CHAPTER 10 U-PB GEOCHRONOLOGY

10.1 Introduction

The general objectives of the geochronological studies were:

1) To determine the age(s) of mafic magmatism in order to evaluate whether nickel mineralization could have been associated with one or more magmatic events. This work was carried out by K. Toope, a M.Sc. student at the University of Alberta working under the supervision of L. Heaman.

2) To characterize the provenance of clastic sediments of the Ospwagan and Grass River Groups. This information will contribute to the paleogeographic reconstruction of the TNB during the deposition of both groups, and may help to limit the maximum age of deposition of the respective sediments. In addition, the ages, if sufficiently different, will provide criteria to distinguish the TNB from the Kisseynew Domain in drill cores from the sub-Paleozoic extension of the TNB. This criterion was applied to drill cores from Falconbridge properties. This work was carried out by N. Machado and A. Potrel at Université du Québec à Montréal (UQAM).

3) To determine the ages of structurally significant units in order to elucidate the tectonic history of the TNB. This work was carried out in close association with structural geologist D. Gapais of the Université de Rennes (France). Petrographic studies provided additional support to the structural-geochronological work and were carried out by E. Harlot of the same university.

During the project, U-Pb ages were obtained by several different techniques. Although the most common and maybe the best known technique (isotope dilution-thermal ionization mass spectrometry: ID-TIMS) yields the most precise and reliable ages, it is labour intensive and time consuming and its throughput is low compared to the other techniques. This technique was used to date the mafic rocks and determine both the timing of tectonic events and the location of the boundaries of the Archean domains (**Sections 10.2**, **10.4** and **10.5**). Included in these discussions are results obtained by W. Bleeker (GSC) on rocks of the TNB (Bleeker and Hamilton, 2001) using the GSC's SHRIMP instrument. Although the throughput is much higher by this technique, the results are less precise than those obtained by ID-TIMS (Stern, 1997). Finally, detrital zircons were analyzed by laser ablation-ICP-MS (LA-ICP-MS) using one of two instruments: a VG PQ+ equipped with an infrared laser, or a multicollector Isoprobe equipped with an ultraviolet (193 nm) laser. Both instruments permit high throughput but yield lower precision than any of the above methods (~50 Ma for the former and < 20 Ma for the latter, Machado and Simonetti 2001). The $^{207}Pb/^{206}Pb$ ages presented in **Section 10.3.2** were obtained with the former instrument whilst those presented in **Section 10.3.3** were obtained with the latter. It should be noted that this project benefited from the recent advances in the development of U-Pb dating by LA-ICP-MS carried out at UQAM (Machado and Simonetti, 2001). Without this technique, unique in Canada, the studies pertaining to dating of detrital zircon could not have been carried out with the available funds.

10.2 U-Pb Geochronology of Mafic Magmatism

10.2.1 Introduction

The age and nature of mafic magmatism in the TNB is of great importance in deciphering the origin of associated nickel mineralization. Based on the timing of Paleoproterozoic mafic magmatism in the western Superior and Churchill Provinces, at least two periods of magmatism can be recognised that span a period of more than 300 Ma. Several samples of the NNE-trending Molson dyke swarm and Fox River sill indicate that perhaps the most prolific period of mafic magmatism occurred at about 1880 Ma (Heaman et al., 1986; Halls and Heaman, 2000), coeval with main arc magmatism in the Trans Hudson Orogen. A significantly older period of mafic magmatism occurred at about 2100 Ma and remnants of this event have been reported from the Split Lake Block (E-W trending mafic dykes: Heaman and Corkery, 1996), Cauchon Lake (Halls and Heaman, 2000) and in the Churchill Province (Hurwitz gabbro: Heaman and LeCheminant, 1993). The specific objectives of the U-Pb dating of mafic rocks were: a) to provide better temporal constraints for the timing of mafic magmatism in the TNB, b) to investigate the timing of high grade metamorphism in the TNB utilizing U-Pb metamorphic zircon dating of amphibolites, and c) to improve our understanding of the tectonic and economic implications of TNB mafic magmatism.

Table 10.1 Summary of Mafic Samples Collected from TNB

	Sample	Location	Rock Type	Age (Ma)	Status/Comments
1	74253	Grass River (INCO core)	Amphibolite		Crushed, zircon present
2	89227	Spur/Pipe (INCO core)	Gabbro		Crushed, zircon present
3	89234A	Mystery Lake E (INCO core)	Granodiorite	1875±2	Emplacement age
4	89234B	Mystery Lake E (INCO core)	Gabbro		Crushed, zircon present
5	98-98-19-1	Mid Lake	Gabbro	1780±6	Metamorphic age
6	98-98-25-1b	Soab	Gabbro	1761±8	Metamorphic age
7	98-98-031-1	Upper Ospwagan Lake	Gabbro	1750±15	Metamorphic age
8	98-98-039-1	Taylor River	Gabbro with sweats		Crushed, zircon present
9	98-98-50-1	Halfway Lake	Amphibolite	1755±3	Metamorphic age
10	98-98-91-1	Grass River	Gabbro		Unprocessed
11	98-98-91-2	Grass River	Pyroxenite		Crushed, no zircon
12	98-98-110-1b	Thompson South Pit	Gabbro		Unprocessed
13	CB97-190	Paint Lake	Pyroxenite	1885	Emplacement age
14	CC9801-2	Bah Lake	Amphibolite		Unprocessed
15	CC9801-3	Bah Lake	Amphibolite		Unprocessed
16	KNT99-02	Sipiwesk Lake	Gabbro	1885±2	Emplacement age
17	98-99-100-2	Molson Lake	Gabbro	1880	Emplacement age
18	98-99-226-3	South of Fox River Belt	Meta-diabase		Crushed, zircon present
19	RP95-15a	Rabbit Point			Crushed, no zircon
20	RP95-15b	Rabbit Point			Crushed, no zircon
21	98-97-228-1	Carrot River	Gabbro	1891±1	Emplacement age

10.2.2 Sample Selection

A large number of the main mafic and ultramafic sills that are known to outcrop in the TNB and western Superior Province were sampled for U-Pb geochronology (a total of 21 samples). The locations of these samples are illustrated in **Figure 10.1**. The majority of these samples were collected from the TNB and generally represent medium- to coarse-grained amphibolites, gabbros and ultramafic rocks (**Table 10.1**). The one obvious exception to this is the Mystery Lake granodiorite core sample 89234A. Other samples included in this study that are located outside the TNB include the Carrot River dyke (98-97-228-1), Bear Island dyke in Sipiwesk Lake (KNT99-02), an E-W trending mafic dyke just south of the Fox River sill (98-99-226-3) and a diabase dyke from the type locality on Molson Lake (98-99-100-2). The majority of the samples were collected in collaboration with Dave Peck as part of the compilation of the MEM geochemistry database. One sample of an ultramafic sill at Paint Lake (CB97-190) was collected with the assistance of Joseph Macek and two samples of drill core from mafic sills at Rabbit Point were provided by Peter Theyer.

At the time of writing, nine of the twenty-one samples collected during the project have been fully processed for U-Pb zircon/baddeleyite age dating, eight others have been crushed and zircons extracted from six of them for dating (still in progress), and four have yet to be processed (**Table 10.1**). Three of the collected samples (98-98-91-2, RP95-15A, RP95-15B) do not contain visible zircon or baddeleyite.

Two types of zircon were identified in the investigated samples: a) colourless equant and often anhedral crystals that are interpreted to be of metamorphic origin (in many cases this is corroborated by their low U content, low Th/U ratios, and young U-Pb ages <1800 Ma), and b) colourless shards and partial prismatic forms that are interpreted to be of primary magmatic origin (corroborated by their high Th/U ratios, typically >1).

10.2.3 U-Pb Results

A summary of the U-Pb zircon age results for mafic magmatism in the TNB and the western Superior Province in general is presented in **Table 10.1**. Most of the new results are preliminary and research is continuing as part of a M.Sc. dissertation. Obtaining precise and accurate U-Pb dates for the emplacement age of these samples hampered by the significant metamorphic overprint that has either resulted in substantial Pb-loss and/or new metamorphic zircon growth. This overprint causes the U-Pb analyses to be distributed along a short mixing line between the time of zircon formation and the time of metamorphism. This phenomena is most notable in the Paint Lake pyroxenite results but is also considered responsible for the slight scatter obtained for the Mystery Lake granodiorite. Primary crystallization ages have been obtained for four samples: the Mystery Lake granodiorite (1875 Ma, zircon), the Paint Lake pyroxenite (1885 Ma, zircon), the Bear Island gabbro dyke (1885 Ma, zircon), and the Carrot River diabase (1891 Ma, baddeleyite). In addition, a preliminary 1880 Ma age has been obtained for a diabase dyke at the type locality on Molson Lake. These ages are similar to the U-Pb zircon age of 1880±2 Ma reported by Hulbert et al., (1998) for the Setting Lake ultramafic sill.

A surprising result from this study is the relatively young U-Pb ages that have been obtained for four samples: Mid Lake gabbro (1779 Ma), Upper Ospwagan Lake gabbro (1750 Ma), Soab Lineament gabbro (1761 Ma) and Halfway Lake amphibolite (1755 Ma). Because the zircon in these samples tends to be subhedral, colourless, and possess low-uranium contents (<50 ppm), these ages are interpreted to reflect the timing of high-grade metamorphism

10.2.4 Discussion

The U-Pb zircon/baddeleyite results for the nine mafic and ultramafic samples from the TNB and adjacent western Superior Province document two discrete periods of zircon growth (**Fig. 10.2**). The older ages (1875-1891 Ma) were obtained on samples where the zircon displays characteristics of primary magmatic zircon and are interpreted as good estimates for the timing of magmatism. This age range coincides exactly with the range of emplacement ages previously reported for unmetamorphosed Molson dykes (Heaman et al., 1986; Halls and Heaman, 2000), the Fox River sill (Heaman et al., 1986) and an ultramafic sill at Setting Lake (Hulbert et al., 1998). At present, there is no geochronological evidence for mafic magmatism older than 1885 Ma in the TNB, despite the existence of circa 2.1 Ga mafic magmatism in the Split Lake Block (Heaman and Corkery, 1996) and at Cauchon Lake (Halls and Heaman, 2000). Although mafic magmatism as young as 1864 Ma has been recognised in the Winnipegosis Belt (Hulbert et al., 1994), similarly young mafic rocks have not been positively identified in the northern TNB. A gabbro dike that crosscuts the gneiss-metasediment unconformity in the Thompson South Pit yielded a preliminary age of 1855+/-13 Ma (Bleeker and Hamilton, 2001). Although this age is considered to be a minimum age, and the authors indicate that the true age is probably less than 1880 Ma, the precision of the result renders it identical, within error, to the 1864 Ma age obtained for the ultramafic unit of the Winnipegosis Belt. Therefore, this result is taken to support the view that the "Molson event" lasted from 1891 Ma to 1864 Ma. In addition, the present study demonstrates for the first time that this event produced a larger variety of rocks types than previously thought, ranging from granodiorite through gabbro to ultramafic lithologies such as pyroxenites.

The 1880 Ma mafic/ultramafic magmatism observed in the TNB appears to be Circum-Superior in distribution, with temporally equivalent magmatism reported from the New Quebec Orogen (Findley et al., 1995, Machado et al., 1997). Indeed, there is a striking similarity between the Paleoproterozoic history of the New Quebec Orogen and the TNB. This includes evidence for rifting between 2170-2142 Ma (the ages for a 2169±4 Ma gabbro sill and mildly alkaline mafic lavas from the Seward Group (Rohon, 1989) and a 2142 Ma rhyolite which is intercalated with the Bacchus Formation tholeiitic basalts), and a younger mafic magmatic event between 1884 and 1874 Ma that includes submarine tholeiitic basalts of the Hellancourt and Willbob formations that are in turn intruded by the voluminous 1884±2 Ma Montagnais gabbroic sills (Findlay et al., 1995, Machado et al., 1997). The age of this mafic volcanism is synchronous with Molson magmatism in the TNB.

The U-Pb results for metamorphic zircon obtained from four of the samples (1750-1780 Ma) are within the range of monazite ages obtained on gneisses and granitoids of the TNB (Machado et al., 1990 and **Section 10.4**). Although zircon is generally considered to have a much higher closure temperature to Pb diffusion than monazite (Heaman and Parrish, 1991), the similarity in monazite and metamorphic zircon U-Pb ages may indicate that either the closure temperature to Pb diffusion in monazite is higher than previously assumed, (maybe even higher than in zircon, as recently suggested by experiments by Cherniak and Watson, 2001), or the region experienced multiple periods of medium to high grade metamorphism, during which the U-Pb system in previously grown monazite was not disturbed.

10.3 Geochronology of Detrital Rocks

10.3.1 Introduction

The objective of dating detrital zircon from clastic rocks is to determine the age(s) of the main source rocks. The pattern of ages can help to unravel paleogeographic reconstructions and, indirectly, elucidate the tectonic setting of sedimentary basins. Whereas the determination of the paleogeography and tectonic setting of the basin filled by the detrital rocks of the Ospwagan Group may help in characterizing the tectonic environment under which mafic-ultramafic magmatism took place, the determination of the paleogeography of the Grass River basin is essential to elucidate the relationship between the TNB and the Reindeer Zone of the Trans-Hudson Orogen. Additionally, the patterns of detrital zircon ages for the Ospwagan and Grass River Groups will permit the delimitation of the western boundary of the TNB in its southern extension, where it is covered by Paleozoic sediments. Such information is important for the delineation of the most likely exploration targets.

10.3.2 Provenance of Ospwagan and Grass River Groups Sediments

10.3.2.1 Ospwagan Group

This group is composed of five formations that represent two different sedimentary environments. The lower sequence of clastic and chemical sedimentary rocks (Manasan Formation-Thompson Formation-Pipe Formation) is typical of sedimentation on a stable platform, whereas the upper sequence of turbidites and the volcanic rocks (Setting Formation-Bah Lake assemblage) are indicative of tectogenic basin filling. This observation, together with the lack of typical rift-filling sequences, suggests that the western boundary of the Superior Province was a passive margin until the time of deposition of the Setting Formation, when it became an active margin.

Ages of 191 detrital zircons from four samples of the Manasan Formation from the Manasan Quarry and the Thompson 1C pit are mostly in the 2.5-2.9 Ga interval and define a modal class at 2.6-2.7 Ga (**Table A8.1**, **Fig. 10.3**). The youngest age, 2235±45 Ma, is the maximum age for the sedimentation of this unit. Only 9 zircons were recovered from a sample of Pipe Formation and they are all in the 2.4-2.6 Ga interval. From the Setting Formation, sampled at Setting Lake, 116 zircon grains were analysed and their ages define a modal class at 2.7-2.8 Ga. The youngest age obtained for these grains (2490±70 Ma) is older than the 2235 Ma age and does not help to limit the timing of sedimentation of the Setting Formation. The sources that fed the Manasan Formation, as represented by the outcrops in the Thompson South Pit and at the Manasan Quarry, were more homogeneous in age than those that contributed detritus to the Setting Formation at Setting Lake. Also, whereas the modal class for the zircon ages for the Manasan Formation is 2.6-2.7 Ga, it is 2.7-2.8 Ga for the Setting Formation (**Fig. 10.3**). This, together with the greater dispersion of ages in the younger unit (Setting Formation), and the similarity with the distribution of U-Pb ages for the western Superior Province (**Fig. 10.4**; compiled from data in Skulski and Villeneuve, 1999) may indicate that either a larger area of the Superior Province was being eroded by the time of deposition of the Setting Formation, or older units became available for erosion at that time. The younger modal class in the Manasan Formation is compatible with sedimentation on a stable Superior margin during which the detrital input was dominated by the erosion of the adjacent 2.64-2.68 Ga Pikwitonei Domain. The change to tectogenic filling, represented by the Setting Formation, could have been accompanied by a change in the drainage pattern such that more of the detrital component was derived from an older source in the interior of the Superior Province. In conclusion, the pattern of detrital zircon ages is coherent with the two sedimentary environments represented in the Ospwagan Group.

The 2235 Ma age cited above is older than the 1974±50 Ma age reported by Bleeker and Hamilton (2001) for a detrital zircon from a metagreywacke interlayered with volcanic rocks "high up in the stratigraphy" of the Ospwagan Group. This result needs confirmation as it is the only Proterozoic age obtained by these authors for a sample with a very low zircon yield. If this age is confirmed, then it, together with the 1855±13 Ma age obtained by the same authors for a mafic dike that crosscuts the Manasan Formation in the Thompson South Pit, would place the end of the sedimentation of the Ospwagan Group in the 1.97-1.86 Ga interval.

10.3.2.2 Grass River Group

LA-ICP-MS $^{207}Pb/^{206}Pb$ ages for 116 zircon grains extracted from eight samples from the Ga and Gc clastic units fall into two main groups: 1.7-2.0 Ga and 2.4-2.6 Ga (**Table A8.2**, **Fig. 10.5**). The youngest ages are in the 1780-1725 Ma range and may indicate that the detritus feeding the Grass River basin was derived from (already metamorphosed) Kisseynew Domain units. However, given the relatively large errors inherent in the method, these young ages will have to be confirmed by ID-TIMS.

The distribution of detrital zircon ages for the Grass River Group metasedimentary rocks is similar to that obtained for the Burntwood and Missi Groups (Machado et al., 1999) and for an arkose from the Sickle Group (Machado, unpublished) suggesting that the source rocks were the same or of the same age as those that fed those groups (**Fig. 10.5**). The scarcity of zircons with ages similar to those found in the Ospwagan Group is striking (**Fig. 10.6**) and indicates that the source rocks for the Grass River Group sediments were mainly located in the Reindeer Zone of the Trans-Hudson Orogen. The results are generally consistent with the picture that is emerging from the stratigraphy of the Ospwagan and Grass River Groups, as described in **Section 5.3**.

10.3.3 Defining the Western Boundary of the Southern TNB

Following a request from Falconbridge Ltd. for help in defining the western boundary of the TNB in the southern extension of the belt, in September 1999 seventy-five samples of detrital rocks were collected from fifteen drill holes in collaboration with Kevin Wells (Falconbridge). All samples were processed and $^{207}Pb/^{206}Pb$ ages are presented for 51 zircons from 6 holes (**Table A8.3**). Samples from two holes were devoid of zircon. The work could not be completed in time for this report owing to a breakdown of the Isoprobe mass spectrometer. Once the instrument is running, the remaining samples will be analysed and the data forwarded to the sponsors in a separate report. The criteria used to define the western TNB boundary are based on previous work that showed that the Grass River and Kisseynew units contain mainly Proterozoic detrital zircons, whereas all the analysed units of the Ospwagan Group which contain almost exclusively Archean zircons.

Forty-five detrital zircons from holes BL99-275, WL94-81 and WL99-265 yielded Archean ages falling mainly in the 2.6-2.7 Ga and 2.7-2.8 Ga classes, whilst all six zircons from holes SM98-233 and SM99-289 yielded ages in the 1.8-1.9 Ga class (**Table A8.3**, **Fig. 10.7**).

These data indicate that the boundary must lie between BL99-275 and SM99-289, a distance of ca. 4 km.

10.4 Timing of Tectonic Events

10.4.1 Introduction

One of the major objectives of this project was to re-evaluate the existing tectonic model for the TNB (Bleeker, 1990b) and, if necessary, propose an alternative interpretation consistent with new structural and geochronological data. In the interpretation of Bleeker (1990b), the key point is the emplacement of an early east verging nappe that was responsible for D1 and D2 phases of deformation. This conclusion was invoked in **Chapter 6**, **Part I** and was adapted by White et al., (1999) to explain their data (their model is sketched in **Fig. 10.8)**.

It was shown in **Chapter 6, Part II** that the kinematic compatibility of all the structures indicates that the TNB strain pattern could have resulted from a single progressive deformation event that evolved from high (partial melting) to low (greenschist) metamorphic conditions. In addition, the overall strain pattern is consistent with west-verging transpressive kinematics, which would have been accommodated by arrays of anastomosing shear zones. It is easier to explain the range and the apparent irregular distribution of metamorphic ages through this model because displacement and fluid activity along specific shear zones could have changed through time. However, the real test for the viability of the transpressive model is provided by the ages of key structural units that are indicative of progressive deformation leading to west-vergent tectonics.

The first section of this discussion (**Section 10.4.2**) describes the results obtained for a pegmatite collected at the eastern boundary of the belt, close to the Pikwitonei Domain, which is interpreted as the eastern limit of the TNB. The second section (**Section 10.4.3**) presents the U-Pb results obtained on six samples that are related to west-verging tectonics and were collected mainly in the eastern part of the belt. The third section (**Section 10.4.4**) reports the results obtained on 5 samples that appear to be related to the last tectonic pulses and were collected within the belt itself (west of highway 6). A total of 64 analyses on these 12 samples are reported in **Table A10.1**. The fourth section presents a summary of the deformation ages obtained in the TNB and a refinement of the tectonic model proposed in **Section 6.10**.

10.4.2 Eastern Boundary of the TNB

Sample TB 20-52a

Background

Whereas the western boundary of the TNB is well defined and corresponds to the so-called "Setting Lake Fault Zone", the eastern limit of the belt is a gradual transition zone where east-west Archean structural trends are progressively reoriented into the northeast-southwest trend of the TNB. One of the questions to be addressed in this project was the definition of the eastern extent of the Proterozoic overprint on the Archean Superior Province. To this end, we collected a sample (TB 20-52a) of pegmatite at the eastern end of South Jonas road, at the junction between the road and the railway (**Fig. 10.9**).

The sample represents a coarse grained pegmatite that was intruded into Archean gneisses. The gneiss in this outcrop is melanocratic and contains a large amount of biotite and garnet. Sub-vertical foliation in the gneiss strikes N 055° with a strike-slip stretching lineation. Folds in the Archean gneisses display horizontal axes and axial planes that are parallel to the foliation. The pegmatite is highly deformed, and displays large, penetrative C-S structures indicative of N 070° dextral shearing. C' bands are also visible and strike N 090°. This outcrop is the only one found in the TNB that shows kinematic criteria indicative of high strain dextral strike-slip motion. Structures in the pegmatite reflect a syn-kinematic cooling.

Results

Three zircons and six monazites from the pegmatite were analysed (**Table A10.1**). Zircon occurs as elongated or conchoidal colourless and limpid fragments, possibly representing a single crystal type. Three analyses of these fragments reveal that U and Th contents are relatively homogeneous (U ranging from 66 to 83 ppm and Th ranging from 56 to 64 ppm: **Table A10.1**). Two analyses are concordant with ages of 2669±2 Ma and 2656±2 Ma. The third is slightly discordant (0.61%) and yielded a minimum age of 2674 Ma (**Fig. 10.10a**; **Table A10.1**).

Monazites form large, golden-yellow and transparent grains. Six analyses of monazite are discordant (between 0.59 and 5.1%, **Table A10.1**) and define a discordia with intercepts at 2643±8 Ma and 1879±56 Ma with a MSWD of 1.9 (**Fig. 10.10b**). The large error on the Proterozoic age is the result the low number of analytical data close to the lower intercept.

Interpretation

Results can be interpreted in three different ways: a) the minimum age of pegmatite emplacement was 2674 Ma (the $^{207}Pb/^{206}Pb$ age of the oldest analysed grain 52a.1z: **Table A10.1**) and the 2669±2 Ma, 2656±2 Ma and 2643±8 Ma ages for the two other zircons and the upper intercept of the discordia calculated with monazite could represent Archean metamorphic events leading to the formation of new minerals, b) the age of intrusion was 2656±2 Ma, the age of the youngest concordant zircon, the older zircons are inherited, and the younger monazite age of 2643±8 Ma dates an Archean metamorphic event, or c) the upper intercept age of 2643±8 Ma dates the emplacement of the pegmatite and all the other zircons were inherited.

Although it is not possible to discriminate between these three hypotheses on the basis of the zircon analyses, the monazite analyses indicate that the pegmatite experienced >2600 Ma event that was responsible for the discordance of the analytical data at 1879±56 Ma. This latter age is within analytical uncertainty of the ages obtained for syn-tectonic, top-to-the-west, granites and pegmatites that were sampled in the area (see below). As a consequence, the pegmatite is interpreted to be of Archean age, to have experienced a Proterozoic thermal event that was responsible for the opening of the U-Pb system, and the structures preserved within it to have formed during syn-emplacement deformation. The most important point is that the monazite yields an age of 2643±8 Ma and was not totally reset by Proterozoic metamorphism. This indicates that it probably did not reach 700°C, the generally accepted closure temperature for the U-Pb system in monazite (Parrish, 1990). Because the pegmatite was collected in the area where the east-west Archean trend is reoriented to the northeast-southwest trend of the TNB (**Fig. 10.9**), its location marks the eastern boundary of the TNB.

10.4.3 Timing of West-Vergent Tectonics

Zircon and monazite from six pegmatites and granites were analysed (TB 20-51, TB 99-42, TB 20-08, TB 20-11, TB 20-87a, and TB 20-69). With the exception of sample TB 20-69, which was collected from the northern part of Setting Lake, these samples were collected along the North and South Jonas roads (see sample location in **Fig. 10.9**).

Sample TB 20-51

Background

This sample is from a small granitic sheet that is intrusive into Archean gneisses in a gravel pit located approximately 15 km to the northeast of the junction between Highway 6 and South Jonas road (**Fig. 10.9**). The foliation in the gneisses is variable, strikes between N 170° and northeast-southwest, and dips moderately to the east. Kinematic indicators are poorly developed, but suggest top to the west motion, and some shear bands are filled with granitic material. The sampled granite is clearly intrusive into the gneiss, with melange-like features and local melting of the gneiss along the intrusive contacts. The granite sheet shows a weak magmatic-type foliation with an overall down-dip mineral lineation. Low strain effects after emplacement are confirmed by the absence of metamorphic fabrics in thin section. Small (metre-scale) granitic dikes are intrusive into the gneiss along foliation. In thin section, the primary mineralogy of the granite shows substantial retrogression towards low temperature assemblages (chlorite, calcite, prehnite, muscovite) and hydrothermally modified magmatic magnetites. These observations are interpreted to indicate that granite emplacement occurred during high temperature deformation (represented by partial melting of the gneiss) and top to the west motion. Because the granite is weakly deformed and contains low temperature mineral assemblages, we conclude that emplacement occurred at the end of the high temperature deformation and that the granite was subsequently retrograded.

Results

Six zircon fractions were analysed from this sample and results are reported **Table A10.1**. The zircon separate is very complex and at least four morphological types can be distinguished. Type I (analyses 51.1z and 51.2z) comprises relatively large, rounded, multifaceted, colourless and transparent grains. Type II (analyses 51.3z and 51.6z) comprises small, colourless and limpid, euhedral prisms. Type III (analysis 51.4z) comprises chips, possibly representing detached overgrowths. Type IV (analysis 51.5z) comprises large, colourless and limpid grains with prismatic terminations. Zircon compositions are variable, with low U and Th contents (ranging from 39 to 173 ppm and from 21 to 199 ppm, respectively) and Th/U ratio that vary from 0.26 to 1.2 (**Table A10.1**). The low U contents of the mineral prohibits the analysis of single grains (except for the largest grains 51.2z and 51.5z) and thus, analyses were performed on multigrain fractions (between 2 and 4 grains each: **Table A10.1**).

A discordia calculated without 51.2z has a MSWD of 6.7 and yields intercepts at 2732±31 and 1838±32 Ma. The errors and the MSWD of these ages can be lowered if analysis 51.3z is also removed from the calculation; intercepts at 1851±10 Ma and 2737 +6/–16 Ma and a MSWD of 0.52 are then obtained (**Fig. 10.11**). Analysis 51.3z plots slightly below the discordia line, possibly because of insufficient air abrasion. A regression calculated using the lower intercept (1850 Ma) and analysis 51.2z yields an age of 2855±12 Ma and a two point regression calculated with analyses 51.2z and 51.3z yields intercepts at 1839±10 Ma and 2854±11 Ma.

Interpretation

Two interpretations are compatible with these results: 1) granite emplacement occurred at 2737 +6/–16 Ma, the older zircon 51.2z is inherited from a 2855±10 Ma old source, and the 1851±10 Ma age dates a Proterozoic event that was responsible for the partial resetting of the U-Pb system in zircon, 2) the granite intruded at 1851±10 Ma and contains inherited zircon from at least two types of older material with ages of 2737 +6/–16 Ma and 2855±10 Ma.

Field observations indicate that: a) the granite sheet was emplaced along the eat-dipping foliation of the country-rocks, b) the emplacement occurred under high-grade metamorphic conditions, and c) the timing of emplacement was late with respect to the development of the fabric in the country rock. On the other hand, the fabric of the country rock is compatible with the regional fabric attributed to the main TNB deformation event. From these observations, we favour the hypothesis of emplacement during the late stages of the high temperature transpressive event (interpretation 2 above). If the intrusion was Archean, zircon discordance would have to be attributed to Paleoproterozoic metamorphism which is incompatible with the observed petrofabrics. The favoured hypothesis is also compatible with the fact that smaller zircons are closer to the lower intercept than the larger crystals. This is the normal case in high temperature resetting of zircon.

Samples TB 99-42 and TB 20-08

Background

Both samples come from a pink to orange, fine-grained granite that is located between Paint Lake and Wintering Lake, close, and possibly related, to the Wintering Lake granite (**Fig. 10.9**). The granite is very weakly deformed, the only deformation features being a slightly developed foliation, possibly of magmatic origin. A petrographic study confirms that the pluton is virtually undeformed and reveals the presence of magmatic magnetite. Thus, this granite presents the same field characteristics and the same mineralogy as the previously described sample TB 20-51.

Results

Two large rounded monazites from sample TB 99-42 (42.1m and 42.2m: **Table A10.1**) were analysed. One yielded a $^{207}Pb/^{206}Pb$ age of 1825 (42.1m, 1.14% discordant) and the other a concordant age of 1846±4 Ma. (**Fig. 10.12a**).

Zircon extracted from sample TB 20-08 occurs as conchoidal, colourless to very light brown fragments. Despite their morphological homogeneity, the analysed grains have variable U and Th contents. Three of them (08.1z, 08.2z and 08.3z: **Table A10.1**) have low U (ranging from 76 to 105 ppm) and Th contents (ranging from 32.3 and 103 ppm), the fourth one (08.4z) is very rich in U (4161 ppm) and Th (318 ppm). Analysis 08.4z displays a very low Th/U ratio of 0.076 and a $^{207}Pb/^{206}Pb$ age of 1798 Ma, the other three analyses having higher but variable Th/U ratios (ranging from 0.31 to 1.12) and older $^{207}Pb/^{206}Pb$ ages, ranging between 2209 and 2624 Ma (**Table A10.1**).

The four fragments do not define a discordia (**Fig. 10.12b**). Because fragment 08.4z differs notably from the other three by its chemical composition, it is possible that this grain formed during the emplacement of the granite and that the other ones are inherited. As the two samples (TB 99-42 and TB 20-08) belong to the same granitic pluton, it is acceptable to regress the analyses from both samples. A regression calculated using zircon 08.4z from sample TB 20-08 and the two monazites from sample TB 99-42 yields intercepts at 1843±8 Ma and 1175±78 Ma with a MSWD of 0.062 (**Fig. 10.12a**). The three zircon analyses 08.1z, 08.2z and 08.3z do not regress with the concordant monazite 42.2m. A regression calculated with this analysis and 08.2z and 08.3z yields an upper intercept at 2693 +16/-15 Ma (MSWD of 0.037) whilst a discordia between concordant monazite 42.2m and zircon 08.1z yields an upper intercept at ca. 2.94 Ga (**Fig. 10.12b**).

Interpretation

The data are interpreted to show that the granitic body was emplaced at 1846±4 (the age of the concordant monazite 42.2m) and that it contains inherited zircons of at least two ages (2.69 Ga and 2.94 Ga). The emplacement age of 1846±4 Ma is within error of the 1851±10 Ma age of intrusion of sample TB 20-51 and confirms the occurrence of granitic magmatism associated with the early deformational events recorded in the TNB.

Sample TB 20-11

Background

This sample is from a pink pegmatite intruded in Archean gneisses and collected in a gravel pit on South Jonas road, approximately 10 km to the northeast of sample TB 20-51 (**Fig. 10.9**). Gneissic foliation strikes N 040° and dips 50°E and the stretching lineation strikes N 060° and plunges 70°NE. In the vertical plane, the foliation is cut and reoriented by shear planes at low angle to the foliation dip. Foliation sigmoids close to the shear bands indicate top to the west kinematics. Two types of pegmatites intrude the gneisses and crosscut the foliation. The oldest one is a white pegmatite that is intersected by a pink pegmatite (from which sample TB 20-11 was taken). Both pegmatites are weakly affected by the same foliation that deformed the gneisses. Because these pegmatites are affected by, but also crosscut the foliation, their emplacement was syn- to late-tectonic. Furthermore, the two pegmatites were affected by low temperature, top to the west shear bands and hence were deformed during the retrograde evolution of the west-verging tectonics in the area. The age of the youngest pegmatite (sample TB 20-11) will therefore give the age of the west-verging tectonics, hence the end of the high temperature deformation in this zone.

Results

Five fractions of zircon and one of monazite were analysed (**Table A10.1**). The zircons belong to a single type that is composed of transparent, light brown to pink conchoidal fragments. The chemical composition of these grains is very homogenous, all analysed fragments having high U and Th contents (U between 1000 and 2300 ppm and Th between 330 and 578 ppm) and a rather constant Th/U ratio (ranging between 0.24 and 0.33). Two zircon and one monazite analysis are concordant at 1820±1, 1815±2 and 1799±1 Ma (11.1z, 11.2z, and 11.1m, respectively: **Table A10.1**; **Fig. 10.13**). The other three zircon analyses are slightly discordant and yield minimum ages of 1817, 1811 and 1802 Ma (analyses 11.3z, 11.5z and 11.4z, respectively).

Interpretation

Field criteria clearly indicate that pegmatite emplacement occurred during the west verging displacement at the end of the high temperature deformation and that the pegmatite was affected by the metamorphic retrogression. U-Pb results can be interpreted in two ways: either the 1799±1 Ma monazite age dates the intrusion of the pegmatite and zircons are inherited, or all the grains crystallized in the pegmatite during the course of its emplacement and deformation, implying that pegmatite intrusion occurred at 1820±1 Ma and that tectono-metamorphic events formed new zircon at 1815±2 Ma and monazite at 1799±1 Ma. In either case, the results obtained for this sample indicate that top to the west tectonics were active from at least 1820±1 Ma to 1799±1 Ma at this location.

Sample TB 20-87a

Background

This sample is from a pegmatite that crops out in a gravel pit in Archean gneisses, southwest of sample TB 20-08 (**Fig. 10.9**). In this outcrop, the gneisses present two foliations: one foliation strikes N 035°-050°, dips 70°W and is associated with a down-dip stretching lineation, the other strikes N 055°, dips 85°E, and is also associated with a down-dip stretching lineation. Sample TB 20-87a is from a pink pegmatitic vein that fills an inverse fault that strikes N 055° and dips 70°E, parallel to the second foliation. The pegmatite crosscuts the first foliation but relicts of it are observed in the dyke. The pegmatite is affected by the second foliation and shows C-S structures that indicate top to the west motion. Consequently, the pegmatite is inferred to have been emplaced late in the establishment of the older foliation and to predates or be coeval with the youngest foliation and top to the west displacement.

Results

Zircons occur as large, sub-euhedral, zoned and colourless crystals, two of which yielded high U (1016 and 1220 ppm) and Th (376.8 and 451.4 ppm) contents and identical Th/U ratios of 0.37 (**Table A10.1**). The two analyses are slightly discordant (1.61 and 1.32% discordance) and yielded an identical $^{207}Pb/^{206}Pb$ age of 1816 Ma (**Fig. 10.13**).

Interpretation

The 1816 Ma $^{207}Pb/^{206}Pb$ age is interpreted as the minimum age of pegmatite intrusion. Given their proximity to concordia, the age probably does not exceed 1820 Ma. This age is also the minimum age for the high temperature deformation and east side up motion in the area.

Sample TB 20-69

Background

This sample is from a small granitic pluton located in northern Setting Lake. The granite shows penetrative C-S bands that indicate inverse, sinistral displacement. Hence, field criteria indicate syn-tectonic intrusion and cooling.

Results

Zircon from this sample is very heterogeneous and at least four types can be distinguished. Zircons belonging to two of these types (I and III: **Table A10.1**) were analysed: four single-grain analyses of rounded, multifaceted, colourless, and limpid crystals (type I: **Table A10.1**) and one analysis of a large, sub-euhedral, cracked, and light brown crystal (type III). This morphological difference is also reflected in the chemical and isotopic compositions: zircons from type I have higher Th/U ratios (0.19 to 0.68 for type I and 0.04 for type III) and older $^{207}Pb/^{206}Pb$ ages (ranging from 2187 to 2272 Ma for type I and 1757 Ma for type III).

These five analyses are highly scattered. Given the morphological, chemical, and isotopic characteristics of zircon 69.5z, it is likely that it crystallized from the melt during emplacement whereas the zircons of the other morphological types were inherited. A regression using analysis 69.5z and a lower intercept of 650 Ma (derived from consideration of results from sample 3000/351 AZ1, see below) yields an upper intercept of 1852 Ma (**Fig. 10.14**), which is similar to ages obtained for granitoid rocks elsewhere in the TNB (described above). The other analyses probably represent inherited zircon with ages estimated at between 2.6 Ga and 3.3 Ga (**Fig. 10.14**).

Interpretation

Results for sample TB 20-69 are inconclusive and further analyses may required in order to understand the U-Pb systematic of this sample. However, because the 1852 Ma age is similar to the 1851 ±10 Ma age of sample TB 20-51, it is possible that it dates pluton emplacement.

10.4.4 Youngest Tectonic Events

The ages of the youngest tectonic events were examined using three samples collected in the western part of the belt, approximately on a N 030° lineament, close to the Kisseynew Domain (**Fig. 10.9**).

Sample 3000/351 AZ1

Background

INCO requested an age determination for a pegmatite in the axial plane of a F3 fold (following the nomenclature of Bleeker (1990b), INCO staff, pers. com., 1998). This pegmatite, collected underground in the T1 Thompson mine at 3000 feet depth, is considered to be intrusive into the Ospwagan Group.

Results

The zircon separate from this sample is very heterogeneous and two types of zircon were analysed: a small, elongated, euhedral, colourless and limpid grain (analysis 351.1z) and a euhedral, flat, brown and zoned crystal (351.2z). The sample also contains numerous large, sub-euhedral monazites of yellow-green to lemon-yellow colour. The two zircon analyses together with the monazite analysis (351.1m) define an upper intercept age of 1773±3 Ma (**Table A10.1**, **Fig. 10.15**).

Interpretation

The age of 1773±3 Ma is interpreted to be the age of pegmatite emplacement. Similar ages were previously obtained on several samples collected in Thompson South Pit (Machado et al., 1990; Bleeker, 1990a).

Sample TNB 99-21A

Background

This sample is from a pegmatite intrusive into the M2 unit of the Manasan Formation (Om2). The pegmatite is boudinaged and folded, but crosscuts a sub-horizontal foliation. A sub-vertical foliation striking N 030° developed in the axial plane of the fold. Hence, field criteria indicate that the pegmatite underwent both the early and the transpressive deformation.

Results

The sample contains very small zircons and a large amount of monazite. Three different types of monazite were distinguished. Type I and II comprise large, euhedral, faceted crystals. Type I is characterized by transparent, inclusion-free and yellow crystals and type II by colourless to light grey crystals that often containing dark inclusions and are partially covered by biotite fragments. Type III is characterized by rounded, "raspberry-like", dark orange or red crystals. Eight monazites of type I and II (analyses 21a.1m to 21a.8m: **Table A10.1**) are concordant or subconcordant with $^{207}Pb/^{206}Pb$ ages that range from 1756 to 1750 Ma and define a discordia with an upper intercept age of 1754±2 Ma (**Fig. 10.16a**). Two type III grains yielded $^{207}Pb/^{206}Pb$ ages of 1720 and 1796 Ma and are 2.14 and 1.33% discordant, respectively (analyses 21a.9m and 21a.10m: **Table A10.1**, **Fig. 10.16a**).

Zircons from this sample are very small, sub-euhedral, colourless, and crack-free. Because of the very small crystal size it was not possible to analyse single grains and 3 to 5 grain fractions were analysed. Results are scattered, variably discordant (between 2.92 and 16.8%) and minimum ages range from 1829 to 2480 Ma (**Fig. 10.16b**). However, analyses 21a.1z, 21a.2z, 21a.3z and monazite 21a.10m define a discordia line with intercepts at 3312 +50/–46 Ma and 1764±7 Ma (MSWD of 0.32). A regression calculated with the monazite 21a.10m and zircon 21a.5z yields intercepts at 2639 +93/-79 Ma and 1755±16 Ma (**Fig. 10.16b**). Analysis 21a.4z falls between these two discordias.

Interpretation

As indicated by field analysis, this sample records both the early and the transpressive deformational events. As type I and II monazites are euhedral and give concordant ages, they date either the emplacement of the pegmatite or a high-grade metamorphic event. If 1754±2 Ma is the emplacement age, then the zircons are inherited, and the early deformation occurred after that age. Alternatively, if the age of emplacement of the pegmatite is Archean, then either: the pegmatite could be as old as ca. 3.30 Ga and underwent two metamorphic events at ca. 2.64 Ga and 1754±2 Ma, the latter will be the age of transpressive tectonics, or the pegmatite was emplaced at ca. 2.64 Ga and grew monazite at 1754±2 Ma during transpressive deformation, implying that the older zircon was inherited. Both hypotheses imply that at least a part of the Ospwagan Group is Archean.

It is not possible to firmly choose between an Archean and a Proterozoic emplacement age for the pegmatite. However, some arguments can be invoked in favour of an Archean emplacement age for the pegmatite. If the pegmatite intruded at ca. 3.3 Ga and underwent two metamorphic events at ca. 2.64 Ga and 1754±2 Ma, then the U-Pb results are in perfect agreement with the field analysis, which indicate that the sample underwent at least two deformation events. Alternatively, if pegmatite emplacement occurred at 1754±2 Ma, then transpressive deformation was younger and has not been recorded by the U-Pb system. This is highly doubtful owing to the very large strain associated with this event (**Chapter 6, Part II**).

If the age of 1754±2 Ma is interpreted as the age of the transpressive tectonics in the area, then it is in agreement with previous ages obtained in Thompson South Pit (Machado et al., 1990; Bleeker, 1990a), Thompson T1 (sample 3000/351 AZ1: 1773±3 Ma), and the metamorphic age obtained on sample TB 99-13d (1741 +37/-36 Ma: see below). In this case, because the pegmatite recorded a previous deformational event, its emplacement age must predate 1754 Ma. At present, the only older ages available for the sample are 1796 Ma obtained on monazite and 2.64 and 3.3 Ga obtained on zircon.

If the pegmatite emplacement age is Archean then at least part of the Ospwagan Group is also Archean, which is not contradicted by the Archean ages for detrital zircon from the Ospwagan Group.

Sample TNB 99-13d

Background

This sample was collected in the northern sector of the Soab Lineament, approximately 5 km south of Pipe pit. The sample is from a ca. 20 cm wide granitic vein that intruded the sedimentary rocks. The vein is intrafolial and weakly foliated. The foliation on the outcrop is N 20-30°, sub-vertical, and in the general trend of the belt. It was therefore postulated during fieldwork that this pegmatite represents a Proterozoic syn-kinematic vein.

Results

Monazites from this sample are of two types. Type I is represented by large, euhedral, flattened, light yellow to dark orange crystals with variable cloudiness. Type II is characterized by rounded, “raspberry-like” dark orange to reddish crystals. Two monazites from type I and one from type II yielded $^{207}Pb/^{206}Pb$ ages of 2667 and 2670 Ma and 2217 Ma (2.8%, 5.7% and 10.33% discordant, respectively: **Table A10.1**). A regression calculated using these three analyses yields intercepts at 2782 +72/-59 Ma and 1741 +37/-36 Ma (MSWD of 0.98: **Fig. 10.17**).

Interpretation

In spite of their poor precision, the ages clearly indicate that the pegmatitic vein is Archean and was metamorphosed at ca. 1.74 Ga. Thus, the field interpretation of a syn-kinematic emplacement for the sample may be valid, but emplacement is interpreted to have occurred in the Archean. Because the pegmatite is parallel to the characteristic foliation of the TNB, the most likely interpretation is that the pegmatitic vein was reoriented parallel to N 030°. This event occurred at ca. 1.74 Ga in this area, consistent with the age of 1754±2 Ma that was obtained on the pegmatitic sample TB 99-21a from Pipe Pit (see above). The Proterozoic deformation that affected this area was weak and of low grade. This as can be inferred from the following observations: 1) deformation appears to be expressed in the form of localized shear bands mainly filled by small-size chloritized biotite, 2) the occurrence in the same outcrop of gneisses with relicts of Opx that are slightly retromorphosed to secondary biotite (sample TNB 99-13c), and 3) the preservation of the Archean age in monazites from type I. Thus, this area appears to represent a more or less passively reoriented zone within the TNB.

10.4.5 Summary

The most significant results and their implications can be summarised as follows:

1) The ages obtained on granites and pegmatites located on North and South Jonas roads clearly indicate that west-verging tectonics and Proterozoic metamorphism occurred in this area from at least 1850 to ca. 1799 Ma. These ages are the oldest so far obtained for metamorphism and deformation in the belt. Furthermore, the structural study indicates that the strain associated with the emplacement of these granitoids is kinematically compatible with the deformation observed everywhere in the TNB. These results therefore unambiguously show that the main tectonic event observed in the TNB began as early as 1850 Ma in the eastern part of the belt.

2) All the samples from the western part of the belt yielded the youngest ages, which range from ca. 1770 Ma to ca. 1750 Ma. In particular, all the ages obtained in the mines are young: 1773±3 Ma for Thompson T1, ca. 1770 Ma for Thompson South pit (Machado et al., 1990; Bleeker, 1990a), 1754±2 Ma for Pipe Pit. These areas are located along a N 030° trend, close to the Kisseynew Domain.

3) These data indicate that tectono-metamorphic activity in the TNB was diachronic. In addition, the diachronism is not simply a function of the distance to the Kisseynew Domain. **Figure 10.19** shows that other factors must control age distribution since the linear pattern is somewhat scattered. As shown in **Figure 10.20**, the ages for syn-tectonic granitoids and for metamorphism are distributed along curved isochronic lines approximately coincident with anastomosed shear zones (as described in **Chapter 6, Part II**). Therefore, it can be concluded that deformation and associated metamorphism and magmatism started in the eastern TNB at ca. 1850 Ma and progressed westward through development of progressively younger shear zones. By 1770-1754 Ma, most of the activity was concentrated on westernmost TNB.

10.4.6 Conclusions

The main conclusions concerning the timing of tectonic events in the TNB are the following:

1) Proterozoic plutonism and deformation occurred in the TNB for more than 100 Ma from ca. 1850 Ma to ca. 1750 Ma and possibly 1720 Ma (e.g. Machado et al., 1990).

2) The overall strain pattern observed in the TNB results from a single event of progressive dextral, top to the W, transpression which started as early as 1850 Ma. The data presented above do not support the contention that transpression was a late tectonic event of restricted significance in the evolution of the TNB (Bleeker, 1990a, 1990b).

3) Transpressive tectonics was diachronic, generally younging to the west. In addition, the occurrences of metamorphic minerals follow approximately the trace of anastomosed shear zones. Further analyses would be necessary to map in detail the development of specific shear zones through time. A three-dimensional reconstitution (**Fig. 6.26**) suggests that anastomosed shear zones are also present at depth, implying that, at the present level of erosion, individual tectonic blocks may record slightly different P-T-t paths. Thus, diachronic metamorphism can explain the pattern of ages of metamorphic minerals and of granitic intrusions present in the TNB.

4) The new U-Pb ages confirm the tectonic model proposed for the belt in **Chapter 6, Part II**. From an exploration point of view, it is important to note that most of the existing mines are located along a N 030° trend in the western sector of the TNB in the zone of the youngest tectonic events (1770-1750 Ma). Whether this area underwent only the latest tectonometamorphic events or all of the tectonic history and erasure of older ages remains speculative. In any case, the results indicate that zones of potentially economic interest underwent the youngest, high strain, greenschist-facies deformation.

10.5 Boundaries of Archean Domains in the TNB

One of the original themes of this project relates to the distribution of Archean gneisses of different ages that were detected by Machado et al., (1990). Specifically, it is of interest to investigate whether the evolution of the TNB was controlled by boundaries between Archean domains, such as the Pikwitonei Domain (characterized by granulite-amphibolite grade rocks with metamorphic ages in the 2.64-2.69 Ga range) and the considerably older (>3.2 Ga) Assean-type gneisses (Böhm et al., 1999). To tackle this problem, Archean orthogneisses (TB 99-27a and TB 99-14) were sampled along the Soab lineament, in the western part of the TNB.

Sample TB 99-27a

Background

This sample was collected approximately 5 km to the south of Pipe pit (**Fig. 10.9**). It contains colourless zircons of several types. Crystals of type I are ovoid and multifaceted. Crystals of type II are also ovoid and multifaceted, but exhibit colourless and thin overgrowths. Crystals of type III are characterized by bi-pyramidal, cracked, and elongated prisms.

Results

Two types of zircons were analysed. A type I zircon yielded a minimum age of 2664 Ma that was 5.6% discordant. Two analyses of type III zircon yielded minimum ages of 2647 and 2694 Ma (7.85% and 14.2% discordant, respectively: **Table A10.1**).

Interpretation

At present, the 2664 Ma age is interpreted as the minimum age of the protolith of the gneiss. If this result is confirmed, it indicates that the sample belongs to the "Pikwitonei-type" gneisses. A Nd model age of 3.18 Ga was obtained for this sample, which indicates that it could be derived by recycling of older Archean crust (**Table 8.9**; **Section 8.7**).

Sample TNB 99-14

Background

This sample of Archean gneiss was collected on the Soab lineament, close to Soab Lake. Zircons from it are heterogeneous in morphology and colour. Three zircon types can be distinguished. The most abundant one comprises prismatic, bi-pyramidal, colourless and cracked grains (type I). Another type includes rounded, multifaceted, colourless and limpid grains (type II). A third type (type III) is composed of small, limpid and crack-free bi-pyramidal prismatic crystals, which were not analysed. Some of the crystals show brown overgrowths. It is not possible to determine optically if these overgrowths occur on a specific type owing to fracturing of the zircon that forms the core of the crystal. This brown type was therefore treated as a separate group (type IV). Two of the analysed zircon crystals (analyses 14.1z and 14.5z) are overgrowths and the third one (analysis 14.4z) was a single brown and ovoid grain with no visible core. It was thus supposed that this grain was only formed by the overgrowth material and that its age would date re-crystallization.

Results

Results are highly scattered and are generally quite discordant (**Table A10.1**; **Fig. 10.18**). The two brown overgrowths 14.1z and 14.5 yield the most concordant analyses (respectively 5.63 and 1.39% discordance), with $^{207}Pb/^{206}Pb$ ages of 1816 and 1802 Ma respectively. A discordia line calculated with these two analyses has an upper intercept of 1797 Ma and a negative lower intercept (ca. -1000 Ma). Analysis of brown zircon 14.4z is 8.92% discordant and yields a $^{207}Pb/^{206}Pb$ age of 2658 Ma. Thus, in spite of their similar colour, these crystals belong to two different types: one Proterozoic and the other Archean. The remaining analyses are highly scattered and discordant and do not define an age (**Fig. 10.18**). Two-point regressions calculated with the most concordant analysis 14.5z and analyses 14.4z and 14.3z point to ca. 2.9 Ga and ca. 3.6 Ga.

Interpretation

Results for this sample are inconclusive owing to the high scatter of the data. However, it is noteworthy that the gneiss underwent a metamorphic event at ca. 1802 Ma. The Archean ages could date either the crystallization of the protolith at 3.6 Ga and a metamorphic event at ca. 2.9 Ga, or date the intrusion at ca. 2.9 Ga and inheritance at 3.6 Ga. The Nd model age for this sample is 3.12 Ga (**Table 8.9**; **Section 8.7**) and does not help in distinguishing between these two possibilities.

10.5.1 Summary

The results obtained for these two samples confirm the previously documented complexity of Archean gneissic rocks of the TNB. Because the determination of the boundaries of Archean crustal blocks would have required more extensive sampling and a much larger number of analyses, it was decided to abandon this objective and to focus the geochronological work on the timing of tectonic events as described above.

10.6 U-Pb Geochronology - Summary and Conclusions

The U-Pb geochronological studies carried out for this project significantly enhance the understanding of the evolution of the TNB. The major achievements and some of their implications are summarised below.

1) Mafic-ultramafic magmatism related to the TNB is now undisputedly dated at ca. 1880 Ma. This magmatic episode, the oldest of the TNB, is most likely at the origin of the Ospwagan Group mafic units and of nickel mineralization. It also produced rare granodiorites, which indicate that magmatism may have been more diverse than previously thought. It is tempting to associate this magmatic event with rifting of the Archean Superior margin and sedimentation of at least part of the Ospwagan Group.
2) The ages of detrital zircons from several units of the Ospwagan Group are mainly Archean and their distribution is similar to the distribution of ages for the western Superior Province. Maximum ages for the deposition of the Ospwagan Group are ~2230

and 1974 Ma (assuming the latter result is confirmed by further analyses). The change from a stable platform to a more active tectonic regime and associated tectogenic sedimentation manifested in the Setting Formation is coherent with the occurrence of mafic magmatism that overlies it. Thus, the age of that formation is probably close to 1891 Ma, the age of the oldest mafic rock so far found in the TNB.

3) There is an age gap of ca. 25 m.y. between the emplacement of the youngest mafic unit at 1875 Ma and the oldest tectonometamorphic event represented by granitoid intrusion at 1851 Ma. Whether this is due to sampling bias or to an absence of rock formation/deformation is not known, but it is a feature observed in the Kisseynew Domain (Machado et al., 1999) and in other orogenic belts.

4) One of the most important contributions of this project is the elaboration of a new tectonic model for the TNB. This achievement is due to a confluence of detailed geochronology, pertinent structural observations, and previous detailed field mapping and illustrates the potential of these techniques when used together. The new model, whereby the overall structure of the TNB results from west-verging, east side up transpressional tectonics, is capable of accounting for the first time for the distribution of ages of granitoids and of metamorphism in the TNB. The older ages occur in eastern TNB, the youngest ones in the west, and the ages are distributed along "isochronic lines" that represent the approximate trace of major shear zones. This is entirely compatible with westerly-directed progressive transpression accommodated in part by an array of anastomosing shear zones.

   Fluid circulation in the shear zones may also account for the occurrence of metamorphic zircon in mafic rocks, thus questioning the concept of closure temperature. It is noteworthy that the mafic rocks with metamorphic zircon are located in the western sector of the TNB, and that the zircon ages are identical to those obtained for metamorphic monazite in gneisses and for zircon and monazite in pegmatites. Therefore, the formation of metamorphic zircon is most likely controlled by fluid circulation rather than by temperature alone.

5) From a mineral exploration point of view, it is noteworthy that all the mines are located in a fault zone where the metamorphic ages are between 1770 and 1750 Ma. In other words, nickel mineralization is associated with tectonism in that age range.

6) In spite of some progress, one of the aspects that remain unclear is the relationship between the TNB and the adjoining Kisseynew Domain. Detrital zircon from units of the Grass River Group is mostly Proterozoic in age and the age distribution is similar to that obtained for the Burntwood, Missi and Sickle Groups. This is taken to indicate that sediments for the Grass River Group originated in the Reindeer Zone. However, structural reconstruction of the group places it facing west as the Ospwagan Group (**Chapter 6, Part I**). This implies that the sources for the Grass River sediments were located to the east, which is incompatible with detrital zircon ages. In addition, metamorphic ages for rocks of the Grass River Group are somewhat older than those found on westernmost TNB, but identical to those for Burntwood metasediments. This suggests separate evolutionary paths until late in the history of the TNB. Thus, further studies are necessary to unravel the relations between the TNB and the Kisseynew Domain.