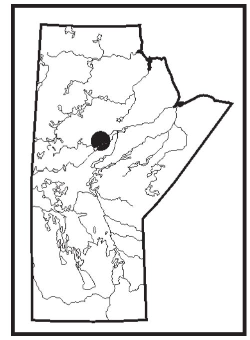
GS-12 Thompson Nickel Belt Project, Manitoba (part of NTS 63P): geology of the South pit, Thompson mine

by J.J. Macek, C.R. McGregor and H.V. Zwanzig



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Summary

The lower part of the Ospwagan Group supracrustal sequence exposed in the South pit of the Thompson mine was mapped. The subdivision of the Manasan and Thompson formations was refined and will serve as a type sequence during regional exploration. A dominant structural feature — large-scale 'mega-boudins' — was documented, as well as related folds and high-strain zones. This newly described structural style may have an influence on the distribution of ore within current and possible future mine sites in the Thompson Nickel Belt, and may serve as a local exploration guide.

Introduction

Due to extensive glacial overburden, the Ospwagan Group supracrustal sequence, which hosts the major nickel deposits in the Thompson Nickel Belt (TNB), is only sporadically and incompletely exposed at naturally occurring outcrops. The best exposures of the Ospwagan Group are those artificially created, either by stripping of quarry cover or by dredging swamps above mine sites. The shoulders of the South pit of the Thompson mine, the last area of such good exposures not mapped in a detail, is located in the heart of the TNB. The area was mapped this summer and the findings are summarized in this paper.

The shoulders of the South pit offer excellent and continuous outcrop for detailed observation of the Archean basement–lower Ospwagan Group lithostratigraphic sequence (the Manasan Formation and part of the Thompson Formation). Nowhere else are these formations so well exposed. Geological mapping was conducted in order to record the details of the lithostratigraphy and ascertain the structural relationship between the basement, the sedimentary cover rocks and the intrusive rocks. This knowledge is useful in the search for additional but still hidden ore pockets in existing mines of the Thompson area, and to fine-tune exploration throughout the TNB. This detailed knowledge of the Ospwagan Group sequence is also crucial during regional exploration of areas where the extension of the TNB is suspected (e.g., the area north and northeast of Thompson), because the same stratigraphic and structural features control ore distribution.

The first part of this paper describes all major lithological units encountered in the mapped area. These are assigned to Bleeker's (1990) lithostratigraphic classification (Table GS-12-1). The M1 and T1 Members are here further subdivided, and the contact between M2 and T1 members is refined. At the South pit, special emphasis was placed on depicting local marker units in order to delineate the large-scale structure.

The second part of the report describes structural features. The mapping revealed large-scale boudins that, due to their size, are not directly apparent in the field. These and related folds and strain zones appear to originate during F_3 folding (Bleeker, 1990). Also described are pre-F_3 folds encountered during mapping.

The final part of the report, 'Economic considerations', discusses possible consequences of the various deformational events on the continuity of the ore zone, including segmentation, repetitions, and lateral and oblique dislocations.

Description of lithological units

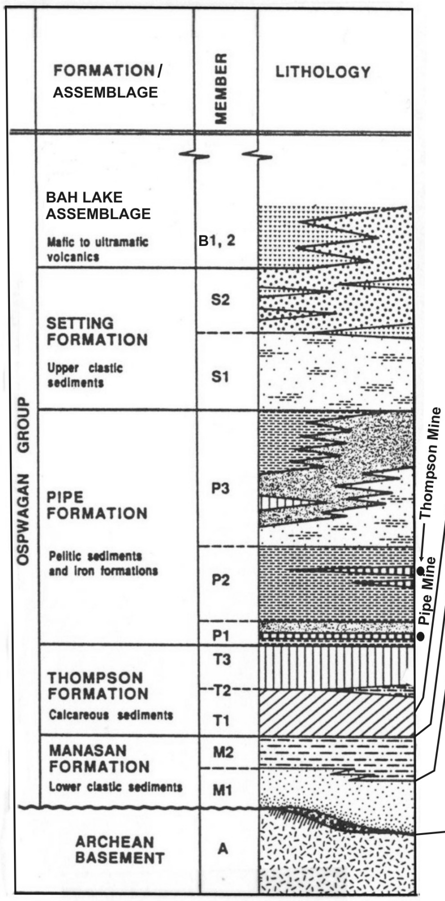
Archean basement

The basement consists of several types of gneiss, including leucocratic quartzofeldspathic gneiss, amphibolite-rich agmatite and feldspar-augen gneiss. The leucocratic quartzofeldspathic gneiss, which is the dominant component of the basement in the map area, is medium grained and weakly to strongly foliated, and contains sporadic grey schlieren, 5–50 cm thick and several metres long, that parallel foliation.

The amphibolite-rich agmatite, which is also common in the map area, consists of plagioclase amphibolite inclusions hosted by the leucocratic quartzofeldspathic gneiss. The inclusions are dark grey to black, medium to fine grained and 5–150 cm in size, and may display a preferred orientation paralleling the gneissosity. They form 30–70% of the migmatite volume. Locally, large plagioclase amphibolite rafts, 5–10 m in size, contain only 5–10% of the leucocratic gneiss in the form of internal schlieren and white aplite or pegmatite veins.

Table GS-12-1: Lithostratigraphy by Bleeker (1990) modified by Zwanzig (2002) on the left and lithostratigraphy identified and mapped at the South pit of the Thompson mine on the right.

THOMPSON NICKEL BELT



SHOULDER EXPOSURES AT SOUTH PIT MINE

MEMBER	SUBMEMBER	DOMINANT LITHOLOGY	LOCAL MARKER UNITS
TI	T1b	Marl	T1b1 Marl, yellow-beige
	T1a	Siliceous marl	
M2		Semipelite wacke	
M1	M1d	Ferruginous arenite	M1d2 Arenite, ferrug., sillimanite bearing
			M1d1 Arenite, ferrug., biotite enriched
	M1c	Calcareous arenite	M1c3 Arenite, layered, weakly calcareous
			M1c2 Arenite, laminated, weakly calcareous
			M1c1 Arkose, calcareous
	M1b	Meta-arkose-subarkose arenite	M1b10 Arenite, quartz- and feldspar-enriched
			M1b9 Arenite, aplite enriched
			M1b8 Arenite, biotite enriched
			M1b7 Arenite, aplite enriched
			M1b6 Quartz arenite
			M1b5 Subarkose arenite
			M1b4 Arenite, light grey
			M1b3 Arenite, carbonate enriched
			M1b2 Arenite, thinly layered, rusty, aplite rich
			M1b1 Arenite, massive layer
	M1a	Metarudite-meta-arenite	Oligomictic conglomerate
ARCHEAN BASEMENT GNEISS AND MIGMATITE			

Feldspar-augen gneiss, which is a subordinate part of the basement, is leucocratic, coarse grained and located in high-strain zones, usually around amphibolite rafts. All three rock types grade into one other and are intruded by metagabbro dikes, which could be part of the Molson Dike Swarm (Scoates and Macek, 1978). Pink pegmatite, aplite and quartz veins, which also cut the Ospwagan Group metasedimentary sequence (Scoates et al., 1977), are the youngest rocks crosscutting and invading the basement rocks.

Ospwagan Group

The South pit of the Thompson mine offers the best exposure of the lower metasedimentary sequence of the Ospwagan Group (e.g., Manasan and Thompson formations). In addition, it clearly displays lithological and structural relations among all of the exposed units.

Manasan Formation

The Manasan Formation is a basal clastic, fining-upward metasedimentary sequence resting on the Archean basement gneiss and migmatite with angular unconformity that varies between 20 and 90°. The sequence is divided into two members. The lower M1 member consists of dominant arenite and subordinate metaconglomerate and granulestone. The upper M2 member is a veined metasedimentary gneiss derived primarily from rhythmically layered semipelite wacke.

M1 Member

In the South pit, the M1 Member is subdivided into four submembers on the basis of changes in composition. In addition, several local markers were mapped in each submember in order to highlight their textural and compositional variations, as well as to highlight overall structure on the map (J.J. Macek et al., work in progress, 2004). All of these differentiated units will not necessarily be observed regionally, due to the variable thickness of the M1 Member and the quality of the outcrops elsewhere.

Metarudite–Meta-arenite (submember M1a)

The metarudite–meta-arenite consists of dark grey to dark purplish grey, thinly layered to laminated wacke, arkosic wacke and arkose. Within a metre above the Archean basement contact, it contains one main oligomictic conglomerate layer (several decimetres thick; Figure GS-12-1a) and, above it, two minor coarse-grained quartzofeldspathic layers that are 2–10 mm thick. Farther up, the sequence becomes thickly and rhythmically layered (5–50 mm thick layers) and enriched in quartz and feldspar relative to mafic minerals. Some layers show faint size grading, which is typically manifested as a light-coloured bottom grading to a bluish grey top that is commonly capped with a thin parting of pelitic wacke. The bottoms of some beds are composed of a coarse-grained quartzofeldspathic aggregate that is pitted by weathering.

M1b – Meta-arkose to subarkose arenite (submember M1b)

The M1b submember consists of a rhythmically layered sequence of arkose to subarkose, the layers ranging from 1 to 10 cm in thickness. These typically alternate with slightly darker weathering, usually pitted, thinly layered intercalations that form 10–50 cm thick groups spaced every 1.5–3.5 m.

Within this monotonous sequence, which forms the bulk of the M1b submember, there are petrographically distinct layers that allow detailed delineation of stratigraphy and structure on a decametre scale. These local marker units, which are shown on the map, are briefly described below.

Massive arenite (local marker M1b1)

This massive arenite layer is the first layer belonging to the M1b sequence. It is a light- to medium-grey layer with a faintly darkened top. It is 40–70 cm thick but, at attenuated limbs of folds, is locally tectonically thinned to 10 cm. This layer is locally crosscut by dextral faults that cause 5 cm offsets.

Thinly layered arenite, rusty, aplite enriched (local marker M1b2)

The thinly layered arenite forms a layer characterized by discontinuous rusty bands at both top and bottom. Abundant rusty patches also occur every 0.5–1 m within this marker. It displays peculiar white siliceous or aplite segregations that resemble deformed letters ‘X’ or ‘Y’ and display preferred orientations. Thin layers and laminae within the arenite are warped around these aplite veinlets and lenses. In some localities, the aplite segregations are almost nonexistent and iron staining is much fainter than normal.

Arenite, carbonate enriched (local marker M1b3)

This arenite is a honey brown weathering, thinly and internally layered marker unit. It is intensively pitted and is 10–70 cm thick. The pitting is caused by the weathering out of minor calcite, which is probably part of saussurite that is replacing plagioclase.

Arenite, light grey (local marker M1b4)

This arenite is characterized by a lighter bluish tint, compared to the general purplish tint of the neighbouring biotite-enriched layers. This colour contrast is subtle but observable on the outcrop and faintly visible on the aerial photos used to map the area. In addition, this unit displays 1–3 cm thick layers, compared to the 2–10 mm thick layers of the biotite-enriched neighbouring units. The bottom of the M1b4 marker contains a pure white, thin (5–20 mm), medium- to coarse-grained quartzofeldspathic layer.

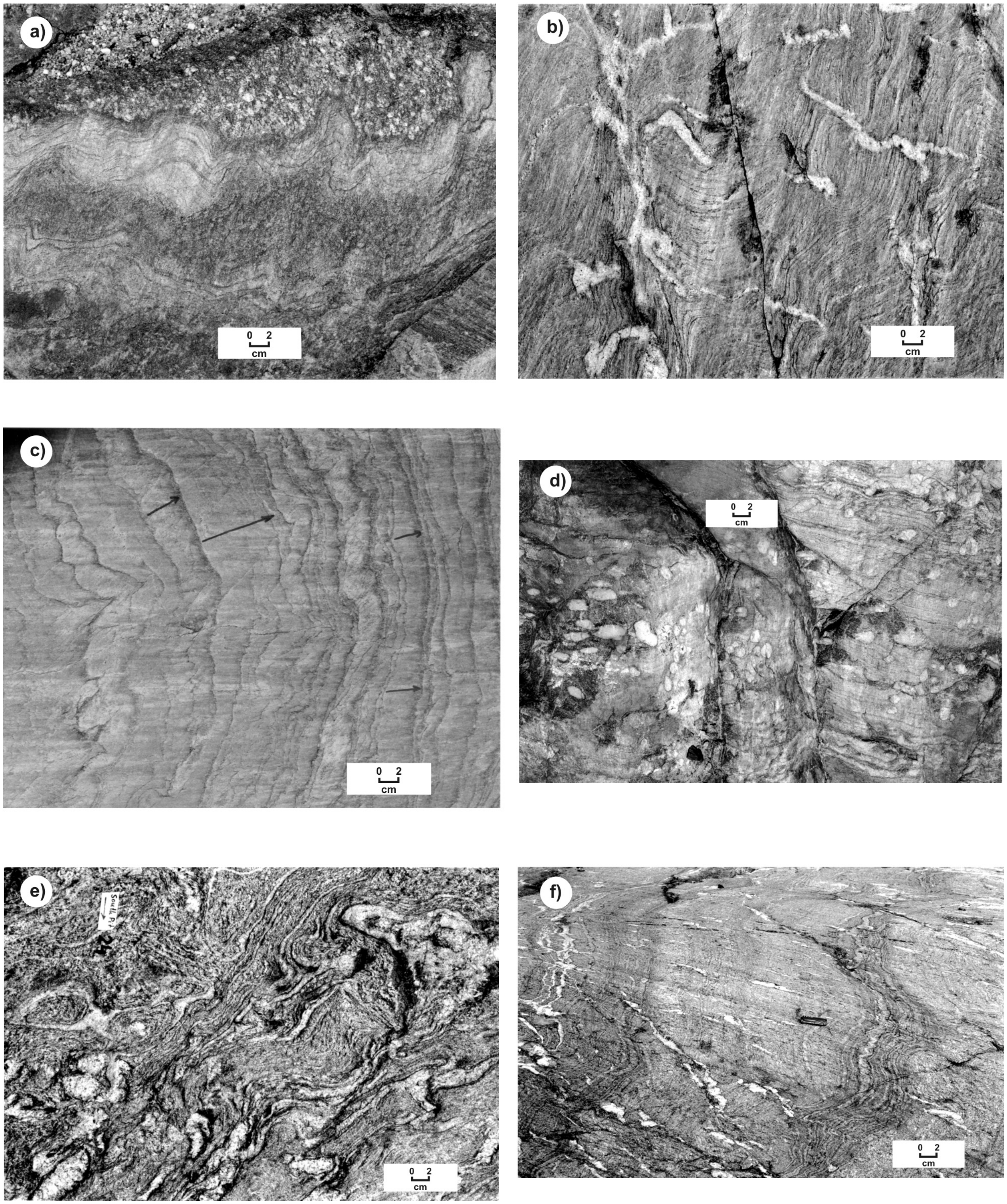


Figure GS-12-1: *Outcrop photographs of the Manasan Formation, South pit, Thompson mine:* ***a)*** *oligomictic metaconglomerate and meta-arenite layers of the M1a submember;* ***b)*** *siliceous veinlets in the M1b7 arenite;* ***c)*** *graded bedding in the M1b9 arenite, with tops indicated by arrows;* ***d)*** *sillimanite-bearing quartzofeldspathic knots in the M1d2 ferruginous arenite;* ***e)*** *M2 biotite gneiss derived from semipelite wacke; and* ***f)*** *faint relicts of the original sedimentary layering in the M2 biotite gneiss, which provided the only means of delineating the fold structure in this otherwise featureless unit.*

Subarkose arenite (local marker M1b5)

The subarkose arenite is a very light grey to white, 2–4 m thick marker unit. Its layers are 2–5 cm thick near the bottom and 10–20 cm thick near the top. The lower contact is gradational over a distance of 10–40 cm, whereas the upper contact is sharp.

Quartz arenite (local marker M1b6)

This is the most silica-rich unit in the sequence and is compositionally close to quartz arenite. It is creamy white to white weathering and layered. The lower contact is abrupt to sharp and, in places, sheared and invaded by pegmatite. The upper contact is always sharp and is locally boudinaged. The lower part of the M1b6 unit is thinly layered, whereas the middle part is thickly layered (10–50 cm thick layers).

Arenite, aplite enriched (local marker M1b7)

This marker unit is grey with a purple tint, thinly layered to laminated and 50–150 cm thick. It contains abundant 'X'- and 'Y'-type siliceous veinlets and aggregates (Figure GS-12-1b), similar to those encountered in the M1b2 marker. They are 20–70 cm apart but often interconnected along the layer surfaces. Oval quartz-sillimanite knots (faserkiesels), 1 cm in size, are common. The lower contact is sharp, whereas the upper one is rapidly gradational.

Arenite, biotite-enriched (local marker M1b8)

This marker unit is dark purple weathering, laminated to thinly layered and 1–2 m thick. It contains a thin greenish (amphibole- or calcsilicate-enriched) layer in the middle.

Arenite, aplite enriched (local marker M1b9)

This arenite (1–4 m thick) is very similar to the M1b7 marker but contains less sillimanite. Some of the knots do not contain sillimanite but rather only quartz and feldspar. The unit is laminated to thinly layered. The upper contact is gradational and marked by an absence of aplite segregations. This marker grades into an ordinary, rhythmically to thinly layered arenite (layers 1–5 cm thick). Some layers are internally laminated and others show faint tops (Figure GS-12-1c).

Arenite, quartz and feldspar enriched (local marker M1b10)

This marker unit consists of half a dozen pale grey, 1–5 cm thick quartzite layers that weather with a bluish cast, in contrast to the adjacent arenite, which displays a darker purplish weathering colour. This marker is visible on the aerial photos and was therefore easily traced and mapped.

Calcareous arenite (submember M1c)

This submember consists of arkose to subarkose layers similar to those in the M1b sequence but intercalated with numerous carbonate-enriched, honey brown to beige-weathering pitted layers. Calcareous intercalations are more abundant in the lower part of the sequence, compared to the upper part where they occur sporadically. Rusty staining occurs only locally.

Calcareous arkose (local marker M1c1)

The calcareous arkose forms pitted, honey brown to beige-weathering, 5–70 cm thick layers that occur either individually or are closely clustered. In some places, individual layers, 2–5 cm thick, are regularly spaced 10–15 cm apart. Elsewhere, a calcareous layer may be thinned to several millimetres or even pinched out. The first significant calcareous arkose layer delineates the beginning of the M1c submember. The contact between M1c1 and M1c2 is placed where the thick layers abruptly cease and the laminated arenite sequence begins.

Arenite, laminated, weakly calcareous (local marker M1c2)

This marker unit is grey to light grey and thinly layered to laminated, with the calcareous component being limited to sporadic thin layers or laminae. Thin layering is the main characteristic of this marker.

Arenite, layered, weakly calcareous (local marker M1c3)

This marker unit is compositionally similar to M1c2 except that it is thickly layered (layers 1–10 cm thick). The bottom of the unit is marked by a thin calcareous arkose layer. The top is just above a thick and folded calcareous arkose layer.

Ferruginous arenite (submember M1d)

Ferruginous arenite forms the upper part of the M1 Member. It represents the transition from the arenite to a semilutite (psammite to semipelite). The lower and upper parts are distinguished on the basis of colour and mineral content.

Ferruginous arenite, biotite enriched (M1d1)

The lower part is very similar to M1b and M1c arenite, except that it displays abundant rusty staining caused by minute amounts of ferruginous minerals (magnetite and pyrite). In addition, the biotite content increases rapidly upward, which gives the rock a dark purple-brown colour on fresh and weathered surfaces. The ferruginous arenite is layered to thickly layered, intensely folded and rusty weathering. It forms rugged outcrops that are typically not suitable for detailed observations.

Ferruginous arenite, sillimanite bearing (M1d2)

This arenite forms the very top of the M1 Member. It is a light grey weathering (with bluish tint), laminated to layered, sillimanite-bearing rock that also displays rusty spots. The sillimanite is present in creamy white oval quartzo-feldspathic lenses that are 1–4 cm in size. (Figure GS-12-1d). Both contacts are sharply gradational.

M2 Member

The M2 Member consists of dark maroon weathering, medium- to coarse-grained biotite quartzofeldspathic gneiss that contains abundant veins, lenses and pods of pink pegmatite. Grey quartz-sillimanite and quartz-muscovite oval knots, 1–7 cm in size, are locally abundant. These knots occur in biotite-enriched diffuse layers or schlieren that are relicts of semipelitic layers enriched in aluminum. Muscovite is a retrograde replacement after sillimanite. In other places, the knots are missing and only regularly spaced pegmatite segregations and veins are present. The gneiss is complexly folded.

The petrographic composition and texture are very similar to some of the Archean basement biotite gneiss, for which it has been mistaken in areas of limited and isolated outcrops or during core logging (Figure GS-12-1e).

The M2 gneiss displays subtle rhythmic layering (on a decimetre to metre scale), which compositionally alternates between biotite-enriched and biotite-depleted layers (Figure GS-12-1f). This original layering is much better preserved in the lower grade metamorphism at the Pipe open pit, where this metasediment is identified as rhythmic semipelite wacke.

The lower contact of the M2 Member (M1d2-M2) is sharply gradational and marked by abundant quartz-sillimanite knots. The upper contact of the M2 gneiss is sharp and marked by a thin concordant pegmatite. It appears that the upward migration of the quartzofeldspathic and pegmatitic mobilizate through the easily permeable M2 Member is stopped and deflected by an impermeable, purplish dark grey, fine-grained, biotite- and amphibole-enriched siliceous layer that belongs to a very different depositional regime. This sharp contact, invaded by the concordant pegmatite, has been chosen as the contact between the Manasan and Thompson Formations. A similar contact is also observed at the Pipe II open pit.

Thompson Formation

The Thompson Formation was deposited on the Manasan Formation and is characterized by the input of calcareous chemical precipitate, ranging between 10 and 90% in volume. Mineralogical composition, colour and textural variations encountered in the Thompson Formation in the 1C pit of the Thompson mine were described by Macek (1986) under ‘calcareous sediments’. The Thompson Formation is divided into T1, T2 and T3 Members. Only the T1 Member, stratigraphically the lowest, is exposed at the shoulders of the South pit. The name ‘skarn’ is a local mine term for the Thompson Formation.

T1 Member

The T1 Member is subdivided into two submembers: the lower T1a siliceous marl, and the upper T1b, a calcsilicate-rich marl.

Siliceous marl (T1a submember)

The siliceous marl is a grey, fine-grained, laminated to thinly layered rock displaying an overall purple tint that coincides with enrichment in fine biotite. Amphibole, biotite, feldspars and quartz are the main constituent minerals. Within a metre above the M2-T1a contact, it hosts several 1–5 cm thick intercalations of green calcsilicate, indicating the onset of the chemical sedimentation process that characterizes the Thompson Formation. The first indication of the chemical sedimentation input is at the contact with the M2 semipelite wacke, where a 1–20 cm thick, dark grey layer enriched in amphibole forms a barrier that confines the migrating pink pegmatite to the M2 pelite wacke (Figure GS-12-2a).

This observation supports a suggestion that the original clastic sedimentation of the porous M2 wacke was at this time complemented by the deposition of a chemically precipitated calcareous component (later recrystallized into amphibole). This calcareous component was precipitating simultaneously with the continuing deposition of the clastic silty or argillaceous components. The commencement of this hybrid process explains the overall biotite abundance, the amphibole enrichment in the dark siliceous layer and its impermeability to pink pegmatite.

Marl, calcsilicate rich (T1b submember)

This unit consists of a sequence of thin to thick layers that vary in colour from yellow-beige to grey-green to brown-green to blue-green, depending on the mineral composition of a given layer. Biotite, diopside, carbonate, feldspars and quartz are common constituents of this unit. The texture varies from medium to coarse grained and the unit, which is strongly foliated to schistose, serves as an excellent regional marker. The yellow-beige variety, occurring in the sequence as two distinct layers, is designated as local marker T1b1.

Intrusive rocks

Melanocratic rocks

Melanocratic rocks exposed in the South pit of the Thompson mine include Archean leuco- and mela-amphibolite rocks and Proterozoic mafic dikes, the latter traditionally assigned to the Molson Dike Swarm.

Archean amphibolite

Archean amphibolite occurs as isolated oval to elongated inclusions, trails of inclusions or elongated subangular rafts that are concordant with the gneissosity in orthogneiss or with the metamorphic layering in stromatic migmatite. A weak preferred orientation of the angular rafts is present in agmatite. The composition of the amphibolite commonly varies from melanocratic to leucocratic plagioclase amphibolite. Amphibole-enriched schlieren in the leucocratic orthogneiss are relicts of a dissolved amphibolite.

Proterozoic mafic dikes

A substantial part of the map area is occupied by a 20–40 m thick Proterozoic composite mafic dike. It consists of three petrographically distinct zones: 1) melanocratic amphibolite (0.1–3 m thick), forming the margins of the dike; 2) layered metagabbro (1–10 m thick), located between the margin and central part of the dike; and 3) garnet leucoamphibolite (5–25 m thick), forming the central part of the dike. This composite dike could be a metamorphic equivalent of a major mafic dike belonging to the Molson Dike Swarm (Scoates and Macek, 1978).

Melanocratic amphibolite

The melanocratic amphibolite, which forms the margin of the dike, is a black, fine-grained rock. The contact between the Archean basement gneiss and this amphibolite is sharp, although it is sheared at some locations. Locally, the amphibolite intrudes the basement rocks as offshoot dikelets several metres long and several decimetres thick. The basement gneiss does not appear to be thermally affected near the dike, nor is there visible indication that the

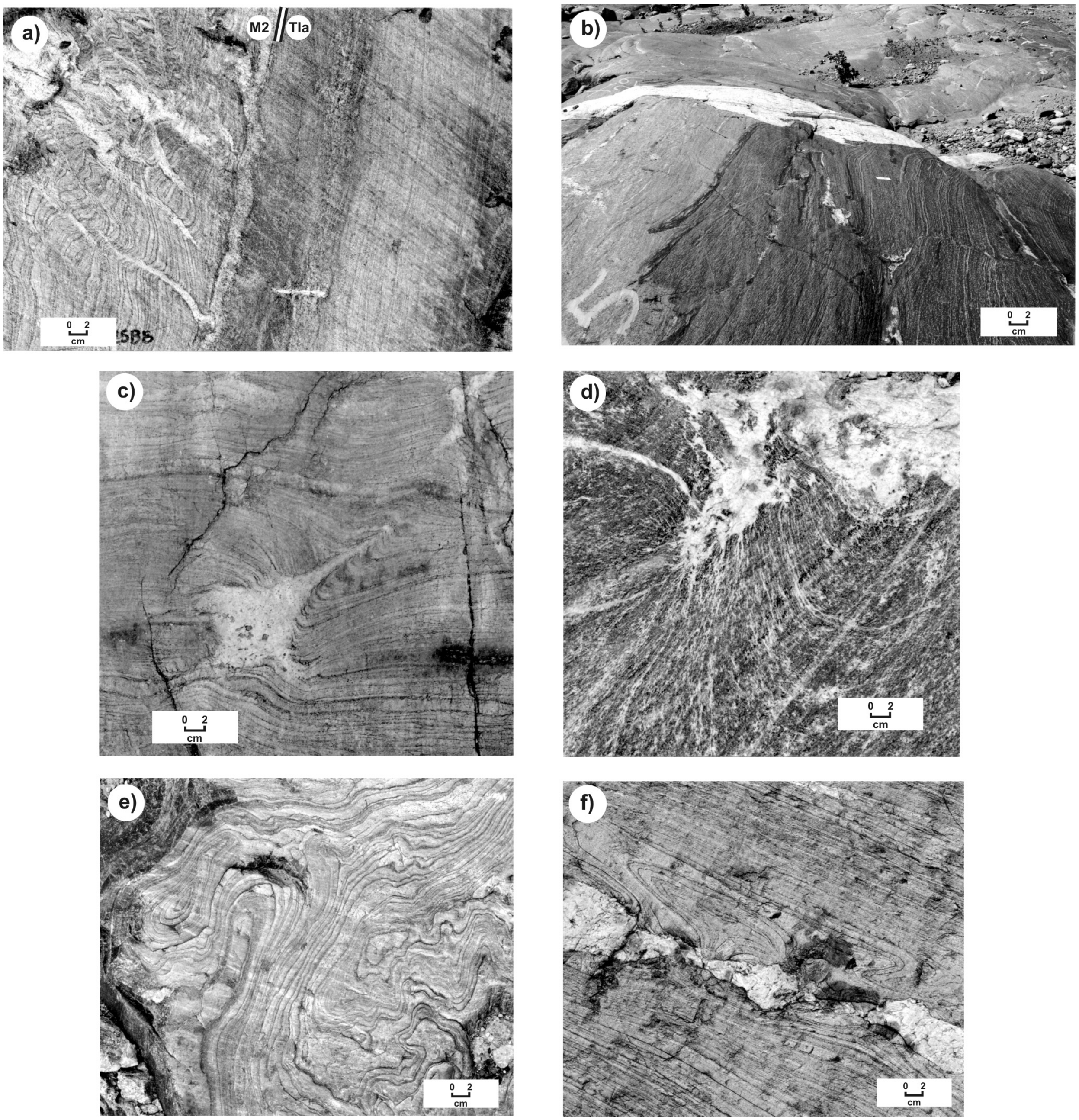


***Figure GS-12-2:** Outcrop photographs of contacts and structures, South pit, Thompson mine: **a)** contact between the Manasan and Thompson formations, located between the concordant pegmatite and the dark, amphibole- and biotite-enriched layer of the T1a siliceous marl; **b)** contact between garnet leucogabbro (left) and rhythmically layered gabbro (right), with pink pegmatite vein cutting across it; **c)** folded layers near the quartzofeldspathic filling of the tension gash in the M1b arenite; **d)** folded layering and foliation in the layered metagabbro near the tension gash filled with aplite and pegmatite; **e)** disharmonic and convolute folds developed in the boudin-neck area; **f)** folds in a high-strain zone in the immediate vicinity of the pegmatite vein.*

amphibolite dikelets are contaminated where they are in contact with the gneiss. The melanocratic amphibolite is interpreted as a chilled margin of the dike.

The contact between melanocratic amphibolite and M1 sedimentary rocks is rarely sharp, but usually forms a hybrid zone (0.1–3 m thick) that displays thermal effects imposed on the sedimentary rocks by the dike. The marginal amphibolite contains numerous inclusions of M1a metasedimentary rocks in various stages of absorption. Some inclusions are still angular, others display amoeboid shapes and still others are simply diffused felsic schlieren. The amphibolite itself is contaminated by the felsic sedimentary material. In addition, this hybrid zone is invaded by later pegmatite and aplite.

The mechanically undisturbed M1a sedimentary rocks (that are in contact with the amphibolite-dominated hybrid zone) are darkened by the thermal effect of the dike. This darkened zone, 10–30 cm thick, is interpreted as hornfels.

Layered metagabbro

The layered metagabbro is a medium- to coarse-grained rock composed of rhythmically alternating, 1–5 cm thick melagabbro and leucogabbro layers (Figure GS-12-2b). The melagabbro layers are dark grey to black, whereas the leucogabbro is light grey. The layered metagabbro is weakly to strongly lineated and locally sheared. The layering is commonly subparallel to the contact.

Garnet leucoamphibolite

The garnet amphibolite occupies the 7–30 m thick central part of the dike. It is reddish green-grey, coarse grained, massive to strongly foliated and locally lineated. Its main constituents are garnet, hornblende, biotite, feldspar and quartz. The premetamorphic composition of this unit could have been leucogabbro or meladiorite.

Leucocratic rocks

Orthogneiss and some pegmatite and aplite are part of the Archean basement. The pegmatite, aplite and quartz veins crosscut Archean basement, Ospwagan Group metasedimentary rocks and mafic dikes, and are therefore Proterozoic in age. Their association with deformation is discussed in the next section.

Structural geology

The South pit of the Thompson mine is situated on the west side of the closure of a large, steeply southwest-plunging antiform developed in the Archean basement gneiss and the overlying Ospwagan Group. This structure has been interpreted as F_3 in the progressive deformation of the TNB (Bleeker, 1990). Most structural features in the map area, including minor- and intermediate-scale folds, prominent boudins, veins and pegmatite dikes, are associated with F_3. Older (F_1 or F_2) structures may include local isoclinal folds and a small thrust fault. Large-scale expressions of the older structures in the vicinity of the pit include the inversion of the entire stratigraphic section in the overturned 'Thompson limb' of a fold nappe (Bleeker, 1990). Thus, the core of the large F_3 antiform is occupied by the Setting Formation, one of the upper units in the Ospwagan Group. The basement gneiss and basal units of the Ospwagan Group exposed in the South pit are overturned toward this fold core and have been interpreted to lie on the overturned 'Thompson limb'.

The location of the South pit in an area near the neutral surface of the F_3 antiform allowed excellent preservation of the lithostratigraphic section, including the angular unconformity at its base.

Boudins and related folds and faults

Participants in the TNB geological field trips are always impressed by the widespread and intensive folding that appears to be the dominant feature on the outcrops of the South pit. Mapping this summer revealed, however, that one of the most significant deformational features is boudins. The local folding, as well as shearing, faulting and associated introduction of pegmatite, aplite and quartz veins, are generally secondary features that developed during the boudinage process.

Boudins and pinch-and-swell structures, which occur at the decimetre, metre and decametre scale, are, in fact, generally boudin-like bodies, as they occur in a layered sequence without strong ductility contrast (pseudoboudins or large-scale foliation fish; e.g., Hanmer, 1986). It appears that, during their development, a tension gash was formed and filled with a siliceous material, and layers above and below were drawn into the boudin neck. The boudin-neck folds die out away from the tension gash toward nearly planar bedding. Such structures are common in the M1 arenite (Figure GS-12-2c) and T1b marl. Siliceous or aplite-like veinlets and lenses, abundant in the M1b2 and M1b7 markers, represent small-scale boudin development. The same deformation process also affects highly competent rocks like the metagabbro dike, where the foliation is curved toward tension gashes filled with aplite and pegmatite (Figure GS-12-2d). The apparent displacement of the deformed material is, in these cases, usually in the order of decimetres.

In larger structures, the tension gashes may be filled with quartz, quartz-rich pegmatite, aplite or pink pegmatite. A quartz-filled tension gash about 2 m long is an example of this size category (Figure GS-12-3a). In addition, a shear zone or a fault (also filled with quartz or pegmatite) is commonly situated in the vicinity of the large pseudoboudin neck. The apparent displacement of the deformed material is usually in the order of metres.

The largest structures, apparent only from the map, involve metasedimentary sequences 20–30 m thick. Identification and mapping of the marker units (described earlier) is crucial in delineation of these 'megaboudins' (Figure GS-12-3b). The centre of the boudin-neck area may occupy 20–40 m^2. These large structures may have formed by sequential coalescence of some of the smaller structures.

Progressive tightening of the boudin-neck folds toward the core of the neck locally leads to dome-and-basin structures or sheath folds (Figure GS-12-4a). Some dome-and-basin structures are culminations on larger sheath folds (Figure GS-12-4b). Several sheath folds, which were cut parallel to their axial plane with a diamond saw, clearly show the strong curvature of the hinge lines in the 'hairpin' fashion typical of such structures. Stretching lineations lie in the long direction of the sheath folds, commonly subparallel to the southwest-plunging hinge. The stretching lineation is interpreted to indicate the direction of flow that produced the sheath folds. The illustrated example (Figure GS-12-4c) indicates east-side-up displacement, with a smaller sinistral component in an adjacent high-strain zone hosting a pegmatite dike (*see* Figure GS-12-3b, location A). The layered rocks, which are pulled into the boudin-neck area at some localities, display disharmonic and convolute fold styles (Figure GS-12-2e). In general, all sheath folds and disharmonic folds are restricted to ductile high-strain zones. It is important to note that the main flow direction in the boudin necks and the associated high-strain zones is interpreted to be subvertical and not in the plane of the map. Consequently the ranges of apparent displacements given in this report are a small fraction of the true displacements. Boudins and pseudoboudins must be the 'chocolate-tablet' type, representing an elongate, pancake-shaped strain ellipsoid. This geometry and kinematic pattern may have important implications for mapping the nickel deposits in the TNB.

The boudin-neck areas are also occupied by abundant pegmatite veins that may be continuous or severely segmented. Offsets of marker units indicates that pegmatite usually fills a system of oblique faults and shear zones that have inferred displacement consistent with the asymmetry of the large and small boudins. The apparent displacement of the units due to the megaboudinage and associated faulting is usually in the order of decametres.

The intensity of the strain in faults and shear zones is also demonstrated by an intense folding in the immediate vicinity of the pegmatite veins that are located away from the megaboudin necks (Figure GS-12-2f).

A complex case of deformation is sketched in Figure GS-12-5a. The M2-T1 sequence, folded during a pre-F_3 event, was subsequently involved in a peculiar case of boudinage in which one part of the synformal sequence appears to be boudinaged and the other part (together with the antiformal sequence) is left nearly undisturbed. Further, the white pegmatite, originally filling a tension gap perhaps about 2 m wide, is pulled apart and a 10 m gap is largely filled with the M2 semipelite wacke. In addition, a thin sliver of the T1a siliceous marl with boudinaged segments of the T1b marl rests not far from the gap filled with the M2 semipelite. The apparent displacement of the units in this case is about 10 m. The contact between the M2 'injected' semipelite and the less disturbed sequence must be a detachment zone (D in Figure GS-12-5a).

Pre-F_3 structures

All deformation features described above are related to the F_3 event in the tectonic scheme established by Bleeker (1990). However, he also illustrated (in the 1C and 1B pits of the Thompson mine) some results of the earlier F_1 and F_2 events (Bleeker, 1989). For example, a case of early boudinage related to F_1 and folded by F_2 is documented. The apparent displacement of the boudinaged segments is in the order of decimetres only; more important, the layer itself is due to the F_2 folding repeated several times, and the lateral displacement is in order of metres.

The M2-T1 sequence in the South pit is repeated several times due to the folding that preceded F_3. Two first-order synforms and antiforms were encountered and the second-order folds are also developed locally (Figure GS-12-5b) The first-order folds are more significant because they cause the local repetition of the stratigraphic sequence and the lateral apparent displacement of some lithological units in the order of decametres. In addition, a fault separates the folded section from a homoclinal section above (to the east). If the fault is interpreted as an early thrust, then the underlying folds are footwall synclines and anticlines. The apparent sense of displacement of this structure is with the hangingwall moving south.

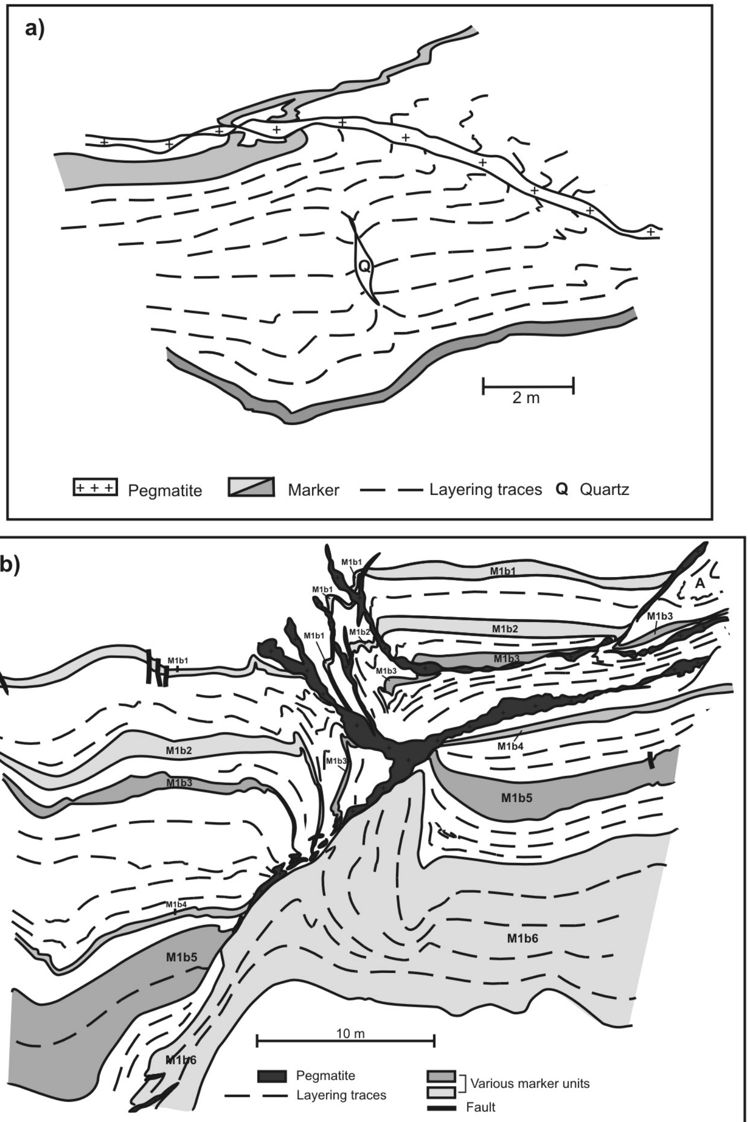


Figure GS-12-3: *Schematic diagrams of boudin structures, South pit, Thompson mine:* ***a)*** *pseudoboudin with 2 m long, quartz-filled tension gash in the M1c calcareous arenite; b) 'megaboudin' structure in the M1b submember (*see *text for explanation).*

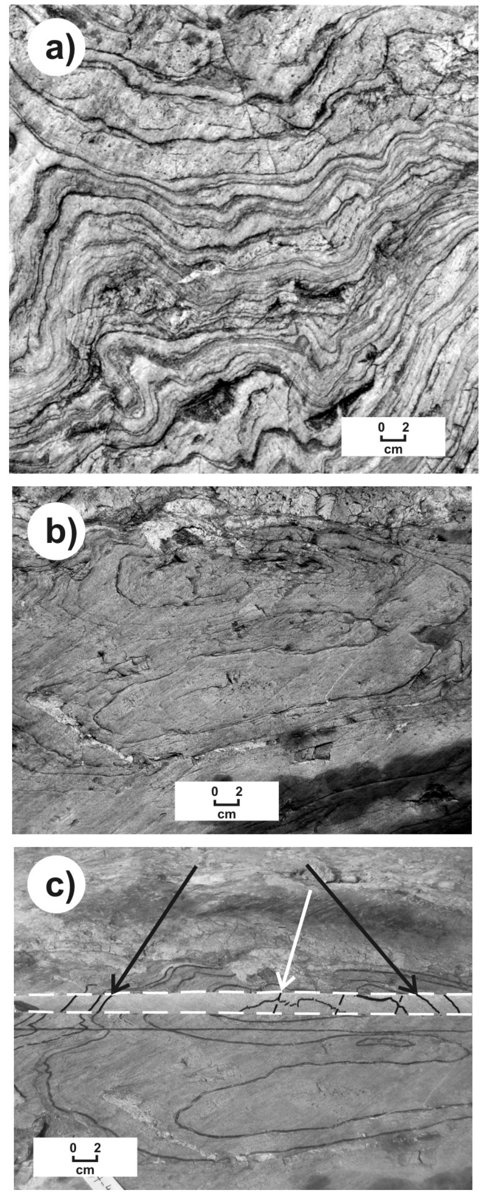
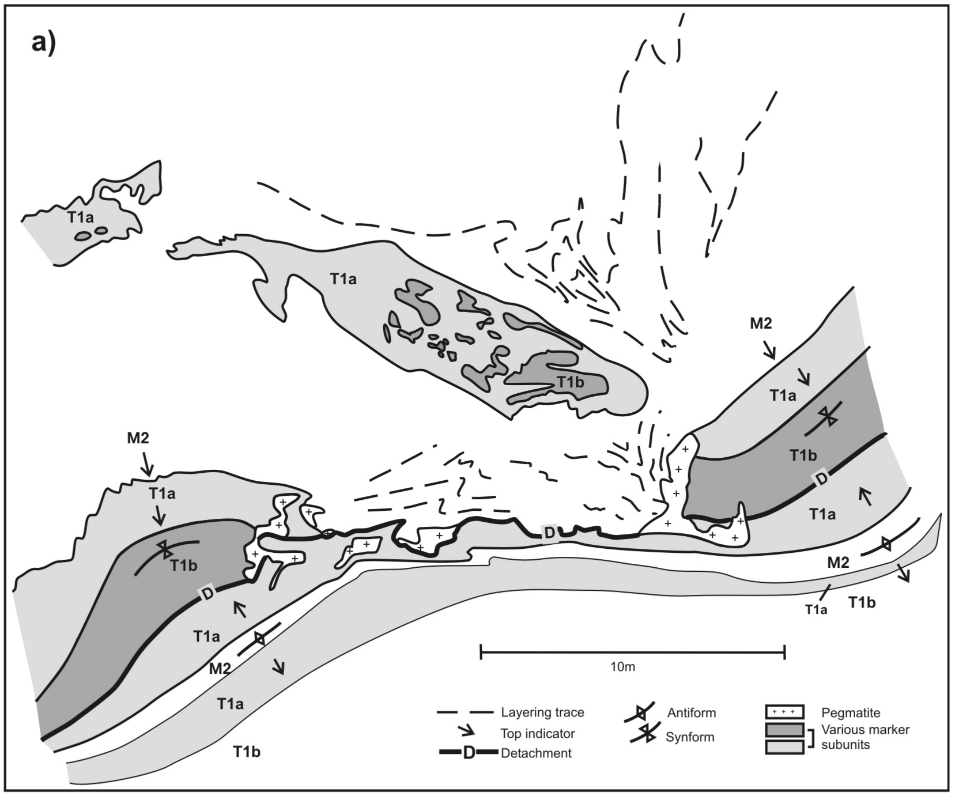


Figure GS-12-4: *Photographs of folds, South pit, Thompson mine:* ***a)*** *complex folds in M1b layered arenite with local antiformal culmination;* ***b)*** *sheath fold in M1b arenite (numbered tape is 10 cm long); and* ***c)*** *same sheath fold as in (b), but cut parallel to the axial surface and folds traced with marker pen; traces in the cut surface (outlined by white dashed line) are parallel to the curved hinge of the fold (hinge lines are indicated by black arrows); dashed lines are parallel to the stretching lineation, the probable direction of flow that produced sheath folding in the rock (stretching lineation indicated by white arrow).*



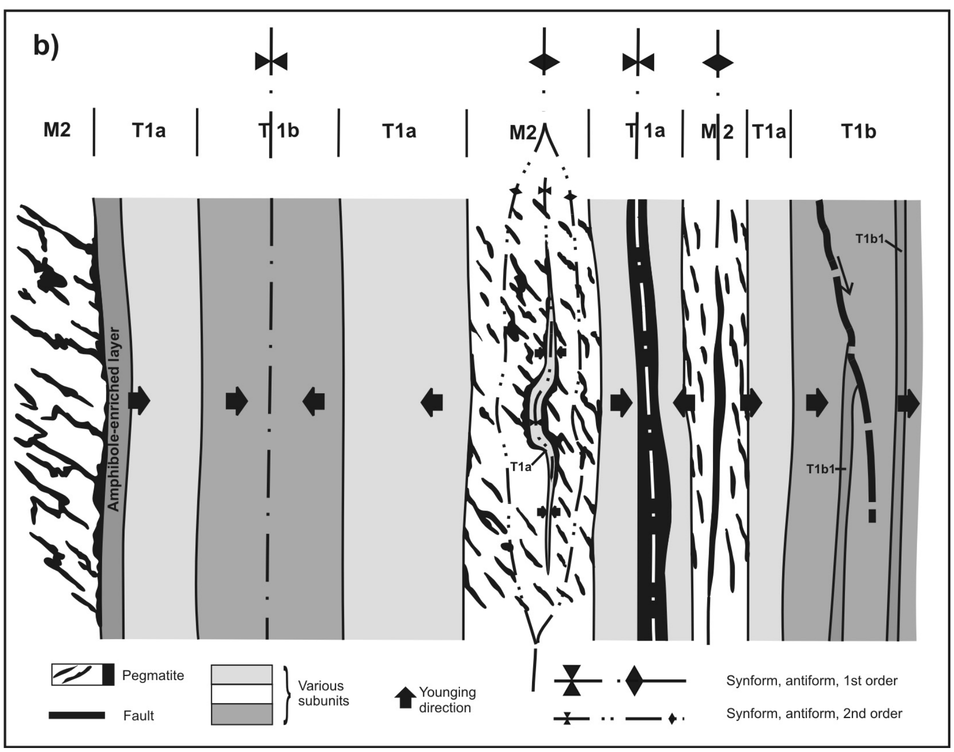


Figure GS-12-5: *Sketches of deformation encountered in the South pit, Thompson mine:* ***a)*** *complex deformation involving boudinage, folding and detachment processes; see text for explanation; and* ***b)*** *schematic sketch of the pre-F_3 folds in the M2-T1 sequence; note that one first-order antiform displays a group of two second-order antiforms and one second-order synform along the strike; fault separates folded sequence from homoclinal one; not drawn not to scale;* see *text for details.*

Economic considerations

The knowledge gained during detailed mapping at the South pit of the Thompson mine can be directly utilized by mine geologists who delineate nickel ore reserves, since the Pipe Formation, which hosts the ore, underwent the same tectonic history as the underlying Manasan and Thompson formations mapped during this study.

Originally, the nickel ore was deposited as a single layer, several metres thick, within the Pipe Formation, as seen exposed after dredging Cook Lake (the present site of the 1C and 1B pits). The ore layer deeper in these pits has been locally deformed, which could be explained by the following steps:

1) **Pre-F_2 boudinage:** The ore layer was segmented.
2) **F_2 folding:** The ore layer or its segments were repeated several times and thus laterally displaced in the order from metres to decametres
3) **F_3 megaboudinage (as reported here):** Segmentation of the tectonostratigraphic sequences into decametre-size blocks (including previously tectonized ore) and/or drawing of the ore into boudin necks probably resulted in the formation of chaotic breccias. The ore was diluted by pegmatite.
4) **D_3 ductile high strain:** The ore was obliquely displaced in the order of decametres.

Detailed observation of the local markers, and folding and kinematic indicators during the underground mapping could help to locate additional ore reserves still hidden in repeated sequences or concentrate the mine exploration in the direction of the highest potential.

Furthermore, a good understanding of the Ospwagan Group sequence is crucial in recognizing it during regional exploration, which has recently expanded to the areas northeast of the classical TNB.

The structural style recognized in the South pit may well have regional application in locating ore potential around ultramafic bodies such as those located in the saddle area between large basement domes (e.g., those near the northeast end of Setting Lake; Thompson Nickel Belt Geology Working Group, 2001). These saddle areas, which locally contain relatively late intrusions, probably acted as boudin necks during D3, so the flow pattern within them is expected to be similar to that described in this paper.

Mapping of the South pit also established a good starting point for detailed structural studies that might advance understanding of the deformation processes affecting the nickel deposits. The conclusions in this paper are preliminary and require more rigorous structural analysis.

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