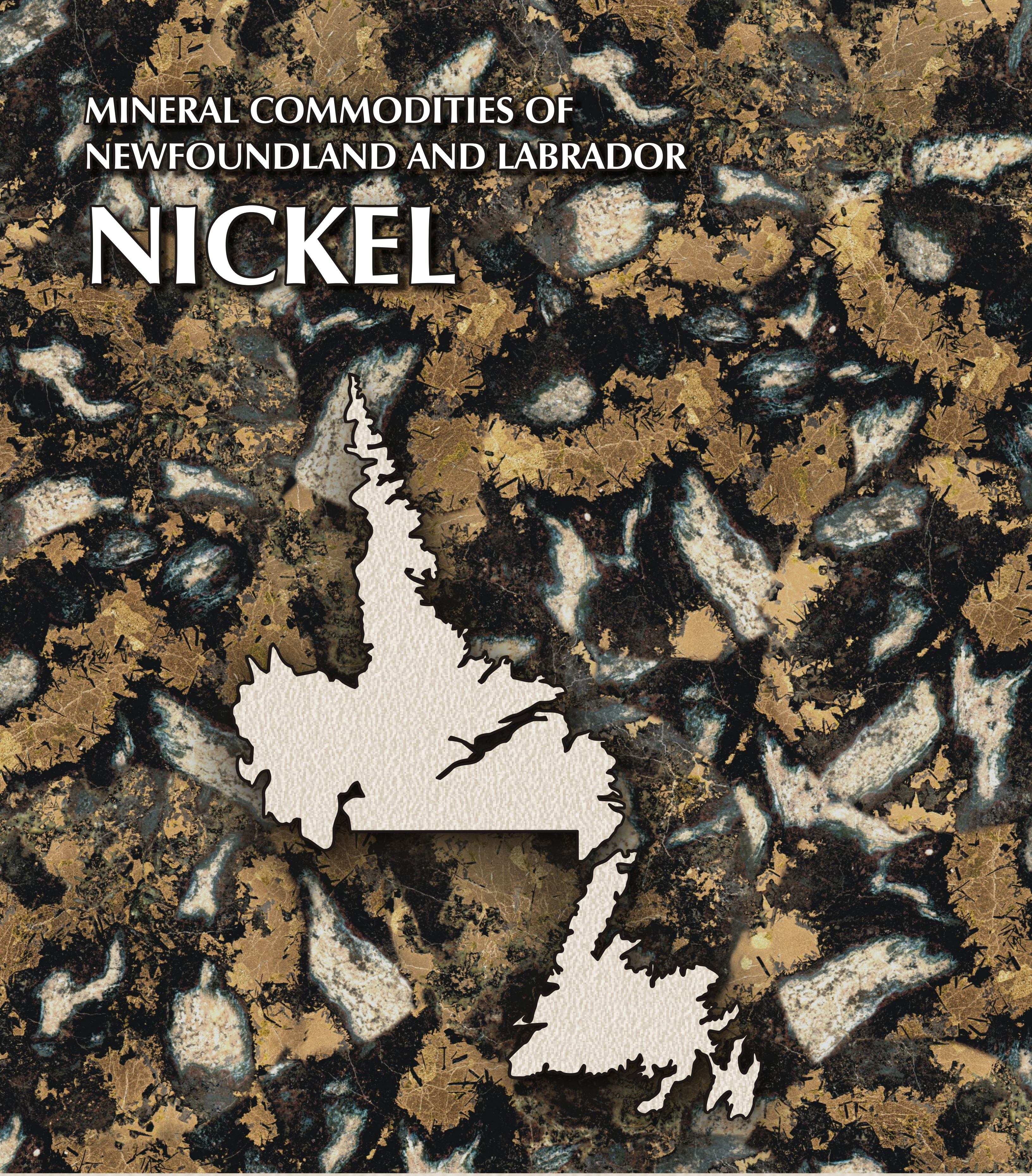
MINERAL COMMODITIES OF NEWFOUNDLAND AND LABRADOR

NICKEL



Newfoundland Labrador

Natural Resources
Mines Branch

Geological Survey
Mineral Commodities Series
Number 2

Mineral Commodities of Newfoundland and Labrador

Nickel

Foreword

This is the second in a series of summary publications covering the principal mineral commodities of the Province. Its purpose is to act as a source of initial information for explorationists and to provide a bridge to the detailed repository of information contained in the maps and reports of the provincial and federal geological surveys, as well as in numerous exploration-assessment reports. The information contained in this series is accessible via the internet at the Geological Survey of Newfoundland and Labrador web site http://www.nr.gov.nl.ca/mines&en/geosurvey/

Other Publications in the Series

Zinc and Lead. (Number 1, 2000, revised 2008); Nickel (Number 2, revised 2005, 2008);
Copper (Number 3, 2000, revised 2007); Gold (Number 4, revised 2006, 2008); Uranium in Labrador (Number 5, 2008)

Additional Sources of Information

Further information is available in the publications of the geological surveys of Newfoundland and Labrador and Canada. The Geological Survey of Newfoundland and Labrador also holds a considerable inventory of exploration-assessment files available for onsite inspection at its St. John's headquarters and for download via the Geological Survey of Newfoundland and Labrador web site http://www.nr.gov.nl.ca/mines&en/geosurvey/. Descriptions of individual mineral occurrences are available through the provincial Mineral Occurrence Database System (MODS), which is accessible from the Survey's web site. Up-to-date overviews of mining developments and exploration activity targeting copper are available on-line at http://www.nr.gov.nl.ca/mines&en/

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Compiled by A. Kerr, 2000, and revised, 2005, 2008
Reprinted, 2005, 2006

Front Cover: The "basal breccia" sulphide ore from the ovoid deposit at Voisey's Bay, Labrador; this material consists of digested country-rock fragments (white areas) entrained in troctolite containing coarse interstitial sulphide.

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Introduction

Newfoundland and Labrador had very little nickel exploration prior to 1994, and the Province's entire nickel production consists of about a hundred tons, recovered as a by-product from copper–zinc deposits at Tilt Cove, Notre Dame Bay. Sporadic exploration for nickel and platinum was conducted in Labrador in the 1970s and 1980s, but waned in the 1990s. Following the Voisey's Bay discovery in late 1994, Labrador became a major target area for nickel exploration. However, the potential of large areas still remains essentially untested.

In 1993, Albert Chislett and Chris Verbiski of Archean Resources Ltd. discovered sulphide mineralization near Nain, Labrador. In late 1994, drilling at this site, now known as Discovery Hill, returned 41 m of 2.96% Ni, 1.89% Cu and 0.16% Co, and the Voisey's Bay story began to unfold. Subsequent exploration by Diamond Fields Resources, and later by Voisey's Bay Nickel Company (a subsidiary of INCO Ltd.) has now defined deposits which, together with associated zones, contain a total resource of 100 million tonnes of 1.94% Ni, 1% Cu and 0.11% Co (calculated from INCO estimates, 2003). The Voisey's Bay discovery generated enormous interest in the nickel potential of the Province, and exploration expenditures in Labrador (excluding Voisey's Bay itself) exceeded $120 million from 1995 to 1999. Development work at the site began in 2003, and production commenced in Summer/Fall 2005.

The latest figures released by INCO (2003) indicate a total resource of 100 million tonnes grading 1.94% Ni, 1% Cu and 0.11% Co. Based on total contained nickel, Voisey's Bay is now the sixth largest magmatic sulphide deposit camp in the world, and is also a major world resource of copper and cobalt. In every definition of the word, it is a world-class ore deposit.

On a worldwide basis, primary nickel (± copper, cobalt and platinum-group elements) sulphide deposits are overwhelmingly of magmatic origin, and are typically associated with plutonic and volcanic rocks of ultramafic and mafic composition. Most nickel mineralization in the Province, excluding that associated with hydrothermal massive sulphide deposits, is of this general type. In Labrador, nickel is mostly associated with Mesoproterozoic plutonic rocks of troctolitic, gabbroic, pyroxenitic and anorthositic composition, and also with Archean ultramafic metavolcanic rocks. In Newfoundland, nickel is associated with Paleozoic gabbroic to dioritic plutonic rocks, and Precambrian mafic gneisses of uncertain, but probably plutonic, origin. In all cases, the nickel is associated with significant copper and cobalt. Minor local enrichments of platinum-group elements (PGE; platinum, palladium, rhodium, ruthenium, etc.) are known in Labrador, but the PGE contents of most other nickel occurrences in the Province appear to be low.

Labrador

Troctolite- and Gabbro-Hosted Mineralization

The Voisey's Bay Deposits. Ni–Cu–Co sulphide mineralization at Voisey's Bay is hosted by the troctolitic Voisey's Bay intrusion, an early member of the Mesoproterozoic Nain Plutonic Suite (Figure 1). The Voisey's Bay intrusion consists of three segments that are linked (Figure 2a, b). In the east, the Eastern Deeps subchamber is a 2 x 1 km troctolite body having a maximum depth extent of over 1000 m. In the west, scattered enclaves of gabbro and troctolite within younger granitoid rocks indicate the western subchamber, most of which lies in the subsurface. The Western and Eastern Deeps subchambers are connected by a dyke-like conduit system, which gradually changes in attitude from south-dipping, through vertical, to north-dipping from west to east (Figure 2a, b). All presently known sulphide deposits at Voisey's Bay are hosted within the conduit or near its junctions with the larger subchambers (Figure 2a, b).

From east to west, the major sulphide bodies are the Eastern Deeps zone (47 million tonnes of 1.39% Ni, 0.6% Cu and 0.09% Co), the Ovoid zone (32 million tonnes of 2.83% Ni, 1.68% Cu and 0.12% Co), the Discovery Hill zone (13 million tonnes of 1.0% Ni, 0.8% Cu and 0.06% Co) and the Reid Brook zone (17 million tonnes of 1.46% Ni, 0.65% Cu and 0.1% Co); these estimates given here were determined in 1999. The remaining resource is dispersed within several smaller zones, some of which physically link the four major sulphide bodies (Figure 2a, b). The individual sulphide bodies all share a common east-

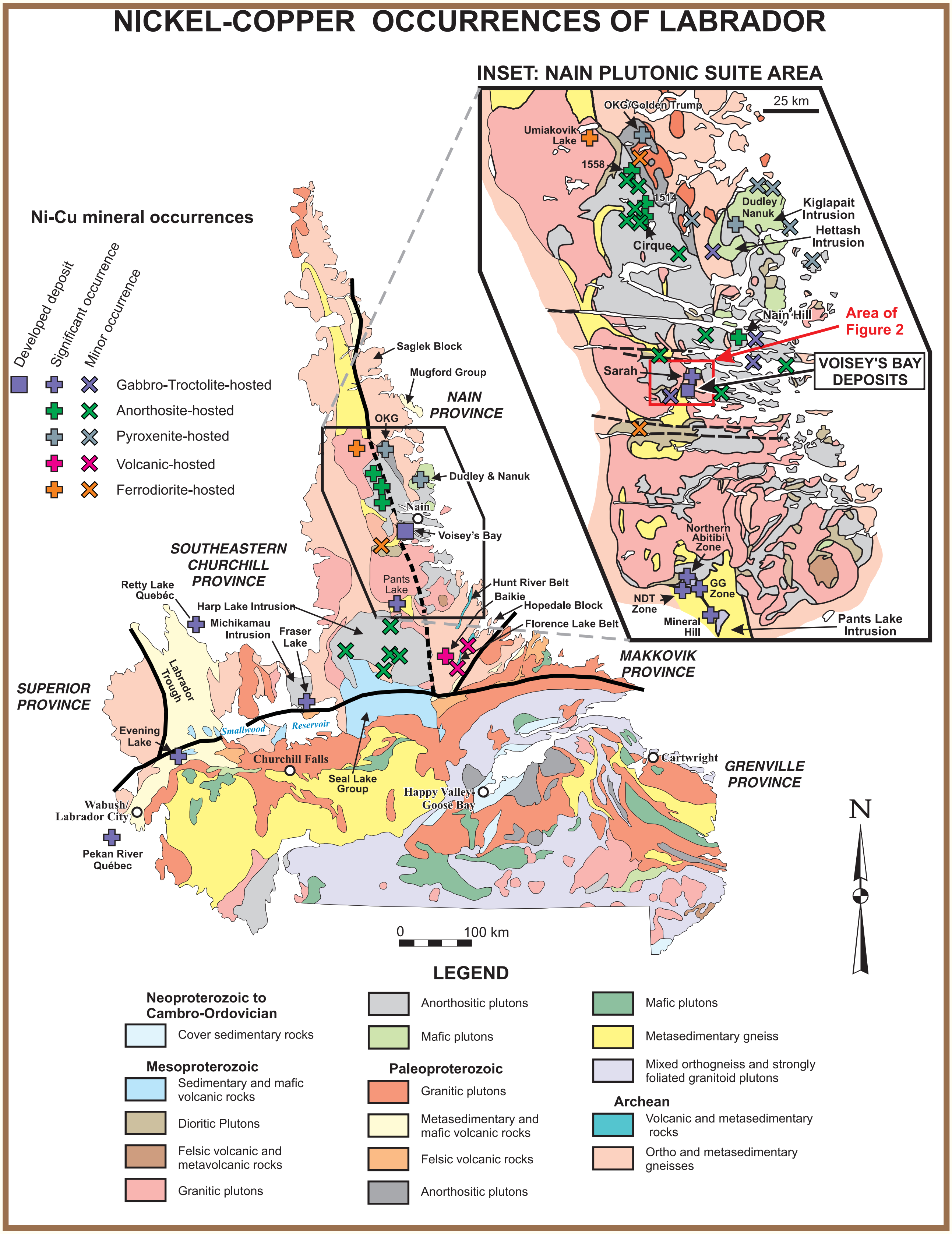

Figure 1. *Simplified geological map of Labrador; showing the locations of major nickel (± copper, cobalt) occurrences. Inset shows the details for the area of the Nain Plutonic Suite in northern Labrador.*

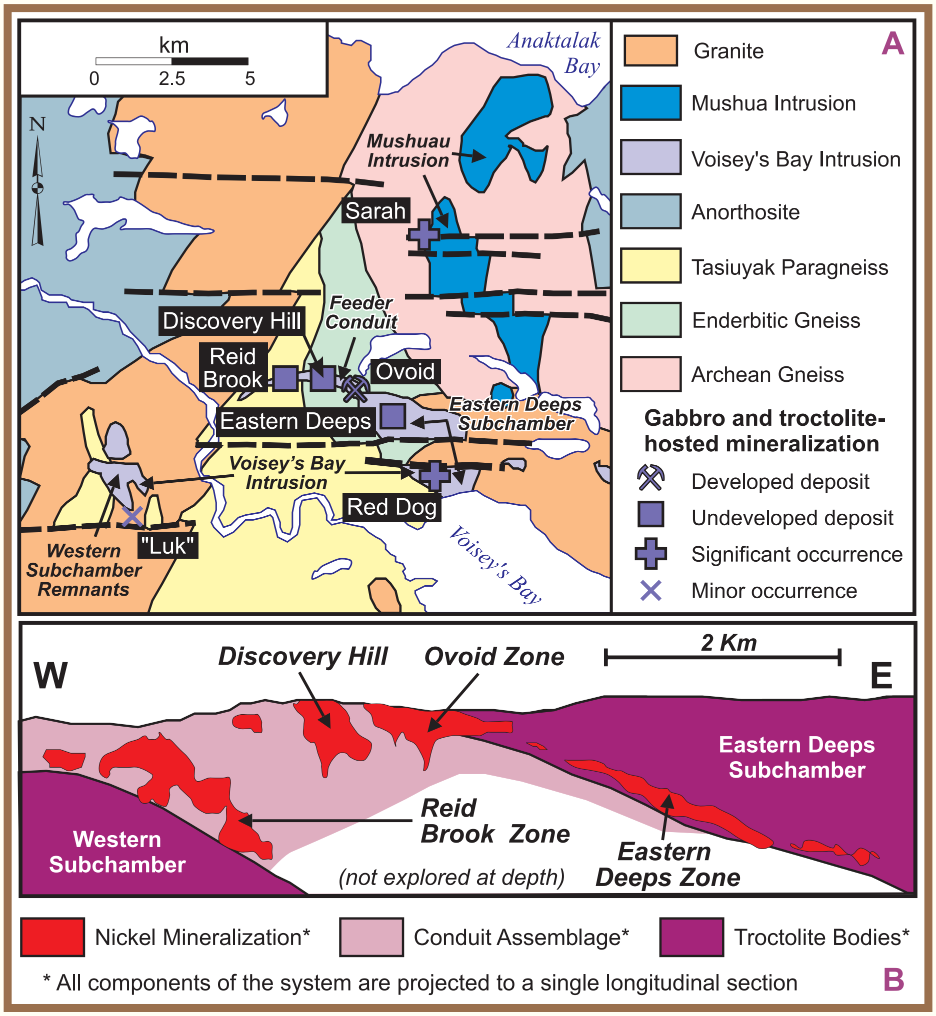

Figure 2. *(A) Simplified geological map of the Voisey's Bay area, showing the Eastern Deeps subchamber, Western subchamber, feeder conduit, and surface projections of the principal sulphide deposits. (B) Schematic longitudinal section through the Voisey's Bay intrusion, showing the relationship between sulphide zones and the conduit system. After Li and Naldrett (1999) and Lightfoot and Naldrett (1999).*

plunging attitude, and are locally superimposed in the third dimension, e.g., the deep (eastern) section of the Reid Brook zone lies vertically below the near-surface Discovery Hill zone (Figure 2b). Sulphide mineralization in all parts of the Voisey's Bay system is very similar, consisting of pyrrhotite, pentlandite, chalcopyrite (± cubanite) and variable amounts of magnetite. Mineralized rocks include coarse-grained, crystalline massive sulphides, disseminated (interstitial) sulphides in troctolites, and complex breccias containing troctolite and gneiss fragments in sulphide-rich matrix (Figure 3). The Voisey's Bay sulphides commonly contain between 3 and 5% Ni, and 1.5 and 2.5% Cu. The textural relationships indicate that the sulphides formed a discrete, immiscible liquid that was transported, in suspension, by associated mafic silicate magmas, from which the sulphides have extracted their metals. The sulphide liquids appear to have been concentrated and trapped as the magma passed through the conduit system en route to the Eastern Deeps subchamber, and the various sulphide bodies are interpreted to represent different structural levels within the system (Figure 4).

Several critical factors were probably important in the geological development of Voisey's Bay. The Nain–Churchill boundary may have facilitated rapid ascent of the mafic magmas. Contamination by the sulphide-bearing Tasiuyak paragneiss promoted the development of sulphide liquids, and interaction between these and successive magma batches facilitated their enrichment in metals. The sulphide liquids were eventually forced through the conduit system toward the Eastern Deeps subchamber, where they became trapped in various settings. Fortuitously, the feeder conduit system is preserved close to the present erosion level.

Other Examples. Outside Voisey's Bay, the best example of Ni–Cu mineralization hosted by mafic plutonic rocks is the composite Pants Lake intrusion (Figure 1), about 100 km south of Voisey's Bay.

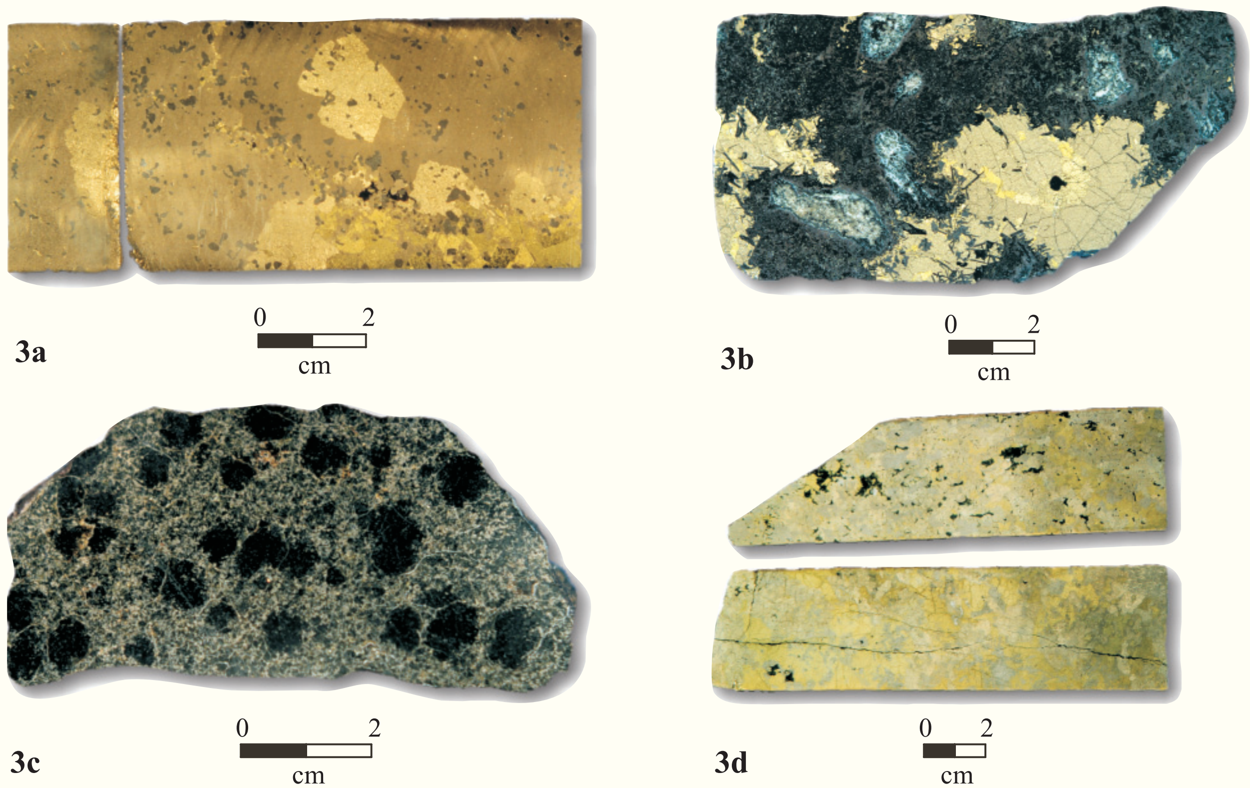

Figure 3. *Examples of sulphide ores and mineralized rocks associated with gabbroic and troctolitic rocks in Labrador. 3a) High-grade massive sulphide ore containing about 4% Ni, Voisey's Bay ovoid deposit. 3b) Complex breccia comprising digested gneiss fragments (white areas) in mineralized troctolite with coarse sulphide patches, Voisey's Bay deposit. 3c) Example of "leopard texture", consisting of pyroxene crystals in mineralized gabbro or troctolite, Pants Lake intrusion (also found at Voisey's Bay). 3d) High-grade, vein-like massive sulphide zone containing 12% Ni, 10% Cu and 0.45% Co, Pants Lake intrusion.*

Magmatic sulphide mineralization is widespread at the base of these intrusions, commonly forming a near-continuous basal unit. Sulphide mineralization and associated rock types are texturally and mineralogically similar to those at Voisey's Bay (Figures 3c and 3d). Several zones of surface and subsurface disseminated mineralization are now defined by drilling, but typically contain less than 1% combined Ni and Cu. Thin, massive sulphide zones contain up to 12% Ni and 10% Cu, but most contain 1 to 2% Ni and 1 to 2% Cu, with up to 0.25% Co. Sulphide metal contents vary, but cluster around 2% Ni and 2% Cu, below typical values for Voisey's Bay sulphides. The potential of the Pants Lake area is far from fully tested, as the intrusion has a surface area about 100 times larger than the Voisey's Bay intrusion, and large areas of its prospective basal contact lie within a few hundred metres of the surface. Virtually all of the gabbroic rocks have been depleted in Ni and Cu by interaction with sulphide liquids, and the amount of missing metal is far larger than can be explained by the mineralization located to date.

Virtually all of the mafic rocks in the Pants Lake intrusion have been depleted in Ni and Cu by interaction with sulphide liquids, and the amount of missing metal is far larger than can be explained by the mineralization located to date.

The *Mushuau intrusion*, near Voisey's Bay, also hosts minor magmatic sulphides near its basal contact. At the Sarah prospect (Figure 2a) thin (<2 m) zones contain 1.4% Ni and 0.6% Cu, and the sulphides contain about 3.5% Ni, similar to grades in the main Voisey's Bay deposits. Local disseminated sulphide mineralization is also hosted by basal leucotroctolites of the Hettash Intrusion (Figure 1), and exhibits similar sulphide metal contents. The Michikamau anorthosite intru-

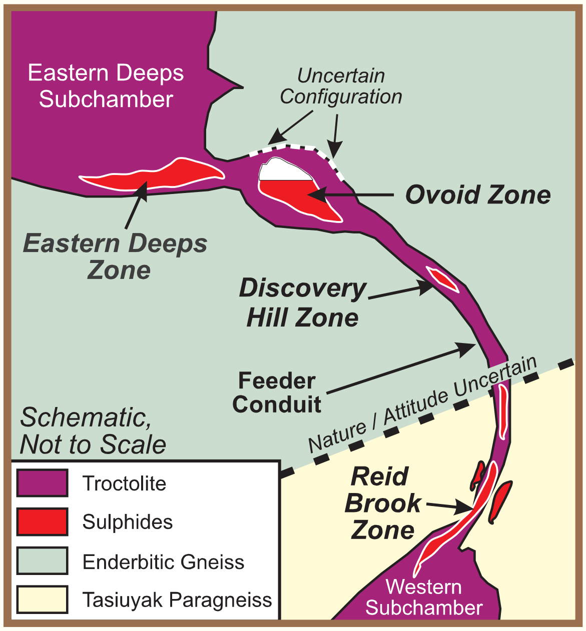

Figure 4. *Schematic illustration of the settings of the different Voisey's Bay sulphide deposits in relation to the original configuration of the conduit system linking the western and Eastern Deeps subchambers. After Lightfoot and Naldrett (1999).*

sion hosts disseminated magmatic sulphide mineralization along its eastern margin (Figure 1), hosted by fine-grained basal olivine gabbro and troctolite at Fraser Lake. Surface mineralization contains up to 0.9% Ni, 0.3% Cu and 0.15% Co, but disseminated mineralization intersected by drilling mostly contains <0.5% combined Ni and Cu.

Despite large exploration expenditures in Labrador since 1995, much of this vast territory remains significantly underexplored. The best potential for further discoveries is within mafic rocks of gabbroic to troctolitic composition, particularly where these have intruded the sulphide-bearing Tasiuyak gneiss.

Pyroxenite-Hosted Mineralization

Minor disseminated sulphide mineralization occurs in, and around, irregular pyroxenitic veins and dykes. These occur around the margins of the Kiglapait Intrusion, at the Dudley and Nanuk prospects, and also at the OKG and Golden Trump prospects (Figure 1). This mineralization commonly has modest Ni and Cu contents, but contains up to 2% Ni in local massive concentrations. It may be part of a broad spectrum that also includes the numerous sulphide zones hosted by anorthosite rocks (*see below*), many of which are probably genetically linked to minor mafic units that intrude these rocks. However, pyroxenite-hosted mineralization tends to be more nickel-rich than most of the mineralization observed in the anorthositic rocks.

Anorthosite-Hosted Mineralization

Nain Plutonic Suite. Numerous small-scale magmatic sulphide concentrations occur within leuconoritic and anorthositic plutonic rocks of the Nain Plutonic Suite (Figure 1). Sulphides typically form irregular massive to semimassive zones hosted by massive, essentially barren, anorthosite. The Ni and Cu contents of these sulphide zones are variable, but most contain <1% Ni, and there is commonly little correlation between Ni and Cu. The best assays reported from drill core are typically about 2% Ni, but sulphide Ni contents rarely exceed 1%. The sulphide zones consist dominantly of pyrrhotite and chalcopyrite, and generally lack coarse pentlandite. The sulphides appear to have "intruded" the anorthosites, and commonly contain numerous corroded inclusions of anorthositic plagioclase. Drilling suggests that there is a common spatial relationship between massive sulphide mineralization and fine- to medium-grained, intrusive, gabbronoritic units that contain syngenetic disseminated sulphides.

Other Anorthosite-Dominated Plutonic Suites. Pre-1995 exploration of the Harp Lake Intrusive Suite detected numerous disseminated sulphide occurrences, located mostly in the eastern part of the intrusion (Figure 1). Many of these sulphide zones appear to be broadly stratiform and flat-lying, and consist of small amounts of disseminated, interstitial sulphide hosted by anorthosite, leucotroctolite or leuconorite. Absolute grades are low (typically <0.5% combined Ni and Cu), but the amount of sulphide is small (<5%). Sulphide metal contents are high, ranging up to 6% Ni and 3% Cu; however, there are no reports of massive sulphide accumulations.

Ferrodiorite-Hosted Mineralization

Disseminated sulphide mineralization is present in magnetite-rich ferrodiorites in several areas of Labrador (Figure 1), but this generally contains very little Ni, Cu or Co.

Volcanic (Komatiite)-Hosted Mineralization

Labrador contains small greenstone belts in the Archean Hopedale Block (Figure 1), which contain several examples of nickel mineralization associated with ultramafic metavolcanic rocks (komatiites). The Baikie showing in the Florence Lake Greenstone Belt (Figure 1) is a small sulphide-rich zone hosted by altered ultramafic rocks invaded by granitoid rocks. Surface samples contain up to 9.8% Ni, and also have significant PGE values up to 0.65 g/t Pt and 1.2 g/t Pd. Mineralization is more extensive in the subsurface, and the best intersection was 11.3 m at 2.2% Ni, 0.22% Cu and 0.16% Co, which includes short sections of massive sulphide containing up to 6.6% Ni. Similar mineralization occurs at the adjacent DCP and Boomerang showings and this may define a single favourable horizon. Also, komatiitic metavolcanic rocks occur in the Hunt River Greenstone Belt (Figure 1), and localized sulphide-rich zones here contain up to 4.3% Cu and 0.57% Ni.

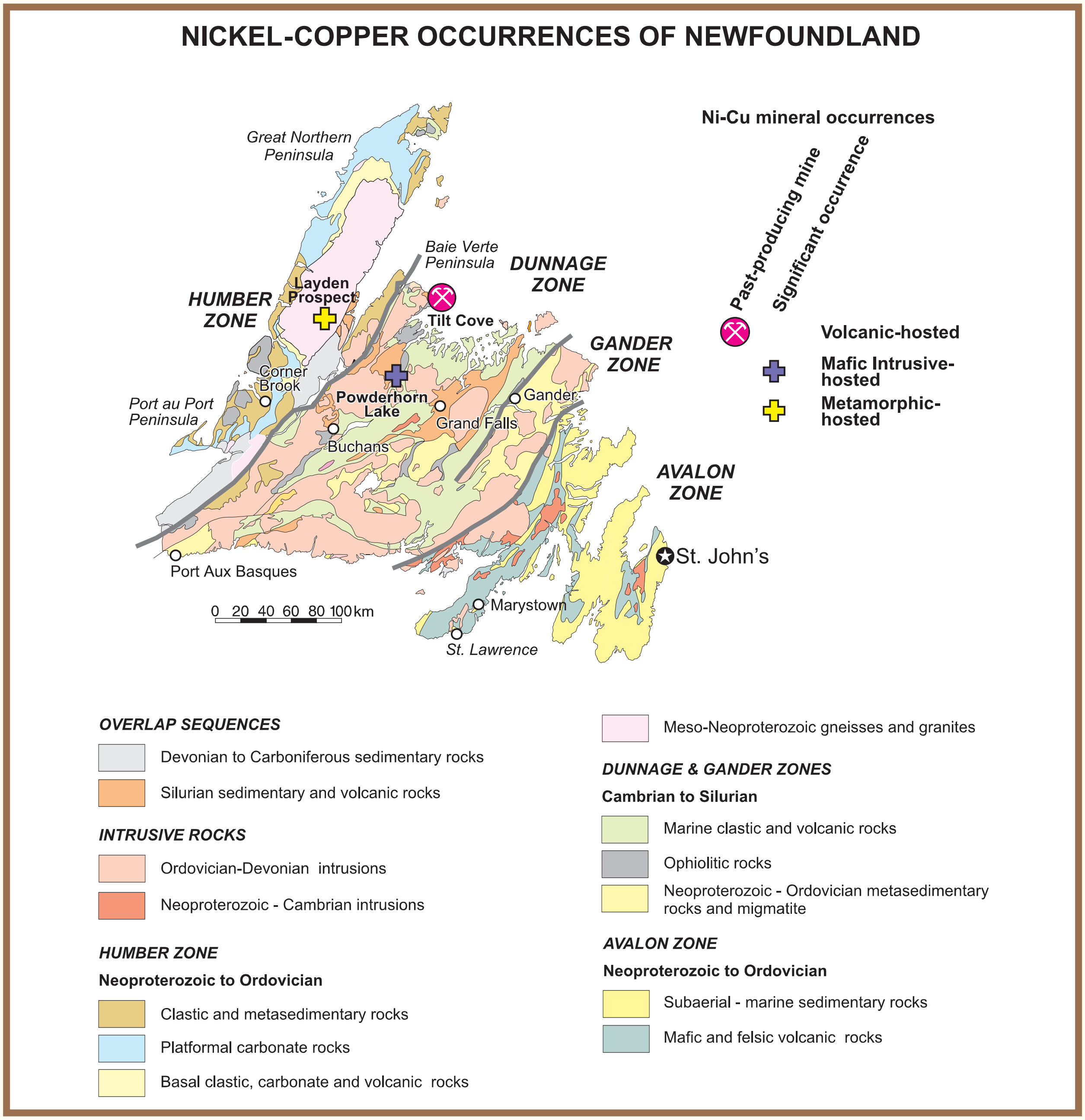

Figure 5. *Simplified geological map of Newfoundland, showing the locations of known nickel (± copper; cobalt) occurrences.*

Newfoundland

Volcanic-Hosted Hydrothermal Mineralization

The only recorded production of nickel from Newfoundland consisted of 411 tons of high-grade ore shipped from the Tilt Cove mine (Figure 5) between 1869 and 1876. This ore came from a small zone at the contact between altered andesitic volcanic rocks and talc–carbonate rocks, adjacent to a larger body of serpentinized peridotite. Nickel sulphide minerals occurred as pods and stringers in altered rocks, and as carbonate-hosted vein material. The nickel is suspected to have been derived from the nearby peridotites during hydrothermal alteration and circulation.

Gabbro-Hosted Mineralization

The only known nickel occurrences of this type in Newfoundland were discovered in 1996 near Powderhorn Lake (Figure 5). The mineralization consists of disseminated to locally semimassive pyrrhotite and chalcopyrite in an altered gabbro or diorite that may be a dyke-like body that intruded sulphide-bearing metasedimentary rocks. Despite alteration, primary magmatic sulphide textures are well preserved. Mineralized rocks contain up to 0.92% Ni and 0.45% Cu, and a short drillhole returned 6 m averaging 0.6% Ni. The sulphides are locally metal-rich, having sulphide metal contents up to 4.7% Ni and 3% Cu, but much of the material contains only about 1% Ni in sulphide.

Mafic Gneiss-Hosted Mineralization

Nickel mineralization was discovered at the southern end of the Mesoproterozoic Long Range Inlier in 1999. The Layden prospect (Figure 5) contains heavy sulphide concentrations in strongly deformed mafic and ultramafic gneisses, that form concordant units within the surrounding granitoid gneisses. Surface mineralization averages 5.4% Ni, 1.05% Cu, 0.1% Co, 0.4 g/t Au, 0.23 g/t Pt and 0.1 g/t Pd. Sulphide metal contents are believed to be high, probably >8% Ni, and the mineralization contains spectacular pentlandite (Figure 6). The host rocks are of uncertain origin, but may be ultramafic to mafic metaplutonic rocks akin to komatiites; the Thompson District in Manitoba may provide a valuable exploration model.

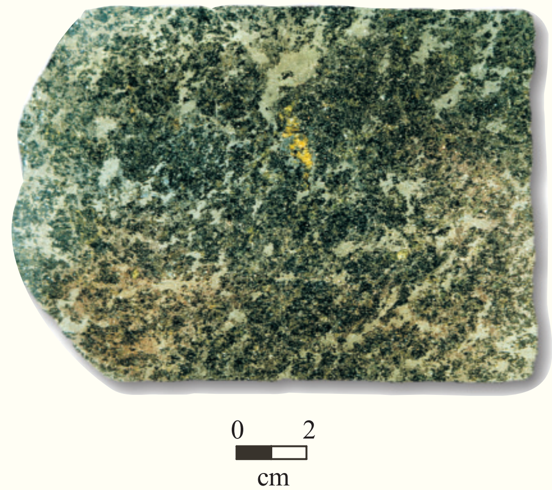

Figure 6. *Example of high-grade nickel sulphide mineralization (mostly pentlandite, with lesser pyrrhotite and chalcopyrite) in biotite-rich mafic gneisses. Layden prospect, Long Range Inlier, Newfoundland.*

Exploration Potential

Despite large exploration expenditures in Labrador since 1995, much of this vast territory remains significantly underexplored. The best potential for further discoveries is within the mafic rocks of gabbroic to troctolitic composition, particularly where these have intruded the sulphide-bearing Tasiuyak gneiss or similar rocks (Figures 1 and 2). Archean metavolcanic rocks in the Hopedale Block are also incompletely explored, and similar supracrustal rocks in the high-grade northern part of the Nain Province (Saglek Block) also represent remnants of greenstone belt sequences, including sulphide-bearing ultramafic rocks.

If the controls inferred for the Voisey's Bay deposits are applied on a regional scale, several other areas in Labrador merit consideration. Mesoproterozoic mafic intrusions across the northern margin of the Grenville Province (Shabogamo and Michael gabbros) intrude many country rocks that include potential sulphur sources. Magmatic sulphide mineralization has been reported from Shabagamo gabbros in western Labrador. Mafic to ultramafic sills reported in a similar environment at Pekan River in Québec (Figure 1) host disseminated to massive sulphide mineralization containing up to 6.25% Cu and 4.1% Ni, coupled with up to 1.2 g/t combined Pt and Pd. In the northern Labrador Trough, large mafic sills are also common, and some of these contain low-grade disseminated magmatic sulphide zones. In this area, sedimentary-hosted syngenetic sulphide zones provide potential sulphur sources. Magmatic sulphide mineralization associated with significant PGE-enrichment (up to 6.4 g/t Pt) occurs in an ultramafic sill at Retty Lake, in Québec (Figure 1), and may indicate similar potential in adjacent parts of Labrador.

In central Labrador, mafic volcanic and associated high-level mafic intrusive rocks within the Seal Lake Group represent flood basalt activity related to Mesoproterozoic rifting. The Seal Lake Group is well known for its redbed-hosted copper mineralization (*see* Mineral Commodities Series Number 3) but has received scant attention for magmatic sulphides. Paleoproterozoic flood basalts also occur in the Mugford Group, north of Nain. Large areas of mafic plutonic rocks also occur within pre-Grenvillian (Labradorian) gneissic terranes in the northern Grenville Province, where they intruded metasedimentary gneisses that are locally sulphide bearing. These areas have received virtually no exploration.

The Island of Newfoundland is not currently known as a nickel province, but its potential should not be discounted. Mid-Paleozoic mafic intrusions were emplaced into country rocks that represent potential sulphur sources, and the known showings demonstrate that they can contain magmatic sulphides having interesting metal values. Similar rocks are known to host magmatic sulphides elsewhere in the Appalachian Orogen. The recent discoveries of nickel-rich sulphide zones in mafic gneisses of the southern Long Range Inlier suggest interesting potential in an essentially unexplored region.

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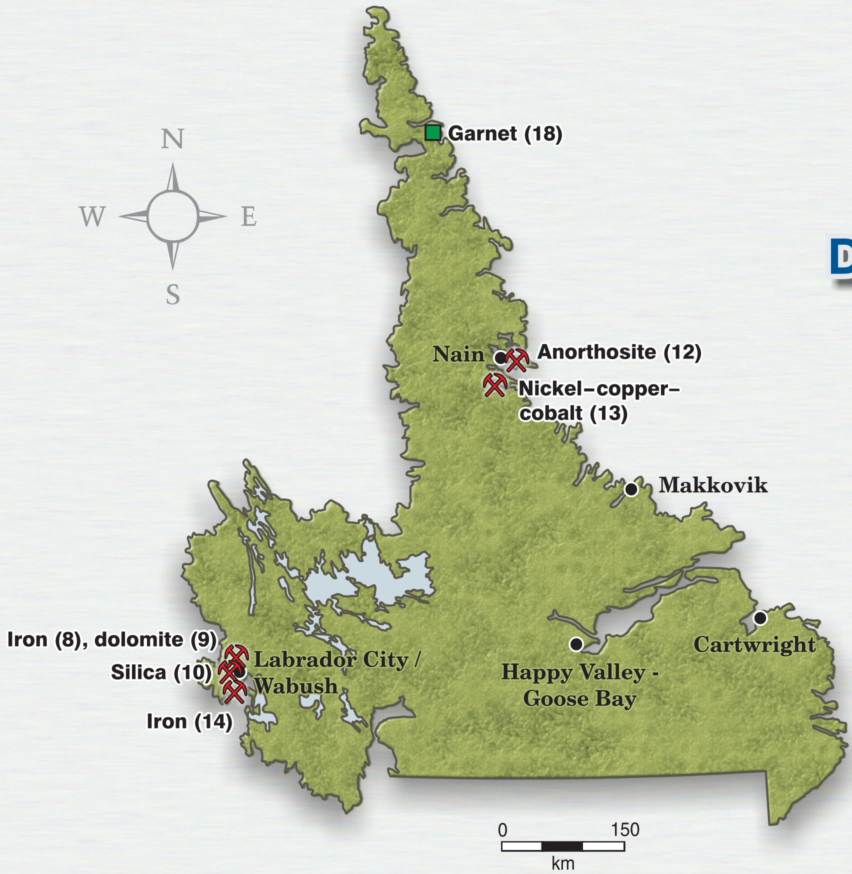
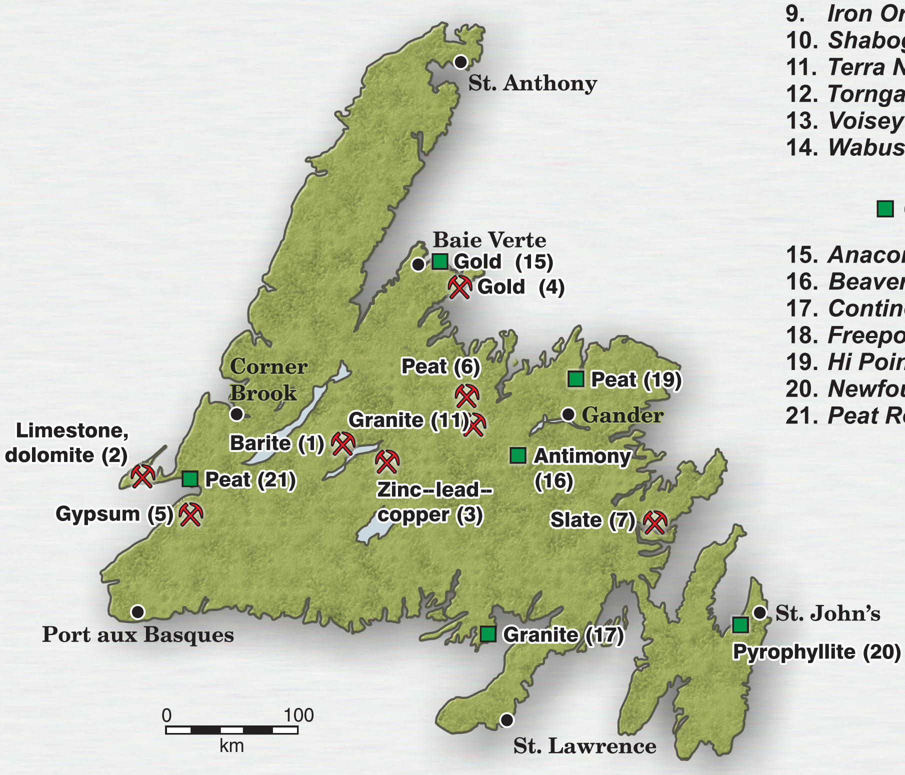
PRODUCING MINES AND DEVELOPING PROPERTIES

WINTER 2008



* Note scale differences of Labrador and Newfoundland maps



Commodities in production

1. *Atlantic Barite Ltd.,* Buchans
2. *Atlantic Minerals Ltd.,* Lower Cove
3. *Aur Resources Inc.,* Duck Pond
4. *Crew Gold Canada Ltd.,* Nugget Pond
5. *Galen Gypsum Mines Ltd.,* Coal Brook
6. *Hi Point Industries (1991) Ltd.,* Bishop's Falls
7. *Hurley Slateworks Company Inc.,* Burgoynes Cove
8. *Iron Ore Company of Canada,* Labrador City
9. *Iron Ore Company of Canada,* Labrador City
10. *Shabogamo Mining & Exploration Ltd.,* Labrador City
11. *Terra Nova Granite Inc.,* Jumpers Brook
12. *Torngait Ujaganniavingit Corp.,* Ten Mile Bay
13. *Voisey's Bay Nickel Company Ltd.,* Voisey's Bay
14. *Wabush Mines Ltd.,* Wabush

Commodities in development

15. *Anaconda Mining Inc.,* Pine Cove
16. *Beaver Brook Antimony Mine Inc.,* Beaver Brook
17. *Continental Stone Ltd.,* Belloram
18. *Freeport Resources,* Hutton Beaches
19. *Hi Point Industries (1991) Ltd.,* Gander Bay
20. *Newfoundland Pyrophyllite,* Manuels
21. *Peat Resources Ltd.,* Stephenville