GS-14 STRUCTURAL INVESTIGATION OF THE THOMPSON MINE SOUTH PIT, THOMPSON NICKEL BELT (PART OF NTS 63P/13)

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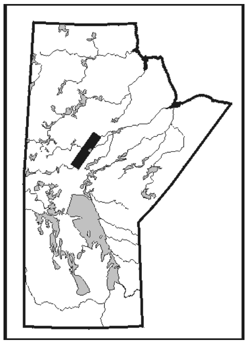

SUMMARY

The Thompson Mine South Pit is located in the southern hinge area of the large doubly-plunging Thompson fold structure in the northern part of the Thompson Nickel Belt (TNB). The TNB is a segment of the external Trans-Hudson Orogen and occurs along the western boundary zone of the Superior craton. Most of the TNB comprises supracrustal rocks of the Ospwagan Group, which unconformably overlie Archean gneisses. In the South Pit, the base of the Ospwagan Group sequence, and the unconformity between these rocks and Archean gneisses, is intruded by the ca. 20 - 40 m thick, (semi) conformable, layered South Pit gabbro. All rocks exposed in the South Pit were deformed by at least four generations of folds, metamorphosed at high-grade conditions, and pervasively retrogressed during uplift. Younging criteria and overprinting relationships indicate that the South Pit gabbro was intruded prior to F_1 nappe emplacement. It appears that the Thompson area hosts mafic intrusions of at least two different ages because elsewhere, a dyke also correlated with the "Molson dyke swarm" postdates F_1. Given the known range of "Molson dyke" ages (2.09-1.86 Ga) in the adjacent parts of the northwestern Superior Province, the existence of both pre- and post-F_1 dykes in the TNB is not surprising.

INTRODUCTION

During the late summer of 1998, the west shoulder of INCO's Thompson Mine South Pit (part of the 2 zone), located above T1 Mine, was remapped at a scale of 1" to 40' and, locally, at 1" to 20'. "Form surface" mapping, based on laser-surveyed grids established by INCO Ltd. and on recently acquired aerial photographs, was undertaken in order to better define the relative timing and styles of the major periods of Proterozoic deformation and metamorphism. Mapping focused on, and adjacent to, a ~40 m wide mafic intrusion, herein referred to as the South Pit gabbro. Based on field observations, the South Pit gabbro is believed to be similar to other mafic dykes in the TNB (see Peck et al., GS-7, this volume). Recent geochronological data for the TNB (Hulbert and Hamilton, written communication, July, 1998) have shown that some of the TNB ultramafic magmatism was coeval with the 1.883 Ga "Molson dykes" (Cuthbert suite; Zhai et al., 1994; Heaman et al., 1986; Bleeker, 1990b). In this note, we evaluate the relative age of emplacement of the South Pit gabbro with respect to deformation and thereby provide age constraints on the early evolution of the TNB.

GEOLOGICAL SETTING

The Thompson Nickel Belt (TNB) forms much of the eastern external zone of the Trans-Hudson Orogen (e.g. Green et al., 1985; Bleeker et al., 1990a, b; Lewry and Stauffer, 1990), and it constitutes the tectonically modified remnants of the Paleoproterozoic continental Superior margin that formed in response to the breakup of a late Archean supercontinent ca. 2.0 Ga ago (Bleeker, 1990a, b; Aspler and Chiarenzelli, 1997, 1998; Heaman, 1997). The rocks of the TNB were deformed and metamorphosed to high grade during the collision of the Superior craton with the domains of the internal Trans-Hudson Orogen associated with the closure of the "Manikewan ocean" (e.g. Stauffer, 1984; Green et al., 1985; Bleeker 1990a, b). The tectonometamorphic evolution of the Thompson Belt, for much of its duration, coincided with the 1.84-1.77 Ga Hudsonian orogeny (Green et al., 1985; Bleeker, 1990a, b).

In the Thompson Mine open pits, a section through reworked migmatitic Archean gneisses and unconformably overlying Paleoproterozoic supracrustal rocks (Ospwagan Group) is exposed (for a stratigraphic column, see Bleeker, 1990b, p. 49). The Ospwagan Group (Scoates et al., 1977) is regarded as a rift sequence that was deposited on the subsiding Superior margin (e.g. Bleeker, 1990a, b). In the Thompson open pits, the Ospwagan Group comprises (from bottom to top): (1) clastic sedimentary rocks of the Manasan Formation (local basal conglomerate, impure quartzites and orthoquartzites, grading upwards into migmatic semipelites); (2) mixed clastic and chemical sediments of the Thompson Formation (calcareous rocks and semi-pelites) and of the Pipe Formation (iron formations, quartzites and pelitic schists); and, (3) clastic sediments of the lowermost (S1) member of the Setting Formation (interlayered quartzites and pelitic schists). Elsewhere in the TNB, the Setting Formation is overlain by mafic volcanic rocks that, in turn, are overlain by clastic sedimentary rocks (Grass River Group; Zwanzig, GS-10, this volume).

GEOLOGY OF THE SOUTH PIT

The stratigraphic sequence examined in this study includes Archean basement rocks, the Manasan Formation, and the T1 member of the Thompson Formation. Previously mapped exposures of the Pipe and Setting formations on the pit shoulders have been lost owing to pit-wall collapse and road construction. The pit walls have not been monitored and stabilized since the early 1990s, so that they are no longer accessible for mapping.

The Archean basement consists of migmatitic biotite gneisses with minor amphibolitic enclaves, both of which are variably banded. Some of the bands are isoclinally folded and transposed. The gneisses in the footwall of the intrusion contain abundant decimetre-scale mafic rafts that may have been derived from the South Pit gabbro. The Archean gneisses are unconformably overlain by basal quartzites (M1 member of the Manasan Formation).

The unconformity between Archean orthogneisses and the Paleoproterozoic Ospwagan Group is exposed at two locations and is sharp. The angles between the banding in the Archean gneisses and the tectonically modified bedding in the quartzite are 12-20° at one location (Fig. GS-14-1) and ca. 80° at the other.

The basal conglomerate, although absent at the exposed unconformity, is very well developed at another location (Fig. GS-14-2), where the top of the gabbro appears to have replaced the top of the Archean basement. Here, the base of the conglomerate appears to be sharp, and there are some "ghosts" of partially melted Archean xenoliths in the uppermost gabbro. The conglomerate is up to 30 cm thick, consists of up to 2 cm long quartz clasts and less abundant, up to 3 cm long feldspar clasts. It is poorly sorted, clast supported, and shows no grading. The dark matrix was determined to be (sub)arkosic (Bleeker,1990b), and the impure carbonate cement gave rise to amphibole that was subsequently retrogressed to biotite. Rare small garnet aggregates (diameter <1 cm) are present in the conglomerate and in the quartzites within 1 m of the gabbro contact. Another conglomeratic horizon (3-10 cm thick), which is laterally discontinuous, appears within the quartzite ca. 1 m above the main conglomerate.

The basal M1 quartzites comprise light grey impure quartzites with intercalated white orthoquartzites. Graded beds and gritty horizons are common. Younging, where recognizable, is towards the stratigraphic hanging wall. The transition of the quartzites to pelitic schists (M2) is marked by dark, strongly carbonaceous quartzites, overlain by thin, light grey weathering quartzites that contain bedding-parallel, white, quartz-feldspar veins and abundant sillimanite nodules (Faserkiesel). All of the M1 quartzites in the South Pit are laminated and reflect alternating melanocratic biotite lamina (< 2 mm) and thicker (0.3 - 8 cm) quartzite or impure quartzite beds. The quartzites, except at their bottom and

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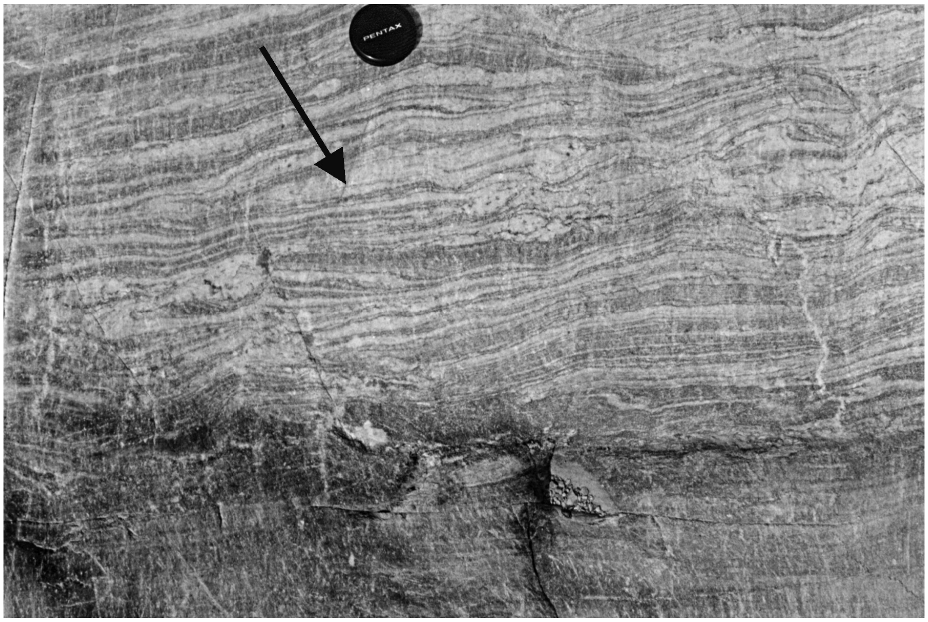

Figure GS-14-1: Banded Archean biotite gneisses (top), unconformably overlain by basal M1 quartzites (bottom). Note the refolded intrafolial fold (arrow).

Figure GS-14-2: Metre-scale S-asymmetric F_3 fold at the base of the M1 quartzite. Note the basal conglomerate (left-centre; immediately to the right of the lens cap).

their top, lack porphyroblasts. The apparent thickness of the basal M1 quartzites, after deformation, is ca. 60 m, considerably greater than their typical thickness of 1-10 m elsewhere in the TNB (Bleeker,1990b). The distribution of abundant marker horizons suggests that this relatively large thickness is not a product of structural repetition related to isoclinal folding.

The basal quartzites are overlain by pelitic schists (M2 member) that, near their base, locally contain carbonaceous quartzites with bands of green calcsilicates, typical of the T1 Formation. This depositional sequence indicates mixed clastic and chemical sedimentation. The calcsilicate-bearing impure sediments appear to grade laterally into schists. In the schists, bedding is only locally preserved; their main anisotropy is a bedding-parallel differentiated cleavage that is interpreted as being the S_1/S_2 transposition foliation (see below). The schists are characterized by ubiquitous red to pink K-feldspar + quartz leucosomes that are associated with biotite-rich melanosomes. These are the only partial melts within the supracrustal rocks of the study area. The comparatively low solidus of the schists may be a result of their high K-content.

The transition to the Thompson Formation is gradational. The base of the T1 member is characterized by impure calcareous quartzites that contain both bands of calcsilicates and thin schistose horizons similar to the M2 member. These are overlain by microcline- and diopside-bearing, thickly banded calcsilicates, and by another thin sequence of impure calcareous quartzites and schists. The latter become more feldspathic towards their top, where they contain leucosomes and thus resemble the M2 schists. The uppermost exposed T1 lithologies comprise a thick sequence of banded calcsilicates.

STRUCTURE

The 2 zone (which includes the study area) of the Thompson South Pit is located in the southern hinge area of the northeast-trending, doubly-plunging, downward-facing F_3 Thompson macrostructure (Bleeker, 1990a; b; Bleeker and Macek, 1996). The Thompson structure refolds the overturned limb of a large F_1 fold nappe, and is thus an antiformal syncline that is cored by the youngest exposed unit (the S1 member of the Setting Lake Formation). The southern termination of the Thompson structure defines a several-hundred-metre-scale W-shaped hinge that plunges moderately to steeply to the south-southeast. The 1C and 1B open pits are located on the eastern long limb of the Thompson structure, which, in the 1A zone, curves into the W-shaped hinge zone. The 2 zone occupies most of the short limb adjacent to this turnaround (Bleeker, 1990a; b; Bleeker and Macek, 1996).

The lithological packages in the 2 zone, according to their position in the large structure, dip on average moderately to steeply to the west-southwest, and define trains of S-asymmetric F_3 folds that are parasitic to the larger Thompson structure.

There are four generations of folds in the South Pit (F_1-F_3 and F_5, following the subdivision of Bleeker, 1990b), the axes of which are moderately to steeply plunging. F_3 and F_5 folds generally plunge in southerly directions, whereas the F_1-F_2 axes plunge into southerly to easterly directions. Rare isoclinal F_1 and F_2 folds range in scale from centimetres to a few metres. Owing to the general lack of both direct overprinting relationships and well-defined axial-plane cleavages associated with diagnostic metamorphic assemblages, most of the F_1 and F_2 folds can only be distinguished on the basis of style. For example, isoclinal folds along layering contacts within the gabbro, believed to be F_1 folds, are flattened and transposed to a much higher degree than neighbouring F_2 folds. In the gabbro, some folds appear to be transected at a low angle by the S_1-S_2 transposition fabric recognized by Bleeker (1990b) that is axial planar to the F_2 folds. In the quartzitic and semipelitic rocks, F_1 and F_2 folds cannot be distinguished. In many accounts, both generations may be developed as centimetre-scale sheath folds with moderate to steep axes.

F_3 folds are the most ubiquitous structures within the South Pit. Most of these folds are open, but some of them are tight, and they generally have no axial-planar cleavage. Metre-scale F_3 folds (Fig. GS-14-2) are characterized by an abundance of small crenulation-like parasitic folds, and by the orientation of their axial planes (generally trending between 030° and 060°, cf. Bleeker, 1990a, b). Mesoscopic F_3 folds generally are, in accordance with their position on the large F_3 fold limb, S-asymmetric. Some mesoscopic F_3 folds are, however, doubly plunging and may be cored by eye structures (sheath folds; Fig. GS-14-3), indicating strongly curvilinear hinges. Associations of minor sheath folds occur near, or in the hinge areas of, larger F_3 "cylindrical" (sheath ?) folds. These sheath folds are, with exceptions, less flattened than the F_1/F_2 sheath folds (Fig. GS-14-3). An axial-planar cleavage, S_3, is only developed in the basal conglomerate. S_3 is defined by a shape fabric in quartz and feldspar grains, and is strictly parallel to the axial planes of the F_3 folds The fabric is accentuated by aligned biotite anastomosing around the clasts. S_3 dips steeply to the southeast and is approximately parallel to the axial plane of the Thompson macrostructure. A composite lineation, which may be defined by stretched quartz grains or aggregates (rods) aligned minerals (amphiboles) or F_3 crenulation axes, is generally well developed and is parallel to the F_3 axes.

Z-asymmetric to symmetrical, open to tight metre-scale folds may correlate with the F_5 of Bleeker (1990b). These steeply plunging folds are characterized by a high amplitude/wavelength ratio. The steep axial planes of these folds trend east-southeast, and thus at a high angle to the structural grain on the large F_3 fold limb. The latest structures are ductile-brittle folds that offset bedding-parallel pegmatites, and brittle features such as faults and joints.

METAMORPHISM

The rocks of the Thompson area were metamorphosed at high grades (above the muscovite-out isograd) during the Hudsonian orogeny (Bleeker, 1990a, b). The thermal peak of metamorphism occurred between F_2 and F_3 (Bleeker, 1990a, b). Calculated temperature estimates for the thermal peak at the Thompson pit vary between 700°C and 775°C at estimated pressures of 5-7 kbar (Bleeker, 1990a, b). The age of the thermal peak is poorly constrained between 1820 and 1790 Ga (Bleeker, 1990a, b; Bleeker and Macek, 1996). The rocks of the Thompson South Pit, however, largely lack mineral assemblages characteristic of high-grade conditions, owing to both the rock composition and strong retrogression. For example, the basal quartzites do not appear to contain sufficient Al for garnet growth. Garnet is thus confined to the contact zone with the gabbro, and may be the result of contact metasomatism during emplacement of the South Pit gabbro. High-grade conditions were prevalent during or after F_2 because, in the M2 pelitic schists, the Faserkiesel overgrew the S_1-S_2 transposition foliation and contain inclusions of aligned biotite grains. In these rocks, the in situ migmatitic sweats are pervasively folded and boudinaged by F_3, and the boudin necks are folded by F_5. In the gabbro, higher temperature diopside-amphibole-garnet assemblages preserved in irregular mafic sweats/veins (deuteric or metamorphic origin) have been replaced locally by biotite and chlorite assemblages.

THE SOUTH PIT GABBRO ("MOLSON DYKE"): ITS RELATIVE EMPLACEMENT AGE AND SIGNIFICANCE FOR TECTONIC INTERPRETATION

The South Pit gabbro constitutes a 20-40 m wide layered intrusion that was emplaced along the Archean-Proterozoic unconformity. Although it is conformable for most of its strike length, the intrusion, at its northern termination, is hosted by Archean rocks and, at its southern termination, by basal quartzites. A preliminary map of the geology of the South Pit gabbro is given in Figure GS-14-4. A petrological, geochemical, and geochronological characterization of the intrusion is currently being carried out by CAMIRO researchers (see Peck et al., GS-12, this volume). Preliminary field observations are presented here.

The intrusion has been subdivided into five broadly conformable and petrologically distinctive subunits, *viz. (from west to east)*: (1) a thin (<2 m), discontinuous "lower" hybrid zone that comprises fine-grained (chilled?) gabbro that locally contains partially melted and locally-derived xenoliths of Archean gneiss; (2) garnetiferous leucogabbro and leucodiorite, up to 30 m wide, that constitutes the main unit within the South Pit gabbro; (3) rhythmically-layered gabbro that comprises a <1 to 10 m wide sequence of cm-thick gabbro + leucogabbro +/- melagabbro +/- pyroxenite rhythmites (Fig. GS-14-5); (4) a <2 m wide massive gabbro; and (5) a well-developed (< 5 m>) "upper" hybrid zone along the gabbro-M1 quartzite contact that comprises ghost-like, partially to almost

Figure GS-14-3: Tubular F_3 sheath fold with southerly plunging axes in basal quartzites.

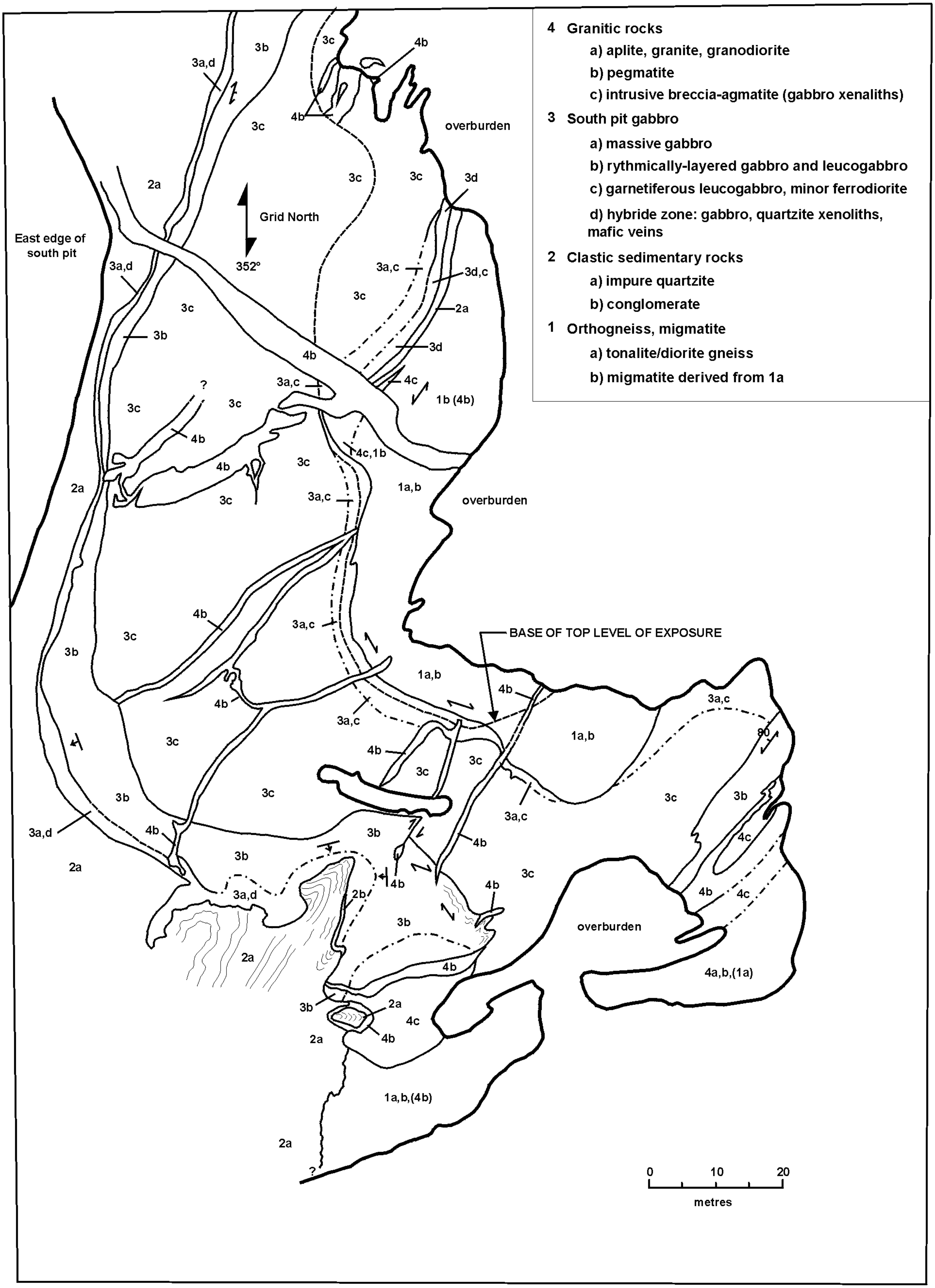

Figure GS-14-4: *Simplified geology of the South Pit gabbro.*

completely digested remnants of locally-derived quartzite or Archean gneiss xenoliths suspended in a fine-grained gabbro to quartz-bearing gabbro matrix (Fig. GS-14-4). The hybrid zone is interpreted as a contaminated chilled margin. The S_0 layering in the South Pit gabbro is partly obscured by the development of a penetrative foliation that intersects the layering at shallow angles (Fig. GS-14-6).

On the basis of the different rock types present on either side of the intrusion, the systematic modal variations within the rhythmically-layered units, the presence of a thicker hybrid zone along the gabbro-M1 contact (east side of the intrusion) relative to the gabbro-Archean contact, and the presence of west-verging scour structures along the contact between the gabbro and the rhythmically-layered unit, we interpret the gabbro as a sill that intruded along (and inflated) the Archean-Proterozoic contact. The roof zone of the South Pit gabbro developed against the base of the Ospwagan Group. Rare miarolitic cavities (diameter ca. 10 cm) near the top of the South Pit gabbro, and vesicles in an apophysis emanating from the gabbro, indicate a relatively shallow intrusion depth.

The distribution of the units suggests that the intrusion, as a whole, is not isoclinally folded. However, like the supracrustal rocks, it contains four generations of mesoscopic scale folds. At one location, a several-metre-scale fold interference pattern comprises a transposed F_1 fold that is refolded by a tight S-asymmetric F_2 fold. The long limbs of the F_2 fold are overprinted by Z-asymmetric open F_3 folds. Open to tight, symmetrical F_5 folds with east- to southeast-trending axial planes and steep axes are developed in favourably oriented, rhythmically-layered gabbro.

On the basis of a set of dykes crosscutting F_1 folds at Pipe II open pit (Bleeker, 1990b), the "Molson dykes" in the TNB were interpreted to postdate the F_1 folds. Implicit in this interpretation is the conclusion that the dykes, if they were all of the same age, must have intruded the overturned limb of the F_1 Thompson nappe (see Bleeker, 1990a, b). Following this logic, if all the mafic dykes in the TNB are coeval, the gabbro and supracrustal rocks in the South Pit should have opposing younging directions and the gabbro should be devoid of F_1 folds; however, this is clearly not the case. Further, the degassing structures in the gabbro (see above) may conflict with a post-F_1 intrusion into rocks that had a minimum pressure of 4 kbar (sillimanite grade; Bleeker, 1990a, b), and thus were at a depth >10 km.

In summary, the younging and overprinting relationships presented here suggest that the gabbro is a shallow layered intrusion that predates F_1 nappe tectonics at the western Superior margin. It thus appears that there are mafic intrusions of at least two different ages in the Thompson area (see Peck et al., GS-12 and Peck and Heaman, GS-25, this volume). Serious problems arise when the term "Molson dyke" is applied, *carte blanche*, to mafic and ultramafic dykes in the TNB. Not only is it unclear

Figure GS-14-5: Rhythmic, cm-scale modal layering in the South Pit gabbro.

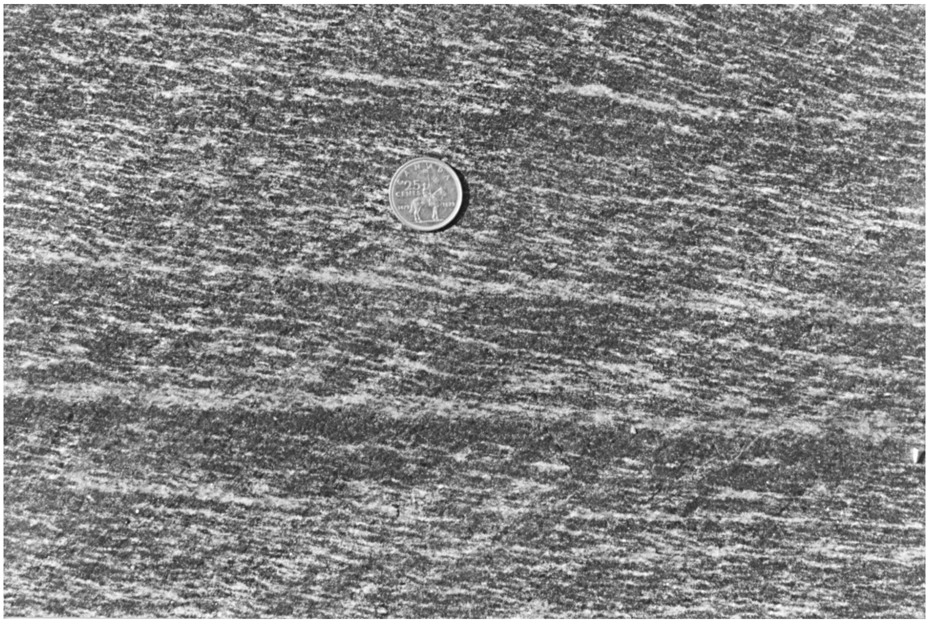

Figure GS-14-6: Development of a penetrative metamorphic foliation at a shallow angle to igneous layering involving cm-scale, diffuse gabbro and leucogabbro bands, South Pit gabbro.

how many TNB dyke ages exist and which, if any, of these dykes are related to the ore-bearing ultramafic intrusions, but the use of the terminology "Molson dyke swarm" has also recently come into question, given that the "swarm" is now inclusive of dykes spanning the period 2.09-1.86 Ga (Heaman et al., 1986; Heaman and Corkery, 1996; Zhai et al., 1994; Peck and Heaman, GS-25, this volume). Although speculative, it is possible that F_1 nappe emplacement is related to the collision of the Thompson belt with the Kisseynew domain after 1.84 Ga (for U-Pb ages, see David et al., 1996, Machado et al., in press).

Ongoing geochronological, lithogeochemical and metamorphic studies of the South Pit gabbro (CAMIRO TNB project; see GS-7 and GS-12, this volume) will provide additional constraints on the age of the intrusion and its metamorphic and structural history.

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