GS-9

Hudsonian regional metamorphism in the Thompson Nickel Belt, Manitoba (parts of NTS 63J15, 16, 63O1, 2, 8, 9, 16, 63P12, 13, 64A4)

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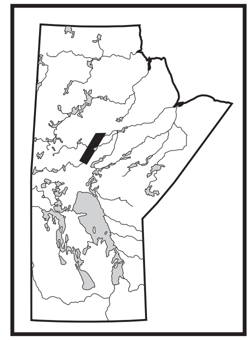

Couëslan, C.G., Pattison, D.R.M. and Macek, J.J. 2007: Hudsonian regional metamorphism in the Thompson Nickel Belt, Manitoba (parts of NTS 63J15, 16, 63O1, 2, 8, 9, 16, 63P12,13, 64A4); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 91–97.

Summary

This report is part of a continuing Ph.D. study on the regional metamorphism of the Thompson Nickel Belt. Metapelitic rocks in the majority of the belt are characterized by upper-amphibolite–facies mineral assemblages (biotite–K-feldspar–sillimanite±garnet). In the northern half of the belt is a central, northeast-trending, trough-like metamorphic low of middle-amphibolite–grade, muscovite- and quartz-bearing metapelitic rocks. The zone of middle-amphibolite–grade rocks extends from the Moak–Mystery lakes area southward beneath the city of Thompson and to the Ospwagan Lake–Pipe mine area. Metamorphic grade increases northwest and southeast away from the central trough. Zones of granulite-facies rocks occur along the northwest margin of the Thompson Nickel Belt and in the Mel Zone–Strong Lake area. These zones are characterized by biotite–cordierite–garnet–K-feldspar metapelitic assemblages and orthopyroxene-bearing semipelitic rocks. The rocks of highest metamorphic grade occur in the Phillips Lake area and in a small zone near Hambone Lake, where orthopyroxene occurs in semipelitic rocks and has been tentatively identified in metabasic rocks. Samples of Ni-Cu ore were collected from the Thompson, Birchtree and Pipe mines to examine the effects of metamorphism on the orebodies.

It is hoped that a better understanding of metamorphism in the Thompson Nickel Belt will lead to a better understanding of the tectonic evolution of the belt. This will lend itself to a greater comprehension of the Trans-Hudson Orogen in Manitoba and to improved exploration strategies. Documenting the Ospwagan Group at various metamorphic grades may help with the identification of these rocks during exploration programs, especially in portions of the belt that have been subjected to higher grades of metamorphism. Differences in metamorphic grade may also have an effect on the mobilization of ore through solid-state, hydrothermal and anatectic processes.

Introduction

The 400 km long by 10–35 km wide, northeast-trending Thompson Nickel Belt (TNB) occurs along the northwestern margin of the Superior craton (Bleeker, 1990a; Hulbert et al., 2005). As part of the Superior Boundary Zone, the TNB marks a segment of the collisional zone between the Superior craton and the juvenile terranes of the Trans-Hudson Orogen. The TNB begins 70 km northeast of Thompson (Zwanzig, 2005) and continues southwest, with the southern half of its total length covered by Phanerozoic rocks. The southeastern margin of the exposed portion of the belt is gradational with the Pikwitonei Granulite Domain. Its northwestern margin is bounded by the Kisseynew Domain of the Trans-Hudson Orogen internal zone.

The TNB is dominated by variably reworked Archean basement gneiss with minor Paleoproterozoic supracrustal and intrusive rocks (Bleeker 1990a, b; Weber, 1990; Hulbert et al., 2005). The Archean basement consists largely of migmatitic gneiss that is believed to be derived from retrogressed Pikwitonei granulite (Russell, 1981; Bleeker, 1990b; Machado et al., 1990; Weber, 1990; Lettley, 2001). The Archean basement gneiss is unconformably overlain by metasedimentary and metavolcanic rocks of the Paleoproterozoic Ospwagan Group (Bleeker and Macek, 1988; Bleeker, 1990a, c). The supracrustal rocks occur in deeply dissected, regional-scale folds or fault slices (Bleeker, 1990a; Weber, 1990).

The Ospwagan Group supracrustal sequence consists, from base to top, of the Manasan Formation, the Thompson Formation, the Pipe Formation, the Setting Formation and the Bah Lake volcanogenic assemblage (Bleeker and Macek, 1988; Bleeker, 1990a, c; McGregor et al., 2006). The Manasan Formation is a siliciclastic sequence of quartzite and semipelite that grades into the overlying Thompson Formation, which consists dominantly of calcsilicate and siliceous marble. The Pipe Formation consists of pelitic schist, sulphide- and silicate-facies iron formations, and siliceous and ferruginous metasedimentary rocks. The Setting Formation is a siliciclastic sequence of interlayered pelitic schist and quartzite. The Bah Lake assemblage consists of mafic to ultramafic volcanic flows with abundant dikes and sills (Zwanzig, 2005). Along the western margin of the TNB, Ospwagan Group rocks are juxtaposed against Burntwood Group metaturbidite of the Kisseynew Domain, with their contact interpreted to be a fault (Bleeker, 1990b).

This report summarizes work undertaken in 2007 as part of an ongoing Ph.D. study into the Hudsonian

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metamorphism of the TNB. The study began with fieldwork in the summer of 2006 and continued in 2007 with finalizing field studies at the Pipe mine and Ospwagan Lake, examining drillcore from throughout the belt and sampling to study the effects of Hudsonian metamorphism on the Molson dike swarm. In addition, samples of ore were also collected in 2007 from the Thompson, Birchtree and Pipe mines to examine the effects of metamorphism on the Ni-Cu deposits of the TNB.

Metamorphism of Molson dikes

The Molson dikes are interpreted to predate Paleoproterozoic metamorphism of the TNB and postdate Archean metamorphic events that have affected the basement gneiss (Halls and Heaman, 2000). Assuming the Molson dikes to be of relatively constant composition, it may be possible to detect variations in metamorphic grade throughout the belt by examining changes in metamorphic mineral assemblages, augmented by phase equilibrium modelling using thermodynamic software such as PERPLEX (Connolly and Petrini, 2002). Samples of the Molson dikes that were collected from Sipiwesk Lake ranged from pristine gabbroic rock in the Pikwitonei Granulite Belt to hydrated and amphibolitized rock affected by varying degrees of deformation within TNB-type gneiss. Samples of plagioclase amphibolite, interpreted as metamorphosed Molson dikes, were obtained from numerous drillcores throughout the belt as well as from outcrop at the Pipe mine and in the Joey Lake area. Because the metamorphism at the Pipe mine is well constrained by spatially associated metapelite assemblages (Couëslan et al., 2006), three Molson dikes were sampled along an east–west transect starting east of the open pit, where metapelite rocks are microcline bearing, and finishing west of the pit, where they are quartz and muscovite bearing. Field examination of Molson dikes within the TNB revealed little mineralogical variation, with the exception of the occasional garnet and the possible presence of orthopyroxene in selected drillcores from the Hambone, Paint, Phillips and Strong lakes areas. Greater variations in mineral assemblages may become apparent in thin sections collected from these dikes.

Regional metamorphism

The majority of this summer's field activities involved logging of diamond-drill core, with a few outcrops visited at the Pipe mine, in the Joey Lake area and at Ospwagan and Paint lakes. Drillcore was examined at CVRD Inco Exploration in Thompson and Crowflight Minerals Inc. in Wabowden. Much of the examined core was telescoped, consisting of 2–6 in. (5–15 cm) lengths of core that had been sampled approximately every 10 ft. (3 m). The locations of the studied drillholes were selected to gain information in areas where suitable outcrop is not available, and in an attempt to improve the resolution of interpreted changes in metamorphic grade. The examined core was also selected based on the rock types described in the original core logs, with emphasis being placed on metapelitic rocks and iron formations. The results presented here are based largely on the metamorphic assemblages visible in core and hand sample, and thus should be regarded as preliminary and requiring verification using the microscope and other analytical techniques.

Metamorphic isograds

The majority of the TNB is characterized by upper-amphibolite–facies rocks; however, rocks of middle-amphibolite facies occur in a northeast-trending, trough-like zone that is generally subparallel to the trend of the belt (Figure GS-9-1). Middle-amphibolite–facies metapelitic rocks are characterized by the presence of biotite, muscovite, quartz garnet, staurolite, andalusite and sillimanite. The isograd marking the boundary between middle-amphibolite and upper-amphibolite facies is manifested by the breakdown of coexisting muscovite and quartz to form potassium feldspar, sillimanite and a melt or vapour phase. Middle-amphibolite–facies metapelitic rocks can be further subdivided into lower and higher middle-amphibolite facies by a sillimanite isograd (the prograde formation of sillimanite through the breakdown of andalusite and/or staurolite). Zones of granulite-facies rocks are also present in the belt. These high-grade zones generally occur towards the periphery of the belt and are subparallel to the overall trend of the TNB. The upper-amphibolite– to granulite-facies transition is marked by the appearance of coexisting cordierite and garnet in metapelite and the presence of orthopyroxene in semipelite and metabasite (Pattison et al., 2003).

Middle-amphibolite–facies rocks are recognized in the Moak–Mystery lakes area, under the city of Thompson, in the Ospwagan Lake–Pipe mine area, and in an area north of Soab Lake (Figure GS-9-1). Rocks in the Ospwagan Lake–Pipe mine area are staurolite and andalusite bearing, and appear to be among the lowest grade metamorphic rocks in the belt (Figure GS-9-2). Metapelitic rocks in the Moak–Mystery lakes area and Soab Lake area contain sillimanite, indicating higher metamorphic grade.

Granulite-facies rocks are recognized along the northwest margin of the TNB and Mel Zone–Strong Lake area; in the Phillips Lake area possibly extending to southern Paint Lake; and in a small zone in the Joey Lake area. At the highest metamorphic grades, the Ospwagan Group metasedimentary rocks may become highly recrystallized such that they are almost indistinguishable from the Archean basement gneiss. In these instances, Thompson Formation marble and calcsilicate rocks, and Pipe Formation iron formation and sulphidic sedimentary rocks become important marker horizons for distinguishing and identifying Ospwagan Group metasedimentary rocks (McGregor et al., 2006).

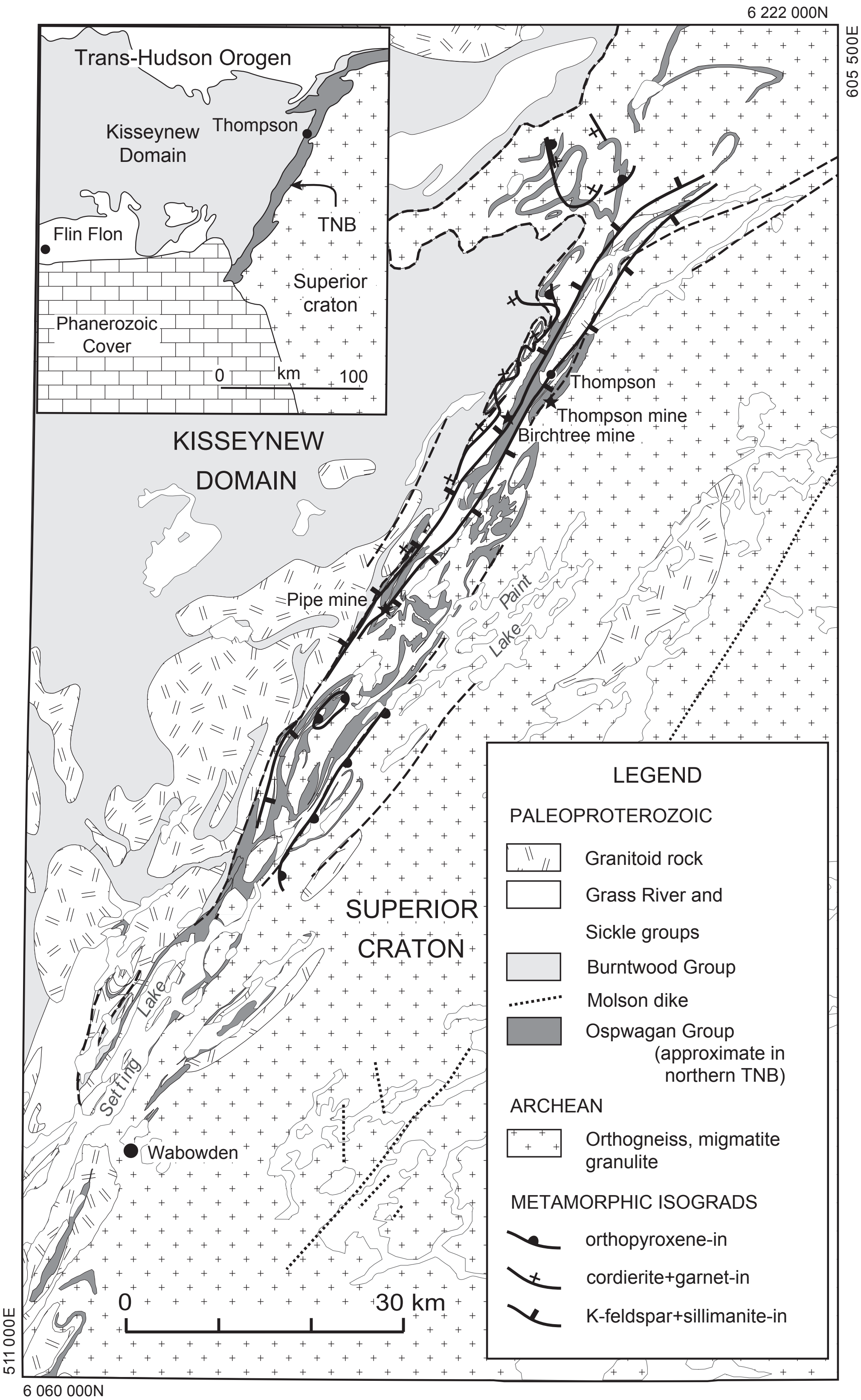

Figure GS-9-1: *Regional geology of the exposed portion of the Thompson Nickel Belt (Zwanzig, 2005). The K-feldspar+sillimanite in isograd marks the boundary between middle-amphibolite– and upper-amphibolite–facies metamorphism in metapelitic rocks. The boundary between upper-amphibolite– and granulite-facies metamorphism is marked by the cordierite+garnet in isograd in metapelitic rocks, and the orthopyroxene in isograd in semipelitic and metabasic rocks.*

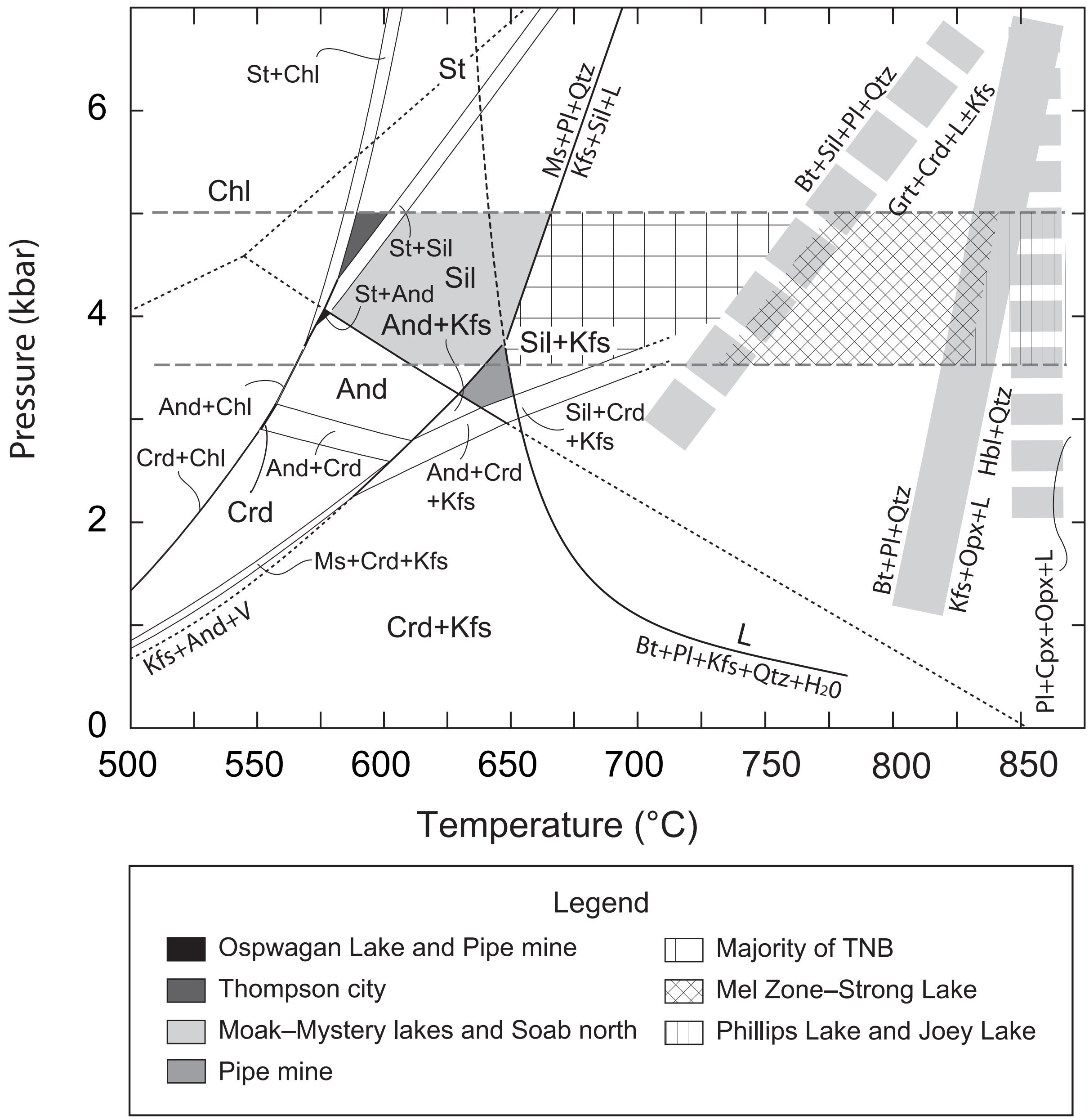

Figure GS-9-2: *Petrogenetic grid showing the metamorphic conditions for mineral assemblages found in the Thompson Nickel Belt. The phase relationships in black lines are for average pelite in the system K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O (Pattison and Vogl, 2005), with broken lines representing metastable assemblages. The reaction curves Ms+Pl+Qtz↔ Kfs+Sil+L and Bt+Pl+Kfs+Qtz+H_2O↔L and the broad reaction curves in light grey are* from *Pattison et al. (2003). Mineral abbreviations: And, andalusite; Bt, biotite; Chl, chlorite; Cpx, clinopyroxene; Crd, cordierite; Grt, garnet; Hbl, hornblende; Kfs, potassium feldspar; L, silicate liquid; Ms, muscovite; Opx, orthopyroxene; Pl, plagioclase; Qtz, quartz; Sil, sillimanite; St, staurolite; V, vapour.*

Pressure and temperature constraints

Pressure-temperature conditions for middle-amphibolite–facies rocks can be constrained based on a thermodynamically modelled petrogenetic grid for world average pelite (Pattison and Vogl, 2005; Figure GS-9-2). The best pressure and temperature constraints in the TNB come from the Pipe mine–Ospwagan Lake area. Peak metamorphic assemblages present in the Pipe Formation metapelite at Ospwagan Lake consist of andalusite–biotite–muscovite–plagioclase–quartz–staurolite±garnet. This assemblage implies temperatures in the range 550–600°C at a pressure of ~4 kbar. A similar assemblage is also present at the Pipe mine. It appears, however, that the Pipe mine was subjected to a relatively steep thermal gradient because approximately 300 m east of the outcrop containing the above assemblage, metapelite horizons in the Setting Formation outcrops contain the metamorphic assemblage biotite–K-feldspar–plagioclase–quartz–sillimanite±garnet (Figure GS-9-3). The K-feldspar appears to have crystallized without the presence of a silicate melt (Couëslan et al., 2006), suggesting temperatures of 610–660°C and a pressure of ~3–4 kbar.

The mineral assemblages in other parts of the TNB provide less constraint on pressure; however, the pressure values indicated above are similar to those obtained by other workers in the belt. Russell (1981) estimated pressures of 4.0–5.0 kbar at Paint Lake using garnet-sillimanite-quartz-plagiolase geobarometry; alternatively, Paktunç and Baer (1986) suggested a pressure of 3.3–4.1 kbar utilizing the same dataset. Paktunç and Baer (1986) also estimated a pressure of 4.8 kbar at the Thompson mine, using garnet-sillimanite-quartz-plagioclase geobarometry. In contrast, Bleeker (1990a) suggested higher pressures of 6.0–7.0 kbar at the Thompson mine and 5.0–6.0 kbar at the Pipe mine.

Assuming the metamorphic pressures in the belt to be between 3.5 and 5.0 kbar, a range of temperatures can be assigned to various parts of the belt (Figure GS-9-2). The majority of metapelitic rocks in the TNB are migmatitic and contain abundant biotite, quartz, K-feldspar and sillimanite±garnet. Such a metamorphic assemblage suggests upper-amphibolite–grade metamorphism and temperatures of ~650–750°C. The lower-grade, middle-amphibolite–facies metapelitic rocks present in the Moak–Mystery lakes area contain sillimanite and muscovite, and reached ~580–650°C. Samples of the Pipe Formation metapelite from beneath the north end of the city of Thompson are staurolite, biotite and muscovite bearing but Al_2SiO_5 free, indicating temperatures of ~575–600°C and pressures above ~4 kbar. Higher grade granulite-facies rocks along the northwest margin of the belt and in the Mel Zone–Strong Lake area attained temperatures of ~725–850°C and are garnet- and cordierite-bearing metapelitic rocks and biotite- and orthopyroxene-bearing semipelitic rocks. The highest temperature rocks occur in the Phillips and Joey lakes areas, where semipelitic rocks contain orthopyroxene and biotite, and orthopyroxene has been tentatively identified in metabasic rocks. In these areas, temperatures may have reached in excess of 800°C.

In general, it appears that the southern half of the exposed portion of the TNB is characterized by widespread, upper-amphibolite– to granulite-facies metamorphism. In contrast, the northern half of the belt is characterized by a trough-like metamorphic low that is oriented to the northeast, subparallel to the trend of the belt. Temperatures appear to increase in either direction away from this central trough, reaching granulite grade along the contact of the TNB with the Kisseynew Domain.

Metamorphism of TNB ore deposits

Samples of Ni-Cu ore were collected from the Thompson, Birchtree and Pipe mines to investigate the effects of metamorphism on ore bodies in the TNB and explore the possibility of sulphide anatexis (cf., Tomkins et al., 2006). Samples of massive sulphide ore, as well as veins and veinlets of sulphide found crosscutting the metasedimentary country rock, were collected underground from the T1 deposit at the Thompson mine. Similar samples were collected underground at the Birchtree mine, along with samples of garnetite, which occurs locally in intimate association with the Ni-Cu ore (C. Pike, pers. comm., 2007). A single sample of ore, consisting of a 3 cm thick vein of massive sulphide in metaperidotite, was collected from the periphery of the open pit at the Pipe mine. Observations made underground suggested at least some of the crosscutting sulphide veins at the Thompson mine are the result of hydrothermal mobilization, as suggested by Chen et al. (1993).

Economic considerations

A better understanding of regional metamorphic data for the Thompson Nickel Belt will aid in the development of a regional tectonic framework for the belt. This is important both for a greater understanding of the Trans-Hudson Orogen in Manitoba and for exploration strategies within the TNB. The local grade of regional metamorphism may also be important, as it may have an effect on the mobilization of ore bodies through solid-state, hydrothermal and anatectic processes. Finally, metamorphic grade affects the characteristics of Ospwagan Group supracrustal rocks. A thorough documentation of their characteristics at different metamorphic grades will greatly increase the ability to recognize Ospwagan Group rocks that have been metamorphosed. This is significant for exploration in the TNB, because the most significant Ni deposits in the belt occur within the P1 and P2 members of the Pipe Formation.

Acknowledgments

The authors would like to thank R. Stewart and C. Pike of CVRD Inco Exploration, and G. Collins and C. Rennie of Crowflight Minerals Inc. for access to their respective company's properties, diamond-drill core and facilities during the 2007 summer field season. The Manitoba Geological Survey and N. Brandson are thanked for providing budgetary and logistical support. Without the assistance of those mentioned above, this project would not be possible.

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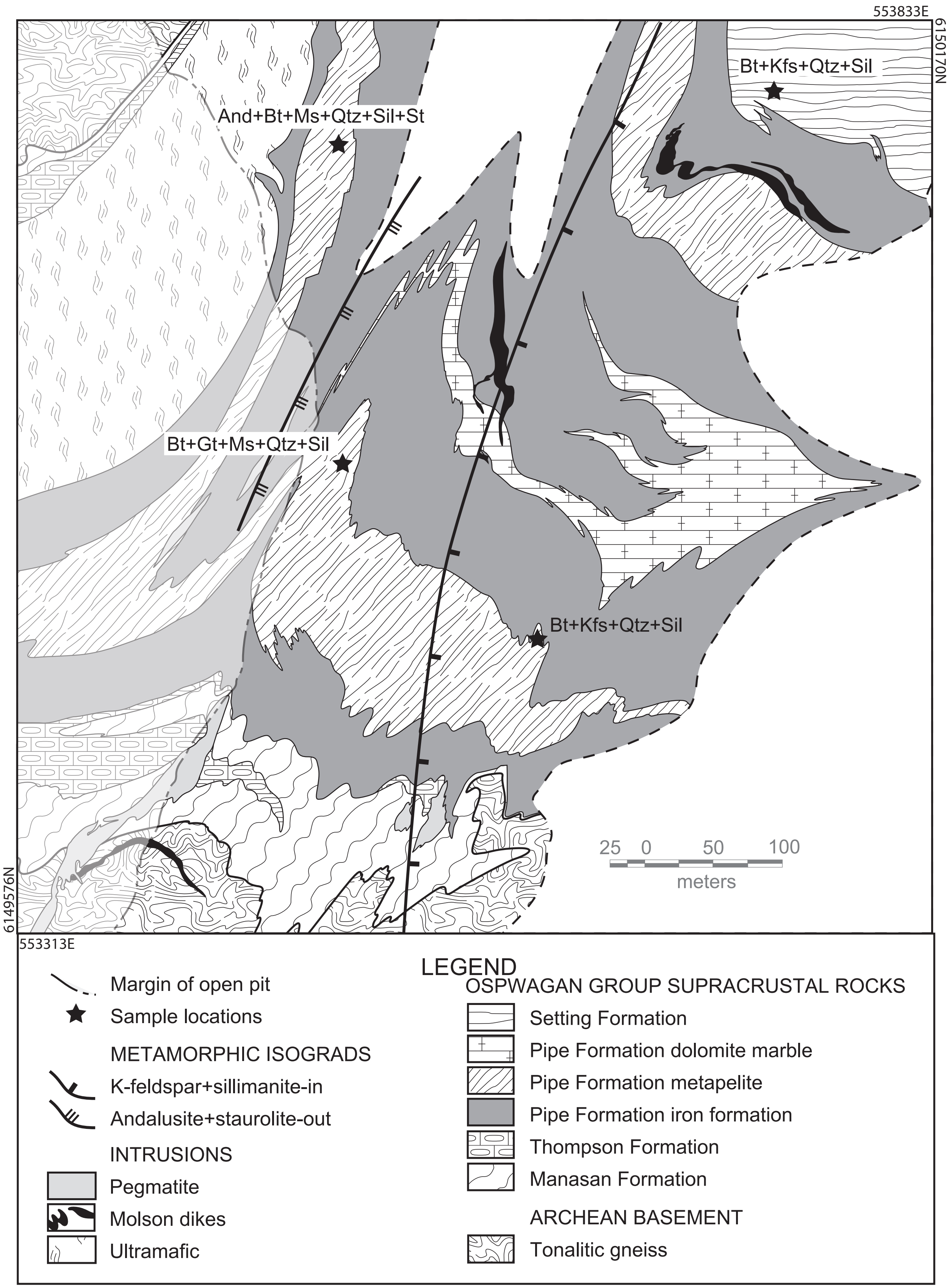

***Figure GS-9-3:** General geology along the eastern margin of the Pipe mine open pit. The metapelite mineral isograd K-feldspar+sillimanite in marks the boundary between middle-amphibolite–grade rocks to the west and upper-amphibolite–grade rocks to the east.*

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