CHAPTER 3 REGIONAL GEOLOGY

The Thompson Nickel Belt (TNB) contains the remnants of a Neoarchean-Paleoproterozoic continental margin sequence (Ospwagan and Winnipegosis groups) and lies within the Circum-Superior Boundary Zone (CSBZ), which in this area separates 3.1-2.6 Ga autochthonous Archean Superior Province rocks in the east from 1.92 - 1.83 Ga allochthonous Proterozoic tectonic domains of the Trans-Hudson Orogen (THO) to the west (**Fig. 3.1**). The TNB contains world-class Fe-Ni-Cu-PGE sulfide deposits, which have been strongly structurally and metamorphically modified, but which exhibit many of the fundamental characteristics of major magmatic sulfide districts. This complexity has obscured many of the geological and stratigraphic relationships between rock units, hampering exploration for new deposits and development of existing ones.

The CSBZ in northern Manitoba represents part of the foreland margin of the Superior craton, which is marked by a major promontory flanked by 100 km-scale re-entrants (e.g., the Winnipegosis Komatiite Belt, WKB and Fox River Belt, FRB: Lucas et al., 1997). It is bordered to the northwest by the internal (Reindeer) zone of the THO, a 400 km wide collage of 1.92-1.83 Ga arc and oceanic volcanic rocks, plutons, and 1.87-1.83 Ga continental and turbidite deposits (**Fig. 3.1**). The SBZ comprises (from southeast to northwest):

1) Autochthonous Archean (3.1-2.6 Ga) Superior basement rocks, including Pikwitonei granulites,
2) Parautochthonous Superior basement rocks in the Thompson Belt, including retrogressed Pikwitonei granulites,
3) Parautochthonous cover units of the TNB of presumed Paleoproterozoic age deposited on the Superior margin (Ospwagan and Winnipegosis Groups),
4) Possible allochthonous Archean crust (3.6 - 3.1 Ga) (Böhm et al., 2000), and
5) Allochthonous Paleoproterozoic (~1.8 Ga) rocks of the juvenile Reindeer Zone of THO.

The Ospwagan Group unconformably overlies retrograded Superior basement and comprises a thin basal quartzite unit that fines upward into semipelites overlain by carbonates, pelites, iron formations, greywackes, and mafic to ultramafic volcanic rocks (Bleeker, 1990a, 1996). Ultramafic sills occur throughout the stratigraphy. The Ospwagan Group and Superior basement rocks are intruded by 1.88 Ga mafic dykes and by granitoid plutons that range in age from 1845 Ma to 1822 Ma (Machado et al. 1990; Potrel et al., this report), most of which contain abundant inherited Archean zircons (Machado, 1990).

Molasse deposits (Grass River Group: Zwanzig, 1997) along the west margin of the TNB have been correlated with 1.85-1.83 Ga continental deposits in the Reindeer Zone and are interpreted to have formed during the latest arc volcanism in THO. The Grass River Group locally overlies mafic rocks of the TNB at the boundary along a sheared unconformity. The significance of this group is still unclear.

The Winnipegosis Group occurs in the sub-Phanerozoic extension of the belt (**Fig. 3.1**), and is characterized by a homoclinal, west-dipping and west-facing section of sub-greenschist facies sedimentary and volcanic rocks (Pearson et al., 1994). It occurs east of the strike-continuation of the Ospwagan Group and does not appear to correlate with it. The Winnipegosis Group stratigraphy includes a thin interval of discontinuous basal conglomerate and sandstone that rests unconformably on Superior basement, overlain by tholeiitic basalts, komatiitic basalts, and carbonate and siliciclastic sedimentary rocks.

Gravity data (**Fig. 3.2**) suggest that only the northern (exposed) part of the TNB lies directly at the (present) cratonic margin; the other belts (FRB and WKB) lie slightly inboard, at the crustal re-entrants, above the dense granulites of the Pikwitonei domain, where they remained largely unmetamorphosed.

Other Proterozoic sedimentary-volcanic belts that are interpreted to represent part of the Circum-Superior Boundary Zone include the *Ottawa-Belcher Islands* in Hudson Bay, the *Cape Smith Belt* in northern Québec, and the *Labrador Trough* in Québec-Labrador. These areas contain stratigraphic sequences of sedimentary rocks, komatiitic and tholeiitic basalts, and ultramafic sills that are broadly similar to those in the TNB, but there are several important differences in sedimentary facies, metamorphic grade, tectonics, and mineralization.

Three seismic reflection profiles were recently acquired across the SBZ as part of the LITHOPROBE project and provide an exceptional view of the along-strike variations in the crustal structure of the belt. The first line crossed the Phanerozoic-covered extension of the Thompson Belt and extended from the autochthonous Superior craton westwards across the Thompson Belt into the buried extensions of the Reindeer Zone. The second line crossed the SBZ in the vicinity of Setting Lake. The third line, which comprises two parts, crossed the boundary zone at Thompson. The seismic reflection data provide a basis for resolving at least some of the apparent contradictions that existed between a) previous geological interpretations (Bleeker, 1990a & b; Weber, 1990); b) potential field data interpretations (Gibb, 1968; Gibb and Walcott, 1971; Gibb et al., 1983; Thomas and Tanczyk, 1994); c) models derived from magnetotelluric (MT) data (Ferguson and Jones, 1995; White et al., 1999); and d) LITHOPROBE seismic images (Lines 1a, 1b: White et al., 1993; Line 2: Lewry et al., 1994; White et al., 1994; White and Lucas, 1994) and line S3b (Lucas et al., 1996).

Coincident regional seismic and magnetotelluric data acquired along two of the profiles that transected the Superior Boundary Zone (SBZ) during the LITHOPROBE program (White et al., 1999) reveal the following features.

From the southern profile:

1) The Reindeer Zone accretionary collage forms an east dipping, eastward steepening, crustal-scale tectonic stack of moderately conductive rocks near the SBZ.
2) The SBZ is characterized at shallow depths (< 5-6 km) by steep to moderately east dipping reflectors. At greater depth, the SBZ crust is highly resistive and is contiguous to the east with resistive crust beneath the Superior craton proper.
3) The Superior Boundary Fault (SBF) is recognised in the subsurface as an abrupt resistivity contrast between the Reindeer Zone and the SBZ, that extends subvertically to 15 km depth.
4) Moderately conductive rocks of the Reindeer Zone extend eastward for 30 km beneath the SBZ at depths of 15-45 km.

Seismic reflection data for the northern profile reveal a similar crustal structure with the following exceptions:

1) The SBF is recognised in the subsurface as a truncation of interpreted collisional fabrics and extends subvertically to ~30 km depth.
2) There is no compelling evidence for the eastward continuation of Reindeer Zone lower crust beneath the SBZ.

A striking feature of these data is that they clearly demonstrate that rocks of the Reindeer Zone dip beneath the SBZ at middle to lower crustal depths, to at least 45 km along the southern transect. This is in contradiction to the generally accepted tectonic model for the SBZ (Bleeker 1990a and b). To accommodate this contradiction, White et al. (1999) propose a model for the evolution of the SBZ, the main features of which are:

1) Lithospheric thinning and subsequent rifting of the Superior craton that resulted in the exhumation of the Pikwitonei granulites, upwarping of the Archean lower crustal fabric, and injection of the 2.12 Ga "Molson dykes".
2) Arc-continent collision involving an unknown (Snow Lake arc?) outboard terrane that resulted in an early east verging thrust and fold belt at >1.883-1.84 Ga.
3) Continent-continent collision between the SBZ and the emerging continental lithosphere of the Flin Flon Belt that resulted in renewed east vergent fold/thrusting in the SBZ, back thrusting in the adjacent Reindeer Zone accompanied by peak metamorphic conditions, and intrusion of anatectic granitoids at <1.83-1.82 Ga.
4) Further convergence that resulted in wedging of the Flin Flon crustal block into the edge of the Superior craton, with associated east-side folding and faulting on both sides of the SBF. It is proposed that these events occurred in the ~1.80-1.77 Ga interval.
5) Intracontinental transpression that continued until 1.72 Ga and resulted in the crustal geometry that is preserved today.

Studies carried out during this project and presented in **Chapter 6** arrive at different models for the evolution of the TNB. One, presented in **Part I** of **Chapter 6**, is based mainly on fold analysis and invokes an early event of east vergent folding and thrusting and is compatible with the models proposed by Bleeker (1990a and b) and by White et al. (1999). The other model, described in **Chapter 6 Part II**, is based on strain analysis and proposes that the structure of the TNB results from east-side up progressive deformation between 1.85 Ga and 1.75-1.72 Ga. The main differences between these models are that the latter does not invoke the emplacement of an east-vergent fold and thrust belt and it can explain the occurrence of multiple ages of metamorphism. In addition, because it considers that the present structure of the TNB can be explained by Superior-side up transpression, the progressive deformation model is entirely compatible with all the seismic and electrical resistivity data, which indicate that the Reindeer Zone rocks dip under the TNB (**Chapter 6, Part II**). This agreement is particularly well illustrated in Figure 7b of White et al. (1999), which depicts a west-verging crustal stack to a depth of ca. 5 km to the east of the Burntwood mylonite zone. In order to compare in greater detail the implications of the progressive deformation model with the geophysical results, a more elaborate strain analysis study of the TNB would be required.

Geochronological data for the TNB are relatively sparse, and the age of the Ospwagan Group, critical to resolving the complex structural and stratigraphic relationships between rock units, is unknown. Bell (1971) originally assumed the group to be of Archean age, but more recently it has more commonly been inferred to be Proterozoic age. The most accurate statement that can currently be made is that it is younger than the Pikwitonei granulites (i.e., <2650 Ma), but older than ~1880-1836 Ma (the age of the Molson dyke event and the oldest intrusive in the TNB, respectively), even though no dyke from the belt itself has given this age. Nd whole-rock model ages for mafic volcanic rocks of the Bah Lake assemblage (formerly named the Ospwagan Formation and inferred to be located at the top of the observed Ospwagan Group stratigraphy) suggest that the Ospwagan Group rocks are younger and were deposited at (or just prior to) about 1.9 Ga (Ansdell and Bleeker, 1997). Although the same data suggest that the siliclastic rocks of the Ospwagan Group were derived from both Archean and Proterozoic sources, they have only yielded Archean detrital zircons to date (Bleeker, 1990a; Machado, this report). Heaman et al. (1986) reported an 1883 Ma U-Pb zircon age for the Fox River sill on the northern margin of the Superior craton. Recent geochronological (Heaman and Corkery, 1996) and paleomagnetic (Zhai et al., 1994) work on mafic dykes that intrude the Pikwitonei granulites and Split Lake Block indicate several distinct generations (cf. Halls and Heaman, 1997), including the NE-trending Cauchon dyke (2092 Ma: Heaman and Corkery, 1996) and Birthday Rapids dyke (2072 Ma: Heaman and Corkery, 1996), the NNE-trending Cuthbert Lake dyke (1883 Ma: Heaman et al., 1986), and the NNE to NNW-trending Molson dyke (1883 Ma: Heaman et al., 1986). Hulbert et al. (1994) have also reported an U-Pb zircon age of 1864 +6/-4 Ma for a coarse-grained, layered unit in the Winnipegosis komatiites.

The mafic to ultramafic volcanic rocks in the Ospwagan and Winnipegois groups appear to be derived from a number of chemically and isotopically distinct sources (cf. Halden, 1991). Volcanic rocks from Ospwagan Lake and Moak Lake have positive ε_{Nd} values at an assumed age of 1900 Ma, whereas volcanic rocks from Assean Lake, located north west of Thompson along the Assean Lake shear zone, have negative ε_{Nd} values at 1900 Ma (N.M. Halden and B.J. Fryer, unpubl. data). Interestingly, the Thompson and Pipe Formations have negative ε_{Nd} values at 1900 Ma (-6 to -10: Ansdell and Bleeker 1997), consistent with derivation from older Archean crust, whereas Winnepegosis komatiites and tholeites have positive ε_{Nd} values (+4.5 to +7.8: Hulbert et al., 1994). TNB ultramafic rocks have ε_{Nd} values at 1900 Ma between -14.8 and +6.8 (this study), which are interpreted to reflect variable degrees of contamination and alteration (**Section 8.4.4.4**) The temporal and spatial relations between the mantle sources giving rise to the mafic and ultramafic lavas, dyke swarms, and mineralized intrusives over the 230 Ma (2.09-1.86 Ga) interval of magmatism in the region are not well understood, but multiple plume sources seem likely.

Definition of the subsurface extension of the boundary between the Thompson Belt and Kisseynew Domain (i.e., Superior-Reindeer Zone boundary) has been difficult owing to similarities in the appearance and potential field response of Ospwagan Group and Kisseynew Domain (Burntwood Group) metaturbidites. However, recent studies by Falconbridge Ltd. between the shield margin and Lithoprobe seismic line S3b (Bleeker et al., 1995; Tirschmann et al., 1996) have employed U-Pb zircon dating of drillcore samples of granitic rocks as a means of distinguishing Thompson Belt lithologies from Kisseynew Domain lithologies. A sample of hornblende-biotite tonalitic gneiss from the Cedar Lake magnetic high has yielded metamorphic zircons with U-Pb ages within the range 1813-1817 Ma and a discordant zircon with a U-Pb age of 1869 Ma (Bleeker et al., 1995; Tirschmann et al., 1996). Titanite from the same sample has a U-Pb age of 1779 Ma. These results, coupled with a low initial whole-rock $^{87}Sr/^{86}Sr$ ratio, led Bleeker et al. (1995) and Tirschmann et al. (1996) to suggest that the Cedar Lake magnetic high is part of the Kisseynew Domain. U-Pb geochronological results from other drillcore samples to the northeast (biotite gneiss: 2735 Ma zircon and metasediment: 1775 Ma monazite; Tirschmann et al., 1996) are typical for the Thompson Belt (cf. Machado, 1990). Results reported in **Section 10.3** for detrital zircon from drill cores clearly show that the boundary can be traced between drill cores that yield Archean zircons (TNB side) and those that yield Proterozoic zircons (Kisseynew side). From these results, it is clear that integrated drillcore, potential field, and geochronological studies can help to constrain the location of the unexposed TNB-Kisseynew Domain boundary.