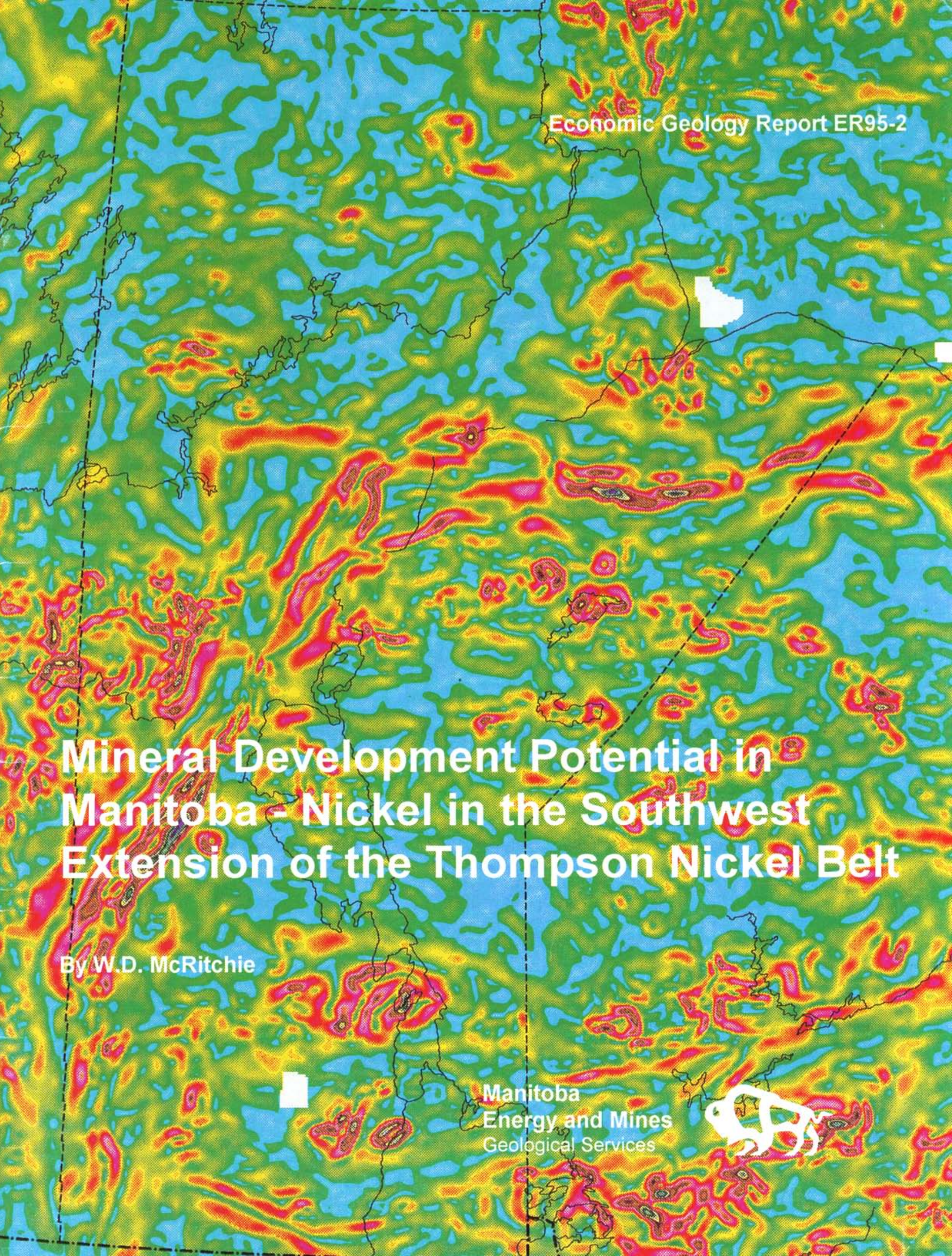

Economic Geology Report ER95-2

Mineral Development Potential in Manitoba - Nickel in the Southwest Extension of the Thompson Nickel Belt

By W.D. McRitchie

Manitoba
Energy and Mines
Geological Services

Front cover: Horizontal gradient of the Bouguer gravity anomaly map of Canada: Selected 1:5 000 000 scale enlargement centred on Manitoba. Note the extreme gravity gradients associated with the Superior Boundary zone in the Fox River region, and the extension of the Thompson Nickel Belt near Rabbit Point, Lake Winnipegosis.

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By W.D. McRitchie
Winnipeg, 1995

Energy and Mines

Hon. Donald W. Orchard
Minister

M.A. Fine
Deputy Minister

Geological Services

W.D. McRitchie
Director

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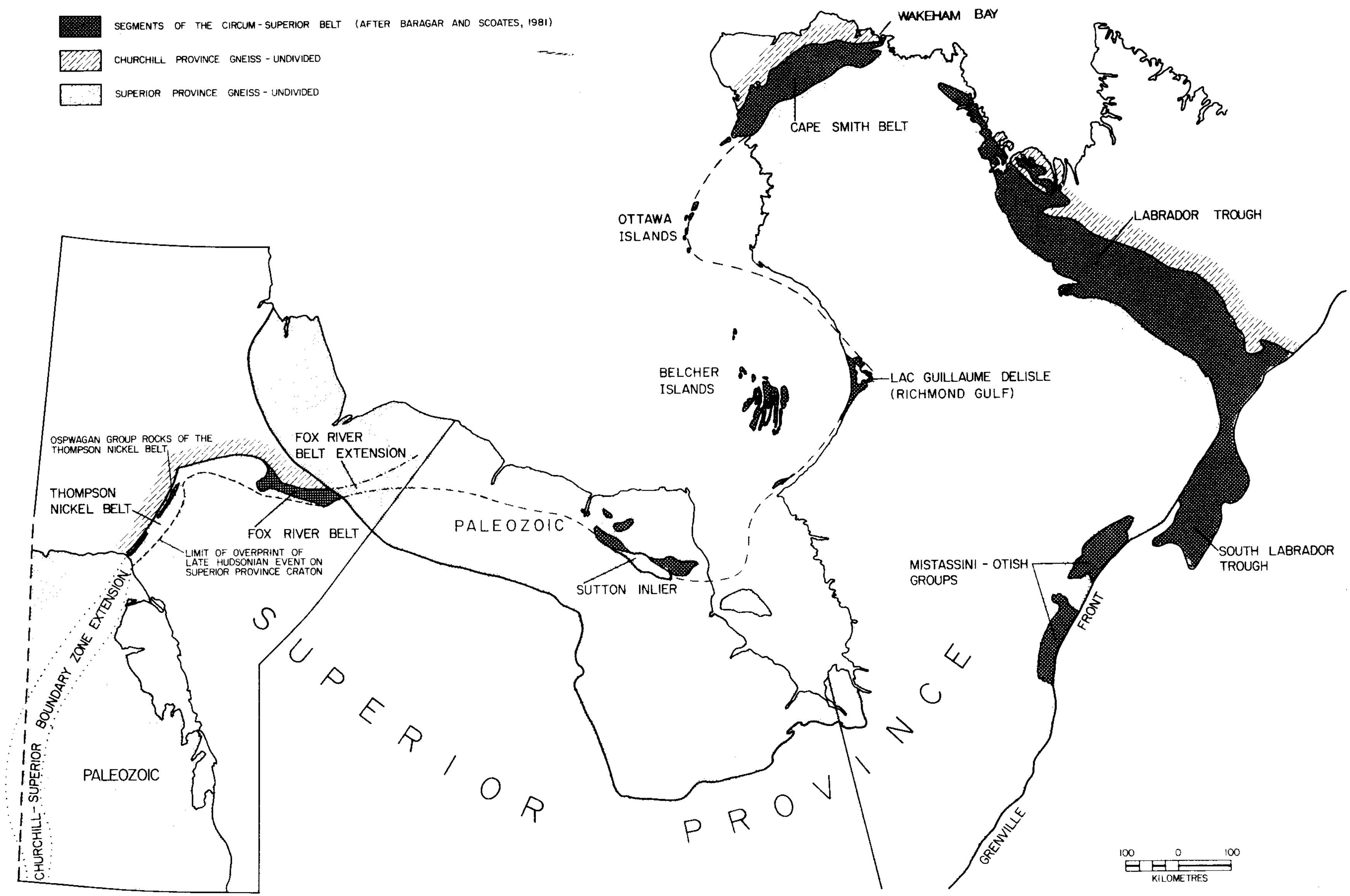


Figure 1: Regional setting of the Thompson Nickel belt (TNB) and Superior Boundary Zone (SBZ) in Canada at the margin of the Superior Craton.

INTRODUCTION

This paper is a brief summary of exploration and geological work centred on the **Thompson Nickel Belt (TNB)**, the principal focus being its southwest extension beneath the Paleozoic rocks of the Williston Basin. The main aim of the paper is to highlight the importance that this geological domain possesses in the context of its abundant world-class nickel deposits, and future exploration potential.

Since Inco's initial discovery of nickel mineralization at Moak Lake, near Thompson in 1952, it has been recognized that nickel-bearing orebodies are locally concentrated in a narrow, northeast-trending (030°) belt of rocks that constitutes part of a larger and more laterally extensive geological entity, the **Superior Boundary Zone (SBZ)**. The **TNB** component of the **SBZ** extends northeast from Thompson for 50 km. The **SBZ** then trends east through the Fox River region towards Sutton Ridges in Ontario, a total distance of 800 km. The geological extension of the **SBZ** continues north and east by way of the Belcher Islands to northern Quebec and the Cape Smith and Wakeham Bay belt (Fig. 1), which is also known to contain abundant ultramafic rocks and nickel mineralization (St-Onge and Lucas, 1993).

Southwest of Thompson the Precambrian **TNB** is exposed for 150 km before being covered by younger Paleozoic carbonate rocks near Ponton. From Ponton, the geophysical expression of the 20 to 60 km wide **TNB** (Fig. 2) continues another 250 km toward the Saskatchewan border and then, as the **SBZ**, south for another thousand kilometres into North and South Dakota beneath 500-2000 m of Paleozoic and Mesozoic rocks.

Over the last forty years, exploration for nickel-bearing orebodies has concentrated on the exposed section of the **TNB**, between Moak and Gormley lakes; numerous new discoveries were made and several mines were brought into production between Thompson and Ponton (Table 1; and Fig. 3).

Southwest of Ponton the Precambrian hostrocks are buried beneath younger Paleozoic carbonate formations, adding considerably to the difficulty and cost of exploration (Fig. 4). Southwest of Grand Rapids formational brines are another obstacle to accurately locating nickel-bearing massive sulphide conductors that are 300 to 500 m below the surface (Fig. 4) (Pearson *et al.*, 1994).

Nevertheless, the Precambrian basement southwest of Ponton possesses diagnostic magnetic and gravity geophysical signatures (Figs. 2 and 5) that have helped target exploration drilling through the carbonate cover, into areas likely to contain nickel mineralization. Several companies have initiated, and subsequently terminated exploration programs costing millions of dollars (to date, records indicate that over 650 holes have been drilled through the carbonate rocks south of Ponton to test targets in the **TNB** basement; C. M^C^Gregor, pers comm.). Until recently, few were able to develop the key criteria that enabled them to successfully target rocks that host the nickeliferous sulphides. However, each company's efforts generated new information on the nature and distribution of the buried Precambrian bedrock, which has sharpened the focus of succeeding attempts at exploration.

TABLE 1
GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL ATTRIBUTES OF THE THOMPSON NICKEL BELT

1. Located at junction between two major Precambrian crustal blocks; the Superior Structural Province and Trans-Hudson Orogen (formerly the Churchill Structural Province). The TNB coincides with the geological entity referred to as the Superior Boundary Zone (SBZ).

In Manitoba the TNB has the following characteristics:

2. Northeast (030°) trending linear structural trends, that are the result of intense deformation (folding and faulting).
3. Linear magnetic anomaly trends and gravity signatures (some with extremely high gradients) can be used to trace the SBZ to the southwest below the younger carbonates.
4. Extended deformational history from older than 3000 Ma to younger than ca. 1600 Ma.
5. Early Proterozoic rocks (>1890 Ma to 1720 Ma) overlie, and are interfolded with, reworked Archean rocks (up to ca. 3000 Ma).
6. Relatively high abundance of ultramafic rocks compared with other sectors of the Superior Craton.
7. Ultramafic rocks are magnesium-rich and have primitive komatiitic chemistry (i.e. derived from primitive, non-depleted mantle).
8. Ultramafic rocks commonly occur within a well defined sequence of Early Proterozoic supracrustal rocks (Ospwagan Group) as well as neighbouring basement gneisses (e.g. at Manibridge Mine).
9. Ospwagan Group shows a high degree of lithologic consistency throughout the region with only minor variations, although layer thickness may vary.
10. Ospwagan Group contains diagnostic lithologies in fixed stratigraphic positions.
11. The Ospwagan Group contains abundant chemical sediments, particularly magnetite-bearing sulphide and/or silicate facies iron formations.
12. Isotopic age of representative flow is 1880-1890 Ma (U/Pb zircon).
13. Metamorphic facies of supracrustals ranges from pristine, unmetamorphosed to upper amphibolite.
14. To date, economic concentrations of nickeliferous sulphide have been found in association with ultramafic rocks hosted by the Ospwagan Group; to a lesser extent other orebodies occur in ultramafics hosted by basement gneisses.
15. Sulphur/selenium ratios in nickeliferous sulphides are unique and indicate mixed sedimentary-magmatic origin, suggesting that absorption of sedimentary sulphides (from sulphide facies iron formation) by magmatic rocks led to precipitation of nickeliferous sulphides as ore bodies. These may have been tectonically separated from the host magmatic rocks during intense deformation.
16. The deeply buried, highly conductive sulphides and other formational conductors (i.e. sulphide iron formation, and graphite) associated with the diagnostic supracrustal sequences can be detected using electromagnetic surveys.

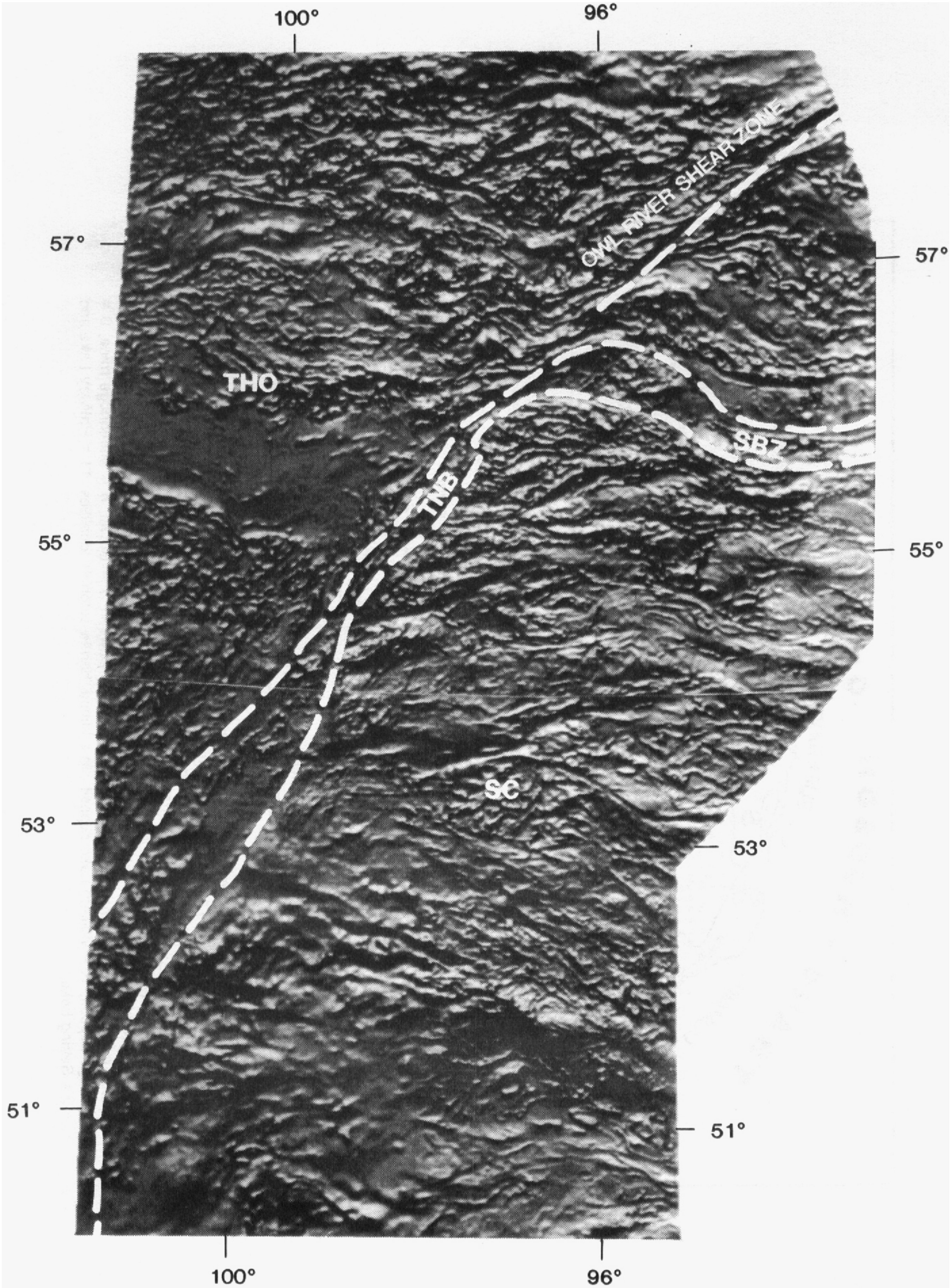
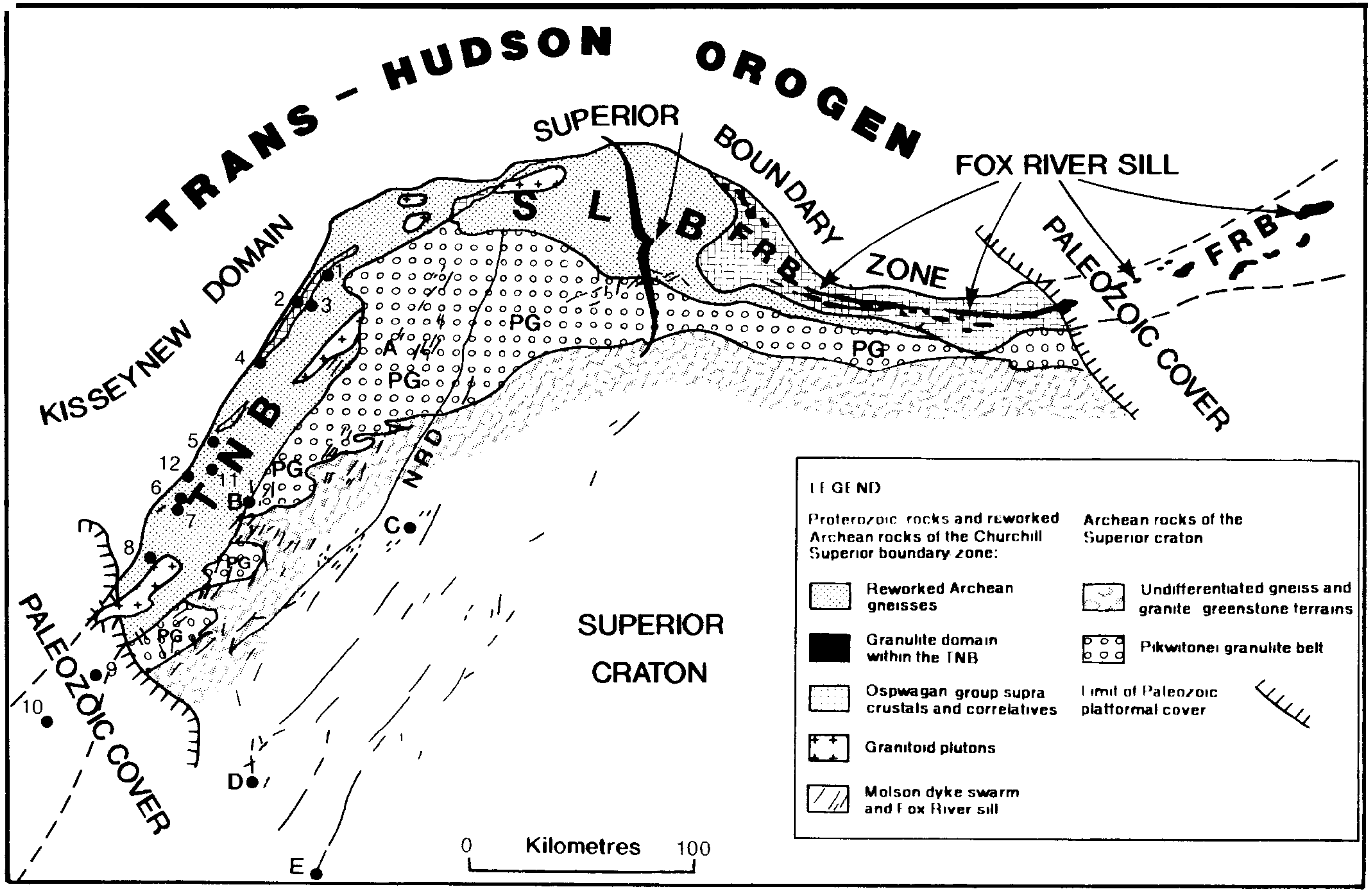


Figure 2: *Shaded, relief aeromagnetic compilation map of Manitoba showing prominent northeast trends associated with the Thompson Nickel Belt (**TNB**), and marked discordance with easterly trends in the Trans-Hudson Orogen (**THO**) and Superior Craton (**SC**). **SBZ** - Superior Boundary Zone.*



Northwestern Superior Craton (Archean) and adjoining Trans-Hudson Orogen (Proterozoic) The Pikwitonei Granulite (PG) terrane is the northeastern-most part of the Superior Craton. The Superior Boundary Zone in this area includes the Thompson Nickel Belt (TNB), the Split Lake Block (SLB) and the Fox River Belt (FRB). The Nelson River Dyke (NRD) is the largest of the Molson Dykes. 1) Fox River Sill, 2) Molson Dykes: A = Cuthbert Lake, B = Sipiwesk Lake, C = Cross Lake, D = Playgreen Lake, E = Belanger River, 3) Thompson Belt nickel deposits: 1 = Mystery Lake, 2 = South Manasan, 3 = Thompson mine, 4 = Pipe No. 2 mine, 5 = Soab South mine, 6 = Bowden, 7 = Bucko, 8 = Manibridge mine, 9 = Minago deposit, 10 = William Lake deposit. In addition, barren sulphide localities: 11 = Halfway Lake and 12 = Setting Lake.

Figure 3: Regional geological setting of the SBZ and TNB; mines and principal nickel deposits. SBZ - Superior Boundary Zone; ORSZ - Owl River Shear Zone.

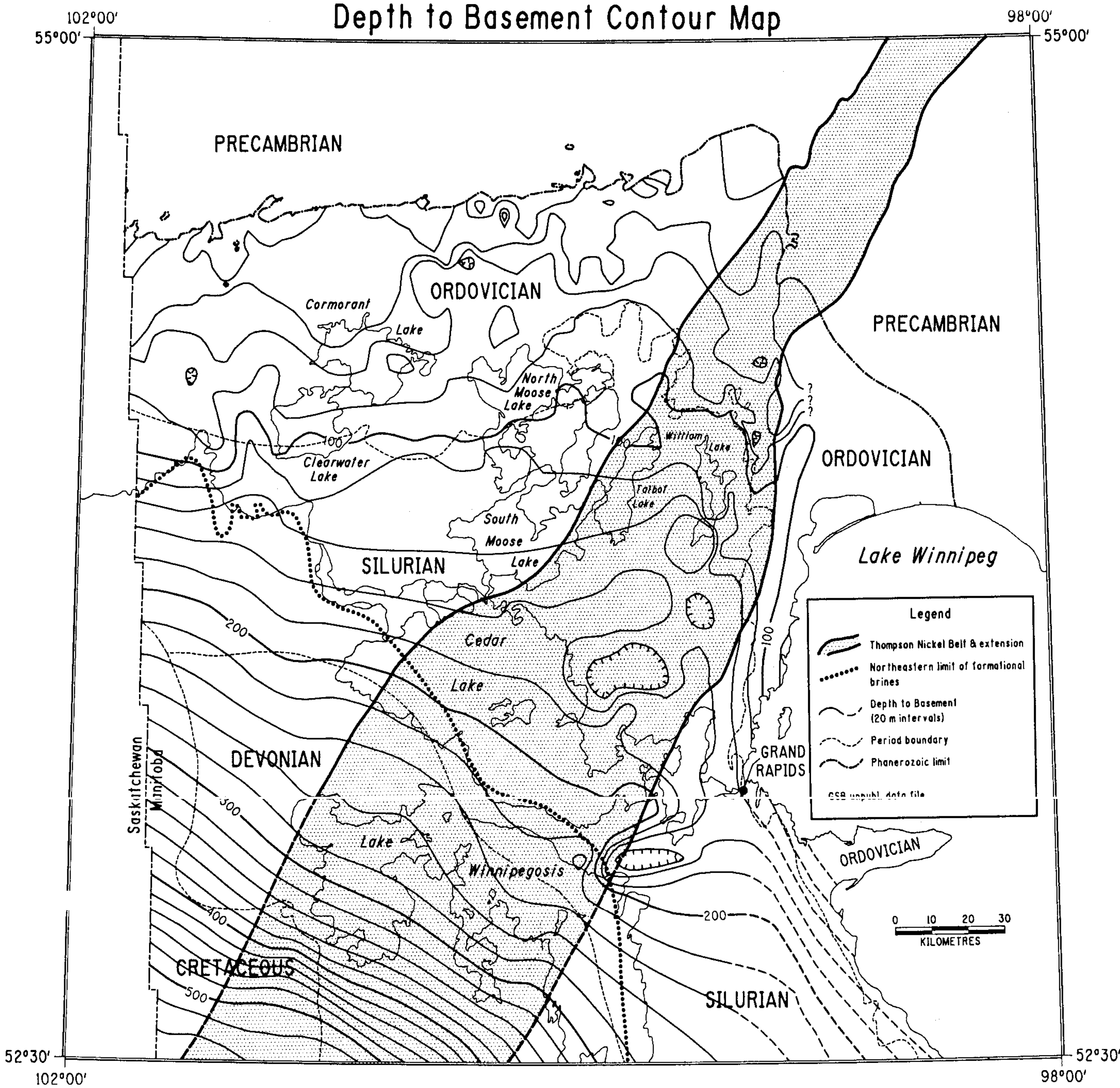


Figure 4: Geological map of Shield Margin with depth to basement contours, Phanerozoic Periods and limit of formational brines, Grand Rapids region, Manitoba. ***TNB*** *- Thompson Nickel Belt and extension;* ***SC*** *- Superior Craton;* ***THO*** *- Trans-Hudson Orogen. Depth to basement database and plot by Ruth Bezys, Glenn Conley and Len Chackowsky; manuscript on file, Geological Services Branch, Manitoba Energy and Mines.*

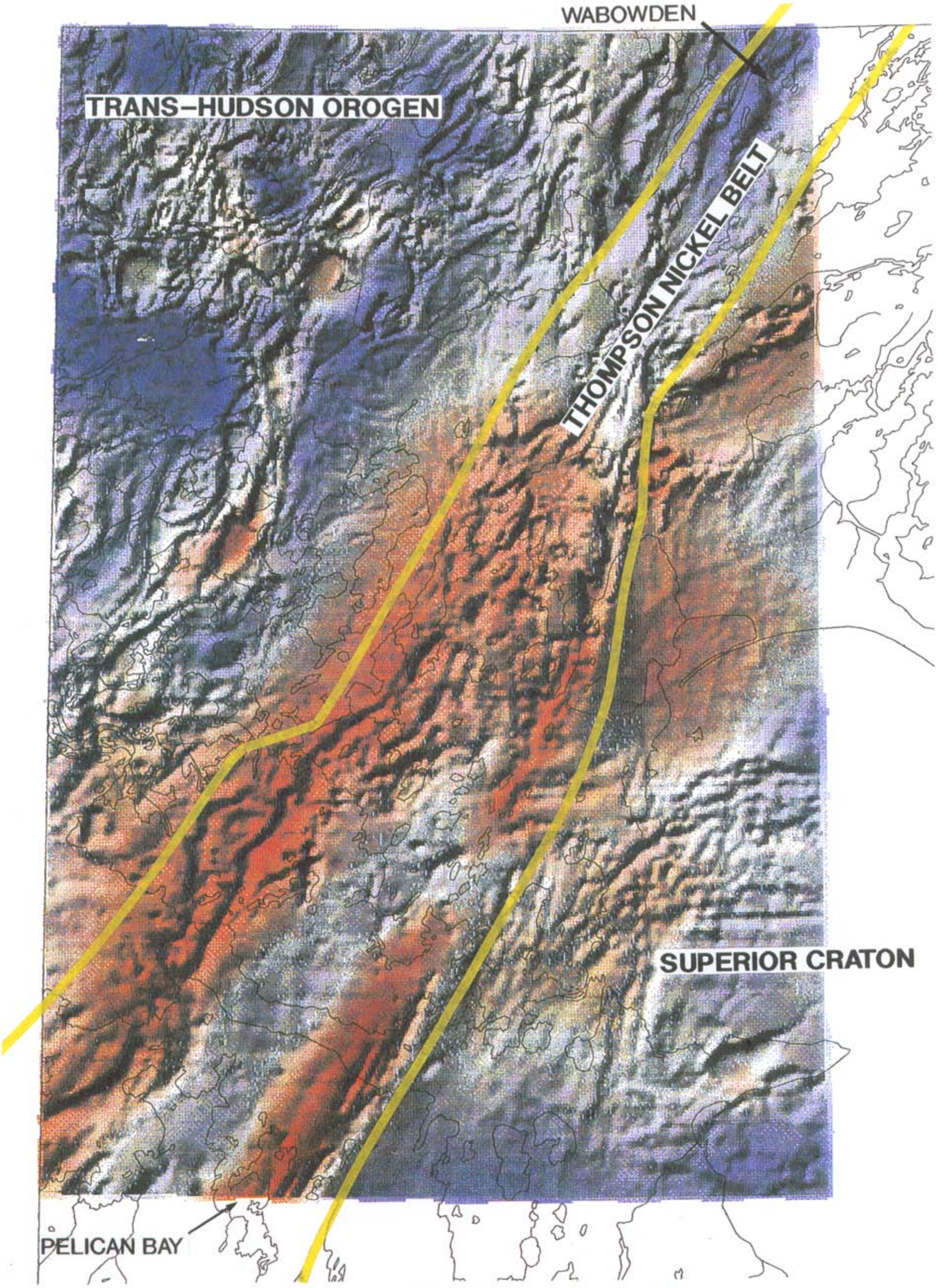


Figure 5: *Combined airborne magnetic signatures and gravity, **TNB** extension, Wabowden to Pelican Bay, Lake Wnnipegosis (J. Broome et al. in press). (Magnetic data: 50 m total field grid resampled to 100 m for image. Gravity data: 2000 rn gravity grid interpolated from 3-5 km spaced measurements. Image: blue = low, grey = intermediate and red = high Bouger gravity intensity; Grey shaded magnetic relief image illuminated from the southeast).*

GEOLOGICAL SETTING AND EVOLUTIONARY MODELS

Comprehensive accounts of the geology of the **TNB** have been presented by Bell (1966, 1971, 1980), Paktunc (1984), Paktunc *et al.* (1986), Peredery (1979), Peredery *et al.* (1982) and Rance (1966). The regional setting of the **TNB** and ideas on its tectonic evolution and origins were presented by Bleeker (1990, 1991), Coates *et al.* (1972), Gibb (1968, 1983), Green (1981), Green *et al.* (1985), Kornik (1969), Kornik and MacLaren (1966), Lewry *et al.* (1994), Lucas *et al.* (1994), Macek and Bleeker (1989), Macek and Scoates (1980), Machado *et al.* (1990), Weber (1990), Weber and Scoates (1978), White *et al.* (1993) and White and Lucas (1994). Fraser (1985) provides a thorough account of Inco's early exploration efforts culminating in their discoveries in the immediate vicinity of Thompson. Additional reviews and geological information are available on Manitoba Energy and Mines bedrock compilation maps for the Nelson House (NTS 63O), Wekusko Lake (NTS 63J) and Sipiwesk Lake (NTS 63P) areas, the latter including marginal notes (Weber, in prep.).

The following summary of **TNB** geology is derived from the work of the foregoing authors. It includes some of the initial insights on deep crustal elements that stemmed from reflection and refraction seismic surveys conducted under the LITHOPROBE Trans-Hudson Orogen Transect project (Hajnal, 1993; Hajnal *et al.,* 1994).

In Manitoba, the 25 to 60 km wide **SBZ** separates unreworked >2.5 Ga Archean crust of the Superior Craton from largely juvenile 1.7-1.9 Ga early Proterozoic crust of the Trans-Hudson Orogen (**THO**) (previously known as the Churchill Province).

THOMPSON NICKEL BELT

The exposed section of the **TNB**, between Moak Lake and Ponton, is dominantly underlain by metamorphosed polydeformed ortho- and paragneisses that represent Pikwitonei granulites and amphibolites of Archean age, that were reworked and retrogressed during the Hudsonian orogeny. Along the western margin of the **TNB** the retrogressed Archean gneisses are intimately associated with narrow, structurally controlled belts of Aphebian metasedimentary and metavolcanic supracrustal rocks referred to as the Ospwagan Group.

The Aphebian supracrustals comprise metasedimentary rocks (greywackes, arenites, impure carbonates and marbles, ferruginous or carbonaceous pelites, chert, and thin, but widespread, magnetite-bearing silicate, and sulphide facies iron formation), and metavolcanics (mafic and locally spinifex-bearing ultramafic flows). The above sequences are intruded by mafic and ultramafic dykes and sills. The nickel sulphide deposits, which are spatially and genetically related to the ultramafic rocks (Bleeker, 1989, 1990; Eckstrand *et al.*, 1989; Halden, 1988; Peredery *et al.*, 1982), are also concentrated along the western side of the exposed **TNB**.

Unlike the Archean gneisses, the Ospwagan supracrustal rocks record only a single (Hudsonian) orogenic overprint with metamorphic grades ranging from lower to uppermost amphibolite facies. The deformational history derived for Thompson and Pipe deposits (Bleeker, 1990) is directly comparable with that for the Kisseynew terrane to the west (Bailes and M^CRitchie, 1978). Metamorphic grades in the Fox River region (Scoates, 1981) are considerably lower with widespread occurrences of prehnite and pumpellyite (i.e. subgreenschist facies). Hulbert *et al.* (1994a and b) report pristine, apparently unmetamorphosed, assemblages in drill core from near Rabbit Point, south of Grand Rapids in the southwest extension of the **TNB**.

Despite the intense structural overprint (prevalent throughout the **TNB**), the supracrustal lithologies exhibit a remarkably consistent sequence of superposition. Stratigraphic 'packages' can be traced within and between isolated fold structures, despite local dismemberment, extreme attenuation or boudinage. Similarities between lithological sequences at Thompson and Pipe Pit led to inevitable comparisons and eventual correlation. Minor variations in thickness, lithology and metamorphic grade, along the length of the **TNB**, were recognized and used to subdivide the Ospwagan Group into several discrete packages referred to as the Thompson, Ospwagan, Pipe, and Setting Lake 'formations' (Macek and Bleeker, 1989). The gross consistency of the lithological sequences constitutes a key indicator that assists interpretation of exploration drill core from the southwest extension of the **TNB** (Macek and Nagerl, 1992).

The age of the Ospwagan Group has only been determined indirectly from its relationship with possible Molson dykes. On this basis the age of the Ospwagan Group is bracketed between 2.4 and 1.88 Ga. Sr-isotope systematics suggest a narrower range, between 2.1 and 1.88 Ga (Brooks and Theyer, 1981). A preliminary age of 1864 Ma on the Winnipegosis komatiites (Hulbert *et al.,* 1994b), is somewhat younger than the age inferred for the Ospwagan Group.

Several Hudsonian granitic intrusions occur along the **TNB**, both in the exposed and buried sectors. Some have migmatitic envelopes and like their counterparts in the Kisseynew domain, contain garnet and muscovite in addition to biotite. Several samples have been collected for dating; one pluton (Wintering Lake granite) has yielded a concordant monazite age of 1822 ± 3 Ma (Machado *et al.,* 1987).

SUPERIOR CRATON

To the south and east, the **SBZ** is flanked by granulitic rocks of the Pikwitonei domain, as well as narrow wedges of less highly metamorphosed greenstone/granite complexes that merge eastward to constitute the dominant terrane of the Archean Superior Craton (Fig. 3). The metavolcanic and metasedimentary greenstone complexes of the northwest Superior Craton range from 2.73 to 2.9 Ga with local indications of crust that exceeds 3.0 Ga. The Pikwitonei domain contains granulite facies granitoid metaplutonic and supracrustal rocks that were metamorphosed during at least two events (2.640 and 2.695 Ga). Components of the granulites in the **TNB** indicate that this section of the Superior Craton was subsequently uplifted and eroded prior to deposition of the Proterozoic Ospwagan Group supracrustal rocks. Ages of uplift between 2200 and 2170 Ma have been proposed by Zhai et al. (1994), based on studies of Molson dykes from the northwest margin of the Superior Craton.

The contact between the **SBZ** and the Superior Craton is defined as the eastern (and southern) limit of the 1.8 Ga Hudsonian tectonic (and metamorphic) overprint. South of Ponton, beneath Paleozoic cover rocks, the eastern boundary of the **TNB** is defined as a magnetic low separating high-intensity east-trending magnetic fabrics of the Pikwitonei granulites from lower-intensity northeast-trending magnetic fabrics of the **TNB.**

In the Fox River region the lateral equivalents of the Pikwitonei granulites lie immediately to the south of, and are in sharp contact with, low grade Aphebian supracrustal and related intrusive rocks that are correlated with the Ospwagan Group at Thompson (Scoates *et al.,* 1977).

TRANS-HUDSON OROGEN

The **SBZ** is flanked to the north and northwest by a collage of dominantly juvenile Proterozoic metasedimentary and metavolcanic terranes and granite complexes that constitute the southern flanks of the **THO.** Extensive isotopic studies within the **THO,** between Lynn Lake and Flin Flon, indicate ages ranging between 1.83 and 2.0 Ga.

The western boundary of the **TNB** with high grade metagreywacke-derived gneisses and migmatites of the Kisseynew domain is abrupt and faulted. The northeast-trending structures of the **TNB** are markedly discordant with the generally easterly trends of juvenile terranes in the **THO.** Nevertheless, Bleeker (1990) reports drill intersects of Ospwagan-like rocks at least 10 to 20 km west of the main (Setting Lake) fault contact, and suggests that **TNB** lithologies may persist at depth below the Kisseynew gneisses in the **THO.**

The northern contact of the 10 to 20 km wide belt of Aphebian supracrustal rocks along the Fox River with high grade (staurolite-, sillimanite- and kyanite-bearing) greywacke-derived gneisses that resemble those of the Kisseynew domain, is not exposed (M^{c}Ritchie, 1977).

Southwest of Ponton the northwest boundary of the **TNB** with the magnetically flat Kisseynew gneisses is sharply defined as far south as latitude 54° 15'N. Further south the contact is inferred as the junction between the northeast-trending aeromagnetic fabrics of the **TNB** and the north or northwest aeromagnetic trends of Proterozoic granitoids and supracrustal rocks that are extrapolated from lithologies exposed in the Snow Lake area (Leclair *et al.,* 1994).

STRUCTURAL SETTING

In keeping with the summary nature of this review, the following description is limited to an outline of the most recent interpretations of the structural fabrics and deformational sequence experienced by this polydeformed terrane. A full account can be found in Bleeker (1990, 1991), with new perspectives stemming from the LITHOPROBE vibroseis transects by White and Lucas (1994).

The rocks comprising the **TNB** have experienced a highly complex and protracted structural history, including several Kenoran tectonic events, as well as the subsequent Hudsonian overprint. Throughout much of the belt the Hudsonian tectonism and metamorphism was extreme enough to completely obliterate all evidence of earlier fabrics in the reworked Archean granulites.

The readily apparent structural and geophysical trends displayed by the **TNB** have strongly influenced interpretations regarding the origin of the belt and its relationship to the adjacent Superior Craton and **THO.** More recently, Bleeker (1990) recognized that the northeast trends reflect in large part relatively late-Hudsonian tectonic overprints related to F_3 folding, associated sinistral strike-slip displacements and subsequent brittle faulting in a transpressional regime.

Structures associated with earlier (F_1 and F_2) recumbent and isoclinal folding were reoriented and transposed into conformity with the later, overprinting fabrics. Bleeker (1990) presented a model in which the edge of the Superior Craton initially plunged northwest beneath the overthrusted nappe pile of Aphebian supracrustals, in response to a generally south or southeast vergence of the **THO.** This interpretation was subsequently challenged when east-dipping reflectors were detected in the upper crust along east-trending vibroseis transects across the **TNB** into the **THO** (Fig. 6) (White *et al.,* 1993). White and Luca (1994) proposed a three stage evolutionary model. Initial east-verging thrusting of the **THO** over the Superior Craton was followed by sinistral compression and underwedging of the thrust pile, and concluded with continued sinistral transpression, strike-slip faulting and backthrusting. The steep, east- dipping, northeast-striking faults and structures in the **TNB** are ascribed to the latter two phases (i.e. F_3 and post-F_3 events).

The intense overprint associated with the later tectonism significantly complicates interpretation of the earlier structures and development of models that would explain the early stages of the Hudsonian orogeny. Over much of its length, the **SBZ** east of Split Lake is east trending, as are the main juvenile belts within the **THO** in Manitoba. Structural interpretations from the southern margin of the Kisseynew domain indicate a southward vergence for the early nappes and thrusts, perpendicular to the trends of the lithological belts in the **THO.** Consequently it may be more consistent to envisage a similar southward vergence for the earlier (pre-F_3) structures in the **TNB,** rather than to use the existing geometry (determined by F_3 and post-F_3 structures) to infer a southeasterly (or easterly) onlap of the **THO** onto the Superior Craton.

Current interpretations equating the geophysical expression of the **TNB-** extension south to the Dakotas with the margin of the Superior Craton are suspect. Certainly, in the exposed section of the **TNB** (where post-collisional fabrics are most prominent), the edge of the Superior Craton is juxtaposed against the **THO**. The inferred extrapolation of post-collisional fabrics to the Dakotas is equally likely. However, the more fundamental west-trending fabrics associated with the earlier, collisional phase of the Hudsonian Orogeny (and presumably the **SBZ**, i.e. the edge of the Superior Craton) persist throughout the Manitoba segment of the **THO** both east and west of the **TNB** (i.e. Lower Nelson River and Kisseynew).

Consequently, given a post-collisional sinistral offset along the **TNB** (Bleeker, 1990), there is a strong possibility that the Superior Craton persists (in the subsurface) west of the **TNB**-extension in The Pas region and to the south. The westward extension of the collisional fabrics associated with the **SBZ** in the Fox River region would be expected to reappear as a generally west-trending splay off the **TNB**-extension between Lake Winnipegosis and Swan Lake. To the west, the trace of the **SBZ** is likely to be highly obscured by later post-collisional offsets, folding transposition and Hudsonian intrusions.

Recent Nd/Sm ages from the basement in Saskatchewan (Collerson *et al.,* 1988, Bickford *et al.,* 1992) suggest the Archean terrane (reworked during the Hudsonian Orogeny) is more widespread than previously expected in the region west of The Pas.

Discrete, spaced, linear, north-trending discontinuities are evident on the smaller scale aeromagnetic compilations covering the TNB. The abrupt truncation of major belts in the Superior Craton is especially apparent west of Limestone Point on Lake Winnipeg. This suggests that the linear discontinuities may be late faults, akin to the Tabbernor system in Saskatchewan. Although major north-trending faults have rarely been mapped, most of the lineaments occur in areas of thick overburden, precluding observation on the ground. Marked changes in the width of the **TNB** and its southwest extension (as inferred from geophysical signatures) coincide with several of the north-trending lineaments, a feature that supports displacement along these zones.

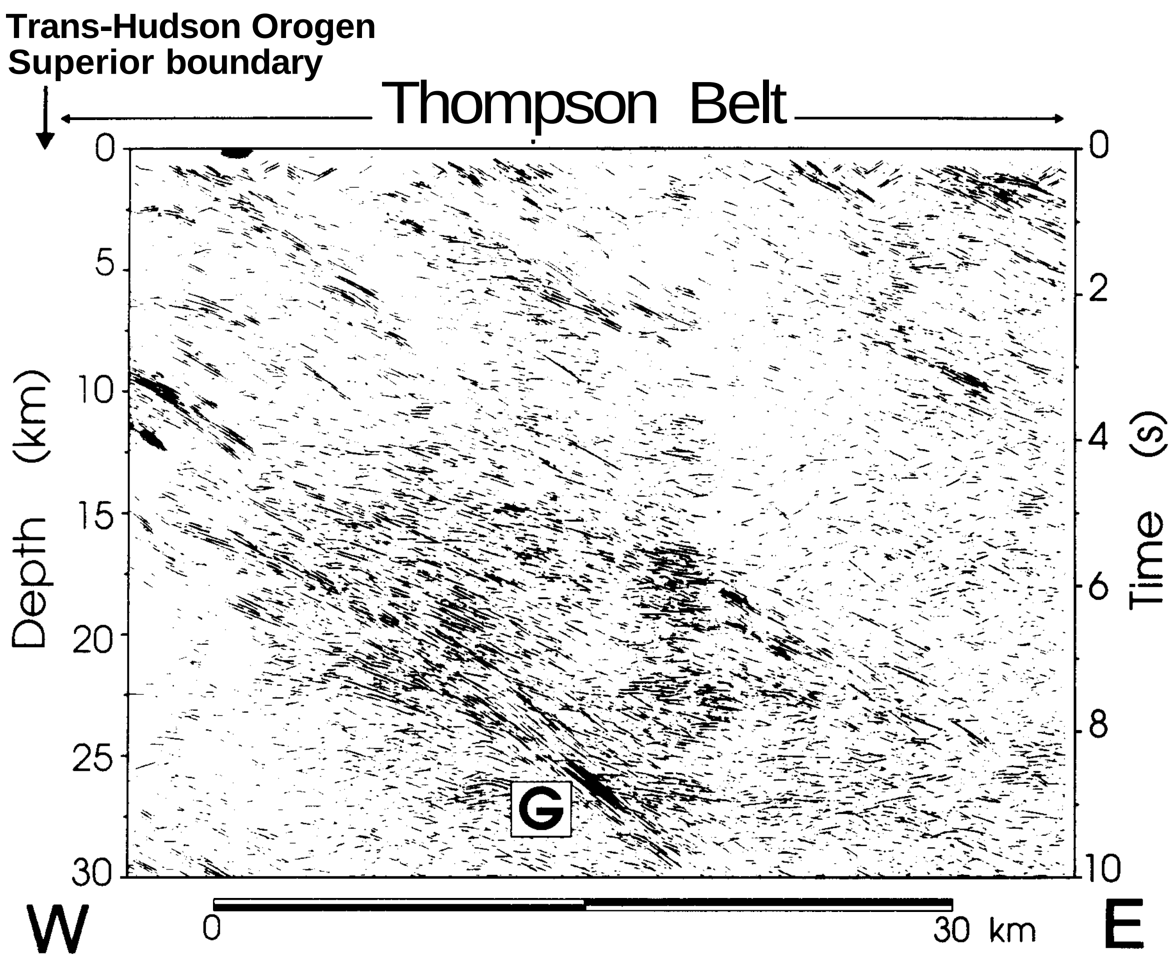


Figure 6: *Coherency-filtered, unmigrated reflection seismic data from the west end of Line 2, LITHOPROBE Trans-Hudson Orogen Transect 1993. A zone of east-dipping reflections (G) extends from the surface location of the THO - SBZ boundary to mid-crustal depths, suggesting that elements of the THO extend eastward beneath the Superior Craton. (Modified after White and Lucas, 7994).*

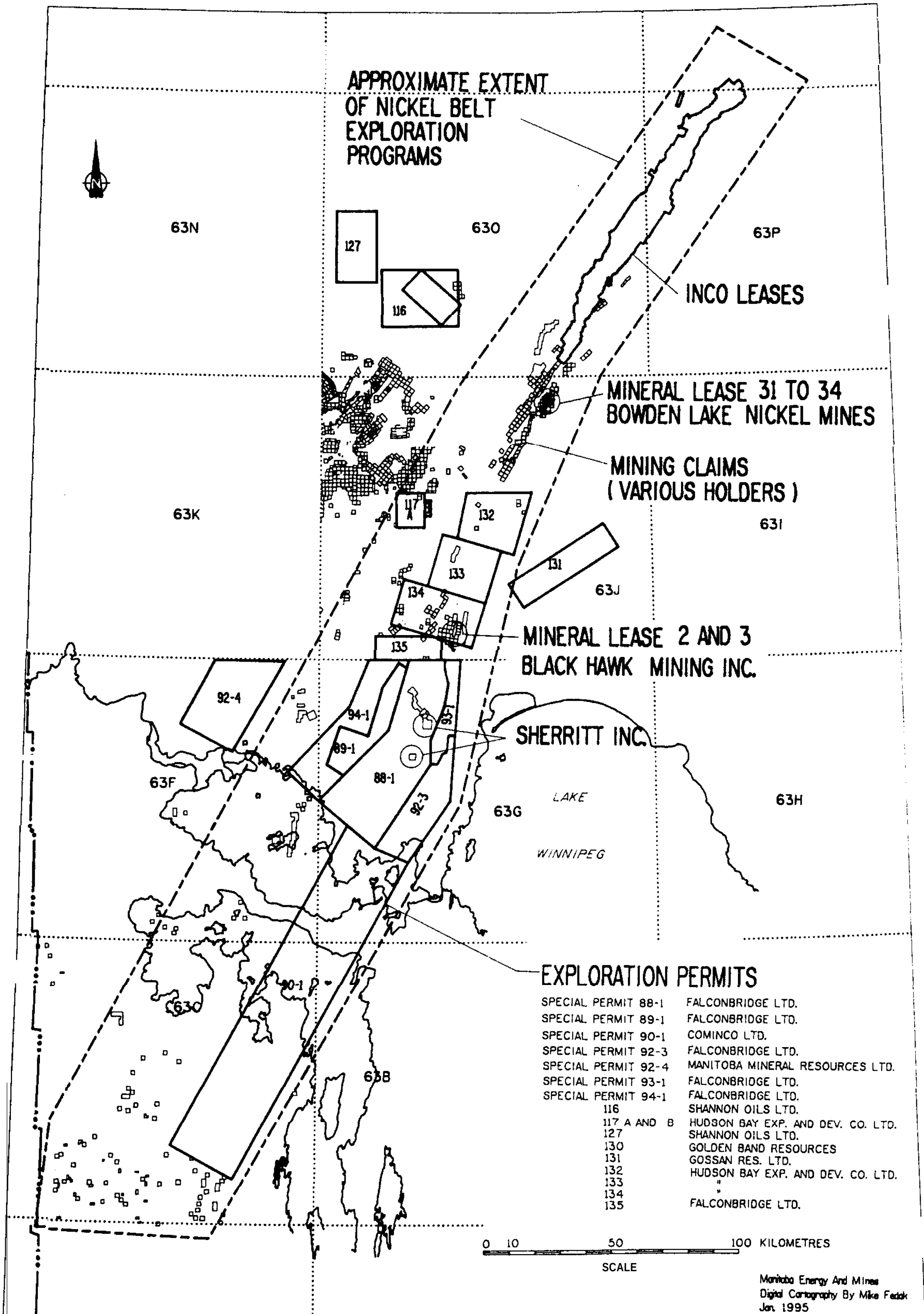


Figure 7: *Mineral dispositions (claims, exploration permits and leases) in the **TNB** and its southwest extension, Ponton to Swan Lake (Black Hawk, Falconbridge, Sherritt Inc., Cominco, Hudson Bay Exploration, Manitoba Mineral Resources etc).*

SUMMARY OF EXPLORATION AND CONCURRENT GEOLOGICAL DOCUMENTATION ALONG THE THOMPSON NICKEL BELT AND ITS SOUTHWEST EXTENSION

MINERAL EXPLORATION

Between 1946 and 1961 International Nickel Company of Canada Limited (Inco) spent $27 M exploring in Manitoba for nickel using airborne magnetic and electromagnetic surveys followed by ground geophysical surveys to define drill targets. (These costs included the Moak Shaft, Pipe Shaft, drilling of the Moak and Thompson orebodies and purchase or option of properties).

Although exploration in the Moak-Setting Belt throughout the period 1946-1954 had been successful in locating several nickel-bearing zones, it wasn't until 1954 that Inco defined enough potential at Moak Lake to warrant underground exploration. By 1956 over 720 000 m of diamond drilling had been undertaken.

The orebody that now marks the site of the town of Thompson was discovered in early February 1956. Subsequent negotiations between Inco and the provincial government laid the foundation for the development of the orebodies, included provision for guaranteed land tenure, supply of hydroelectric power (Kelsey generating station on the Nelson River) and construction of the mining complex and town of Thompson. The final item of documentation needed to formally register Inco's initiative was approved on December 4, 1956, thereby opening the door for business. Two and a half years later, in April 1959, the company announced its decision to build a refinery that would use the electrolytic process at Thompson.

In 1957, new ore zones were discovered on the Thompson property and on the Pipe property south of Upper Ospwagan Lake. Development of the Moak Lake Mine was suspended in 1958, when it was found that the ore zone lacked depth, and that mining (extraction) problems might be encountered. Accordingly all efforts were redirected toward development of the Thompson Mine.

Over the following four years while the Thompson complex was being constructed, exploration continued in other parts of the TNB as well as the Gods Lake-Island Lake-Fox River areas, motivated by the conviction that nickel ores were more likely to be found in belts containing peridotite.

By 1958, Inco had staked most of the ground in the TNB deemed to have potential value, and the neighbouring tracts between Moak and Setting lakes were staked by a host of other companies during the winter of 1958.

During 1959 and 1960 "Inco exploration crews performed a variety of exploration work in the Thompson Belt, at Island Lake, at Gods-Oxford lakes, in the area west from Setting Lake to Wekusko Lake and ***south into the Paleozoic formations"*** (Fraser, 1985, p. 292). This was the first indication that explorationists suspected that the nickel-bearing zones continued southwest beyond the southern end of Setting Lake, a fact that was to be confirmed by AMAX Exploration Inc. ten years later.

In March 1961 production began from the Thompson Mine. At this time Inco held 8000 claims in the TNB, and the company had conducted 128 000 km of aeromagnetic surveys, 112 000 km of airborne electromagnetic surveys and 17 600 km of ground geophysical surveys (Fraser, 1985).

From 1961 to 1971 Inco spent $270 M to bring Thompson, Birchtree, Pipe 1, Pipe 2, Soab North and Soab South mines into production (Table 1). With falling nickel prices and dropping demand in the early 1970s, Inco closed all but the Thompson and Pipe open pit mines by 1977. Pipe Pit closed in 1984. However, in anticipation, construction of the $87 M Thompson Open Pit North was announced in 1981. The Thompson Pit was brought into production in 1986. Inco committed itself to a $108 M development program in 1986 that included mining of the Thompson 1-C orebody between the 732 m and 975 m levels, reactivation of the Birchtree Mine and construction of the Thompson Open Pit South. In October 1990, Inco announced a further $287 M investment that included mining of the Thompson 1-D orebody with three shafts to 1100 m level and deepening of the Birchtree shaft from the 1045 m level to the 1295 m level (Bamburak, 1990). The latter has been deferred to 1996.

In addition to investing in mine development, Inco also announced an increase in its 1991 exploration expenditures to $7 M for further delineation of ore reserves in the 126 km long TNB. During the period 1958/1968 the total accumulated Manitoba income resulting from the Thompson mining developments was estimated at $850 M by Hedlin-Menzies *et al.*, (1970).

After the initial discovery of the large nickel deposits along the exposed section of the TNB, and the opening of several mines by Inco Ltd. and Falconbridge Nickel Mines Limited (Table 1), exploration extended into the southwest extension of the TNB in the 1970s. At that time, the Minago "Nose" deposit (225 km south of Thompson), presently owned by Black Hawk Mining Inc., was discovered by AMAX Exploration Inc. (Fig. 7). The deposit contains reserves estimated to the 549 m level at two different cut-off grades (1.1% and 0.6%) as 10.5 million tonnes grading 1.19% nickel, or 20.5 million tonnes grading 1.02% nickel, respectively (1993 Annual Report, Black Hawk Mining Inc.). In early 1994, Black Hawk staked an additional ten claims (1 626 hectares) on ground adjacent to the main property where the previous owner identified five magnetic anomalies interpreted as ultramafic bodies.

Between 1988 and 1990, Strathcona Mineral Services Limited staked ten claims in the Little Limestone Lake region on behalf of Sherritt Inc. (Fig. 7). Ground magnetometer, gradiometer and pulse EM surveys, nine diamond drill holes and a downhole pulse EM survey were completed in 1989 and 1990. Principal intersections of note were 0.56% Ni over 140.8 m, including 1.04% Ni over 10.0 m; 0.50% Ni over 81.0 m, including 0.95% Ni over 9.0 m; and 0.59% Ni over 78.1 m,

Aeromagnetic Total Field / Gradiometer / VLF–EM Surveys

(Canada / Manitoba Mineral Development Agreements 1984–89 & 1990–95)

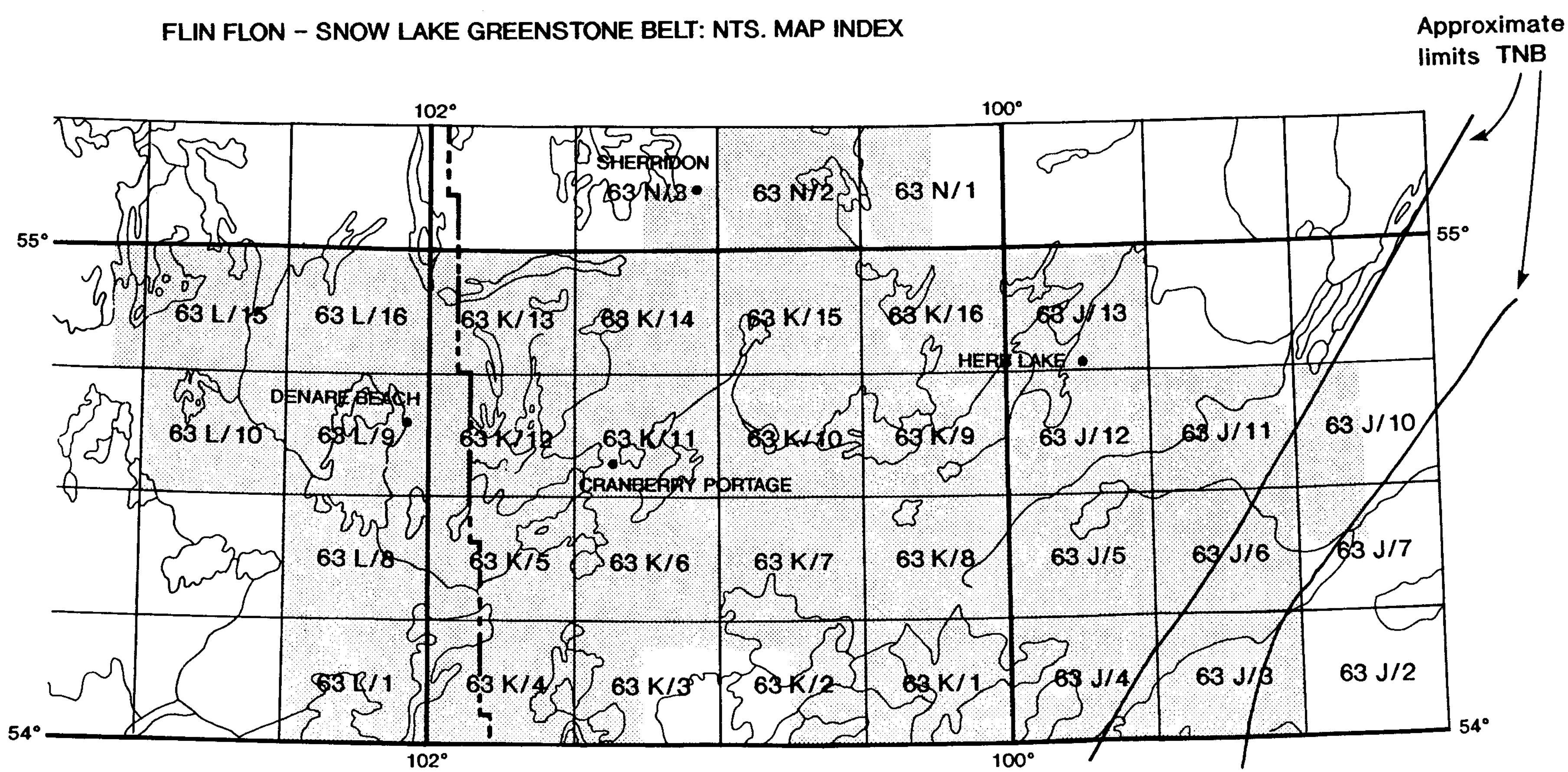


Figure 8: Index map of airborne gradiometer coverage Flin Flon/Grandl Rapids reigon (including the TNB extension).

including 1.10% Ni over 4.0 m (Sherritt Inc., pers. comm., 1995). The claims are still in good standing.

Two major companies, Falconbridge and Cominco, are spearheading efforts to define nickel mineralization along the southwest extension of the TNB (Fig. 7) using state of the art geophysical instrumentation and extensive geological experience gained in the exposed section of the TNB and similar terranes elsewhere in the world

Falconbridge's five-year, $8 M exploration program has identified significant nickel mineralization at William Lake, 70 km north of Grand Rapids. The principal deposit is one of six nickel occurrences that the company discovered during the period 1991-1994 (Falconbridge Limited Annual Reports 1991, 1992 and 1993; Lee *et al.,* 1993). Drill intersects on the principal deposit gave assay results of up to 3.9% nickel over 3.6 m and 1.6% nickel over 25.1 m; and several grams per tonne of platinum group metals. The best intersection on the other occurrences assayed 0.74% nickel over 32.0 m (Falconbridge Limited, public announcement September 27, 1994).

The occurrences are spread over a distance of 20 km and drill holes are too far apart to determine reserves at this time.

In 1994 Falconbridge completed extensive airborne electromagnetic (GEOTEM) and magnetic surveys to improve the regional delineation of the more prospective zones on its properties. Falconbridge intends to mount a follow-up diamond drilling program to consolidate ground holdings. Plans call for additional exploration expenditures, in the southwest extension of the TNB, of between $10-15 M over the next five years.

Since 1990 Cominco Limited has explored for nickel-copper deposits along the eastern edge of the TNB in the Cedar Lake-Lake Winnipegosis area (Fig. 7). The geophysical environment in the southern two-thirds of the area is particularly hostile in that saline aquifers inhibit the use of airborne and ground electromagnetic surveys. This adds to the difficulty of investigating targets buried beneath 140 to 500 m of Paleozoic carbonates. The surveys have identified many formational conductors. Twelve drill holes intersected extremely fresh, almost unmetamorphosed supracrustal rocks, including thin to thick komatiite flows; massive, pillowed and layered magnesian tholeiite with interflow sulphidic argillite; and black shale, calcareous siltstone and dolomite intruded by gabbro and peridotite-dunite. Based on the limited amount of drilling completed, it appears that potential exists for both Kambalda- or Katiniq-type nickel deposits associated with komatiitic flows, as well as Thompson-type nickel deposits associated with dunite and peridotite intruded along sulphide-rich horizons (Pearson *et al.,* 1994).

Several other companies are actively exploring the southwest extension of the TNB, most notably Hudson Bay Exploration and Development Company Limited, which holds claim groups 117a and b, 132, 133, 134, and Manitoba Mineral Resources Ltd. (Fig. 7).

GEOLOGICAL MAPPING AND INVESTIGATIONS

Since the early 1970s the provincial Geological Services Branch (GSB) has assisted private sector exploration for copper, zinc and nickel deposits concealed beneath the Paleozoic cover, by compiling geological maps of the Precambrian basement using exploration drill core and existing federal/provincial airborne magnetic surveys. The available database was sparse, fragmentary, and inconsistent, containing records generated by numerous different explorationists over an extended period of time. Nevertheless, the early interpretations confirmed the continuity of the more prospective greenstone belts (Snow Lake and **TNB**) beneath the carbonate cover to the south and west. A series of federal/provincial airborne gradiometer surveys was initiated during the period 1979-1992 to complete coverage of the Flin Flon/Snow Lake region to latitude 54° and from the Saskatchewan/Manitoba border as far east as 98° 45'E (i.e., including the **TNB** extension; Fig. 8). In concert with the new geophysical information the federal and provincial Geological Surveys initiated complementary projects to standardize the logging of available and new exploration drill cores; scout drilling to fill gaps between the exploration properties; and compilation projects to assemble and interpret the new data (see GSB Annual Reports of Activities 1982-1994). The GSC largely focussed its work on the region northwest of the **TNB** (NTS 63K), the GSB on the **TNB** extension and immediately contiguous areas (NTS 63J and 63G).

The GSB continues to log and interpret Precambrian drill intersections; develop depth-to-basement maps based on analysis of the Paleozoic intersects (Bezys, in prep.); and conduct stratigraphic drilling to aid mapping of the Paleozoic carbonates and scout drilling to define the general geology and southeastern limits of the buried TNB (Bezys, 1990, 1991, 1992, 1993, 1994; Macek and Weber, 1994; McGregor, 1988, 1994; McGregor and Macek, 1992a and b, 1993). Investigations of ground conditions and groundwater systems in the Grand Rapids region have also been initiated (McRitchie, 1989, 1994).

GSC contributions include a new gravity survey blanketing the region between Ponton and Easterville (Lucas *et al.,* 1993; Broome *et. al.,* in prep.); interpretation of the multi-parameter potential field data (Thomas and Tanczyk, 1994; White and Lucas, 1994); geochemical investigations into the genesis of the massive sulphide ores (Eckstrand *et al.,* 1989) and the associated volcanic rocks (Baragar and Scoates, 1981, 1987; Bleeker, 1991); and isotopic and geochemical definition of Cominco's Precambrian intersects southwest of Grand Rapids (Hulbert *et al.,* 1994a and b).

A Vibroseis reflection seismic transect was completed along Provincial Highway #60 from Long Point to Westray, during the summer of 1994, as part of the NSERC- and NRCan-funded LITHOPROBE Trans-Hudson Orogen Project coordinated through the Universities of Saskatoon and Regina and the GSC (Hajnal *et al.,* 1994). The results of this survey will be combined with results from earlier reflection and refraction seismic surveys to the north (Hajnal, 1992, 1993 and 1994), in order to better define the fundamental crustal structures in the Trans-Hudson Orogen, the western Superior Craton, the **TNB** and its extension.

Within the exposed Precambrian Shield the GSB and GSC have collaborated on several detailed mapping projects focussed on Setting Lake, Thompson Open Pit, Ospwagan Lake and Pipe Pit (Albino and Macek 1981, Albino *et al.*, 1981a, and 1981b; Macek, 1980, 1986, 1987a, 1987b; Bleeker and Macek, 1988a, 1988b, 1989; Macek and Russell, 1978a, 1978b). The principal product was a much enhanced documentation and understanding of the supracrustal sequences that constitute the Ospwagan Group, its contained ultramafic intrusions and the associated nickel-bearing massive sulphide zones. Site-specific studies generated benchmark documentation of type localities that are now showcased regularly in field trips for industry explorationists. The structural and stratigraphic relationships derived from the detailed studies were also used as a platform to reinterpret the geological evolution of the **TNB** (Bleeker, 1990, 1991; Galley *et al.*, 1990). The resultant models provided new insights and guidelines that contributed significantly to subsequent exploration programs throughout the belt.

RESOURCE ASSESSMENTS AND EXPLORATION POTENTIAL

The mineral potential of the Little Limestone Lake area was briefly appraised by the GSC (Anglin, 1993). This review was requested by Parks Canada as background to a feasibility study of potential sites for a new National Park in Manitoba's Lowland area. The GSC uses a seven-point scale of mineral potential ratings (Scoates *et al.,* 1986), for geological resource assessments of proposed park areas on federal lands. The Little Limestone Lake area was given the highest ranking ("Very High") in its potential for nickel deposits.

The "Very High" ranking was justified by three key criteria:

- very favourable geological environment,
- known significant deposits in the geological domain.
- presence of additional undiscovered deposits very likely (based on mineral deposit models).

In addition Anglin (1993) noted that "the rocks of the **Thompson Nickel Belt**, which extend underneath the Paleozoic strata in the area of the National Park study, host world-class nickel sulphide deposits where they occur to the northeast." Moreover "the Little Limestone Lake area is under active exploration for nickel and there have been recent discoveries."

Concurrently, the GSB conducted a parallel assessment of the nickel belt and its southwest extension. The geological and geophysical database was used to define the boundaries and extent of the **TNB**. Figuratively, the **TNB** was subdivided into four segments each with a different history/intensity of exploration, quality of database, attendant level of geological understanding, and resource assessment potential (Fig. 9). These range from segment 1, with numerous nickel-bearing orebodies and an established record of mining, to segment 4, in which mineralization has not yet been discovered, but which possesses a favourable geophysical signature likely to attract exploration in the future.

The segments are:

1 - Thompson to Ponton
exposed Precambrian Shield with past and present nickel mining, and undeveloped orebodies; active exploration

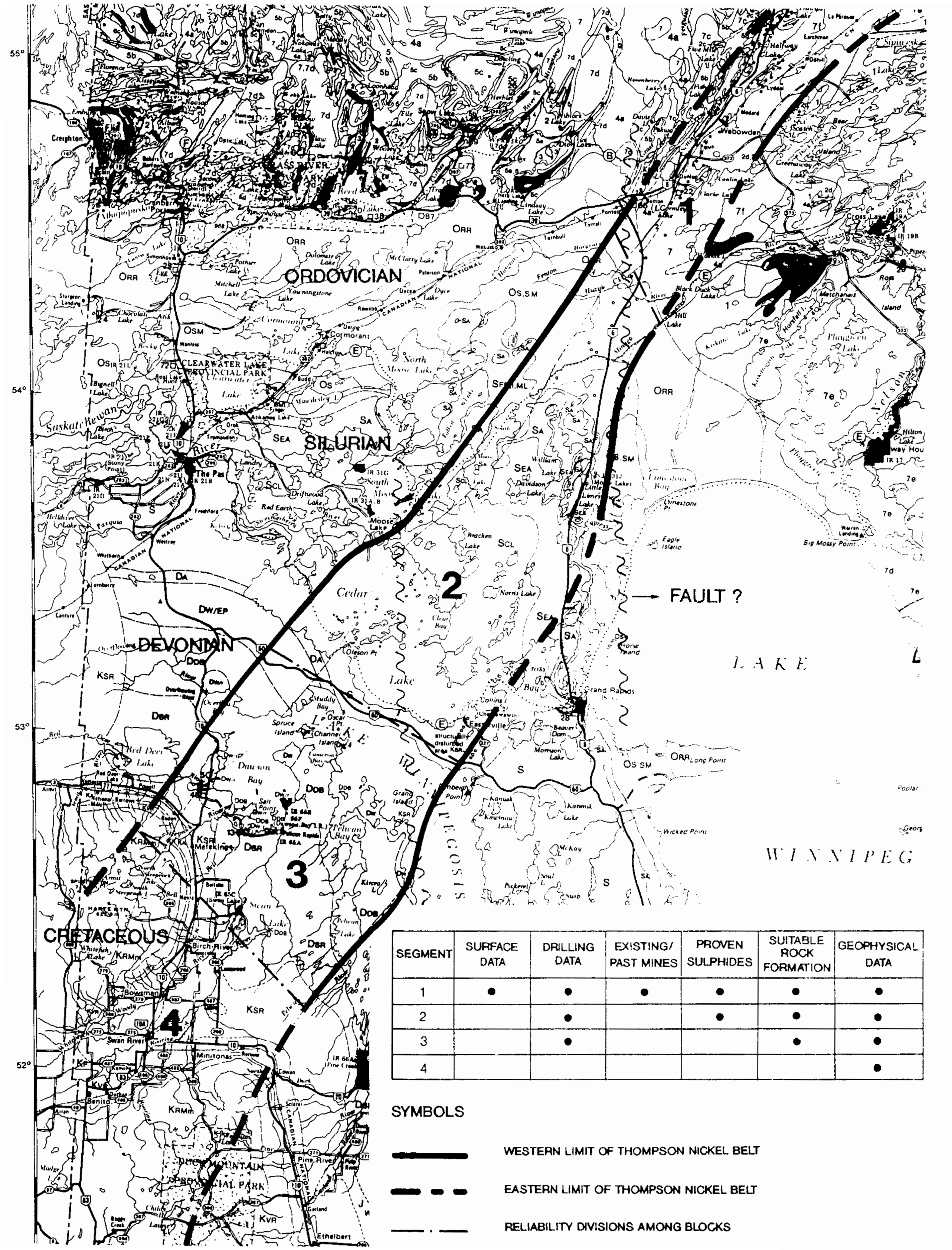
2 - William Lake
Precambrian Shield buried beneath Paleozoic cover; well defined by geophysical surveys and abundant exploration drill holes; favourable geology similar to the Thompson to Ponton segment; nickel mineralization discovered in potentially economic sulphide bodies; active exploration

3 - Denbeigh Point
geophysically well defined, relatively few drill holes, favourable geology with highly primitive komatiitic flow sequences; significant mineralization not yet encountered; active exploration

4 - Swan River
geophysically defined, sparse drill hole information; exploration dormant; thickest (>500 m) cover of younger post-Precambrian rocks; most expensive exploration and potential mining costs.

The above subdivision also provides a generalized ranking of discovery potential (1 and 2 - very high; 3 - high, 4 - medium to low), in a domain with known nickel mineralization. The GSB assessment concluded that **"The unique geological attributes, setting, and mineral endowment of the entire TNB have, and will continue to focus exploration for nickel along this belt. At this time, the recently proven existence of significant nickel mineralization in the William Lake segment, has greatly elevated this region's immediate importance from an endowment and discovery-potential perspective."**

Accordingly it was recommended that special recognition be given to the region's residual mineral exploration and development potential and that potentially conflicting land-use designations be avoided. Acceptance of this position was expressed in a press release by the Department of Natural Resources, November 18, 1993. It was indicated that the **TNB** extension was to be withdrawn from consideration in the Manitoba Lowlands National Park Feasibility Study (Fig. 10).



SEGMENT	SURFACE DATA	DRILLING DATA	EXISTING/ PAST MINES	PROVEN SULPHIDES	SUITABLE ROCK FORMATION	GEOPHYSICAL DATA
1	●	●	●	●	●	●
2		●		●	●	●
3		●			●	●
4						●

SYMBOLS

WESTERN LIMIT OF THOMPSON NICKEL BELT

EASTERN LIMIT OF THOMPSON NICKEL BELT

RELIABILITY DIVISIONS AMONG BLOCKS

Figure 9: *Fourfold subdivision of **TNB** in context of exploration intensities/availability of data/difficulty of exploration.*

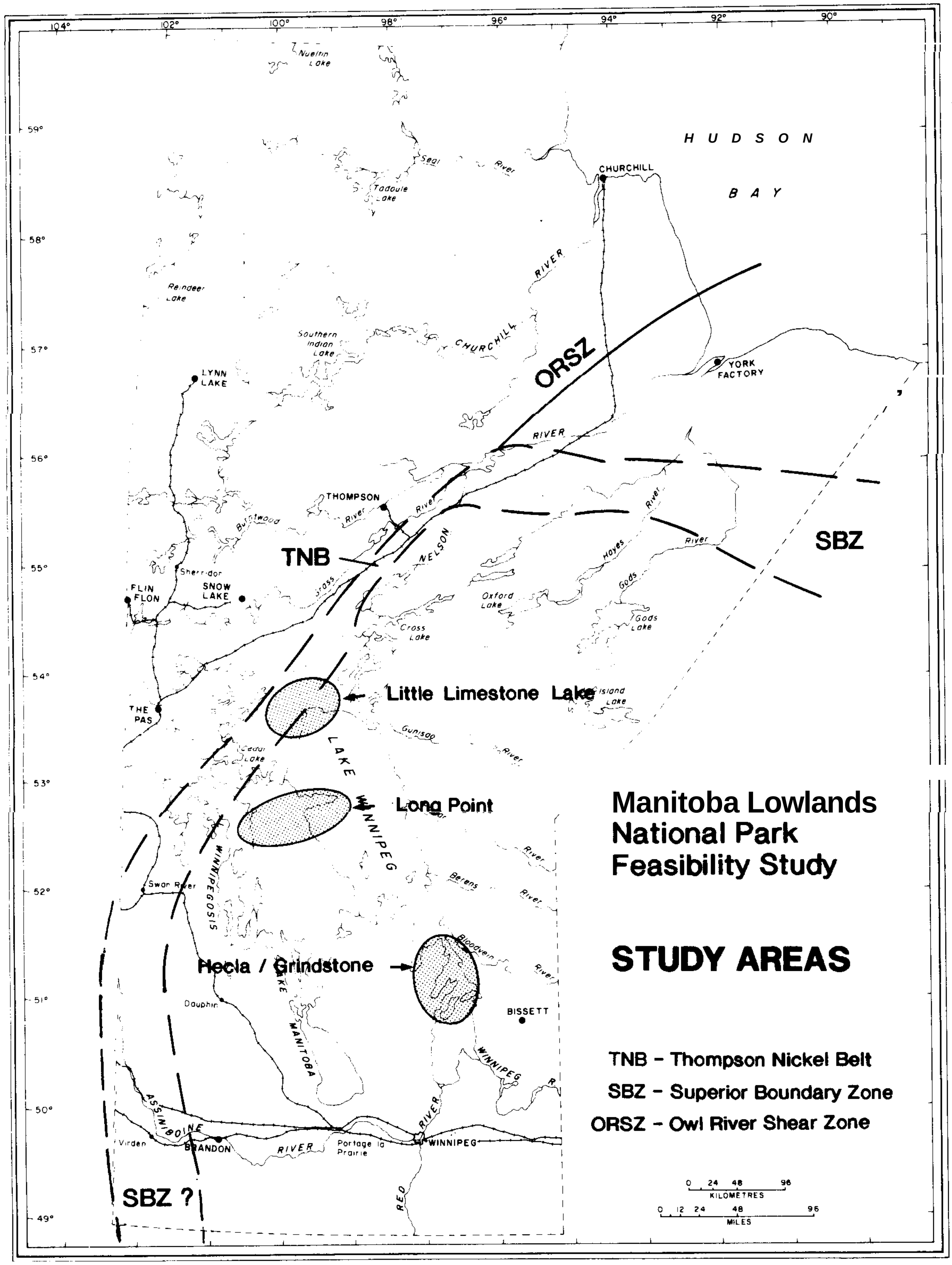


Figure 10: *Index map showing **SBZ** and **TNB** in context of Manitoba Lowlands National Park Feasibility Study areas.*

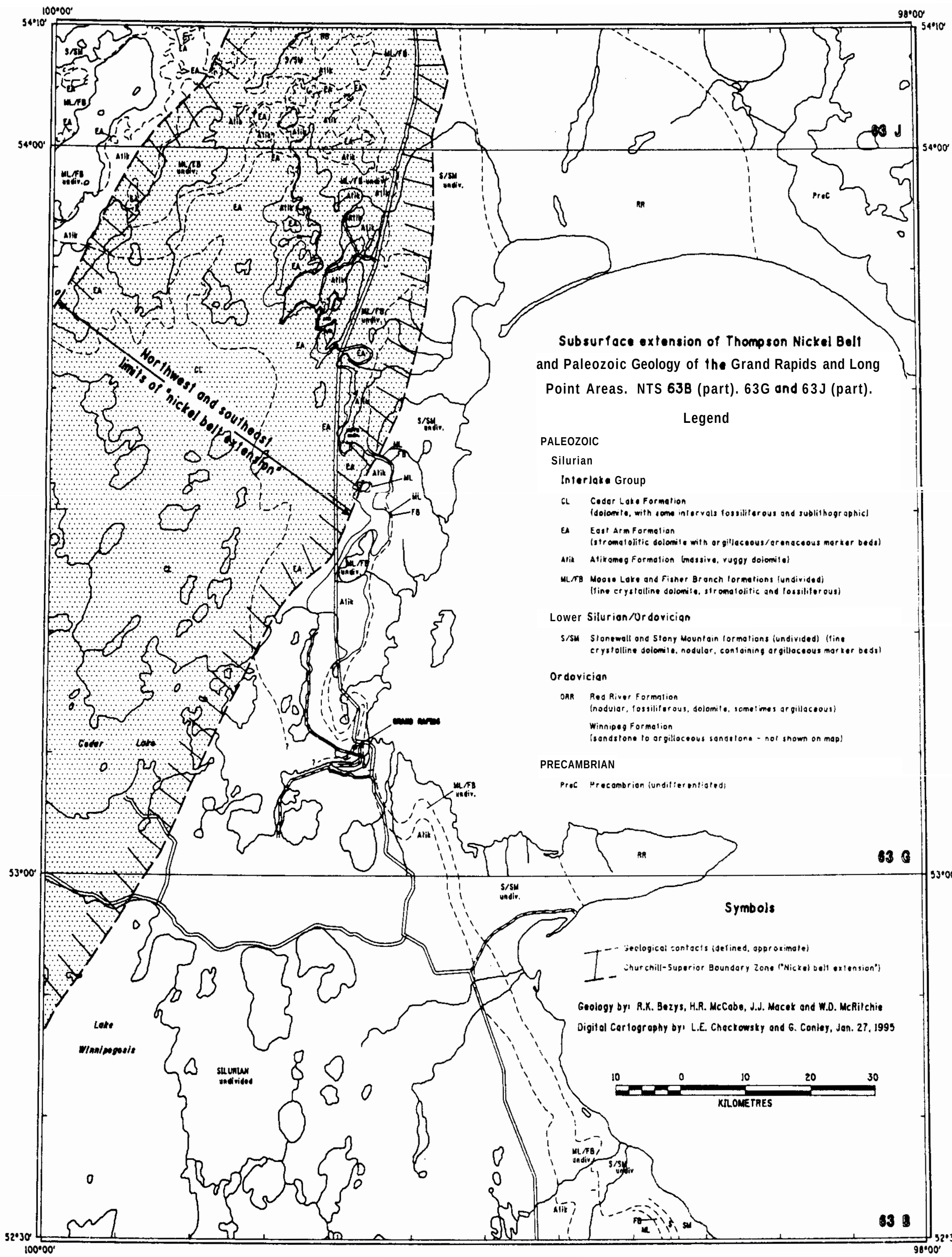


Figure 11: *Map showing southeast and northwest boundaries of the **TNB** extension as interpreted from airborne geophysical signature, gravity anomalies, exploration drillcore, and scout drilling in the William Lake area. Paleozoic geology after Bezys et al. (1994).*

CONCLUDING STATEMENT

The geological attributes of the more prospective zones along the southwest extension of the **TNB** are much better understood as a result of more recent exploration and geological work (Table 2). Gravity and other potential field data delineate the northwest and southeast boundaries of the **TNB** extension (Fig. 11).

Falconbridge's William Lake deposit is conclusive evidence that the geological environments hosting significant nickel sulphide mineralization persist at least 100 km southwest of the most southerly mined deposit at Manibridge. Drilling by Cominco and Falconbridge within the **TNB** extension has intersected several occurrences of komatiitic ultramafics that (in other sectors of the **SBZ**) are commonly associated with nickel mineralization. Logging of drill core has also confirmed the existence of Ospwagan Group sequences at numerous locations between Ponton and Easterville. Accordingly, there is increasing evidence that suggests numerous new nickel sulphide deposits will be discovered in the southwest extension of the **TNB** between Ponton and Swan Lake.

Revenues and employment stemming from the development of new deposits will contribute substantially to Manitoba's economy in the twenty-first century.

In the context of past production it should be noted that in the four year period 1990-1993 the combined value of nickel, cobalt, platinum group metals and copper extracted from the exposed section of the **TNB** averaged $578 M per annum. This significantly exceeded the average value of wheat production for the entire province, which for the same four-year period averaged $513 M per annum (Table 3).

The latest discovery announced in the belt by Inco Exploration and Technical Services Inc. (valued at $600 M) was the Pipe Deep deposit 32 km south of Thompson, with a reported 4 million tonnes, grading 2.32% nickel at depths of between 855 and 1590 m (Winnipeg Free Press, October 12, 1994).

The continued vitality and productivity of the **TNB** is also reflected in Inco's most recent development, the Thompson 1-D orebody, which is expected to be the most economic source of nickel in Inco's Manitoba Division. By January 1995, Inco had spent $90 M on the first phase of exploration and development, which outlined 7.7 million tons of ore. Reserves for the deposit are estimated at 20.9 million tons grading 2.51% nickel. The next phase of activity will focus on exploration and development of additional reserves (The Northern Miner, Jan. 2, 1995).

TABLE 2
METALLIC MINES AND MINERAL DEPOSITS, THOMPSON NICKEL BELT: (BAMBURAK, 1990; REVISED TO JANUARY 1995)

Name/ Commodity	Location/ Coordinates	Holder/ Operator	Status	Mineralization/Resources Development		
Mel Zone (Ni)	55° 58.41' 97° 46.20'	Inco Limited	Mineral Deposit	mineralization: nickel development: Explored Area Lease No. 12 in 1976.		
Moak (Ni)	55° 56.08' 97° 34.87'	Inco Limited	Mineral Deposit	resources: 45 million tonnes running 0.7% Ni, widths up to 90 m development: capital cost $2 million, exploration shaft reached depth of 404 m with levels at 213, 305, and 396 m. Production shaft to 695 m begun in 1957 never completed due to Thompson discovery.		
Mystery Lake (Ni)	55° 49.70' 97° 45.41'	Inco Limited	Mineral Deposit	resources: 227 million tonnes at 0.6% Ni, 225.8 million tonnes at 0.46% Ni or 45 million tonnes at 0.5% Ni.		
				Capacity (tonnes/day)	Production	Resources
Thompson (Ni, Cu, Co, Pt, Pd, Au, Ag)	55° 43.20' 97° 51.24'	Inco Limited	Present Producer	total present 5600 1600 by 1995	1960 full production from new development in 1990	1-C deposit - 4.5 million tonnes of nickel ore to be produced over 15-17 years from 183 to 726 m long orebody
				3200 by 1997	July 1994 from 1-D orebody. By 1997, 17 million kg capital cost of $209 million.	19.0 million tonnes grading 2.51% Ni, a 20-year supply of ore, the most economical source of nickel in Inco's Manitoba division. To the end of 1994, Inco had spent $90 million on the first phase, which outlined 7.0 million tonnes of ore.
				3000	Nov./85 ten year open pit life for first phase. Dredging to be completed June 1990 in second phase	average grade about 2.4% Ni for North open pit. South pit estimated to contain 68 million kg of nickel

Birchtree (Ni, Cu, Co, Pt, Pd, Au, Ag)	55° 42.14' 97° 51.24'	Inco Limited	Present Producer	4100 by 1997	<u>1969-77</u> 136 million kg Ni production resumed May 16, 1989. By 1997, 15 million kg Ni/year	contains 317 million kg Ni, 20-year supply of ore
				<u>development</u>: capital cost $117 million, development of upper portion of mine essentially completed as of end of 1993. Startup of the shaft deepening phase was deferred until 1996.		
Pipe (Ni, Cu, Co, Pt, Pd, Au, Ag)	55° 29.80' 98° 09.44'	Inco Limited	Past Producer (Standby)	900	<u>1970-71</u> production to mid-1971	
				3600	<u>1969-1984</u> 18 million tonnes interstitial, breccia and massive sulphide ore mined	none
				900	only from upper part of orebody by open pit method	
Pipe Deep (Ni, Cu, Co, Pt)	55° 30' 97° 51'	Inco Limited	Mineral Deposit	<u>mineralization</u>: similar in grade to that of Thompson. <u>resources</u>: 3.6 million tonnes grading 2.32% Ni and about 0.1% Cu between 855 and 1590 m below surface. The deposit valued, at $600 million, is open along strike and at depth. <u>development</u>: four drills on property in 1994 and drilling to continue throughout 1995. Following this, an engineering study will be conducted to determine the feasibility of production; possibly in three years and employing 100 people.		
Hambone-Maralgo (Ni)	55° 17.30' 98° 19.99'	Inco Limited	Mineral Deposit	<u>resources</u>: indicated 3.27 million tonnes at 0.81% Ni to 305 m depth in #1 zone and 1.09 million at 1.10% Ni in North Creek zone & #2 zones		
Grass (Ni)	55° 14.30' 98° 21.13'	Inco Limited	Mineral Deposit	<u>mineralization</u>: large body of low grade nickel-bearing material <u>development</u>: explored by extensive diamond drilling prior to August, 1953		

Name/ Commodity	Location/ Coordinates	Holder/ Operator	Status	Mineralization/Resources Development		
Soab North (Ni, Cu)	55° 13.95' 98° 24.11'	Inco Limited	Past Producer (Standby)	900	<u>1967-71</u> mining ceased due to several factors leading to a decrease in ore. Predicted mine life 12-15 years.	pre-production 90 000 to 0.9 million tonnes mineralized material grading up to 1.5% Ni
Soab South (Ni, Cu)	55° 12.60' 98° 25.28'	Inco Limited	Past Producer (Standby)	2700	<u>1967-71</u> mining ceased due to several factors leading to a decrease in ore. Predicted mine life 12-15 years.	included in Soab North
Bowden (Ni)	54° 55.37' 98° 38.60'	Bowden Lake Nickel Mines Limited. 95.3% interest held by Falconbridge Limited	Mineral Deposit	<u>resources</u>: indicated 87 919 000 tonnes at 0.627% Ni to at least 300 m <u>development</u>: exploration shaft sunk to 91 m		
Discovery (Ni)	54° 54.15' 98° 37.27'	Bowden Lake Nickel Mines Limited	Mineral Deposit	<u>resources</u>: 6000 tonnes per vertical m at 0.89% Ni plus 3000 tonnes per vertical m at 1.36% Ni in three zones to at least 240 m or 4.5 million tonnes at 1% Ni		
Bucko (Ni)	54° 52.76' 98° 39.37'	Bowden Lake Nickel Mines Limited 95% interest held by Falconbridge Limited	Mineral Deposit	<u>resources</u>: 18.8 million tonnes at 1.0% Ni or 2.5 million tonnes at 2.23% Ni and 0.17% Cu to 884 m <u>development</u>: three compartment shaft sunk to 340 m with 300 m exploration drift driven at 300 m level, additional drilling done in 1990		
Resting Lake (Ni, Cu)	54° 51.70' 98° 42.62'	Falconbridge Limited	Mineral Deposit	<u>resources</u>: 90 million tonnes at 0.30% Ni-Cu to 305 m. Locally large volumes of rock reported to exceed 0.40% Ni-Cu.		

Manibridge (Ni, Cu)	54° 42.14' 98° 50.23'	Falconbridge Limited	Past Producer (shaft completed to 434 m with seven levels)	900	June 1971-1977 937 912 tonnes 1.81% Ni, 0.14% Cu Mine closed due to insufficient production of economic grade ore.	May 1969 before production 1 278 000 tonnes (including 15% dilution) grading 2.55% Ni and 0.27% Cu to the 381 m level
Minago (Ni)	54° 05.30' 99° 11.20'	Black Hawk Mining Inc. Canamax Resources Inc. 1.5% net smelter. Interest Granges Inc. 25%	Mineral Deposit (6-9000 m diamond drilling program begun Sept/90)	resources: geological ore reserves, in six lenses, estimated to 549 m level at cut-off grades of 1.1% Ni and 0.6% Ni are 10.5 million tonnes grading 1.19% Ni or 20.5 million tonnes grading 1.02% Ni, respectively. development: predicted 3200 tonne/day operation producing 7.5 million kg of nickel per year, capital cost $120 million, employing 150-180 people, mine life 15-18 years.		
William Lake (Ni)	53° 49.50' 99° 23.42'	Falconbridge Limited	Mineral Deposit	mineralization: drill intersects 3.9% Ni over 3.6 m and 1.6% Ni over 15.1 m. William Lake is one of six nickel occurrences discovered in the period 1991-1994. Best intersection on the other occurrences assayed 0.74% Ni over 32.0 m. Mineralization has a strike length of 500 m and vertical extent of 400 m and occurs under 100 m of limestone.		

TABLE 3
VALUE OF MINERAL PRODUCTION - THOMPSON NICKEL BELT (COPPER VALUE ESTIMATED AT 5% OF MANITOBA'S TOTAL COPPER PRODUCTION) AND VALUE OF FARM CASH RECEIPTS WHEAT PRODUCTION

				$ 000's		
Year	**Nickel**	**Cobalt**	**PGM**	**Copper**	**Total**	**Wheat**
1990	682,286	7,328	17,822	8,738	716,174	568,040
1991	588,342	15,781	17,717	7,426	629,266	558,924
1992	496,556	30,556	16,925	8,420	552,457	426,845
1993	379,832	14,219	11,747	7,758	413,556	496,960

REFERENCES

Albino, K.C. and Macek, J.J.
1981: Thompson Nickel Belt project: Setting Lake; **in** Manitoba Energy and Mines, Mineral Resources Division, Report of Field Activities 1981, p. 30-36.

Albino, K.C., Macek, J.J., Kujanpaa, R.B., Zimrner, F.G., Deverill, B.D., and McNeill, D.D.
1981a: Setting Lake Northeast; Manitoba Energy and Mines, Preliminary Map 1981T-1, 1:25 000.
1981b: Setting Lake Southwest; Manitoba Energy and Mines, Mineral Resources Division, Preliminary Map 1981T-2, 1:25 000.

Anglin, C.D.
1993: Summary of the geology and mineral potential of the Little Limestone Lake area. Unpublished report prepared for Parks Canada, Geological Survey of Canada.

Bailes, A.H. and M^C^Ritchie, W.D.
1978: The transition from low to high grade metamorphism in the Kisseynew sedimentary gneiss belt, Manitoba; **in** Metamorphism in the Canadian Shield (J.A. Fraser and W.W. Heywood, eds.); Geological Survey of Canada, Paper 78-10, p. 155-178.

Bamburak, J.D.
1990: Metallic mines and mineral deposits of Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report OF90-2.

Baragar, W.R.A. and Scoates, R.F.J.
1981: The Circum-Superior Belt: A Proterozoic plate margin? **in** Precambrian Plate Tectonics (A. Kroener, ed.); Elsevier, New York, p. 297-330.
1987: Volcanic geochemistry of the northern segments of the Circum-Superior Belt of the Canadian Shield; **in** Geochemistry and Mineralization of the Proterozoic Volcanic Suites (T.C. Pharaoh, R.D. Beckinsale and D. Rickard, eds.); Geological Society, London, Special Publication No. 33, p. 113-131.

Bell, C.K.
1966: Churchill-Superior boundary in northeastern Manitoba; Geological Survey of Canada, Paper 66-1, p. 133-136.
1971: Boundary geology, Upper Nelson River area, Manitoba and Northwestern Ontario; **in** Geoscience Studies in Manitoba (A.C. Turnock, ed.); Geological Association of Canada, Special Paper 9, p. 11-39.
1980: Geology of the Wekusko Lake sheet, Manitoba; Geological Survey of Canada, Map 1423A, 1:250 000 (with Memoir 384).

Bezys, R.K.
1990: Stratigraphic mapping and core hole program 1990 (NTS 63G); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities 1990, p. 140.
1991: Stratigraphic mapping (NTS 63K and 63F) and core hole program 1991; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities 1991, p. 61.
1992: Stratigraphic mapping and core hole program 1992; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities 1992, p. 123-131.
1993: Stratigraphic mapping and core hole logging; **in** Manitoba Energy and Mines, Geological Services, Report of Activities 1993, p. 127.
1994: Stratigraphic mapping (NTS 63G and 63F) and core hole program 1994; **in** Manitoba Energy and Mines, Geological Services, Report of Activities 1994 p. 136-141.
1995: Sub-Paleozoic structure in Manitoba's northern Interlake along the Churchill-Superior Boundary Zone: a detailed investigation of the Falconbridge William Lake study area; Manitoba Energy and Mines, Open File Report 94-3.

Bickford, M.E. Collerson, K.D., Lewry, J.F., and Orrell, S.E.
1992: Pegmatites and leucogranites as probes of crust beneath allochthonous orogenic rocks in the Glennie and LaRonge domains; **in** Summary of Investigations 1992, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 92-4, p. 124-129.

Bleeker, W.
1989: Lithostructural map of the Thompson open pit, Thompson Nickel Belt, Manitoba; Geological Survey of Canada, Open File 2089, 1:1200, with report, 27 p.
1990: New structural - metamorphic constraints on Early Proterozoic oblique collision along the Thompson Nickel Belt, northern Manitoba, Canada; **in** The Early Proterozoic Trans-Hudson Orogen of North America (J.F. Lewry and M.R. Stauffer, eds.); Geological Association of Canada, Special Paper 37, p. 57-74.
1991: Evolution of the Thompson Nickel Belt and its nickel deposits, Manitoba, Canada; University of New Brunswick, Ph.D. Thesis (unpublished), 400p.

Bleeker, W. and Macek, J.J.
1988a: Thompson Nickel Belt project - Pipe Pit Mine; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1988, p. 111-115.
1988b: Pipe open pit mine; Manitoba Energy and Mines, Preliminary Geological Map 1988T-1 to T-8; 1:400.

Brooks, C. and Theyer, P.
1981: Rb-Sr geochronology in the Thompson belt, Manitoba; implications for Aphebian crustal development and metallogenesis; Canadian Journal of Earth Sciences, v. 18, p. 932-943.

Broome, J. et al.,
in prep: Integrated potential field image of the Cedar Lake area, Grand Rapids, Manitoba; Geological Survey of Canada; Open File.

Coates, C.J.A., Quirke, T.T., Bell, C.K., Cranstone, D.A. and Campbell, F.H.A.
1972: Geology and mineral deposits of the Flin Flon, Lynn Lake and Thompson area, Manitoba, and the Churchill-Superior Front of the Western Precambrian Shield; 24th International Geological Congress, Guidebook, Field Excursion A31-C31.

Collerson, K.D., Van Schmus, R.W., Lewry, J.F. and Bickford, M.E.
1988: Buried Precambrian basement in south-central Saskatchewan: provisional results from Sm-Nd model ages and U-Pb zircon geochronology; in Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Cranstone, D.A. and Turek, A.
1976: Geological and geochronological relationships of the Thompson Nickel Belt, Manitoba; Canadian Journal of Earth Sciences, v. 13, p. 1058-1069.

Eckstrand, O.R., Grinenko, L.N., Krouse, H.R., Paktunc, A.D., Schwann, P.L. and Scoates, R.F.J.
1989: Preliminary data on sulphur isotopes and Se/S ratios, and the source of sulphur in magmatic sulphides from the Fox River Sill, Molson Dykes and Thompson nickel deposits, northern Manitoba; **in** Current Research, Part C, Geological Survey of Canada, Paper 89-IC, p. 235-242.

Falconbridge Review
1990: Exploring for tomorrow, p. 9

Falconbridge Review
1991: Exploration Highlights, p. 9

Falconbridge Review
1992: Exploration Manitoba, p. 9

Falconbridge Limited
1994: Nickel discovery in the Thompson Nickel Belt, Manitoba; Public Release Notice, Winnipeg, September 27, 1994.

Fraser, H.S.
1985: A Journey North, The Great Thompson Nickel Discovery; lnco Limited, Manitoba, p. 388.

Fueton, F. and Robin, P.
1989: Structural petrology along a transect across the Thompson Belt: dip-slip at the western Churchill-Superior boundary; Canadian Journal of Earth Sciences, v. 26, p. 1976-1989.

Galley, A.G., Bailes, A.H., Syrne, E.C., Bleeker, W., Macek, J.J. and Gordon, T.M.
1990: Geology and mineral deposits of the Flin Flon and Thompson belts, Manitoba; Geological Survey of Canada, Open File 2165, 8th IAGOD Symposium Field Trip Guidebook, 136p.

Geological Survey of Canada
1969: Grand Rapids, Manitoba; Geological Survey of Canada, Aeromagnetic Series, Geophysics Paper 7740, Map 7740G, 1:250 000.

Gibb, R.A.
1968: A geological interpretation of the Bouguer anomaly adjacent to the Churchill-Superior boundary zone in northern Manitoba; Canadian Journal of Earth Sciences, v. 5, p. 439-453.
1983: Model for suturing of Superior and Churchill plates: an example of double indentation tectonics; Geology, v. 11, p. 413-417.

Green, A.G.
1981: Results of a seismic reflection survey across the fault zone between the Thompson Nickel Belt and the Churchill tectonic province, northern Manitoba; Canadian Journal of Earth Sciences, v. 18, p. 13-25.

Green, A.G., Hajnal, Z. and Weber, W.
1985: An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States; Tectonophysics, v. 116, p. 281-322.

Halden, N.M.
1988: Tectonic setting of Circum-Superior mafic and ultramafic magmatism in Manitoba; **in** Manitoba Energy and Mines, Report of Field Activities 1988, p. 116-123.

Hajnal, Z.
1993: LITHOPROBE 1993 seismic refraction program; **in** Manitoba Energy and Mines, Geological Services, Report of Activities, 1993, p. 125.

Hajnal, Z., Bzdel, L., Clowes, R.M., Ellis, R.M., Spence, G., Asudeh, I., White, D., Forsyth, D.A. and Argyle, M.
1993: The LITHOPROBE Trans-Hudson Transect: preliminary results from the seismic refraction survey of July 1993 (Abstract); Eos, v. 74, p. 442.

Hajnal, Z., Clowes, R.M., Spence, G., Asudeh, **I.** and White, D.
1994: 1993 Refraction Experiment; **in** Report of LITHOPROBE Fourth Trans-Hudson Orogen Transect Workshop, Report 38, p. 27-34.

Hedlin-Menzies and Associates
1970: Thompson Manitoba: "An historical impact analysis of resource development"; Prepared for the International Nickel Company of Canada, Limited, Toronto, Ontario.

Hulbert, L., Kyser, K., Carlson, R., Lesher, M. and Joudrie, C.
1994a: The Winnipegosis Komatiite: a new komatiite belt, central Manitoba (Abstract); **in** Geological Survey of Canada, Minerals Colloquium Program and Abstracts, January, 1994.

Hulbert, L., Stern, R., Kyser, T.K., Pearson, J., Lesher, M. and Grinenko, L.
1994b: The Winnipegosis Komatiite Belt, Central Manitoba (Abstract); **in** Manitoba Mining, Minerals and Petroleum Convention, Winnipeg, Program and Abstracts, November 1994.

Kornik, L.J.
1969: An aeromagnetic study of the Moak Lake - Setting Lake structure in northern Manitoba; Canadian Journal of Earth Sciences, v. 6, p. 373-381.

Kornik, L.J. and MacLaren, A.S.
1966: Aeromagnetic study of the Churchill-Superior boundary in northern Manitoba; Canadian Journal of Earth Sciences, v. 3, p. 547-557.

Leclair, A.D., Lucas, S.B. and Stern, R.A.
1994: Tectonic and economic significance of distinct lithotectonic domains in the sub-Phanerozoic portion of the Flin Flon Belt (Abstract); **in** Manitoba Energy and Mines, Manitoba Mining, Minerals and Petroleum Convention '94, Program and Abstracts, November 1994.

Lee, J.E., Nagerl, P.J., Tirschmann, P.A. and Watts, A.H.
1993: The William Lake nickel discovery: sub-Paleozoic exploration in the southern Thompson Nickel Belt (Abstract); **in** Manitoba Energy and Mines, Manitoba Mining, Minerals and Petroleum Convention '93. Program and Abstracts, November 1993.

Lewry, J.F., Hajnal, Z., Green, A., Lucas, S.B., White, D., Stauffer, M.R., Ashton, K.E., Weber, W. and Clowes, R.
1994: Structure of a Paleoproterozoic continent-continent collision zone: a LITHOPROBE seismic reflection profile across the Tran-Hudson Orogen, Canada; Tectonophysics, v. 232, p. 143-160.

Lucas, S.B., Green, A., Hajnal, Z., White, D., Lewry, J., Ashton, K., Weber, W. and Clowes, R.
1993: Deep seismic profile across a Proterozoic collision zone: surprises at depth; Nature, v. 363, p. 339-342.

Lucas, S.B. White, D. Hajnal, Z., Lewry, J., Green, A., Clowes, R., Zwanzig, H., Ashton, K., Schledewitz, D., Stauffer, M., Norman, A., Williams, P.F. and Spence, G.
1994: Three-dimensional collisional structure of the Trans-Hudson Orogen, Canada; Tectonophysics. (in press).

Macek, J.J.
1980: Halfway Lake; Manitoba Energy and Mines, Preliminary Map 1980T-1, 1.25 000.
1986: Lithological investigation in INCO's Thompson open pit mine; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1986, p. 167-171.
1987a: Geological mapping at Pipe Mine; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1987, p. 137.
1987b: Thompson Open Pit Mine - 1C Pit Cross Section (part of 63P/12W); Manitoba Energy and Mines, Preliminary Map 1967T-1, 1:5000.

Macek, J.J. and Bleeker, W.
1989: Thompson Nickel Belt Project - Pipe Pit Mine, Setting and Ospwagan Lakes; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1989, p. 73-87.

Macek, J.J. and Nagerl, P.
1992: Sub-Paleozoic Precambrian geology of the Churchill-Superior Boundary Zone between Hargrave and Minago Rivers (63J); Manitoba Energy and Mines, Geological Services, Open File OF92-3.

Macek, J.J. and Russell, J.K.
1978a: Ospwagan, Middle and Mid lakes; Manitoba Department of Mines, Resources and Environmental Management, Preliminary Map 1978T-1, 1.25 000.
1978b: Thompson Nickel Belt project: Paint and Ospwagan lakes; **in** Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, Report of Field Activities 1978, p. 43-46.

Macek, J.J. and Scoates, R.F.J.
1980: Thompson Nickel Belt project; **in** Manitoba Energy and Mines, Mineral Resources Division, Report of Field Activities 1980, p. 23-30.

Macek, J.J. and Weber, W.
1994: Precambrian drilling along the sub-Paleozoic eastern boundary of the Thompson Nickel Belt; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities 1994, p. 130-133.

Machado, N.
1990: Timing of collisional events in the Trans-Hudson Orogen: Evidence from U-Pb geochronology for the New Quebec Orogen, the Thompson Belt, and the Reindeer zone (Manitoba and Saskatchewan), **in** The Early Proterozoic Trans-Hudson Orogen of North America (J.F. Lewry and M.R. Stauffer, eds.); Geological Association of Canada, Special Paper 37, p. 433-441.

Machado, N., Heaman, L.M., Krogh, T.E. and Weber, W.
1987: U-Pb geochronology program; Thompson Belt-Northern Superior Province; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1987, p. .

Machado, N., Krogh, T.E. and Weber, W.
1990: U-Pb geochronology of basement gneisses in the Thompson Belt (Manitoba): evidence for pre-Kenoran and Pikwitonei-type crust and early Proterozoic basement reactivation in the western margin of the Archean Superior Province; Canadian Journal of Earth Sciences, v. 27, p. 794-802.

Manitoba Mineral Resources Division
1979: Geological map of Manitoba; Manitoba Department of Mines, Natural Resources and Environment, Map 79-2, Scale 1:1 000 000.

Manitoba Energy and Mines
1993: Manitoba Energy and Mines, Wekusko Lake, NTS 63J; Bedrock Geology Compilation Map Series, Prelimmary Edition, 1:250 000.

McGregor, C.R.
1988: Subsurface Precambrian geology of The Pas-Grand Rapids area; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1988, p. 157.
1994: Relogged drill core from sub-Paleozoic Precambrian basement in NST 63J; **in** Manitoba Energy and Mines, Geological Services, Report of Activities 1994, p. 136.

McGregor, C.R. and Macek, J.J.
1992a: Interpretation of exploration drill core from the southwestern extension of the Thompson Nickel Belt; Manitoba Energy and Mines, Preliminary Report PR92-1, p. 361.
1992b: Relogged drill core from the sub-Phanerozoic SW extension of the Thompson Nickel Belt (NTS 63J, NTS 63G); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities 1992, p. 110.
1993: Relogged drill core from sub-Phanerozoic Precambrian basement in NTS 63J; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities 1993, p. 126.

McRitchie, W.D.
1977: Fox River regional correlation - Part B; Rainbow Falls-"Afternoon Rapids" (Fox River); **in** Manitoba Energy and Mines, Mineral Resources Division, Report of Field Activities, 1977, p. 64-65.
1989: Lead-zinc potential in Paleozoic rocks, northern Interlake region: spring and creek waters and sediments; **in** Manitoba Energy and Mines, Minerals Division, Report of Field Activities 1989, p. 95-102.
1994: Spring water and marl geochemical investigations, Grand Rapids Uplands (NTS 63G); **in** Manitoba Energy and Mines, Geological Services, Report of Activities 1994, p. 148-162.

Paktunc, A.D.
1984: Petrogenesis of ultramafic and mafic rocks of the Thompson Nickel Belt, Manitoba; Contributions to Mineralogy and Petrology, v. 88, p. 348-353.

Paktunc, A.D. and Baer, A.J.
1986: Geothermobarometry of the northwestern margin of the Superior Province; implications for its tectonic evolution; Journal of Geology, v. 194, p. 381-394.

Patterson, J.M.
1963: Geology of the Thompson-Moak Lake area; Manitoba Department of Mines and Natural Resources, Publication 60-4, 50 p.

Pearson, J.G., Joudrie, M.C., Powell, B.W. and Lum, B.T.
1994: Exploration for Ni-Cu deposits in the Thompson Nickel Belt under deep Paleozoic cover (Abstract); **in** Manitoba Mining, Minerals and Petroleum Convention, Winnipeg, Program and Abstracts, November 1994.

Peredery, W.V.
1979: Relationships of ultramafic amphibolites to metavolcanic rocks and serpentinites in the Thompson belt, Manitoba; Canadian Mineralogist, v. 17, p. 187-200.

Peredery, W.V. and Geological Staff
1982: Geology and nickel sulphide deposits of the Thompson belt, Manitoba; **in** Precambrian Sulphide Deposits (R.W. Hutchinson, C.D. Spence and J.M. Franklin, eds.); Geological Association of Canada, Special Paper 25, p. 165-209.

Rance, H.
1966: Superior-Churchill structural boundary, Wabowden, Manitoba; University of Western Ontario, Ph.D. Thesis (unpublished), p. 131.

Russell, J.K.
1981: Metamorphism of the Thompson Nickel Belt gneisses; Canadian Journal of Earth Sciences, v. 18, p. 191-209.

Scoates, R.F.J.
1981: Volcanic rocks of the Fox River Belt, Northeastern Manitoba; Manitoba Energy and Mines, Geological Report GR81-1, p. 109.

Scoates, R.F.J., Jefferson, C.W. and Findlay, D.C.
1986: Northern Canada mineral resource assessment; **in** Prospects for Mineral Resource Assessments on Public Lands: Proceedings of the Leesburg Workshop; U.S. Geological Survey Circular 980, p. 111-139.

Scoates, R.F.J., Macek, J.J. and Russell, J.K.
1977: Thompson Nickel Belt Project; **in** Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, Report of Field Activities 1977, p. 47-53.

St-Onge, M.R. and Lucas, S.B.
1993: Geology of the eastern Cape Smith Belt; parts of the Kangiqsujuaq Cratere du Nouveau-Quebec and lacs Nuvilik map areas, Quebec; Geological Survey of Canada, Memoir 438, p. 110.

Stephenson, J.F.
1974: Geology of the Ospwagan Lake (east half) area; Manitoba Department of Mines, Resources and Environmental Management, Mines Branch, Publication 74-1, 69 p.

Stern, R.A., Syme, E.C. and Bailes A.H.
1993: Arc volcanism in the Flin Flon Belt: the geochemical and isotopic context of volcanic massive sulphide deposits (Abstract); **in** Manitoba Energy and Mines, Manitoba Mining, Minerals and Petroleum Convention '93, Program and Abstracts, November 1993.

Thomas, M.D. and Tanczyk, E.I.
1994: Progress in gravity and magnetic analysis along the LITHOPROBE Trans-Hudson Orogen Transect; **in** Report of LITHOPROBE Fourth Trans-Hudson Orogen Transect Workshop, Report 38, p. 135-150.

Weber, W.
1990: The Churchill - Superior Boundary zone, southeast margin of the Trans-Hudson Orogen: a review; **in** The Early Proterozoic Trans-Hudson Orogen of North America (J.F. Lewry and M.R. Stauffer, eds.); Geological Association of Canada, Special Paper 37, p. 42-55.

Weber, W.
in prep: Sipiwesk Lake, NTS 63P; Bedrock Compilation Map, 1:250 000. Manitoba Energy and Mines.

Weber, W. and Scoates, R.J.F.
1978: Archean and Proterozoic metamorphism in the northwestern Superior Province and along the Churchill-Superior boundary, Manitoba; **in** Metamorphism in the Canadian Shield (J.A. Fraser and W.W. Heywood, eds.); Geological Survey of Canada, Paper 78-10, p. 5-16.

White, D.J., Lucas, S.B., Hajnal, Z., Green, A.G., Lewry, J.F., Weber, W., Bailes, A.H., Syme, E.C. and Ashton, K.
1993: Paleoproterozoic thick-skinned tectonics: LITHOPROBE seismic reflection results from the eastern Trans-Hudson Orogen; Canadian Journal of Earth Sciences, v. 31, p. 458-469.

White, D.J, and Lucas, S.B.
1994: A closer look at the Superior Boundary Zone; **in** LITHOPROBE Trans-Hudson Orogen Transect, Report of Fourth Transect Meeting, p. 35-42.

Zhai, Y., Halls, C, and Bates, M.P
1994: Multiple episodes of dike emplacement along the northwestern margin of the Superior Province, Manitoba; Journal of Geophysical Research, v. 99, No. B11, p. 21717-21732.

Zurbrigg, H.F.
1963: Thompson Mine geology; The Canadian Mining and Metallurgical Bulletin, v. 56, p. 451-460.

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