fluviatile environment. It is noteworthy that both fluvial and deeper water turbidite depositional environments are indicated for the San Antonio assemblage (possibly analogous

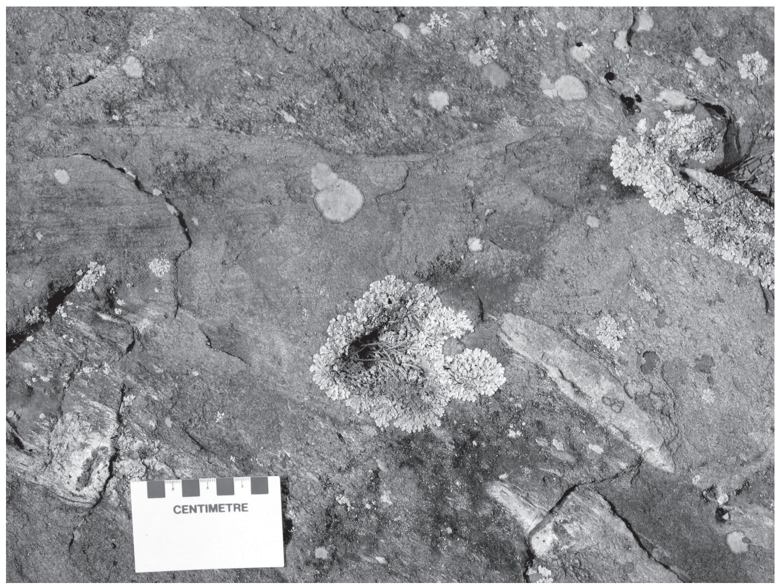


Figure GS-13-4: *Flanders Lake Formation. Fluvial sandstone displays S_0-S_2 discordance where a basal pebble-lag deposit has scoured the underlying, laminated arkosic wacke. Felsic granules, pebbles and sporadic cobbles are flattened parallel to the foliation.*

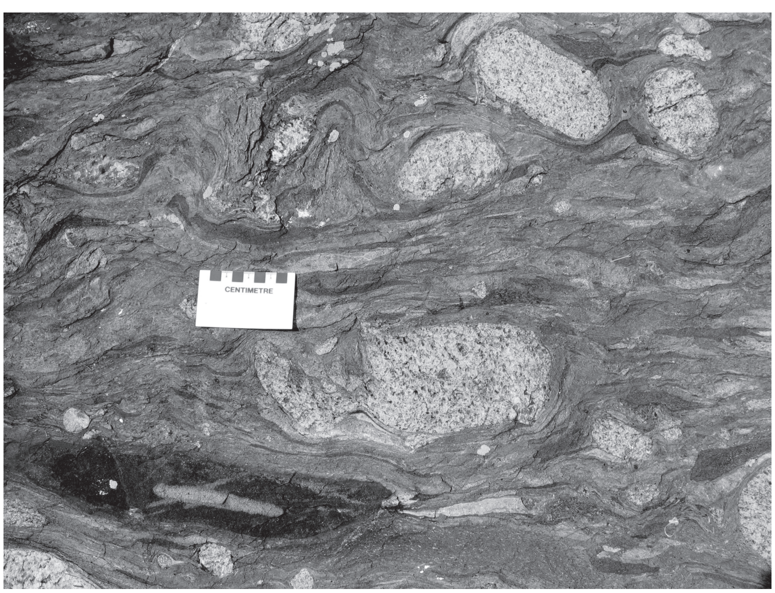


Figure GS-13-5: *Flanders Lake Formation. Polymictic conglomerate contains a variety of volcanic, sedimentary and tonalitic clasts. At lower left in the photograph, a mafic cobble displays an altered, epidotized core. Most mafic clasts are strongly flattened parallel to S_1 and deformed by F_2, with concomitant dextral rotation of the more resistant tonalitic clasts, which are massive to weakly foliated.*

stratigraphically to the Flanders Lake Formation), which occurs within the Rice Lake greenstone belt approximately 70 km northwest of Flanders Lake (Anderson, 2004). The San Antonio assemblage is predominantly a fluvial-alluvial sequence, but locally contains subordinate intercalations of greywacke-siltstone turbidite; the assemblage is a late Neoarchean (ca. 2.7 Ma) cover sequence that rests unconformably on the underlying volcanosedimentary sequence (Stockwell, 1938; Anderson, 2004). In the Bird River belt, the base of the Flanders Lake Formation is interpreted by the author as similarly unconformable with the underlying volcanic and sedimentary rocks, but the contact relationship has not been confirmed by field observations. At map scale, the Flanders Lake Formation displays an angular unconformable relationship with the Bernic Lake and Peterson Creek formations (Cerny et al., 1981).

Booster Lake Formation

The Booster Lake Formation in the eastern part of the Bird River belt is a greywacke-siltstone turbidite sequence that is deformed by major northwest- to west-trending folds of inferred D_1 age (Figure GS-13-6). Sedimentary structures that are characteristic of deposition by turbulent, sediment-laden currents provide

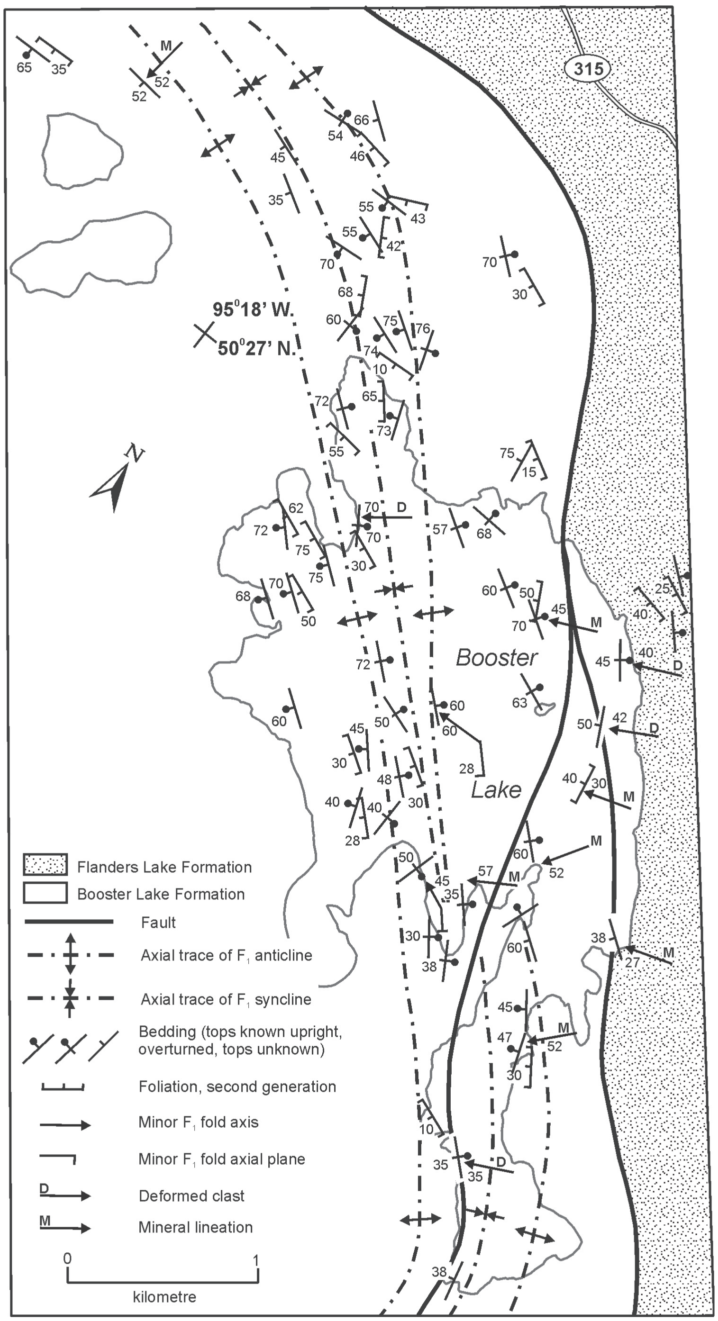


Figure GS-13-6: *Structural geology of the Booster Lake area.*

unequivocal stratigraphic-facing directions. The turbidites display cyclic ABD or ABCD Bouma (1962) sequences, characterized by a variety of features that include graded bedding, crossbedding, siltstone rip-ups, parallel lamination, synsedimentary folding, disrupted bedding and load structures such as flames and ball structures. (Figures GS-13-7, -8, -9). Calcareous concretions are rare, although these sedimentary rocks probably contain a calcareous component in the fine-grained matrix. The rocks have been subjected to regional, amphibolite-facies metamorphism and contain stratabound, subhedral to anhedral, ovoid blasts (typically 3–15 mm long) that were interpreted on outcrop as cordierite and/or andalusite (Figure GS-13-10). These porphyroblasts are locally associated with small (1–3 mm) red garnets and elsewhere with white (feldspathic?) blasts. The turbidite cycles are typically 0.2–0.6 m thick, although some graded cyclic units are only 8 cm thick (Figure GS-13-11). Sporadic, more thickly bedded (0.5–1.5 m) greywacke-siltstone deposits in the north part of Booster Lake are attributed to deposition in a more proximal part of the sedimentary basin.

Conglomerate units and sulphide-bearing iron formation are intercalated with fine-grained turbidites in the west part of the Booster Lake Formation (Cerny et al., 1981). These sedimentary deposits are interpreted as proximal relative to more distal rocks farther to the east (Cerny et al., 1981).

Structural geology

D_1 deformation

The earliest of four deformation events recognized in the east part of the Bird River belt (Table GS-13-2) resulted in northwest- to west-trending major folds (F_1) in the Booster Lake Formation (Figure GS-13-6). Minor

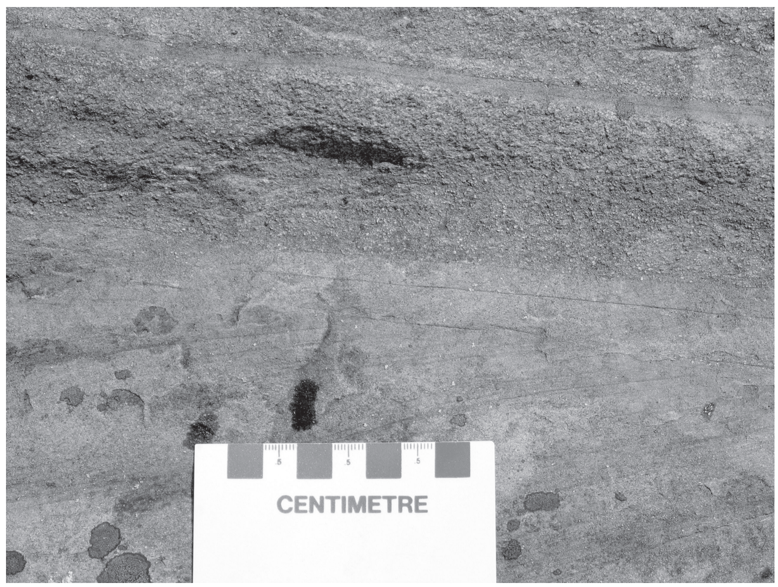


Figure GS-13-7: *Booster Lake Formation turbidite. Crossbedding in graded greywacke-siltstone sequence.*

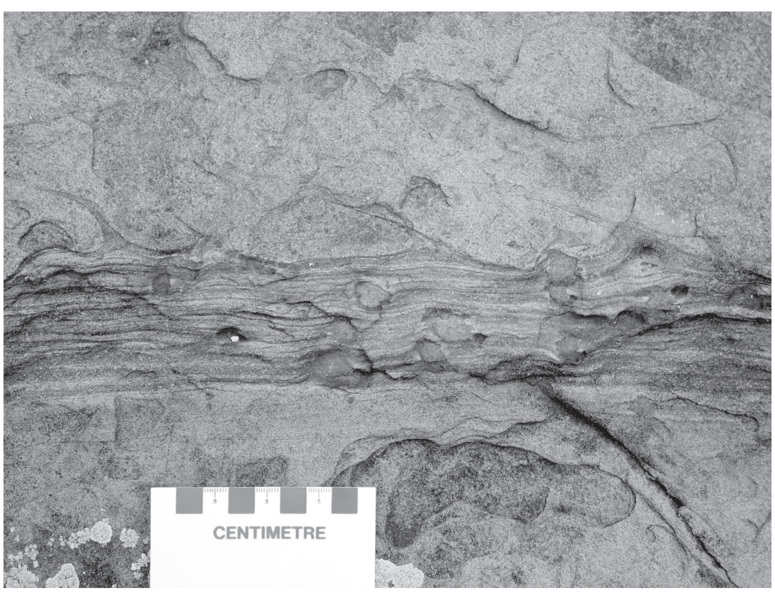


Figure GS-13-8: *Booster Lake Formation turbidite. The fine-grained sedimentary rocks display fine parallel lamination (Bouma division D) and flame structures at the graded base of the overlying turbidite unit.*

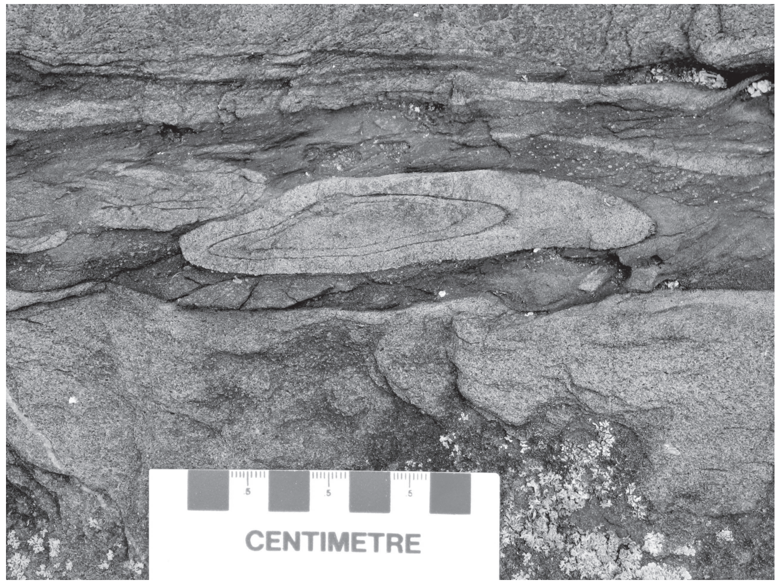


Figure GS-13-9: *Booster Lake Formation turbidite. The ovoid arenaceous body within dark grey siltstone is interpreted as a 'ball structure' that was detached from the overlying greywacke bed, due to loading and soft-sediment deformation of the unconsolidated sedimentary deposits. Concentric fine laminae are attributed to synsedimentary folding during detachment.*

Figure GS-13-10: *Booster Lake Formation turbidite. The thin siltstone bed within a graded greywacke section contains andalusite (?) porphyroblasts that were subsequently deformed and show a dextral sense of rotation. The S_2 foliation, discordant to S_0, is confined to the siltstone unit.*

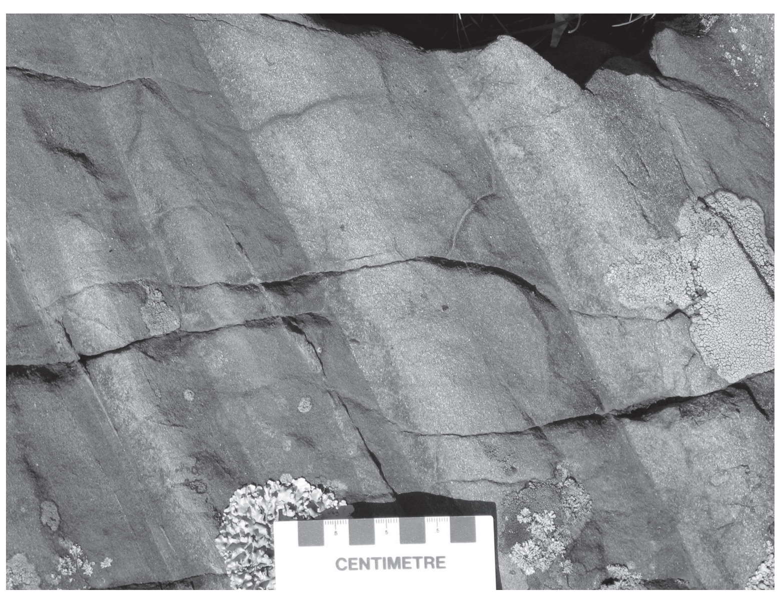


Figure GS-13-11: *Booster Lake Formation turbidite. Graded bedding in thin (8–10 cm) cyclic units.*

Table GS-13-2: Deformation history in the east part of the Bird River belt.

Deformation event	Structural features	Tectonic fabric elements
D_4	Brittle fracturing and faulting, generally at high angles to the regional S_0-S_1 trends	Local brecciation or schistosity spatially related to D_4 faults
D_3	Regional open fold with northeast-trending hinge line	No discernible fabric elements at outcrop scale
D_2	Major folds with moderate to tight closure plunge southwest at 30–45°	S_2 foliation is subhorizontal or with moderate south to southwest dip (av. 42º). L_2 stretching lineations parallel minor parasitic F_2 folds
D_1	Isoclinal folds plunge west with axial planes dipping moderately southwest	S_1 regional foliation parallel to S_0 except at F_1 fold closures

folds associated with the D_1 event are rare; at one locality in north-central Booster Lake, an isoclinal F_1 minor fold plunges 60° west, with the axial plane dipping southwest at 35° (Figure GS-13-12, -13). Regional S_1 foliation is coincident with S_0.

D_2 deformation

A second deformation event is documented by S_2 micaceous foliation that is common within turbiditic sedimentary rocks at Booster Lake and dips south or southwest at very shallow to moderate angles. The S_2 foliation intersects bedding (S_0) obliquely (average S_0 = 134°/56°; average S_2 = 124°/42°; Figure GS-13-13c). In most cases, the S_0-S_2 angular relationship is characterized by a (numerically) lower bearing for the strike of the foliation (i.e., S_2 is oriented counter-clockwise relative to the strike of the bedding; Figure GS-13-14). The opposite relationship exists in approximately one-quarter of the observations that were made. Variation of the S_0-S_2 angular relationship is not systematic relative to the F_1 fold pattern at Booster Lake, showing that the discordant S_2 foliation postdates the F_1 structure.

Figure GS-13-12: Booster Lake Formation turbidite. F_1 fold in the north-central part of Booster Lake. A pale-weathering arenaceous unit outlines the early isoclinal fold, the core of which contains porphyroblastic siltstone.

The S_2 foliation is assumed to be related to the major antiform immediately east of Booster Lake, the hinge line of which extends northwest to west through the Flanders Lake Formation. (Figure GS-13-15). This antiform is delineated by folded conglomeratic units within the Flanders Lake arkosic sandstone terrane (Cerny et al., 1981) and is interpreted as an F_2 fold because it deforms both the bedding (S_0) and the S_1 foliation. Plots of bedding and S_1 foliation on both limbs of the F_2 antiform indicate that the fold axis plunges approximately 238°/32° (Figure GS-13-16) and the axial plane dips southwest at approximately 45º. On the map of Cerny et al. (1981), the major F_2 fold deforms F_1 axial planes, a considerable number of which are indicated in the east part of the Bird River belt. Although there are insufficient field data from this study to substantiate the detailed pattern of F_1 folds shown in the map of Cerny et al. (1981), the present investigation has validated local details of this pattern, for example in the area south of Stalker Lake (Figure GS-13-15).

Polymictic conglomerate of the Flanders Lake Formation is characterized by variously deformed clasts, some of which were strongly attenuated during D_1 and subsequently crenulated or rotated by D_2 deformation (Figure GS-13-5, -17). Stretching lineation (mineral lineations and deformed clasts in conglomerate) is widely developed in the Booster Lake turbidite deposits and Flanders Lake fluvial sedimentary rocks (Figure GS-13-18). At Booster Lake, the lineation plunges southwest at 30–70° (average 49°) and is consistent with the direction of extensional strain inferred during both D_1 and D_2 deformation events. The lineation is attributed to D_2 deformation because the plunge varies consistently with the attitude of S_2 foliation and, furthermore, the stretching

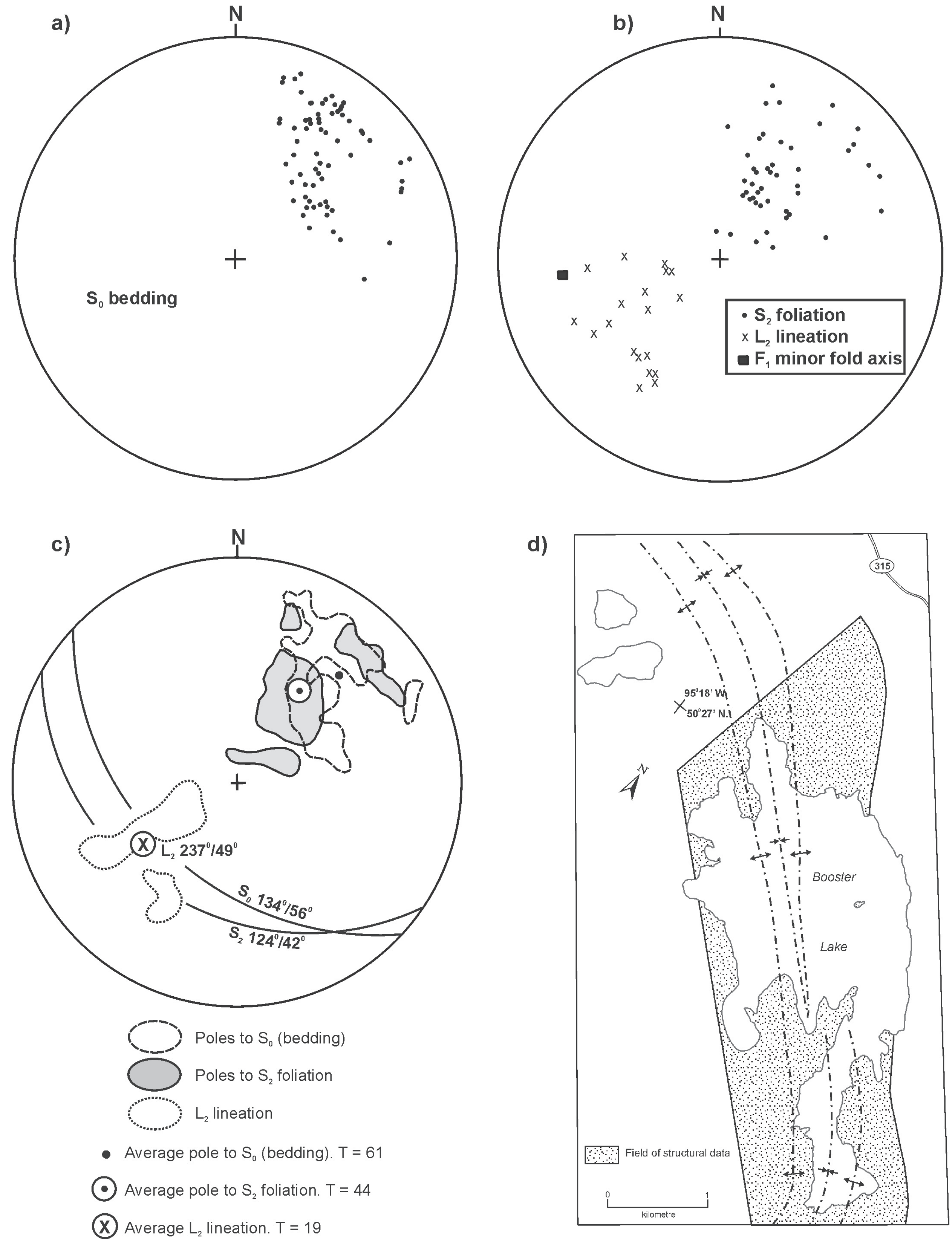


Figure GS-13-13: *Lower hemisphere stereographic plots of structural data in the Booster Lake area:* ***a)*** *poles to bedding (S_0);* ***b)*** *poles to S_2 foliation, L_2 lineation and F_1 minor fold axis;* ***c)*** *average poles to bedding and S_2 foliation and L_2 lineation; and* ***d)*** *field of structural data at Booster Lake.*

Figure GS-13-14: *Booster Lake Formation turbidite. Porphyroblastic silty horizons within graded greywacke display S_0-S_2 discordance. The strike of S_2 is oriented ‘counter-clockwise’ relative to S_0. Another metamorphic fabric, which is well preserved within the feldspathic greywacke and is interpreted as S_1, is oriented ‘clockwise’ relative to S_0. One interpretation of these fabrics is that the earlier S_1 fabric is overprinted by S_2, but only within the siltstone layers.*

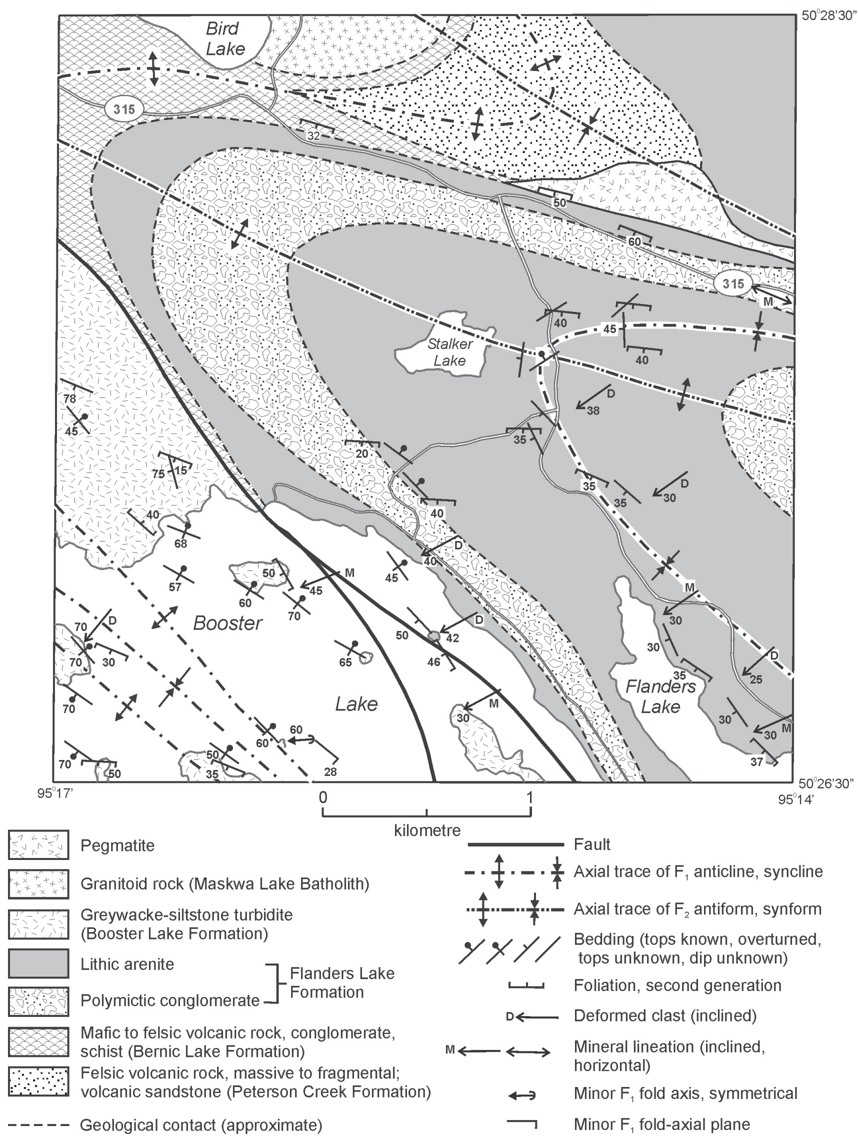


Figure GS-13-15: *Stratigraphic and structural details in the vicinity of Stalker Lake, showing the geological formations and fold axial traces mapped by Cerny et al. (1981).*

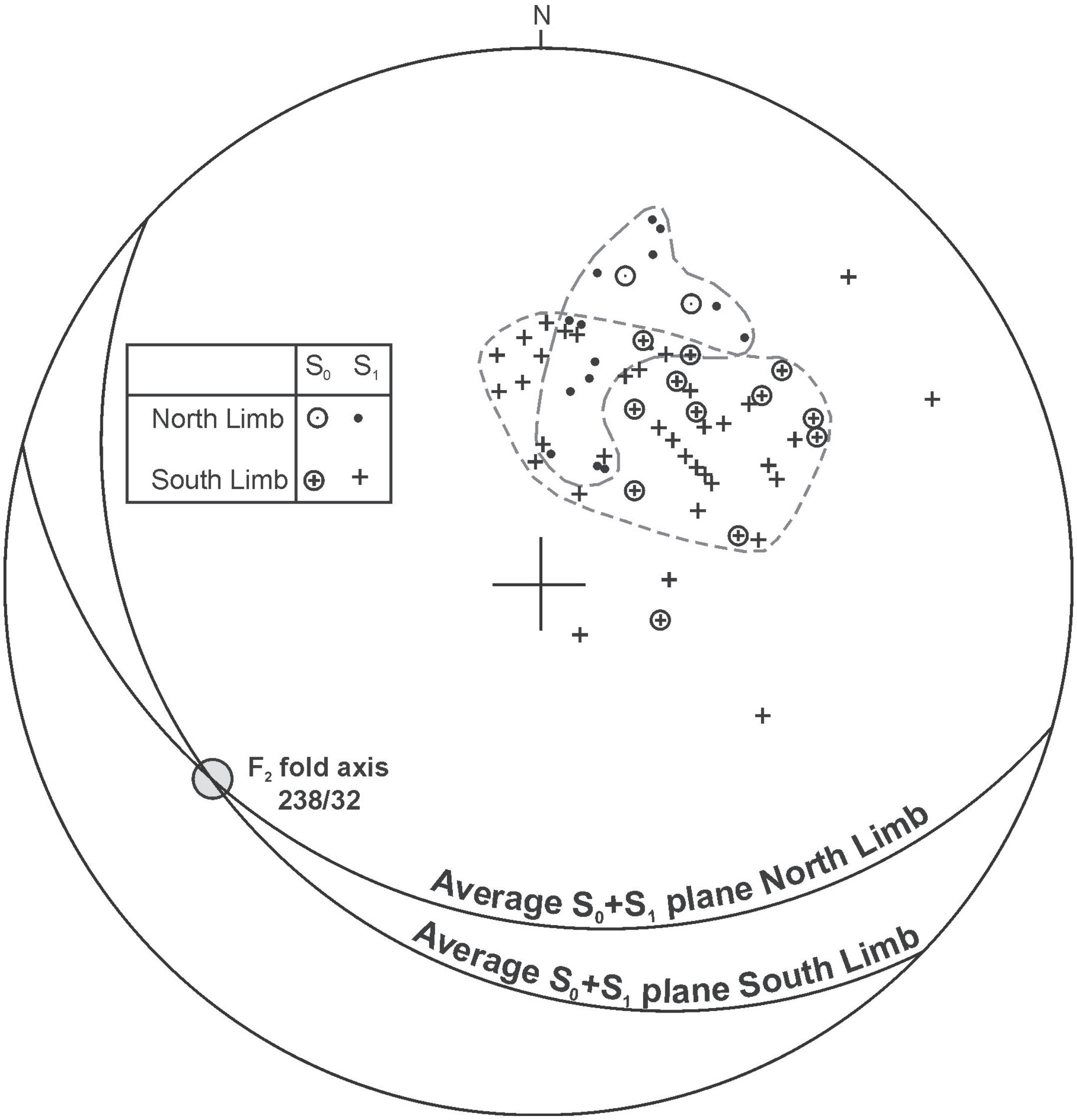


Figure GS-13-16: *Lower hemisphere stereographic plot of bedding, foliation and the F_2 major fold axis in the area east of Booster Lake.*

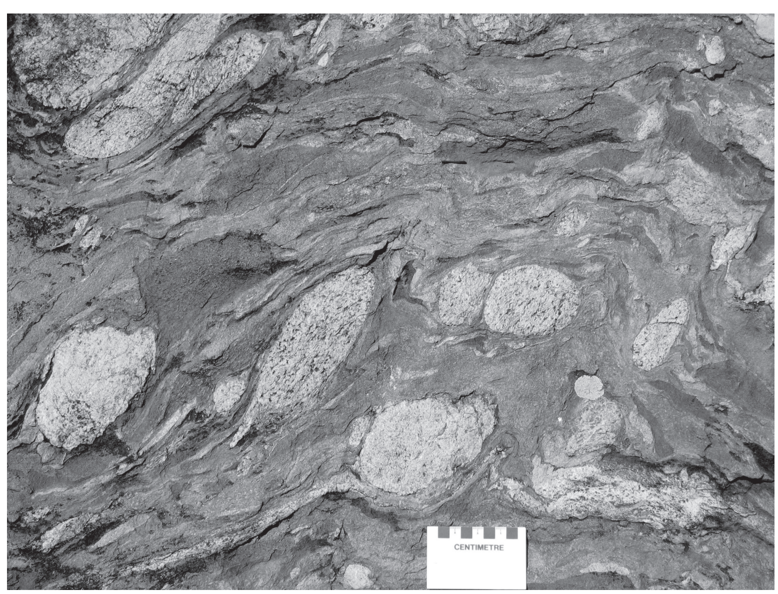


Figure GS-13-17: *Flanders Lake Formation. Polymictic conglomerate displays D_2 deformation effects. Mafic clasts, flattened by D_1, have been crenulated by D_2. Ovoid tonalite cobbles, which are less strongly deformed, are aligned parallel to the axial planes of F_2 folds.*

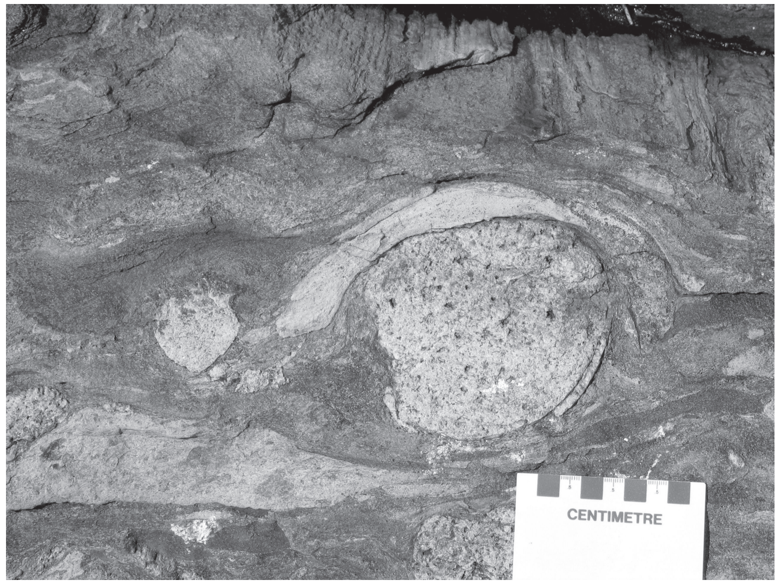


***Figure GS-13-18:** Flanders Lake Formation. Polymictic conglomerate contains a rotated, spheroidal tonalitic cobble, partly enveloped by a flattened felsitic fragment. At the top of the photograph, conspicuous L_2 lineation occurs at the margin of a fluvial sandstone lens within the conglomerate deposit.*

lineation does not appear to be scattered by subsequent folding and is thus unlikely to predate D_2.

Porphyroblasts in the Booster Lake Formation (interpreted as cordierite and/or andalusite) are typically anhedral to subhedral and stratabound, parallel to the bedding. At some localities, the blastic minerals are oriented parallel to S_2 or elongate parallel to the L_2 stretching lineation, consistent with the inferred M_2 age for the amphibolite-facies metamorphism that produced the porphyroblasts. Localized rotation of the porphyroblasts, interpreted as a result of D_2 deformation, invariably indicates a dextral sense of movement (Figure GS-13-10). A dextral kinematic direction is also shown by rotated cobbles in the Flanders Lake Formation conglomerate (Figure GS-13-5) and is consistent with the strain that would be anticipated within the S_0-S_1 plane in rocks on the southwest limb of the major F_2 antiform.

D_3 deformation

A third deformation event (D_3) resulted in a northeast-trending open fold that deformed the Booster Lake Formation and axial traces of the major F_1 folds. The hinge line of the F_3 fold is located in the area immediately northwest of Booster Lake (Figure GS-13-6). Interference patterns of minor folds in fine-grained metasedimentary rocks east of Bird Lake are attributed to both the D_2 and D_3 deformational events (Figure GS-13-19).

D_4 deformation

Localized brittle deformation that resulted in fractures and faults at high angles to earlier D_1 and D_2 structural trends is attributed to a final D_4 event. Coarse-grained tonalite and pegmatite dikes are locally emplaced along fractures of inferred D_4 age. In the area west of Bird Lake, north-northwest- to northwest-trending late faults that dissect the Bird River Sill are characterized by displacements of tens to several hundreds of metres (Trueman, 1971).

Economic considerations

The Bird River belt mapping project was initiated, in part, in response to the present high level of exploration activity in the Bird River area. Exploration drilling was carried out this summer by North American Palladium Ltd. on the Bird River Sill; in addition, Mustang Minerals Corp. conducted drilling to test airborne electromagnetic anomalies at the Mayville property north of Maskwa Lake (Figure GS-13-2), and helicopter-borne geophysical surveys were carried out in the area. In support of the ongoing exploration, the investigations by the author in 2005 highlighted the need for a reevaluation of the most recently published geological maps (Cerny et al., 1981), as well as remapping of parts of the Bird River belt at a scale of 1:20 000. This mapping will include an investigation of the possible extension of the mafic-ultramafic Bird River Sill in the area immediately west of the currently known, exposed part of the intrusion, and may yield new targets for Ni-Cu and PGE exploration. New mapping is also expected to further elucidate the deformation history and possibly constrain the timing of economically important pegmatite intrusions. The mapping will also provide the geochemical database needed to reassess the economic potential for volcanogenic massive sulphide mineralization in the juvenile-arc and (inferred) rifted-arc components that make up the Bird River greenstone belt.

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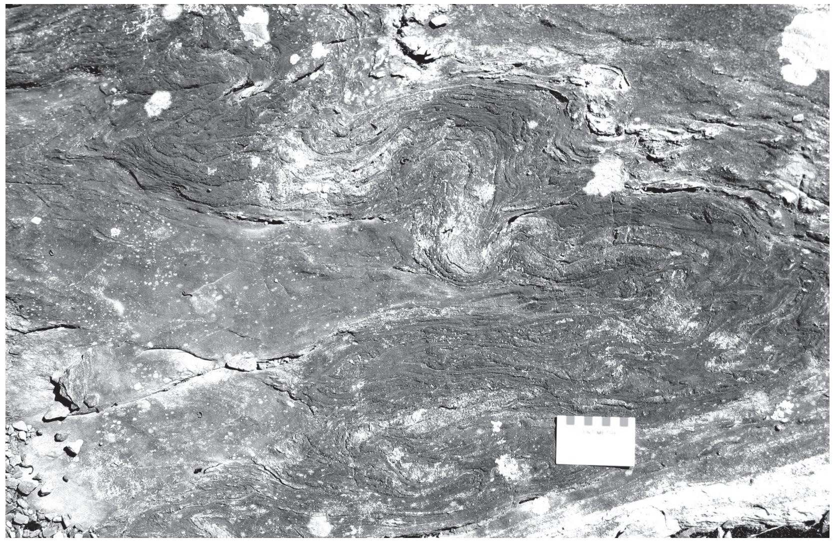

Figure GS-13-19: *Flanders Lake Formation. Fold-interference pattern in laminated metasedimentary rocks. The fine lamination, attributed to S_0 and parallel S_1, is deformed by isoclinal F_2 folds (axial planes roughly parallel to the scale card) and later, more open D_3 folds.*

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