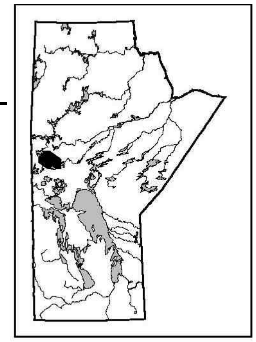
GS-3 JOSLAND LAKE SILLS: U-PB AGE AND TECTONOSTRATIGRAPHIC IMPLICATIONS (PARTS OF NTS 63K AND 63N)

by H.V. Zwanzig, A.H. Bailes and Ch.O. Böhm[1]



Zwanzig, H.V., Bailes, A.H. and Böhm, Ch.O. 2001: Josland Lake sills: U-PB age and tectonostratigraphic implications (parts of NTS 63K and 63N); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 28-32.

SUMMARY

The age, geochemistry and field relationships of the mafic, layered Josland Lake sills require a re-evaluation of the tectonic history of the Flin Flon Belt and adjacent parts of the Kisseynew Domain. A sample of quartz diorite from the upper, Fe-rich portion of a differentiated mafic sill northwest of Reed Lake has yielded a U-Pb zircon age of 1886 ± 3 Ma (95% confidence level, MSWD = 0.68) that is interpreted to be the age of crystallization of the sill. The sill, 24 km long and up to 2 km thick, belongs to the suite of Josland Lake sills. These sills have a unique geochemical fingerprint throughout their 100 km regional extent from Snow Lake and Reed Lake, in the Flin Flon Belt, to Kississing Lake, on the south flank of the Kisseynew Domain. They are interpreted to represent a major igneous province, which includes the 1881 +3/-2 Ma Mikanagan Lake sills in the Flin Flon area that formed at the close of early juvenile-arc volcanism, before the pre-1876 Ma tectonic amalgamation into the Amisk collage. The trace-element geochemistry of the sills and their common occurrence in early volcaniclastic basin fill suggest that they are a product of arc rifting. Elevated platinum-group elements (PGEs) and gold deposits in the sills make them a mineral-exploration target. Because the sills intrude the Amisk collage, the Reed Lake ocean-floor assemblage and the Snow Lake arc assemblage, these various host rocks may have been part of a composite arc and back-arc terrane that separated into segments during the 1881 to 1886 Ma rifting. Structural slices of ca. 1.85 Ga metaturbidite, extending from Reed Lake into the Kisseynew Domain along volcanic arc- and back-arc–assemblage boundaries, suggest that the composite terrane was reassembled during the continental collision tectonics that involved closing of the Kisseynew basin and deformation of the 1.85 Ga turbidite.

INTRODUCTION

Large, mafic, layered sills that intrude early arc and back-arc assemblages are concentrated in several areas in the Flin Flon Belt and along the south flank of the Kisseynew Domain (Fig. GS-3-1). They include the Mikanagan Lake sills, northeast of Flin Flon (Bailes and Syme, 1989), and the Josland Lake sills (Bailes, 1980), extending from Reed Lake north and northwest to Kississing Lake (Zwanzig, 1994). The distinctive high iron contents in the upper portions of both sets of sills (some with more than 20%, expressed as Fe_2O_3) and the high albite content and Fe/Mg ratios of their most felsic differentiates suggest that these extensive sills are correlative (Zwanzig, 1994).

Validation of the correlation of the Josland Lake and Mikanagan Lake sills requires them to have a similar age of crystallization. Only one sill (Mikanagan Lake sill) has previously yielded a precision U-Pb zircon age of 1881 +3/-2 Ma (Stern et al., 1999). An attempt to date zircon in the Josland Lake sills has yielded only a poorly constrained minimum age of ca. 1855 Ma (K. Ansdell, pers. comm., 2001; Connors, 1996). In this contribution, we report a new precision U-Pb zircon age from the largest Josland Lake sill northwest of Reed Lake, and discuss its regional stratigraphic and tectonic implications. Above-background values of PGEs (Peck et al., 2000) and the presence of two subeconomic gold deposits in the sills (Zwanzig, 1994) make these sills a potentially important mineral-exploration target.

GEOLOGY OF SILLS AND HOST ROCKS

The Josland Lake sills extend along a series of structural breaks from Reed Lake to Kississing Lake. They straddle the tectonic boundary between early juvenile volcanic assemblages of the Amisk collage and the coeval volcanic rocks to the east and north that, unlike the Amisk collage, are structurally interleaved with younger greywacke turbidite (Burntwood Group). The sills intrude three different volcanic assemblages: the Fourmile Island arc assemblage (part of the Amisk collage), the Northeast Reed ocean-floor assemblage and the Snow Lake arc assemblage (Fig. GS-3-1; Syme et al., 1995; Syme and Bailes, 1996). Fault slices of the Burntwood Group occupy the contacts between these volcanic assemblages. Although abundant near the fault contacts, Josland Lake sills do not intrude the Burntwood Group. The sills and their host assemblages are best preserved between Reed Lake and File Lake, an area where metamorphic grade ranges from middle greenschist facies to middle amphibolite facies and where the rocks are cut into northeast- to northwest-trending fault blocks and deformed into large upright folds (Bailes, 1980). Highly metamorphosed equivalents of the sills extend northwest to Kisseynew and Kississing lakes for a strike length of 100 km (Zwanzig, 1994, 1996). The higher grade sills are strongly foliated and attenuated, and were refolded by recumbent to upright structures during multistage continental collision (Zwanzig, 1999).

Field relationships north of Reed Lake indicate that the Josland Lake sills are early orogenic intrusions. The various sills show complex pre- and postkinematic relations to the earliest deformation of their volcanic host rocks (Bailes, 1980). Some sills postdate at least part of the early deformation in the area, and one of these was sampled for the U-Pb geochronology.

[1] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3

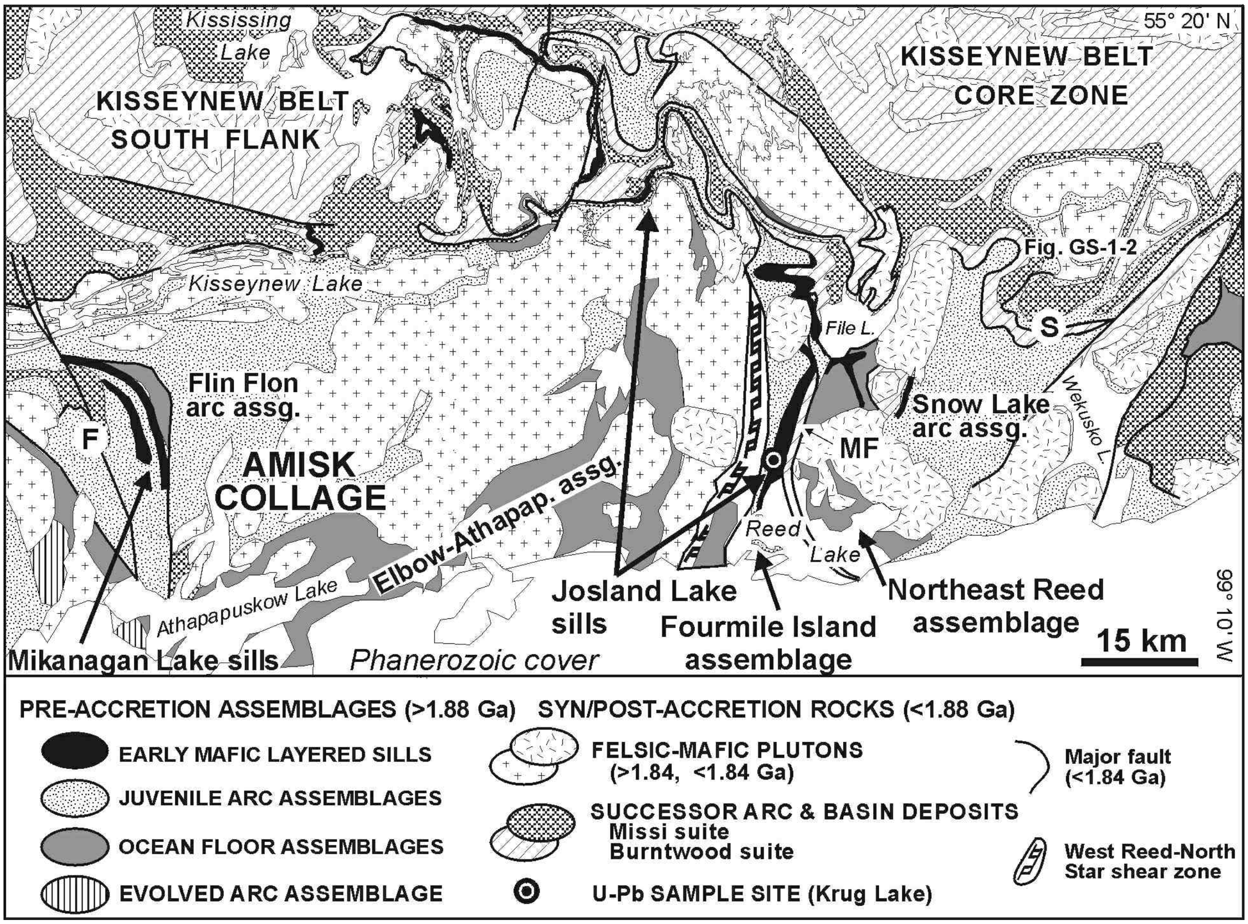


Figure GS-3-1: Simplified geology of the Flin Flon Belt and the south flank of the Kisseynew Domain, showing the tectonic assemblages mentioned in the text and the locations of major Josland Lake sills, the Mikanagan Lake sills and the sampling site for the U-Pb age.

Despite the range in metamorphic grade and structural style of the various Josland Lake sills, their composition, layering and intrusive habit are similar and closely resemble that of the Mikanagan Lake sills (Bailes and Syme, 1989). The best preserved Josland Lake sills are layered differentiated bodies that average 500 to 700 m in thickness (Bailes, 1980). They have a lower zone of leucogabbro and melagabbro, a central zone of ferrogabbro and an upper zone of granophyric quartz diorite to albite tonalite, typically in proportions of 5:3:2. The upper amphibolite-facies equivalents of the sills in the Kisseynew Domain have the same zoning as in the Flin Flon Belt but range from 150 m to only a few metres in thickness.

Gabbro zones in the sills have sharp lower contacts and chilled margins. Weak rhythmic modal layering (particularly near the top of the gabbro zones) and cumulate textures are present (Bailes, 1980). Original minerals (generally present as pseudomorphs) were augite, labradorite and ilmenite. Gabbro norite was noted in the more completely studied Mikanagan Lake sills (Bailes and Syme, 1989) and is probably also abundant but not recognized in the Josland Lake sills. In the Kisseynew Domain, gabbro is recrystallized to medium-grained amphibolite with platy and fibrous amphibole, diopside and lesser plagioclase. Sills in high-grade metamorphic areas rarely show rhythmic layering, but their lowermost division is melagabbro, containing only minor amounts of plagioclase.

Ferrogabbro zones weather black at all metamorphic grades where primary pyroxene is replaced by secondary amphibole. The base of the ferrogabbro zone, which is gradational over a few metres with the gabbro zone, shows strong rhythmic layering in the low-grade metamorphic areas, but ferrogabbro is generally uniform in the Kisseynew Domain, with scattered garnet porphyroblasts 1 to 2 mm in diameter. The upper part of the ferrogabbro in the high-grade metamorphic domain has centimetre-scale modal layering of garnet (<30%) and magnetite, and has been mistaken locally for iron-formation (Zwanzig and Schledewitz, 1992).

Granophyre zones in the Josland Lake sills grade over a short distance from ferrogabbro to quartz diorite (<40% mafic minerals) and upward to tonalite that is rich in albite (<5% mafic minerals). Some upper contacts show signs of roof-zone contamination, but thinner sills have chilled upper margins. Granophyric intergrowth between sodic plagioclase and quartz is preserved only in the lower grade rocks. Radiating clusters of metamorphic fibrous amphibole in the medium-grade rocks (Bailes, 1980) occur as a mottled gneissic texture in the Kisseynew Domain. Pale pink-weathering albite is abundant in this felsic gneiss.

GEOCHEMISTRY

The various Josland Lake sills have a single, distinctive set of geochemical characteristics similar to the Mikanagan Lake sills (Bailes and Syme, 1989). All sills show extreme iron enrichment in the ferrogabbro, quartz diorite and ferrotonalite zones (Bailes, 1980; Zwanzig and Bailes, work in progress, 2001) The major- and minor-element geochemistry of the Josland Lake and Mikanagan Lake sills is unique within the Flin Flon Belt and Kisseynew Domain, and strongly suggests that all these sills are related and were emplaced in a single tectonic environment.

Chilled gabbro falls into the field of enriched mid-ocean ridge basalt (E-MORB) on Th/Nb/Zr and Th/Yb vs. Nb/Yb diagrams (unpublished data, not shown). Extended element plots (N-MORB normalized) of chilled gabbro from various sills do not display the negative high-field-strength element (HFSE) anomalies that would be typical for arc volcanic rocks (Fig. GS-3-2a). The plots have a relatively smooth negative slope, with somewhat elevated light rare-earth elements (LREE) and Nb, similar to E-MORB. This characteristic and the slightly elevated Th are also typical of contaminated MORB and arc-rift basalt from the Flin Flon area (Fig. GS-3-2a), and are consistent with the local melting in the roof zone noted by Bailes (1980).

A systematic increase of incompatible elements in the upper zones of one typical sill is apparent in extended element plots (Fig. GS-3-2b). However, TiO_2 was contained in at least one crystallizing mineral phase; it is concentrated in the ferrogabbro and depleted in the overlying Na-tonalite, probably through crystal settling of ilmenite.

SAMPLING AND GEOCHRONOLOGY

The geochronology sample is from the ‘type’ Josland Lake sill, which extends from the northwest shore of Reed Lake for 24 km to the north-northeast (Fig. GS-3-1). Samples from the upper, more fractionated leucotonalite did not provide zircon for dating the Josland Lake sill (T. Gordon, pers. comm., 1989) or yielded only a 1881 ± 4 Ma titanite age for the Mikanagan Lake sill (Stern et al., 1999). The sample in this study was taken across a strike interval of 20 m lower in the sill, near the base of the quartz diorite to ferrotonalite zone east of Krug Lake (6060625N, 400234E, UTM zone 14, NAD 27). The quartz diorite at this locality consists of 2 to 4% remnant blocky clinopyroxene (overprinted by 15% ferroactinolite); 20% elongate, 3 to 15 mm amphibole phenocrysts (replaced by actinolite); 50% blocky, 1 to 3 mm, twinned sodic plagioclase (partly altered to sericite and carbonate); 10% equant, 0.5 to 1 mm quartz grains; 5% micrographic intergrowth of quartz and plagioclase; and 1 to 3% magnetite (partly altered to leucoxene).

Approximately 30 kg of Josland Lake quartz diorite (sample 07-2000-1727-1-2) were processed for U-Pb dating at the University of Alberta Radiogenic Isotope Facility in Edmonton. After crushing and Bico disc milling, heavy minerals were separated by standard procedures using a Wilfley table, methylene iodide heavy liquid and a Frantz magnetic separator. The applied U-Pb analytical methods are described in Böhm et al. (1999).

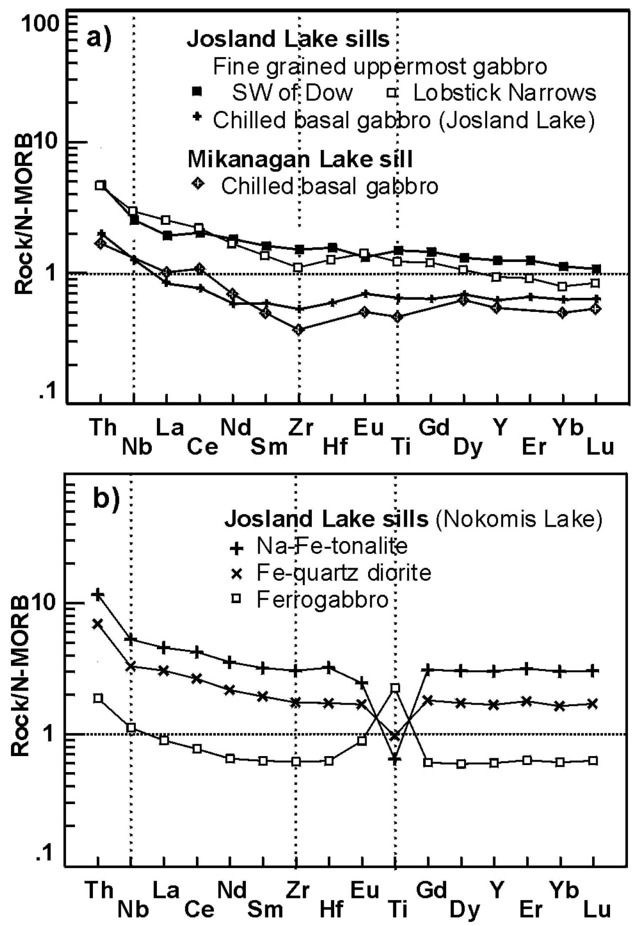


Figure GS-3-2: Extended element plots (N-MORB normalized) of a) chilled gabbro samples of the Josland Lake sills and Mikanagan Lake sill; and b) successive zones of the Josland Lake sill on Nokomis Lake, south flank of the Kisseynew Domain.

The quartz diorite sample yielded less than a dozen zircon grains in the nonmagnetic mineral separate (1.8 A), including few larger, partly resorbed crystals that contain abundant inclusions and may indicate an inherited component. After careful inspection of more magnetic fractions, however, abundant zircon (>50 grains) was recovered from the 1.0 and 0.8 A mineral separates. This more magnetic zircon generally consists of colourless to light brown prisms and fragments of poor quality. In order to minimize multiple age components, portions containing fractures, inclusions and alteration were broken off individual zircon crystals and removed. Relatively homogenous and clean zircon fragments were subsequently air abraded. Three analyses of such single-zircon fragments yielded moderate uranium contents (613–1266 ppm) and high Th/U rations (1.8–2.8), which is typical of zircon crystallizing from a mafic magma. The three U-Pb zircon analyses have similar $^{207}Pb/^{206}Pb$ ages, ranging from 1872 to 1883 Ma; a best-fit regression line defines an upper intercept age of 1886 ± 3 Ma (95% confidence level, MSWD = 0.68; Fig. GS-3-3).

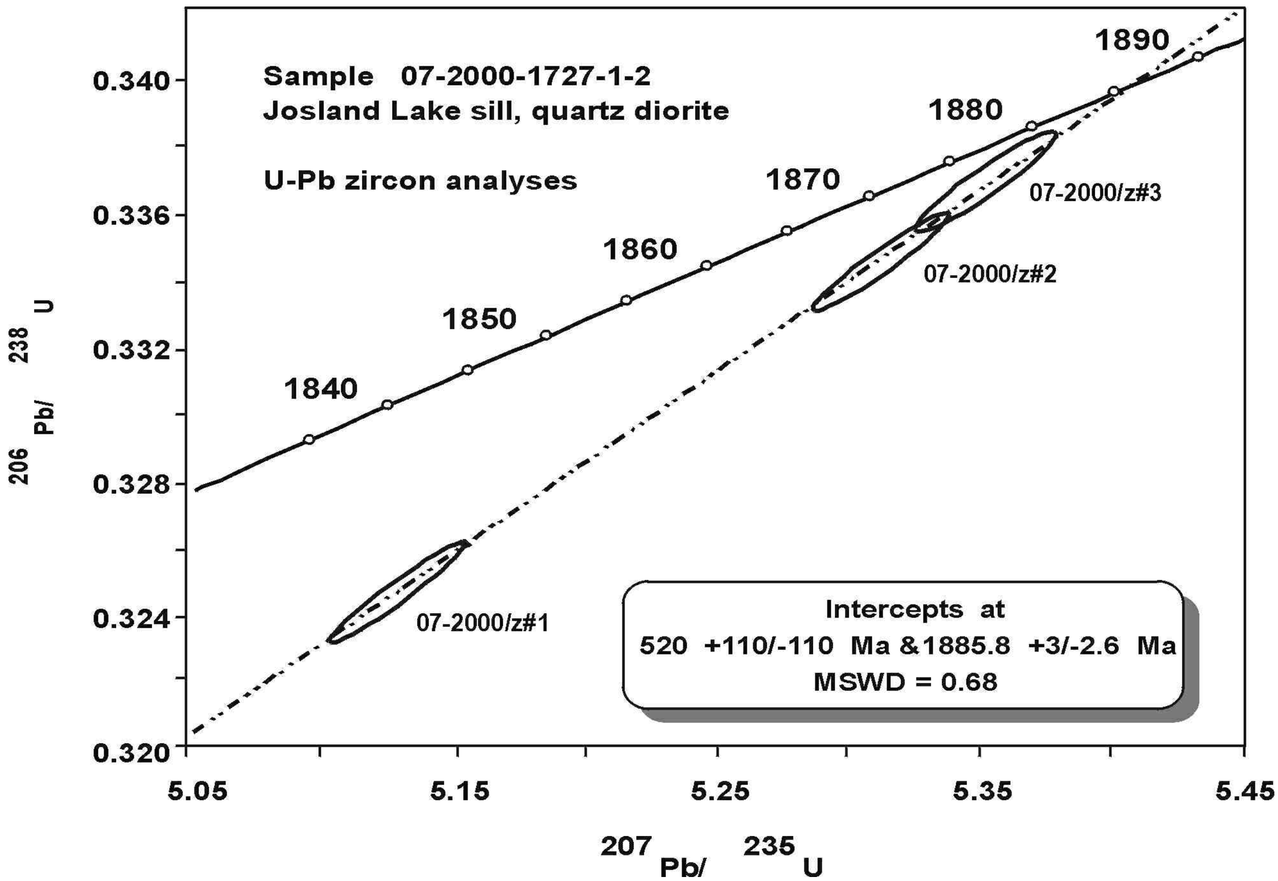


Figure GS-3-3: Concordia diagram of U-Pb zircon isotopic analyses from quartz diorite zone of layered gabbro sill (Josland Lake sill). Analytical uncertainty is 2s standard error.

IMPLICATIONS

The new U-Pb zircon age from Fe-rich quartz diorite in the type Josland Lake sill northwest of Reed Lake is interpreted to represent the age of crystallization of the sill. This sill belongs to the group that cuts other previously folded Josland Lake–like sills (Bailes, 1980) and therefore provides a minimum age for the latter. The close petrographic and geochemical similarity of the entire suite of Josland Lake sills and the similar age of the Mikanagan Lake sills provide evidence that the intrusions represent a single 1881 to 1886 Ma magmatic province that encompasses parts of the Flin Flon Belt and the south flank of the Kisseynew Domain.

The various Josland Lake–type sills intrude a variety of adjoining tectonic assemblages in the Flin Flon–Snow Lake–Kississing Lake region. The correlation of these sills suggests that, during the 1886 Ma magmatism, this region was part of a single composite terrane that included the Amisk collage. The sills are concentrated along the north and east margins of the Amisk collage, particularly in the upper sedimentary formation in the Fourmile Island assemblage (Yakymiw Formation of Bailes, 1980). They also occur in the upper sedimentary formation in the Snow Lake arc assemblage (Parisian Formation of Bailes, 1980), as well as in the intervening Northeast Reed ocean-floor assemblage. Similarly, the Mikanagan Lake sills intrude the upper part of a thick arc-rift volcanic succession (Bailes and Syme, 1989; Syme et al., 1999). Thus, the episode of sill intrusion represents an end stage in the early volcanism in the Flin Flon–Snow Lake region, during a period of basin development and basin-fill sedimentation. The similarity of the geochemistry of the chilled magma to that of E-MORB or arc-rift basalt suggests that the sill intrusion and sedimentation are the result of arc rifting. We conclude that this was a widespread event throughout the Flin Flon Belt and at least in parts of the Kisseynew Domain.

Early folds that deformed some Josland Lake sills were intruded along their axial planes by relatively young Josland Lake sills, including the one described herein and dated at 1886 Ma. This critical field relationship demonstrates that the folding overlapped the 1886 Ma episode of magmatism. All the sills were originally emplaced as horizontal sheets that became strongly differentiated and layered. Thus, the sills that occupy axial planes demonstrate that the folds were recumbent at the time of intrusion. This recumbent folding represents the earliest deformation documented to date in the Flin Flon Belt. We speculate that the recumbent structures and coeval sills may have been related to extensional collapse with vertical shortening of parts of the Glennie–Flin Flon Complex during the development of an arc-rift basin. Local recumbent folding has been reported from the margin of other extensional basins (Sharp et al., 2000).

The tectonic juxtaposition of various arc and back-arc assemblages with the Burntwood Group turbidite in the Reed Lake area has led to a model of renewed terrane accretion after 1.85 Ga turbidite sedimentation (Syme et al., 1995). This event represents an early stage of the protracted continental collision tectonics that affected the area (Zwanzig, 1999). The tectonic model suggests that an ocean basin, which existed between Flin Flon and Snow Lake, was closed during the renewed accretion. The proposed arc rifting, accompanied by intrusion of Josland Lake sills, at 1886 Ma may have led to the opening of this early basin. The continuity of the structural slices of the Burntwood Group, the Josland Lake sills and their host volcanic assemblages, from Reed Lake into the Kisseynew Domain, suggests that the proposed arc-rift basin was part of an ancestral Kisseynew basin (an ocean of unknown size and shape). The basin probably closed during late successor-arc magmatism and the coeval deposition of the Burntwood and Missi groups, 40 m.y. after the initial rifting, and thus incorporated the younger sedimentary rocks into the expanding tectonic collage.

In light of the elevated PGE content of some of the sills (Peck et al., 2000), and the presence of gold deposits and showings in the felsic differentiate above the ferrogabbro (Zwanzig 1994; Zwanzig and Schledewitz, 1992), the proposed episode of widespread arc rifting ca. 1881 to 1886 Ma is important in understanding the distribution of precious metals in the region. Volcanic massive sulphide (VMS) deposits may have formed in the earliest stage of the arc rifting (Zwanzig and Bailes, work in progress, 2001), similar to other VMS deposits in the Flin Flon Belt that are associated with intra-arc extension (Syme et al., 1999).

REFERENCES

Bailes, A.H. 1980: Geology of the File Lake area; Manitoba Department of Energy and Mines, Mineral Resources Division, Geological Report 78-1, 134 p. plus 1 map at 1:25 000 scale.

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon–White Lake area; Manitoba Energy and Mines, Geological Services, Geological Report 87-1, 313 p. plus 2 maps at 1:20 000 scale.

Böhm, Ch.O., Heaman, L.M. and Corkery, M.T. 1999: Archean tectonic evolution of the northwestern Superior craton margin: U-Pb zircon results from the Split Lake Block; Canadian Journal of Earth Sciences, v. 36, p. 1973–1987.

Connors, K.A. 1996: Unraveling the boundary between turbidites of the Kisseynew Belt and volcano-plutonic rocks of the Flin Flon Belt, Trans-Hudson Orogen, Canada; Canadian Journal of Earth Sciences, v. 33, p. 811–829.

Peck, D.C., Theyer, P., Hulbert, L., Xiong, J., Fedikow, M.A.F. and Cameron, H.D.M. 2000: Preliminary exploration database for platinum-group elements in Manitoba; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2000-5, 1 CD-ROM.

Sharp, I.R., Gawthorp, R.L, Underhill, J.R. and Gupta, S. 2000. Fault-propagation folding in extensional settings: examples of structural style and synrift sedimentary response from Suez rift, Sinai, Egypt; Geological Society of America Bulletin, v. 112, p. 1877–1899.

Stern, R.A., Machado, N.D., Syme, E.C., Lucas, S.B. and David, J. 1999: Chronology of crustal growth and recycling in the Paleoproterozoic Amisk collage (Flin Flon Belt), Trans-Hudson Orogen, Canada; Canadian Journal of Earth Sciences, v. 36, p. 1807–1827.

Syme, E.C. and Bailes, A.H. 1996: Geochemistry of arc and ocean-floor metavolcanic rocks in the Reed Lake area, Flin Flon belt; *in* Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p. 52–65.

Syme, E.C., Bailes, A.H. and Lucas, S.B. 1995: Geology of the Reed Lake area (parts of NTS 63K/9 and 10); *in* Report of Activities 1995, Manitoba Energy and Mines, Geological Services, p. 42–60.

Syme, E.C., Lucas, S.B. and Stern, R.A. 1999: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon Belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, p. 1767–1788.

Zwanzig, H.V. 1994: Geologic setting of the Nokomis Lake gold deposit (NTS 63N/3); *in* Report of Activities 1994, Manitoba Energy and Mines, Geological Services, p. 35–38.

Zwanzig, H.V. 1996: Geology of the Dow Lake–Martell Lake area (parts of NTS 63K/15 and 63N/2); *in* Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p. 21–28.

Zwanzig, H.V. 1999: Structure and stratigraphy of the south flank of the Kisseynew Domain in the Trans-Hudson Orogen, Manitoba: implications for 1.845–1.77 Ga collision tectonics; Canadian Journal of Earth Sciences, v. 36, p. 1859–1880.

Zwanzig, H.V. and Schledewitz, D.C.P. 1992: Geology of the Kississing–Batty Lakes area: interim report; Manitoba Energy and Mines, Geological Services, Open File Report OF92-2, 87 p. plus 1 map at 1:20 000 scale and 2 maps at 1:50 000 scale.