Geological setting

The southern Wekusko Lake map area (NTS 63J12NW), which is located 20 km southeast of Snow Lake, Manitoba, is part of the Paleoproterozoic Flin Flon Belt (Lucas et al., 1996; Ansdell et al., 1999; Syme et al., 1999; Hudson Oregon). Supracrustal rocks of the Flin Flon Belt are part of a structurally complex collage of diverse components, most of which have counterparts in modern oceanic arcs, such as the Tonga-Kermadec arc (Ewart and Hawkesworth, 1987) and the Fiji arc (Gill, 1987). These components include 1) geochemically distinctive volcanic assemblages of juvenile arc, arc rift, ocean floor and oceanic island affinity; 2) sedimentary and minor volcanic rocks that record the development of, and erosion from, intraoceanic island and volcanic arc edifices; and 3) plutonic rocks, studies over the last decade (David et al., 1996; Lucas et al., 1996; NATMAP Shield Margin Working Group, 1998) have chronicled a detailed magmatic and tectonic history spanning a period of approximately 100 million years (1.91–1.83 Ga), which includes the inception of arc magmatism (1.91–1.88 Ga), subsequent 'successor arc' magmatism and sedimentation (1.87–1.84 Ga), and collisional orogeny (1.84–1.83 Ga).

The southern Wekusko Lake map area contains no less than five distinct tectonostratigraphic supracrustal components (south Wekusko Lake, Hayward Creek, Puella Bay, Burntwood Group, Missi Group), together with parts of two major plutons (Goose Bay and Alward Lake). These components are juxtaposed by a complicated network of the 'Crowduck Bay Fault' (of Ansdell and Connors (1997), into sections and contain parts that contain significantly different stratigraphic and structural components. The fault, which extends from the northeast corner to the south margin of the map area, traverses the south Wekusko Lake ocean floor basalt sequence (units F1 to F3) and separates the 1.88 Ga Hayward Creek juvenile oceanic arc volcanic rocks (units J1 to J4) to the west from the 1.876 Ga Puella Bay epiclastic and volcaniclastic rocks (unit P1) and the Burntwood Group (unit B1) to the east. The Burntwood Group consists of detrituls of 1.85–1.84 Ga (David et al., 1996) Burntwood Group greywacke, siltstone and mudstone turbidite and derived paragenesis (units B1a and B1b) more than 10 km wide. The area east of the fault is dominated by a sequence of Missi Group fluvial-alluvial sedimentary (units M1 and M2) and volcanic rocks of a similar 1.85–1.83 Ga age (Ansdell et al., 1992). The Missi Group has been interpreted as a possible continental facies equivalent of the marine-facies Burntwood Group (Lucas et al., 1996).

Geochemical data for volcanic rocks in the south Wekusko Lake area (south Wekusko Lake, Hayward Creek, Puella Bay, Burntwood Group, Missi Group) are presented in Syme et al. (1999). Detailed descriptions of petrographic, geochemical plots, lithological details of the analysed rocks, and field photographs showing details of selected rock units in the map area. These geochemical plots and field photographs are referenced as Figures 1–32 in the following text.

Description of units

Oceanic volcanic, sedimentary and intrusive rocks (units F and J; ~1.88 Ga)

Most of the supracrustal components of the Flin Flon Belt range in age from 1.91 to 1.88 Ga (Lucas et al., 1996) and represent the products of ocean floor volcanism and arc magmatism (Syme and Bailes, 1993; Stern et al., 1995a, b). Variations in lithology and geochemical associations demonstrate that these sequences are disparate parts of various ocean floor and arc assemblages, tectonically juxtaposed during intraoceanic accretion at ca. 1.88–1.87 Ga, and subsequent continental collision at ca. 1.84–1.79 Ga (Lucas et al., 1996). The arc and ocean floor assemblages vary in size from large, laterally extensive volcanic-sediment packages (VMS deposits, with most VMS deposits associated with arc volcanic assemblages (Syme and Bailes, 1993).

South Wekusko Lake ocean floor volcanic and intrusive rocks (units F1–F3)

This sequence comprises pillowed (Figures 1–3), aphyric, tholeiitic basalt flows (unit F1), related gabbro sills (unit F2), and minor felsic tuff units (unit F3) (Figures 4–6). Unit F1 forms the ocean floor basalt sequence south of the south end of Wekusko Lake and a west-facing sequence on the east shore of Wekusko Lake. Similar to other ocean floor assemblages in the Flin Flon Belt, the south Wekusko Lake assemblage is devoid of felsic volcanic rocks and volcaniclastic units, except for volumetrically minor autoclastic facies of mafic flows. South Wekusko Lake basalt is characterized by a flat to slightly negatively sloping rare earth element (REE) profile, similar to that of N-MORB but with lower overall REE content. The south Wekusko Lake assemblage is similar to the 1.91 Ga Snow Lake arc, but is geochemically akin to normal and enriched mid-ocean ridge basalt (N- and E-MORB; Stern et al., 1995b) of the 1.90 Ga (Stern et al., 1995b) Elbow–Athapapuskow ocean floor assemblage of the south-central part of the western Flin Flon Belt, and may represent a tectonic remnant of that ocean floor terrane.

Hayward Creek juvenile arc volcanic, intrusive and sedimentary rocks (units J1 to J4)

The Hayward Creek domain (Gilbert, 1994) is dominated by volcanic fragmental rocks. It consists of a lithologically diverse suite of basalt (unit J1), mafic fragmental rocks (unit J2), mixed felsic flows and fragmental rocks (unit J3), and volcaniclastic grey-wacke and mafic tuff (unit J4). The mafic flows (unit J1) are typically massive and aphyric to plagioclase-phyric types with basal zones of flow breccia, pillows occur only sporadically in these flow units (Figures 7–9). The mafic fragmental units (unit J2) are typically well bedded, fine to medium grained, crystal tuffs stratigraphically associated with subordinate, lesser felsic rhyolite units (Figures 8–9) and heterolithic volcanic fragmental deposits of possible mass-flow and turbidity-current origin. Volcaniclastic and epiclastic rocks (units J2 and J4) vary from coarse (boulder-cobble) to fine grained (silt-mud) and are typically well bedded and commonly graded. The felsic rocks (Figures 9–12), to fine grained tuff, crystal tuff and related tuffaceous sediments in the southeast corner (Figure 12). The mafic volcanic and volcaniclastic-epiclastic deposits are overlain, at the north margin of this domain, by a conformable (200 m thick) unit of extensive rhyolite and related felsic volcaniclastic rocks (unit J3; Figures 14–16).

The Hayward Creek juvenile arc volcanic rocks display elevated contents of light rare earth elements (LREE), high Th and depleted high-field-strength elements (HFSE; Figure 1, plots b and c). They are geochemically akin to I-IB Ga (David et al., 1996) volcanic rocks of the Snow Lake arc assemblage of Bailes and Galley (1999). Nb depletions are less than in the Snow Lake arc assemblage, and Nb contents are slightly higher than in comparable Hayward Creek volcanic rocks, although Nb analytical data are not available for the latter suite. Their transitional, tholeiitic to calc-alkaline geochemical affinity, and trace-element signature, together with the prevalence of fragmental lithological types, are most similar to the upper, geochemically more evolved and volcaniclastic-dominated part of the Snow Lake arc assemblage (Bailes and Galley, 1996).

Because the Snow Lake arc assemblage contains most of the VMS deposits in the eastern Flin Flon–Snow Lake belt (see Bailes and Galley, 1999), the Hayward Creek suite is considered to provide above-average potential for the discovery of VMS deposits. However, the lack of known exploration activity and the paucity of VMS deposits, as is common in the Hayward Creek juvenile arc rocks, are attributed to early surface alteration that could also be partly due to cryoclastic hydrothermal systems.

'Successor' volcanic, sedimentary and hypabyssal intrusive rocks (units S, B and M; 1.88–1.83 Ga)

Volcanic, volcaniclastic and sedimentary rocks younger than the 1.92–1.88 Ga tectonostratigraphic assemblages occur throughout the Flin Flon Belt and have been termed 'successor basin' deposits (NATMAP Shield Margin Project Working Group, 1998). These sedimentary and volcanic rocks may represent the remnants of volcanic arcs and depositional basins that were built upon accreted older 1.92–1.88 Ga oceanic assemblages. The 'successor arc and basin' deposits fall into two contrasting types: older (~1.85 Ga) marine to subaerial volcaniclastic and epiclastic rocks (Burntwood Group and Hayward Creek volcanic rocks) and younger (1.84–1.83 Ga) fluvial to alluvial rocks (Missi Group) and Burntwood Group fill) derived by erosion of successor arc volcanic and plutonic rocks, as well as older tectonostratigraphic assemblages (NATMAP Shield Margin Project Working Group, 1998).

Puella Bay volcanic, volcaniclastic and sedimentary rocks (1.88–1.87 Ga; units S1 to S4)

The Puella Bay suite consists of a basal mafic mudstone (unit S1), a heterolithic tracky-andesite cobble to boulder conglomerate with subordinate andesite interlayers (unit S2), amygdaloidal aphyric to plagioclase-phyric massive andesite flows (unit S3), and scoriaceous dacite tuff to lapilli tuff and massive dacite (unit S4). These rocks were included in the 1.88 Ga 'Sickle-Wekusko Suite' that was interpreted to be part of a protoarc(intraoc) 'successor arc' succession built on the older, already accreted 'juvenile oceanic arc' (NATMAP Shield Margin Working Group, 1998). However, the Puella Bay suite is younger than the 1.88 Ga Hayward Creek juvenile arc rocks. This, in turn, indicates the sequence to be transitional in age between the 1.88 Ga 'juvenile oceanic arc' and the 1.87–1.84 Ga 'successor arc' successions. It is thus uncertain whether this volcanism is part of an old 'successor arc' or a young juvenile oceanic arc' sequence.

The basal mafic mudstone (unit S1) forms a zone, less than 5 m wide, that is exposed in a shoreline outcrop at the southeastern boundary of the map area (Figure 17). Its contacts with the structurally underlying south Wekusko Lake basalt (unit F1), located to the north, is not exposed but is interpreted to be a fault. In contact with the directly overlying tracky-andesite cobble to boulder conglomerate (unit S2) is conformable and gradational.

Aphyric to plagioclase-phyric amygdaloid andesite (unit S3) is volumetrically minor and typically occurs as discrete bodies in the heterolithic tracky-andesite conglomerate (unit S2). Some bodies may be intrusive, but their high vesicularity, local poly-pond cooling joints and lateral continuity, parallel to lawsen bedding in bostrocks, suggest they are most likely flows.

Felsic volcanic rocks (unit S4) form the top of the exposed Puella Bay sequence. They consist of a lower layered sequence of scoriaceous dacite tuff and lapilli tuff (unit S4a) and an overlying massive dacite (unit S4b). Well-preserved scoria-rich dacite tuff and lapilli tuff, which contain a high abundance of pumiceous fragments, are interpreted to have been deposited by pyroclastic eruptions. The massive dacite (unit S4b) contains abundant quartz-phyric lapilli and with local subvolcanic dacite and rare poly-pond joints (Figure 21). Massive dacite (unit S4b) dominates the north shore of Puella Bay, but locally includes fragmental varieties and intermixed lenses of flamework-supported pebble and boulder conglomerate (Figure 22); clasts in these lenses are typically well-rounded, probably due to subaerial transport.

Geochemically analysed samples of unit S2 andesite boulders, unit S3 andesite flows and unit S4 monolithic dacite tuff and lapilli tuff are calc-alkaline and have a transitional to tholeiitic affinity. They are similar to other ocean-floor volcanic rocks by their significantly higher LREE and HFSE contents and Ca/Sr values (Figure 1, plots a–c). Their trace-element contents and steep, negative-sloping REE profiles are consistent with a geochemically evolved, calc-alkaline magma source. The Puella Bay suite is characterized by a negative Nb anomaly that suggests it originated in a subduction-zone tectonic setting.

Burntwood Group (1.85–1.84 Ga; unit B) and Missi Group (1.85–1.83 Ga; unit M)

The Burntwood Group and Missi Group sedimentary rocks occur spatially throughout the Flin Flon Belt and together are the dominant constituents of the adjacent Kisseynew sedimentary belt, located north of the Flin Flon Belt. The eastern end of the Flin Flon Belt has the highest abundance of these sedimentary rocks, which are commonly intruded by 1.84–1.80 Ga peraluminous leucogranite plutons (Ansdell et al., 1999). Rocks of the Burntwood Group are equivalent to the adjacent Kisseynew belt. The Burntwood Group includes mainly greywacke, siltstone and mudstone, with bedforms and sedimentary structures indicating deposition by turbidity currents in a submarine fan environment (Bailes, 1980a, b). The Missi Group includes subaerial alluvial and braided stream deposits of arenite and local conglomerate. Overlap in age of the 1.855–1.84 Ga Burntwood Group submarine fan deposits with the 1.85–1.83 Ga Missi Group alluvial deposits (Ansdell et al., 1992; Lucas et al., 1996) indicates that these two groups were formed contemporaneously and represent propinqua alluvial and submarine fans that fed into the adjacent Kisseynew sedimentary basin from an elevated landmass in the Flin Flon Belt. Subsequent horizontal shortening accompanying (ca 1.84–1.81 Ga continental collision tectonics has juxtaposed the Burntwood Group and Missi Group sedimentary rocks against each other and with earlier formed assemblages. As a result, most sedimentary assemblage contains in the eastern Flin Flon Belt are thrust faults (Connors et al., 1999).

In the eastern Flin Flon Belt, Ansdell and Connors (1994) have postulated an older (~1.845 Ga) and a younger (~1.835 Ga) phase of Burntwood Group sedimentary rocks. The younger phase is the most extensive and is the exposed core of Puella Bay, in the southern Wekusko Lake map area, belong to the younger (~1.835 Ga) package. This is important, as these sedimentary rocks clearly postdate the 1.855–1.84 Ga (David et al., 1996) Burntwood Group sedimentary rocks exposed on western Wekusko Lake.

The Burntwood Group greywacke, siltstone and mudstone turbidites (unit B1a) in the Wekusko Lake area occur mainly west of the Crowduck Bay Fault, where they form a 10 km wide domain that extends from Goose Bay into the northern part of Wekusko Lake. They also occur sporadically along the west shore of the lake toward its south end, as a narrow belt between the south Wekusko Lake basalt (unit F1) and the Hayward Creek juvenile arc rocks (unit J1) along shore of Puella Bay. The main arc of Burntwood Group sedimentary rocks exposed on Wekusko Lake is internally deformed by a series of early regional (F$_1$) folds, out by a series of late-tectonic granitic plutons (unit P) that were emplaced at ca. 1.845–1.835 Ga (David et al., 1996) regional metamorphism. Most of these Burntwood Group sedimentary rocks contain well-preserved primary features, such as graded bedding, flame structures, sandstone dikes, sedimentary folds, scour structures, and internal cyclic fineness bed-sedimentation, consistent with deposition by turbidset density currents (Figure 23–26).

Missi Group rocks east of Puella Bay are composed mainly of massive to trough-crossbedded arenite (unit M1) but include a 200 m wide conglomerate (unit M2). The conglomerate (unit M2) is polymictic and composed mainly of well-rounded volcanic-derived clasts, together with a wide variety of accessory, pebble- to boulder-sized fragments that are similar to the 1.88 Ga Hayward Creek juvenile arc rocks and the 1.87–1.84 Ga successor arc rocks. Boulders of granite up to 1 m in diameter were observed at an outcrop on the west shore of Puella Bay. The Missi Group arenite and conglomerate exhibit features characteristic of continental, fluvial-alluvial fan deposits.

Intrusive rocks (units Q, P and P1; ~1.84 Ga)

Mafic to felsic intrusive rocks occurring as dikes, small stocks and irregularly shaped intrusions, are common in the southern Wekusko Lake map area. Many of these intrusions are clearly late-tectonic, as they cut across 1.84–1.83 Ga 'successor arc' plutons (unit P) and 1.855–1.83 Ga Burntwood Group and Missi Group sedimentary rocks (units B and M). The ages of other intrusions placed in unit G and intruding older assemblages are uncertain; some of these intrusions could be as old as the host volcanic assemblages.

Mafic to ultramafic intrusions (unit G)

Gabbroic intrusions within the Hayward Creek juvenile arc assemblage include several small stocks and sporadic diabase dikes (unit G1). Most of these intrusions are massive, aphyric and homogeneous, but, in some cases, diverse porphyritic and leucocratic to melanocratic phases are associated together within the same gabbroic stock. The age of the intrusive phenocrysts, whereas some of the units are probably syn-volcanic, there is no definitive evidence for their age of emplacement.

Granitoid plutons and related rocks (1.84–1.83 Ga; unit P)

The eastern end of the Flin Flon Belt is intruded by a series of 1.84–1.83 Ga (Gordon et al., 1990; David et al., 1996) syntectonic granitoid plutons (Figure 27). These 1.84–1.83 Ga granitic plutons, together with other 1.84–1.83 Ga granitic rocks form a series of oval plutons that structurally stitch together disparate lithostratigraphic components assembled during D$_1$ deformation and (perhaps earlier) crustal shortening (e.g., Snow Lake arc assemblage volcanic rocks and Burntwood Group sedimentary rocks). Observation of enteromorphic F$_1$ fold structures in Burntwood Group sedimentary rocks being truncated at pluton margins is consistent with these large-scale structural relationships.

In the southern Wekusko map area, this episode of 1.84–1.83 Ga granitic magmatism is represented by a series of massive, oval, diorite to granodiorite and tonalite plutons. They include the Goose Bay porphyry (unit P1), Alward Lake pluton (unit P2), southwest Wekusko Lake pluton (unit P3), Broad Bay pluton (unit P4) and Wekusko Lake pluton (unit P5).

The Goose Bay porphyry (unit P1) is a moderately to strongly foliated, lineated to cliffdike, quartz-feldspar porphyritic felsic intrusion emplaced within the volcanic rocks of the Hayward Creek assemblage. Located along strike from Hayward Creek felsic volcanic rocks (unit J2), in the upper part of this juvenile arc volcanic sequence, this body could be the co-volcanic intrusive equivalent of the felsic volcanic rocks. However, the intrusion is provisionally interpreted to be younger in age due to the lack of definitive field or geochemical evidence to link it to the extensive felsic rocks of unit J2.

The Alward Lake pluton (unit P2) comprises granoiod rocks and associated granitoid gneiss outcropping west of Alward Lake and south of the Hayward Creek volcanic rocks (unit J2). The pluton is a 1.84–1.83 Ga tectonic sheet of early diorite phase (unit P2b) that is intruded by younger quartz diorite to leucotonalite rocks (unit P2a). Abundant granite to granodiorite dikes near the margin of the Alward Lake pluton are interpreted to emanate from the adjacent Wekusko Lake pluton (unit P3). Xenoliths of fine-grained sedimentary rocks and associated semipelitic paragneiss of the Burntwood Group (unit B1b) at the margin of the Alward Lake pluton constrain the age of this intrusion to the 1.84–1.83 Ga Burntwood Group deposition. The Alward Lake pluton is similar to the phases and the 1.845 Ga (Machado et al., 1989) age of the younger dioritic phase in Burntwood Group greywacke.

The southwest Wekusko Lake pluton (unit P3), an oval felsic granitoid body at the southwest end of Wekusko Lake, contains similar rock types and displays similar age relationships of phases to those in the Alward Lake pluton (unit P2). For example the southwest Wekusko Lake pluton consists of an older, subordinate diorite phase (unit P3b) in north, east and west margins that is crosscut by the main tonalite quartz diorite phase of the intrusion (unit P3a). A granodiorite-granite phase (unit P3c), which is present in the north-central part of the pluton, is similar to unit P5 of the Wekusko Lake pluton. The southwest Wekusko Lake pluton intrudes the Burntwood Group sediments and contains the contact between the Hayward Creek juvenile arc assemblage (unit J) and Burntwood Group submarine fan sedimentary rocks (unit B). Thus, the pluton represents a piercing point that stitches together two assemblages that were likely juxtaposed along a D1 thrust fault. Although this D$_1$ structure was not observed during mapping, the distribution of map units here and in the map area to the north are most simply explained by the presence of such a D$_1$ structure.

The Broad Bay pluton (unit P4), which outcrops on the southeast shore of Wekusko Lake, is a tonalite-granodiorite to granite (Corny et al., 1981) that intrudes the contact between the south Wekusko Lake ocean-floor assemblage basalt (unit F1) and the younger Puella Bay 'successor arc' volcanic rocks (unit S). Although the contact between the south Wekusko Lake and Puella Bay rocks is not exposed, it is anticipated that the contact is a D$_1$ fault, with the Broad Bay pluton structurally stitching these assemblages together.

The Wekusko Lake pluton is a pear-shaped intrusion of massive, nonfoliated, pink-weathering granite and granodiorite (unit P5) that contains minor amounts of biotite, hornblende, largely altered to chlorite. This one-mica intrusion, with a U-Pb zircon crystallization age of 1834 ~8 Ma (Gordon et al., 1990), is emplaced into localmafic F$_1$ folded Burntwood Group greywacke, siltstone and mudstone (unit B1a) and occupies the core of a later, open, northeast-trending D$_2$ fold (Figure 28). The Wekusko Lake pluton is a post-tectonic granitoid emplacement, contrasting with local ca. 1.845 Ga (Ansdell et al., 1992) thrust-accretional sedimentation in the Missi Group (unit M) of the eastern part of Puella Bay. Similar to other unit P plutons in the Snow Lake area, the Wekusko Lake pluton structurally stitches together various volcanic and sedimentary assemblages that were previously juxtaposed during D$_1$ deformation.

Late intrusive rocks (unit L)

The youngest intrusive rocks in the southern Wekusko Lake map area include diorite and quartz diorite (unit L2a), quartz-plagioclase porphyry (unit L2b), gabbro (L1a), anorthositic gabbro and quartz gabbro (unit L1b), and diabase (unit L1c, d, e); these rocks occur as minor dikes and stocks intruding the 'successor arc' granitoid plutons (unit P) and the older assemblages.

An ovoid diorite to quartz diorite stock (unit L2a) is emplaced within the Wekusko Lake pluton in the northwest corner of the map area. Plagioclase-phyric diabase dikes (L1c) that are spatially related to the stock are assumed to be genetically related to the stock and are, therefore, interpreted to be approximately the same age as the stock and to be younger than all other intrusions. The younger porphyry bodies crosscut diabase intrusions (units L1c, d, e), whereas an older set of porphyry intrusions is intimately associated and probably penecontemporaneous with diabase intrusions (Figure 29). Other quartz-plagioclase-porphyry dikes are clearly associated with brittle fragmentation of granitoid hornblende (unit P) and the development of 'intrusion breccia'.

Diabase dikes (unit L1c, d, e) are common throughout the southern Wekusko Lake map area (Figure 30). Some occur as easterly- to east-southeasterly-trending swarms of narrow dikes cutting the unit P granitoid plutons. Others occur as isolated dikes that have northeasterly trends. The dikes are typically fine grained, massive, aphyric and southeast-trending swarm of tractylite diabase (unit L1d), which occur throughout the western half of the map area, cutting the Hayward Creek juvenile arc (unit J), the F$_1$-folded Burntwood Group sedimentary rocks (unit B) and the 'successor arc' granitoid plutons (unit P). These dikes and related intrusions are always fine grained, have chilled margins and are up to 70 m wide. They are characterized by tabular plagioclase phenocrysts (1–3 cm long) ± hornblende ± quartz phenocrysts, set in a fine grained, dark, aphyric groundmass. The tractylite diabase (unit L1e) contains large (2–8 cm) plagioclase megacrysts and smaller (0.5–1 cm) plagioclase crystals aggregated in ovoid clusters up to 10 cm in diameter (Figure 32). Whereas tractylite diabase postdates the main granitoid emplacement, the tractylite dikes are cut by a set of quartz-plagioclase-porphyry dikes (unit L2b). Petrographically, late quartz diorite phases in both the Alward Lake (unit P2) and south Wekusko Lake (unit P3) plutons, indicating that the mafic dikes probably represent a young intrusive phase of 'successor arc' magmatism. Several east-northeast-trending dikes of very coarse grained, anorthositic gabbro and magnetite-bearing quartz gabbro, which postdate the south Wekusko Lake and Alward Lake plutons, are also interpreted to be relatively young, successorary intrusions.

Structural history

Numerous detailed structural studies carried out in the Flin Flon–Snow Belt (Lucas et al., 1996; Ansdell et al., 1999; Syme, 1995; Connors, 1996; Connors et al., 1999) have identified deformation events recording early accretion (1.88–1.87 Ga) to late tectonic continental collisions (1.77 Ga). Deformation associated with rifting occurred during the interval of 1.88–1.87 Ga, as evidenced by the development of the 1.876 Ga Puella Bay epiclastic and volcanic rocks, indicated by a U-Pb zircon age of 1.876 ~ 3 Ga (Corkery et al., 2001) for the syn-sedimentary sill of the Boland Lake gabbro sills that postdates isoclinal recumbent folding of the early volcanic arc assemblages (Zwanzig et al., 2001). The gabbro is geochemically comparable to, and interpreted as penecontemporaneous with, arc-rift basalt in the Snow Lake arc assemblage (Zwanzig et al., 2001).

In the southern Wekusko Lake area, three deformation events (D$_1$–D$_3$) have been recognized, all of which postdate the early folding that accompanied intrusion of the Josland Lake gabbro sills (Gilbert, 1993). Structures of D$_1$ which include the main penetrative fabric and most of the folds in the map area, are interpreted to have developed between ca. 71.84 Ga in age. Both D$_1$ and D$_2$ are interpreted as result from the southward tectonic transport of Burntwood Group greywacke-turbidite from the Kisseynew belt over the Flin Flon Belt (Kraus and Williams, 1999). The D$_1$ and D$_2$ events are characterized by tight isoclinal folding and associated low-angle 'flover' faults. The D$_3$ deformation is interpreted to result from central shortening that occurred syn to post peak regional metamorphism (Connors et al., 1999). The regional deformational event is largely manifested by upright, open to closed folds (F$_3$) and associated steeply dipping faults.

Structures belonging to D$_1$ are common west of Wekusko Lake. They include tight isoclinal F$_1$ folds, which are disjoinous in the 1.84 Ga Burntwood Group turbidites (unit B1a), as well as associated D$_1$ thrust faults; the latter typically define contacts between lithotectonic assemblages and are cut-linear due to subsequent folding during D$_2$ deformation. The Hay and Creek Creek juvenile arc volcanic rocks west of the south end of Wekusko Lake are characterized by many early F$_1$ folds whose axial traces are roughly parallel to an early S$_1$ foliation and are conformable with the regional trend of the lithotectonic units. The F$_1$ folds are cut by the Crowduck Bay Fault, which is a D$_1$ thrust that roughly coincident with the shoreline and the fields, is interpreted to be a low-angle thrust associated with the D$_1$ event. The F$_1$ folds and D$_1$ thrust faults west of Wekusko Lake are bracketed in age by the crosscutting 1.84–1.83 Ga (David et al., 1996) granitic plutons (unit P) and younger 1.83 Ga dextral zircon (Machado et al., 1989) in the Burntwood Group greywacke (unit B).

Fold structures belonging to D$_2$, which were first identified at Snow Lake by Kraus and Williams (1999), can be recognized throughout the length of Burntwood Group sedimentary rocks on Wekusko Lake. When observed, the F$_2$ folds are isoclinal and coaxial with F$_1$ folds, with their prominent axial-planar foliation and plane of flattening likely a product of coaxial D$_1$ and D$_2$ deformation. Both Connors et al. (1999) and Kraus and Williams (1999) indicated that D$_2$ deformation, similar to the earlier D$_1$ deformation, involves low-angle 'flover' faults. Connors et al. (1999) showed that the 1.84–1.83 Ga granitic plutons (unit P) were emplaced into the core of the D$_2$ structure and are, therefore, contemporaneous with the 1.84–1.83 Ga granite magmatic event (unit P) and predate the D$_2$ event affecting the Burntwood Group rocks (unit B). This has some important implications, including the interpretation of the bedding-parallel foliation and low-angle faults in the Missi Group rocks (units M1 and M2) east of Puella Bay, as most likely being a product of D$_2$ rather than D$_1$ deformation.

Deformation structures of D$_3$ are ubiquitous in the eastern Flin Flon Belt. In the southern Wekusko Lake map area, they are mainly manifested as east-northeast-trending open F$_3$ folds that are eye to pear-peak ca. 1.810 Ga (David et al., 1996) granitic intrusions (unit P). The D$_3$ folds are commonly associated with D$_3$ thrust faults, which are steeply dipping and but sometimes localized in broad zones corridors adjacent to highrisetm zones such as the D$_1$ Crowduck Bay Fault (Connors et al., 1999). East of Wekusko Lake, an L$_3$ extension lineation is typically northeast to southeast plunging, whereas, west of the lake in the Hay-ward Creek domain, it is predominantly southeast plunging (Gilbert, 1993). The crosscutting configuration of the Hay-ward Creek Fault and F$_3$ folds in the Hay-ward Creek juvenile arc rocks south of Wekusko Lake, and the F$_3$ folds in the Burntwood Group sediments east of Wekusko Lake, with emplacement of the contiguous southwest Wekusko Lake pluton immediately south of the arc volcanic rocks.

Economic geology

Mineral exploration has been conducted in the southeastern part of Wekusko Lake since the 1920s. In southeastern Wekusko Lake, exploration has been focused on the Hayward Creek volcanic rocks, which underwent extensive quartz veins hosted by dacitic rocks of the Puella Bay suite (Assessment File 94053; 94081; 94095, Manitoba Industry, Economic Development and Mines). Subsequent investigations indicated that the mineralization occurs within quartz veins in a northeasting shear zone; assay yielded up to 2.7% Zn, 1.9% Pb, 180 ppm Au, 48 ppm Ag and minor Cu (location 1 in Ferreira and Fedikow, 1998). Southeast of Broad Bay, minor Au values have been reported in quartz-sericite-pyrite zones in felsic tuff (Assessment File 94095). The Puella Bay volcanic rocks are considered to be felsic to intermediate tuff of the Puella Bay suite occur on the peninsula west of Puella Bay, where a 2 m wide section of 'solid graphite' contains up to 40% pyrite (A# 92429, 92430). A similar pyrite section with minor Au (20 g/t) occurs at a higher stratigraphic level within the same volcaniclastic sequence just south of Puella Bay (A# 92481). Further details of mineral exploration since 1900 in the southeastern Wekusko Lake area are provided in Assessment File 94053 (Ferreira and Fedikow, 1998; Ferreira, 1999).

At the southwest corner of Wekusko Lake, base-metal mineralization in Hayward Creek juvenile arc volcanic rocks was discovered in the late 1920s ('Copper-Man deposit'); the locality, 0.5 km west of the lakeshore, has subsequently been the focus of a series of exploration programs that continue to the present time. The VMS deposit is approximately 250 000 tonnes and contains Cu and Zn (average grades of 3–4 %) and minor Au, Ag and Cd (Mineral Resources Division, 1993; Syme et al., 1999). Exploration in the vicinity of the Copper-Man deposit (Hudson Bay Mining and Smelting Co. Limited reported a 27 m long kimberlite section within diamond-drill core at the same 'Copper-Man' locality; the brecciated kimberlite occurs within Burntwood Group greywacke, just offshore from the VMS deposit. In 1993, European Ventures Inc. found diamond indicator minerals within this kimberlite (European Ventures Inc., 1993); two stratigraphically separate kimberlite units occur at the locality.

A significant economic prospect for base-metal sulphide mineralization occurs within Burntwood Group metasedimentary rocks at Goose Bay, in the western part of Wekusko Lake. At this locality, massive pyrite-pyrrhotite lenses, up to approximately 1 m thick, occur in a 10 m wide zone of intercalated sulphidic metasediments (A# 92862); these intersects, together with the numerous formational TM anomalies that occur within the sedimentary sequence, suggest the Burntwood Group rocks may have potential to host base-metal ore deposits. This economic potential is further reinforced by the fact that stratigraphically equivalent paragneiss in the Kisseynew sedimentary gneiss domain, northeast of Wekusko Lake, contains massive sulphide deposits (ZnCu BOR Zone and ZnPb-Ag Zone; Zwanzig et al., 1999). The Goose Bay prospect occurs within a 2 km long, northeast-trending zone of Burntwood Group rocks at Goose Bay; it coincides with mineralized diffuse interseptum and a 2.7 km long formational EM anomaly (A# 90580, 94047); a prominent, positive aeromagnetic anomaly also extends along this northeast-trending zone. The Goose Bay prospect is considered to have good exploration potential and warrants continued exploration. Mineralization at Goose Bay occurs over a 17 m section within Bailes (unit J1), adjacent to the Goose Bay porphyry intrusion (unit P1). The mineralized rocks are part of the Hay-ward Creek arc assemblage, which is characterized by widespread silicic, sericite and chloritic alteration zones that are considered favourable indicators for mineralization. Similar alteration is common in juvenile arc rocks that host base-metal ore deposits elsewhere in the Flin Flon Belt.

References

Ansdell, K.M. and Connors, K.A. 1993: Lithological and structural relationships in the east Wekusko Lake area, Flin Flon Belt, Manitoba, Manitoba, in Report of Activities, 1993, Manitoba Energy and Mines, Geological Services, p. 108-111.

Ansdell, K.M. and Connors, K.A. 1994: Geochronology of continental sedimentary and volcanic rocks in the Flin Flon Domain: new results, in LITHOPROBE Trans-Hudson Orogen Transect: Report of Fourth Transect Meeting, J. Hajnal and J.F. Lewry, J.F. (ed.), LITHOPROBE Secr retariat, University of British Columbia, LITHOPROBE Report 38, p. 205-212.

Ansdell, K.M., Connors, K., Stern, R.A. and Lucas, S.B. 1999: Crustal sedimentation, magmatism, and fold-thrust belt development in the Trans-Hudson Orogen (Canada): ion microprobe U-Pb geochronology from the Wekusko Lake area, Manitoba, Canada, in NATMAP Shield Margin Project, Volume 5, S.B. Lucas (ed.), Canadian Journal of Earth Sciences, v. 36, no. 2, p. 291–312.

Ansdell, K.M., Kyser, T.K., Stauffer, M.R. and Edwards, G. 1992: Age and *sm-nd* of distal (cratonic) turbidites in the Missi Formation, a Proterozoic molasse deposit, Trans-Hudson Orogen, Canada: *in* Precambrian Sedimentation, R.J. Rice (ed.), Canadian Journal of Earth Sciences, v. 29, no. 12, p. 2583–2594.

Bailes, A.H. 1980a: Geology of the Flin Flon area; Manitoba Energy and Mines, Mineral Resources Division, Geological Report 78-1, 114 p.

Bailes, A.H. 1980b: Origin of early Proterozoic volcaniclastic turbidites, south margin of the Kisseynew sedimentary gneiss belt, Flin Flon, Manitoba; *in* Early Precambrian Volcanology and Sedimentology in the Light of the Recent E. Dimroth, J.A. Donaldson and J. Vicent (ed.), Precambrian Research, v. 12, no. 1–4, p. 197–225.

Bailes, A.H. and Galley, A.G. 1999: Evolution of the Paleoproterozoic Snow Lake arc assemblage and geochemistry of Manitoba, Geological Survey, Manitoba Energy and Mines, Geological Services, p. 56–64.

Bailes, A.H. and Galley, A.G. 1996: Tectonostratigraphic setting of Paleoproterozoic massive sulphide deposits, Snow Lake, Manitoba, *in* Winning '96, Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Winnipeg, Mai. 27–29, 1996, Program with Abstracts, v. 21, p. A5.

Bailes, A.H. and Galley, A.G. 1999: Evolution of the Paleoproterozoic Snow Lake arc assemblage and geochemistry of Manitoba, Geological Survey, Manitoba Energy and Mines, Geological Services, p. 56–64.

Corny, P., Trumbak, D.L., Zalibike, D.V., Goud, B.E. and Paul, J. 1981: The Cat Lake–Winnipeg River and the Wekusko Lake geophysical fields, Manitoba; Manitoba Energy and Mines, Mineral Resources Division, Economic Geology Report R6-1, 173 p.

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

Connors, K.A., Ansdell, K.M. and Lucas, S.B. 1999: Crustal sedimentation, magmatism and fold-thrust development in the Trans-Hudson Orogen: propagation of deformation into an active continental margin, Wekusko Lake area, Manitoba; Canadian Journal of Earth Sciences, v. 36, no. 11, p. 275–291.

David, J., Bailes, A.H. and Machado, N. 1996: Evidence for Snow Lake portion of the Paleoproterozoic Flin Flon and Kisseynew belts, Trans-Hudson Orogen, Manitoba, Canada; Precambrian Research, v. 80, no. 1–2, p. 107–124.

European Ventures Inc. 1993: Microprobe analysis confirms G10, other diamond indicators; European Ventures Inc., News-Release, July 26, 1993.

Ewart, A. and Hawkesworth, C.J. 1987: The Pleistocene-Recent Tonga-Kermadec arc lavas: interpretation of new isotopic and rare earth data in terms of a depleted mantle source model; Journal of Petrology, v. 28, p. 429–468.

Fedikow, M.A.F. 1991: Sulfide-in-bored ZnCu (H.B. Zone) and ZnPb-Ag (Korbar-Rubb) massive sulphide type deposits, Snow Lake area (NTS 63J11); *in* Report of Activities 1990, Manitoba Energy and Mines, Minerals Division, p. 41–46.

Ferreira, K. and Fedikow, M.A.F. 1998: Mineral deposits and occurrences in the Hare Lake area, NTS 63J12; Manitoba Energy and Mines, Geological Services, Mineral Deposit Series Report 21, 105 p.

Geological Survey of Canada 1992: Vertical gradient magnetic map, McClarty Lake; Geological Survey of Canada, Geophysics Division, sauit 117840.

Gilbert, H.P. 1993: Geological investigations in the southwest Wekusko Lake area (NTS 63J12); *in* Report of Activities 1993, Manitoba Energy and Mines, Geological Services, p. 100–107.

Gilbert, H.P. 1994: Southwest Wekusko Lake project; *in* Report of Activities 1994, Manitoba Energy and Mines, Geological Services, p. 89–103.

Gill, J.B. 1987: Early geochemical evolution of an oceanic island arc and back arc: Fiji and South Fiji Basin; Journal