# Distribution and exploration potential of platinum-group elements in Québec

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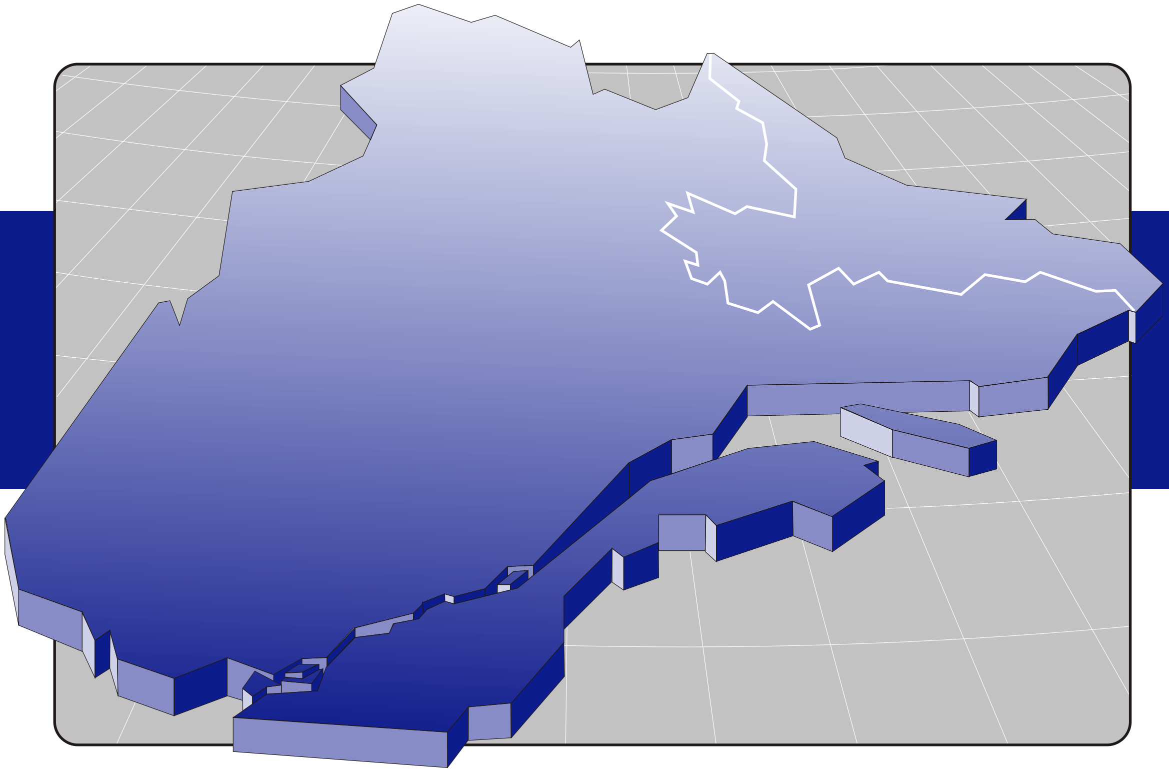
**PRO 2001-06**



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# *PRO 2001-06 : Distribution and exploration potential of platinum-group elements in Québec*

***Thomas Clark***

## *ABSTRACT*

This document is a review of the distribution, geological environments, and exploration potential of platinum-group elements (PGE) in Québec. PGE-bearing mineralizations are subdivided into (1) PGE-dominant deposits with Ni and Cu as possible co-products, of which few examples are known in Québec, and (2) Ni-Cu-dominant deposits with co-product PGE, a much more common type of deposit. The qualitative evaluation of the PGE potential is based on geological environments, PGE grades, and interelement ratios such as Cu/Pd, Ni/Pd, Cu/Ir, and Cu/Pt. Québec boasts several favorable environments, in which PGE-fertile magmas may have existed and produced economic mineralizations. Other, less favorable environments, with deposits associated with PGE-depleted magmas, are also numerous. Some Québec deposits show strong hydrothermal enrichment of PGE. The importance of exploring for deposits similar to those discovered at lac des Îles and East Bull Lake (Ontario) is emphasized.

## *INTRODUCTION*

The currently favorable prices for the platinum-group elements (PGE) have led to a renewed interest in PGE exploration in Québec. As an aid to explorationists unfamiliar with PGE in Québec, this document reviews the distribution and potential of these elements in the province. Magmatic deposits in Québec have been classified as either PGE-dominant, with possible Ni and Cu as co-products, or Ni-Cu-dominant, with possible PGE as co-products (Naldrett, 1981). Examples of PGE-dominant deposits are few, but numerous Ni-Cu-dominant deposits exist, in various tectonic environments. Examples of PGE deposits of hydrothermal origin are also noted below. The locations of deposits and intrusions mentioned in the text are shown in Figure 1. Selected references are given in the caption to the figure. Representative analytical results are provided in Tables 1 and 2. Results from the Abitibi area are from Barnes ***et al***. (1993a).

## *EVALUATION OF PGE POTENTIAL*

The qualitative approach used in this document for the evaluation of Québec's PGE potential consists in determining, from the composition of samples from known deposits, the degree of enrichment or depletion of the sulfides in PGE. This information may indicate whether the associated magmas were sufficiently fertile in PGE to produce either PGE-dominant deposits or Ni-Cu deposits with PGE at the co-product level. The information may also suggest whether possible post-cumulus processes (e.g., fluid activity) would have acted on a protolith that was enriched or depleted in PGE. The Ni-Cu potential of the deposits is not evaluated here, but this aspect must be considered for a Ni-Cu deposit with PGE at the co-product level (e.g., Clark, 1998, 2000). The evaluation of the PGE potential is based on interelement ratios such as Cu/Pd, Ni/Pd, Cu/Ir, and Cu/Pt, as well as mantle normalized base and precious metal concentrations, in the manner used by Barnes ***et al***. (1993a, 1993b) in their evaluation of the PGE potential of the Abitibi area. Plots illustrating the relations between various pairs of these ratios (such diagrams are not included in this document) show to what degree mineralized samples are enriched or depleted in PGE compared with variably evolved volcanic rocks (e.g., komatiites, high-Mg basalts, calc-alkalic basalts, flood basalts).

Intrusions and volcanic flows formed from magmas that were fertile in PGE are considered good targets for PGE exploration. To form a magmatic deposit enriched in PGE, the magma should become saturated in sulfide just before arriving at the site of emplacement. At that moment, the magma should also contain sufficient PGE to form PGE-rich rocks. Flows and intrusions depleted in PGE are considered less desirable targets. Even in such a context, however, flows or the parts of an intrusion stratigraphically below the sampling site, a feeder dike to a depleted intrusion, or a related deeper magma chamber may host a PGE deposit (Barnes ***et al***., 1993a). Magmas fertile in PGE can be generated by a high degree of partial melting (more than about 25 %) in the mantle source region, so that all available sulfide and incompatible PGE (i.e., Pd, Pt, Rh) in the

***FIGURE 1 (see following page)*** – Locations of deposits and intrusions mentioned in the text (with selected references).

# *LEGEND*

**APPALACHIAN PROVINCE AND PLATFORMS**

**Paleozoic**

🟧 Permo-Carboniferous
🟪 Siluro-Devonian: Acadian terrains
▒ Cambro-Ordovician: Taconic terrains
P Ordovician-Silurian: Hudson Bay, Ungava Bay, and other platforms
🟪 Cambrian-Silurian: Saint Lawrence platform

**Precambrian**

🟧 Proterozoic

**GRENVILLE PROVINCE** (Archean and Proterozoic)

🟥 Granitic rocks (Trans-Labrador batholith)
🟫 Charnockitic rocks (jotunite, mangerite, charnockite)
🟫 Anorthositic rocks (anorthosite, gabbro/norite); ultramafic rocks
🟦 Paragneiss, marble, etc.; slightly metamorphosed, sedimentary and volcanic rocks
⬛ Metamorphosed equivalents of Kaniapiskau Supergroup (Labrador Trough) and associated gabbro
⬜ Unsubdivided orthogneiss, paragneiss, amphibolite, and intrusive rocks

**UNGAVA OROGEN**
(Archean and Lower Proterozoic)

🟩 Metavolcanic and metasedimentary rocks (Ungava Trough or Cape Smith Belt)
🟥 Gneiss (Narsajuaq terrane)
⬜ Unsubdivided orthogneiss, paragneiss, and intrusive rocks (Archean)

**NEW QUÉBEC OROGEN (Labrador Trough)**
(Archean and Lower Proterozoic)

🟦 Metasedimentary rocks
🟨 Metavolcanic and metasedimentary rocks
🟦 Paragneiss, paraschist
⬜ Orthogneiss

**SOUTHEAST CHURCHILL PROVINCE (Rae)**
(Archean and Lower to Middle Proterozoic)

🟨 Sedimentary cover rocks
🟧 De Pas batholith
⬜ Unsubdivided gneiss and granitic rocks

**TORNGAT OROGEN**
(Archean and Lower Proterozoic)

🟦 Paragneiss, amphibolite
⬜ Unsubdivided orthogneiss, paragneiss, and intrusive rocks

**POST OROGENIC INTRUSIVE ROCKS**
(Middle to Upper Proterozoic)

🟥 Granitic rocks
🟧 Anorthosite

**MAKKOVIK OROGEN** (Middle Proterozoic)

⬜ Unsubdivided orthogneiss, paragneiss, and intrusive rocks

**SUPERIOR PROVINCE** (Archean)

🟨 Sedimentary cover rocks and mafic sills (Lower Proterozoic)
🟪 Granitic rocks (biotite/hornblende, biotite/muscovite)
🟫 Granitic rocks (orthopyroxene)
🟫 Anorthosite
🟩 Unsubdivided metavolcanic and metasedimentary rocks
🟦 Metasedimentary rocks, paragneiss (amphibolite to granulite facies)
⬜ Unsubdivided orthogneiss, paragneiss, and intrusive rocks (amphibolite facies, except granulite facies in Minto and Ashuanipi subprovinces)

**NAIN PROVINCE** (Archean)

🟪 Unsubdivided paragneiss, orthogneiss, and granitic rocks

***FIGURE 1 (see the previous page) –*** Locations of deposits and intrusions mentioned in the text (with selected references). ***Site 1***, Gagnon, Gayot, Base Line, L (Mines d'Or Virginia, press releases, 99-11-5, 00-5-9; Gosselin and Simard, 2000); ***2***, Marbridge mine (Naldrett and Cabri, 1976; Barnes ***et al***., 1993a); ***3***, La Trêve I and II (Murgor Res., press releases, 00-08-14, 00-12-18; Mines d'Or Virginia, press release, 01-08-22; Barnes ***et al***., 1993a); ***4***, RM-Nickel (Barnes ***et al***., 1993a); ***5***, Lantagnac (Barnes ***et al***., 1993a); ***6***, Amos sill (Barnes ***et al.***, 1993a); ***7***, Trécesson (Barnes ***et al***., 1993a); ***8***, Crête de Coq (Chown, 1969; Hocq, 1985; Lachapelle and Couture, 1989; MRN, SIGÉOM database); ***9***, Menarik (Goutier ***et al***., 1998; Pelletier, 1990, anal. 316730; Houlé, in progress); ***10***, Nadine (Goutier ***et al***., 2000); ***11***, Midrim (Aurora Platinum, press release, 01-03-12; Barnes ***et al***., 1993a); ***12***, Lac Croche (Barnes ***et al.***, 1993b); ***13***, Lac Kelly (Barnes ***et al***., 1993a); ***14***, Lac Sheen (Barnes ***et al***., 1993a); ***15***, Katinniq (Barnes ***et al***., 1982; Lesher, 1999); ***16***, Donaldson West and East (Dillon-Leitch ***et al***., 1986; Picard ***et al***., 1994; Lesher, 1999); ***17***, Lac Cross (Giovenazzo, 1991; Barnes ***et al***., 1982; Lesher, 1999); ***18***, D8 (Giovenazzo, 1991; Picard ***et al***., 1994); ***19***, D9 (Giovenazzo, 1991; Picard ***et al***., 1994); ***20***, Expo Ungava (Canadian Royalties, press releases, 01-06-20, 01-07-19); ***21***, Méquillon (Tremblay, 1990); ***22***, Delta 3 (Picard ***et al***., 1994; Giovenazzo, 1991); ***23***, Lafortune (Wares ***et al***., 1988; Wares and Goutier, in prep.); ***24***, Gillet (Osisko, press releases, 00-03-27, 00-08-16, 00-09-13); ***25***, Lac Nadeau (Poirier, 1988); ***26***, Lac Mitaine (Clark and Gobeil, 1997); ***27***, Hall (Gauthier ***et al***., 1990; Tanguay ***et al.***, 1990; Hébert and Bédard, 2000); ***28***, Finneth #1 (Gauthier ***et al***., 1990); ***29***, Lambly-Nadeau (Gauthier ***et al.***, 1990); ***30***, Cold Spring Rapids (Bell River) (Barnes ***et al***., 1993a); ***31***, Doré Lake complex (Barnes ***et al***., 1993a; Allard, 1976); ***32***, Lac à l'Eau Jaune (Barnes ***et al.***, 1993a); ***33***, Cummings complex (Barnes ***et al.***, 1993a); ***34***, Laforce (Barnes ***et al***., 1993a); ***35***, Lorraine mine (Barnes ***et al.***, 1993b); ***36***, Qullinaaraaluk (Labbé ***et al***., 2000); ***37***, Lac Rocher (Bandyayera and Morin, 1999; Brisson ***et al.***, 1998; D. Bandyayera, pers. comm., Jan. 2001); ***38***, Blue Lake 1 (Clark, 1989, 1991a; Rohon, 1986, 1989; La Fosse Platinum Group reports); ***39***, Centre and Pogo Lake (Beaudoin and Laurent, 1989; Rohon, 1986, 1989; Laurent, 1995); ***40***, Chance Lake (Rohon, 1987, 1989); ***41***, Chrysler 2 (Wares and Goutier, 1989 and in prep.; Ward, 1989); ***42***, Leslie 2 (Fournier, 1983; Wares and Goutier, 1989 and in prep.); ***43***, Erickson 1 (Fournier, 1981; Wares and Goutier, 1989); ***44***, Lepage (Fournier, 1982; Lacroix and Darling, 1991); ***45***, 2EZ (Clark and Gobeil, 1997); ***46***, Lac Mora (Plante, 1985; Kish, 1968; MRN, SIGÉOM database); ***47***, Lac Uniforme (Plante, 1985; Kish, 1968; MRN, SIGÉOM database); ***48***, Lac 108 (Clark, 2000; Yassa and Giovenazzo, 1993; MRN, SIGÉOM database); ***49***, Réservoir (Clark ***et al***., 1998; MRN, SIGÉOM database); ***50***, Villeray (Yassa and Giovenazzo, 1993; MRN, SIGÉOM database); ***51***, Lac Edgar (Indarès, 1993); ***52***, Lac Volant (Perreault ***et al.***, 1997; Nabil, 1999; Gobeil ***et al***., 1999; Clark, 2000); ***53***, Ann (Gobeil ***et al***., 1999; MRN, SIGÉOM database); ***54***, AB-7 (Gobeil ***et al***., 1999; MRN, SIGÉOM database); ***55***, Lac Méchant (MRN, SIGÉOM database); ***56***, Lac Louis (Clark, 1991b); ***57***, Millage 80 (Clark, 1991b); ***58***, B-50 (Clark, 1991b); ***59***, Lac Édouard mine (Poirier, 1988; Osisko, pers. comm.); ***60***, Lac Kennedy (Poirier, 1988); ***61***, Lac Matte (Poirier, 1988); ***62***, Rochette (Osisko, pers. comm.); ***63***, Renzy Lake mine (Johnson, 1972; Poirier, 1988); ***64***, Sainte-Véronique (Rive, 1976; Poirier, 1988); ***65***, Havre-Saint-Pierre (Chevé ***et al***., 1999; MRN, SIGÉOM database); ***66***, Tortue (Gobeil ***et al***., 1999; MRN, SIGÉOM database); ***67***, Rivière-Pentecôte (Nantel and Martignole, 1991; MRN, SIGÉOM database); ***68***, Chutes-des-Passes (MHY) (Mines d'Or Virginia, press release 00-12-01); ***69***, Dupont (Kénogami) (Vaillancourt, 2001); ***70***, McNickel (Clark and Hébert, 1998); ***71***, De La Blache (Outardes 4) (Gobeil ***et al***., in prep.; MRN, SIGÉOM database); ***72***, Shawinigan (Felder, 1974; Poirier, 1988); ***73***, Morin (Notre-Dame-de-la-Merci) (Lacasse and Poisson, 1996; MRN, SIGÉOM database); ***74***, Sept-Îles complex (Babineau, 1993; Fraser, 1993; Cimon and McCann, 2000); ***75***, Cartouche (Roger and Boucher, 1997); ***76***, Hopes Advance 1 (Fournier, 1983; Wares and Goutier, 1990 and in prep.); ***77***, Pio Lake (Fournier, 1983; Wares and Goutier, 1990 and in prep.); ***78***, B-30 (MRN, SIGÉOM database); ***79***, Réservoir Taureau (Poirier, 1988).

***TABLE 1*** – Representative PGE, Ni, and Cu grades - Good targets (sites 1-29 on figure 1).

| Site | Deposit | PGE grades | Ni and Cu grades | Cu/Pd | Sample | Rock |
|---|---|---|---|---|---|---|
| 1 | Gagnon | 3.4 g/t Pd, 1.8 g/t Pt | 6.10 % Ni, 0.38 % Cu | 1120 | 4 gs | SF-rich komatiite |
| | | 17 g/t Pt+Pd max. | | | 1 gs | MS |
| 2 | Marbridge mine | 0.4 g/t Pd+Pt | 2.2 % Ni, 0.13 % Cu | 4200 | 1 gs | Komatiite + SF |
| 3 | La Trêve I | 2.78 g/t Pd, 1.18 g/t Pt | 0.22 % Ni, 0.65 % Cu | 2300 | 9 gs | Mafic dike, SF |
| | | 2.8 g/t PGE avg. | | | 10 m, channel | SF zone |
| 3 | La Trêve II | 0.7 g/t Pd, 0.4 g/t Pt | 0.25 % Ni, 0.57 % Cu | 8600 | 1 gs | Komatiite, DS |
| 4 | RM-Nickel | 0.7 g/t Pd, 0.2 g/t Pt | 0.18 % Ni, 0.27 % Cu | 3800 | 15 gs | Gabbro, DS |
| | | 5.8 g/t Pd, 0.9 g/t Pt max. | | | 1 gs | Andesite + SF vein |
| 5 | Lantagnac | 0.19 g/t Pd, 0.09 g/t Pt | 0.14 % Ni, 0.19 % Cu | 10,500 | 22 gs | Pyroxenite, DS |
| | | 0.8 g/t Pd max.; 0.4 g/t Pt max. | | | 2 gs | Pyroxenite, DS |
| 6 | Amos | 0.19 g/t Pd, 0.10 g/t Pt max. | 0.02 % Ni, 0.04 % Cu max. | 2100 | 1 gs | Pyroxenite, DS |
| 7 | Trécesson | 34 ppb Pd, 13 ppb Pt max. | 0.01 % Ni, 0.01 % Cu max. | 2800 | 1 gs | Gabbro |
| 8 | Crête de Coq | 0.6 g/t Pd, 0.3 g/t Pt | 0.49 % Ni, 0.20 % Cu | 3500 | 1 gs | Pyroxenite, DS |
| 9 | Menarik | 0.3 g/t Pd, 0.8 g/t Pt max. | | | 1 gs | Chromitite, 16 % Cr |
| 10 | Nadine | 0.4 g/t Pd, 0.4 g/t Pt | | | 1 gs | Dunite |
| 11 | Midrim | 2.14 g/t Pd, 0.67 g/t Pt | 1.81 % Ni, 1.92 % Cu | 9000 | 41 m, drill core | Gabbro, MS to DS |
| 12 | Lac Croche | 1.54 g/t Pd, 0.53 g/t Pt | 0.78 % Ni, 1.11 % Cu | 7200 | 11 gs | Gabbro, DS |
| 13 | Lac Kelly | 0.36 g/t Pd, 0.47 g/t Pt | 0.44 % Ni, 0.38 % Cu | 10,500 | 10 gs | Gabbro, DS |
| 14 | Lac Sheen | 1.33 g/t Pd, 1.99 g/t Pt | 0.28 % Ni, 1.29 % Cu | 9700 | 3 gs | Amphibolite, DS |
| | | 3.0 g/t Pd, 4.2 g/t Pt max. | | | 1 gs | Amphibolite, DS |
| 15 | Katinniq | 2.90 g/t Pd, 1.34 g/t Pt | 4.49 % Ni, 1.22 % Cu | 4200 | 23 gs | DS to MS, representative |
| 16 | Donaldson East | 1.12 g/t Pd, 0.47 g/t Pt | 3.18 % Ni, 0.50 % Cu | 4500 | 14 gs | DS to MS |
| | | 1.65 g/t Pd, <6 ppb Pt, 3.7 g/t Au | 6.92 % Ni, 4.13 % Cu | 25,000 | 14 cm, drill core | Hydrothermal vein |
| 16 | Donaldson West | 2.99 g/t Pd, 2.32 g/t Pt | 3.17 % Ni, 0.79 % Cu | 2700 | 41 gs | DS to MS |
| 17 | Lac Cross | 1.76 g/t Pd, 0.56 g/t Pt | 2.11 % Ni, 0.46 % Cu | 2600 | 5 gs | SMS |
| 18 | D8 | 0.63 g/t Pd, 0.92 g/t Pt | 7.27 % Ni, 0.93 % Cu | 14,700 | 11 gs | MS |
| | | 17.5 g/t Pd, 3.3 g/t Pt | 0.33 % Ni, 0.49 % Cu | 278 | 3 cm, drill core | Hydrothermal vein |
| 19 | D9 | 2.74 g/t Pd, 1.85 g/t Pt | 5.55 % Ni, 1.47 % Cu | 5400 | 7 gs | MS |
| 20 | Expo Ungava | 1.99 g/t Pd, 0.36 g/t Pt | 0.71 % Ni, 0.70 % Cu | 3500 | 26 m, drill core | Ultramafite, SF |
| 21 | Méquillon | 0.52 g/t Pd, 0.16 g/t Pt | 0.23 % Ni, 0.19 % Cu | 3,709 | 22 gs | Olivine gabbronorite, DS |
| 22 | Delta 3 | 3.1 g/t Pd, 0.43 g/t Pt | 0.90 % Ni, 0.28 % Cu | 900 | 12 gs / 2 km | Pegmatitic gabbro, DS |
| 23 | Lafortune | 1.65 g/t Pd, 2.55 g/t Pt | 0.08 % Ni, 1.45 % Cu | 8800 | 4 gs | Pegmatitic gabbro, DS |
| 24 | Gillet | 4.40 g/t Pd, 0.74 g/t Pt | 0.08 % Ni, 0.57 % Cu | 1300 | 7 gs | Pegmatitic gabbro, DS |
| 25 | Lac Nadeau | 0.32 g/t Pd, 0.09 g/t Pt | 0.22 % Ni, 0.19 % Cu | 5800 | 21 gs | Pyroxenite, gabbro, DS |
| | | 1.10 g/t Pd, 0.33 g/t Pt max. | | | 1 gs | DS |
| 26 | Lac Mitaine | 0.26 g/t Pd, 0.26 g/t Pt. | 0.20 % Ni, 0.11 % Cu | 4300 | 9 gs | Olivine gabbronorite, DS |
| | | 0.55 g/t Pd, 1.30 g/t Pt max. | | | 1 gs | Olivine gabbronorite, DS |
| 27 | Hall | 2.0 g/t Pd+Pt, 1.1 g/t Os+Ir+Ru | | | avg., gs | Chromitite, cumulate |
| 28 | Finneth #1 | 2.6 g/t Pd+Pt, 0.2 g/t Os+Ir+Ru | | | avg., gs | Chromitite, cumulate |
| 29 | Lambly-Nadeau | <20 ppb Pd+Pt, 2.9 g/t Os+Ir+Ru | | | avg., gs | Chromitite, tectonite |

Notes : Grades are averages when >1 sample; gs, grab sample; SF, sulfides; DS, disseminated sulfides; SMS, semimassive sulfides; MS, massive sulfides

***TABLE 2*** – Representative PGE, Ni, and Cu grades - Less important targets (sites 30-79 on figure 1).

| Site | Deposit / Intrusion | PGE grades | Ni and Cu grades | Cu/Pd | Sample | Rock |
|---|---|---|---|---|---|---|
| 30 | Cold Spring Rap. (Bell R.) | 16 ppb Pd, <6 ppb Pt | 0.03 % Ni, 0.02 % Cu | 12,500 | 3 gs | Pyroxenite, DS |
| 31 | Lac Doré complex | 19 ppb Pd, 16 ppb Pt | 0.04 % Ni, 0.06 % Cu | 31,600 | 14 gs | Gabbro, DS |
| 32 | Lac à l'Eau Jaune | 43 ppb Pd, 101 ppb Pt | 0.23 % Ni, 0.20 % Cu | 46,000 | 5 gs | Pyroxenite, DS |
| | | 7 ppb Pd, <6 ppb Pt | 0.01 % Ni, 0.04 % Cu | 53,800 | 8 gs | Gabbro+veins |
| 33 | Cummings complex | <6 ppb Pd, <6 ppb Pt | 0.07 % Ni, 0.18 % Cu | >300 000 | 9 gs | Pyroxenite, DS |
| | | <16 ppb Pd, <14 ppb Pt | 0.44 % Ni, >5 % Cu max. | | 32 gs, 5 showings | Hydrothermal veins |
| 34 | Laforce | 65 ppb Pd, 40 ppb Pt | 1.07 % Ni, 0.78 % Cu | 120,000 | 7 gs | Pyroxenite, gabbro, DS |
| 35 | Lorraine mine | 0.91 g/t Pd, 0.55 g/t Pt | 2.23 % Ni, 7.26 % Cu | 90,200 | 16 gs | MS |
| 36 | Qullinaaraaluk | 73 ppb Pd, 77 ppb Pt | 2.17 % Ni, 0.38 % Cu | 52,000 | 9 gs | MS |
| 37 | Lac Rocher | 0.59 g/t Pd, 0.44 g/t Pt | 12.70 % Ni, 0.94 % Cu | 16,000 | 2 gs | MS |
| | | 0.19 g/t Pd, 0.35 g/t Pt | 1.28 % Ni, 0.48 % Cu | 25,000 | 26 gs | Pyroxenite, gabbro, DS |
| 38 | Blue Lake 1 | 0.78 g/t Pd, 0.26 g/t Pt | 0.56 % Ni, 1.02 % Cu | 13,200 | 32 gs | MS |
| | | 3.32 g/t Pd, 0.06 g/t Pt | 0.39 % Ni, 0.55 % Cu | 1,700 | bulk (1 tonne) | Chloritite |
| 39 | Centre + Pogo Lake | 0.80 g/t Pd, 0.22 g/t Pt | 0.60 % Ni, 1.03 % Cu | 12,900 | 24 gs | MS |
| 40 | Chance Lake | 0.31 g/t Pd, <0.07 g/t Pt | 0.45 % Ni, 0.24 % Cu | 7700 | 1 gs | Peridotite, SF |
| | | 0.25 g/t Pd, <0.07 g/t Pt | | | 1 gs | MS |
| 41 | Chrysler 2 | 0.59 g/t Pd, 0.13 g/t Pt | 1.19 % Ni, 2.25 % Cu | 37,800 | 3 drill holes, avg. | MS |
| | | 1.68 g/t Pd, 0.20 g/t Pt, 0.29 g/t Au | 0.18 % Ni, 3.44 % Cu | 20,500 | 2 drill holes, avg. | Chloritic rock |
| 42 | Leslie 2 | 0.15 g/t Pd, 0.04 g/t Pt | 0.40 % Ni, 1.24 % Cu | 83,800 | 1 gs | MS |
| | | 0.09 g/t Pd, 0.04 g/t Pt | 0.12 % Ni, 0.25 % Cu | 27,600 | 16 gs | Pyroxenite, gabbro, DS (>4%) |
| 43 | Erickson 1 | 0.13 g/t Pd, 0.03 g/t Pt | 0.17 % Ni, 0.27 % Cu | 20,000 | 13 gs | Pyroxenite, gabbro, DS (>4%) |
| 44 | Lepage | 0.60 g/t Pd | 0.09 % Ni, 0.90 % Cu | 15,000 | 4 gs | Pyroxenite, DS |
| 45 | 2EZ | 4 ppb Pd, <4 ppb Pt | 0.14 % Ni, 0.07 % Cu | 182,500 | 9 gs | Gabbronorite, DS |
| | | 16 ppb Pd, 11 ppb Pt | 0.61 % Ni, 0.46 % Cu | 281,000 | 6 gs | SMS (vein) |
| 46 | Lac Mora | <11 ppb Pd, <12 ppb Pt | 1.34 % Ni, 0.06 % Cu | >58 000 | 1 gs | MS |
| | | <8 ppb Pd, <6 ppb Pt | 0.12 % Ni, 0.06 % Cu | >73 800 | 6 gs | Gabbronorite, DS |
| 47 | Lac Uniforme | 13 ppb Pd, <6 ppb Pt | 0.23 % Ni, 0.09 % Cu | 66,900 | 1 gs | Norite, DS |
| 48 | Lac 108 | 3 ppb Pd, 4 ppb Pt | 0.16 % Ni, 0.06 % Cu | 200,000 | 4 gs | Late pyroxenite, DS |
| 49 | Réservoir | 65 ppb Pd, 50 ppb Pt | 0.85 % Ni, 1.35 % Cu | 207,700 | 6 gs | SMS, MS (veins) |
| | | 110 ppb Pd, 112 ppb Pt max. | | | 1 gs | SMS, MS (veins) |
| | | 8 ppb Pd, <7 ppb Pt | 0.12 % Ni, 0.09 % Cu | 117,500 | 6 gs | Late pyroxenite, DS |
| | | 25 ppb Pd, 11 ppb Pt | 0.15 % Ni, 0.07 % Cu | 29,600 | 6 gs | Layered mafic rocks, DS |
| 50 | Villeray | 4 ppb Pd, <2 ppb Pt | 0.09 % Ni, 0.07 % Cu | 169,200 | 8 gs | Gabbronorite, DS |
| 51 | Lac Edgar | 38 ppb Pd, 39 ppb Pt | 0.02 % Ni, 0.37 % Cu | 97,400 | 12 gs | Pyroxenite, DS |
| 52 | Lac Volant | 0.29 g/t Pd, 0.13 g/t Pt | 1.82 % Ni, 2.07 % Cu | 71,200 | 22 gs | MS |
| | | 0.10 g/t Pd, 0.03 g/t Pt | 0.54 % Ni, 0.72 % Cu | 75,700 | 15 gs | Gabbronorite, DS |
| 53 | Ann | 20 ppb Pd, 35 ppb Pt | 0.54 % Ni, 0.31 % Cu | 155,000 | 1 gs | MS |
| | | 8 ppb Pd, 5 ppb Pt | 0.09 % Ni, 0.13 % Cu | 152,700 | 5 gs | Gabbronorite, DS |
| 54 | AB-7 | 2 ppb Pd, 2 ppb Pt | 0.22 % Ni, 0.28 % Cu | 1,400,000 | 3 gs | Gabbronorite, DS |
| 55 | Lac Méchant | 14 ppb Pd, 5 ppb Pt | 0.20 % Ni, 0.42 % Cu | 300,000 | 1 gs | Olivine gabbronorite, DS |

***TABLE 2*** - Continued.

| Site | Deposit / Intrusion | PGE grades | Ni and Cu grades | Cu/Pd | Sample | Rock |
|---|---|---|---|---|---|---|
| 56 | Lac Louis | <5 ppb Pd, <5 ppb Pt | 0.37 % Ni, 0.09 % Cu | >180 000 | 5 gs | Gabbronorite, DS |
| | | 27 ppb Pd, 42 ppb Pt | 0.55 % Ni, 0.34 % Cu | 125,900 | 2 gs | MS (veins) |
| 57 | Millage 80 | <6 ppb Pd, 7 ppb Pt | 0.13 % Ni, 0.27 % Cu | >450 000 | 2 gs | Gabbronorite + SF veins |
| 58 | B-50 | <7 ppb Pd, <6 ppb Pt | 0.40 % Ni, 0.13 % Cu | >185 700 | 2 gs | Peridotite, gabbronorite, DS |
| 59 | Lac Édouard mine | <70 ppb Pd, <70 ppb Pt | 2.62 % Ni, 0.24 % Cu | >34 400 | 4 gs | MS |
| 60 | Lac Kennedy | 15 ppb Pd, <27 ppb Pt | 0.25 % Ni, 0.22 % Cu | 144,000 | 11 gs + drill core | Pyroxenite, DS |
| 61 | Lac Matte | <70 ppb Pd, <70 ppb Pt | 0.13 % Ni, 0.04 % Cu | >5800 | 5 gs | Pyroxenite, DS |
| 62 | Rochette | | 0.98 % Ni, 0.18 % Cu | | 15 gs + drill core | Pyroxenite, gabbro, DS |
| 63 | Renzy Lake mine | 100 ppb Pd, 100 ppb Pt | 0.80 % Ni, 0.83 % Cu | 83,000 | bulk sample | DS ore |
| 64 | Ste-Véronique | 77 ppb Pd, 53 ppb Pt | 0.28 % Ni, 0.35 % Cu | 45,700 | 3 gs | Olivine pyroxenite, DS |
| | | 1 g/t Pt max. | 0.24 % Ni, 0.28 % Cu | | 1 gs | Pyroxenite, DS |
| 65 | Havre-St-Pierre | 59 ppb Pd, 47 ppb Pt | 0.66 % Ni, 0.17 % Cu | 28,300 | 3 gs | MS |
| | | 16 ppb Pd, 26 ppb Pt | 0.14 % Ni, 0.23 % Cu | 143,800 | 8 gs | Orthopyroxenite, DS |
| 66 | Tortue | 12 ppb Pd, 17 ppb Pt | 0.10 % Ni, 0.13 % Cu | 106,700 | 3 gs | Orthopyroxenite, DS |
| 67 | R.-Pentecôte (Coro, B-20) | 4 ppb Pd, 3 ppb Pt | 0.17 % Ni, 0.14 % Cu | 337,500 | 2 gs | Orthopyroxenite, DS |
| 68 | Chutes-des-Passes (MHY) | <10 ppb Pd, <10 ppb Pt | 0.82 % Ni, 0.50 % Cu | >500 000 | drill holes avg. | MS to DS |
| 69 | Dupont (Kénogami) | 75 ppb Pd, <8 ppb Pt | 0.21 % Ni, 0.08 % Cu | 10,500 | 8 gs | Gabbronorite, DS |
| 70 | McNickel | <6 ppb Pd, <5 ppb Pt | 0.06 % Ni, 0.03 % Cu | >62 400 | 19 gs + drill core | Pyroxenite, gabbronorite, DS |
| | | 19 ppb Pd, 13 ppb Pt | 0.42 % Ni, 0.55 % Cu | 287,000 | 11 gs + drill core | MS (veins) |
| 71 | De La Blache (N block) | 2 ppb Pd, 2 ppb Pt | 0.14 % Ni, 0.09 % Cu | 471,700 | 10 gs | Websterite, gabbronorite, DS |
| 72 | Shawinigan | 2 ppb Pd, <11 ppb Pt | 0.21 % Ni, 0.10 % Cu | 500,000 | 14 gs | Norite, DS |
| 73 | Morin (N.-D.-de-la-Merci) | 5 ppb Pd, <10 ppb Pt | 0.12 % Ni, 0.10 % Cu | 200,000 | 7 gs | Pyroxenite, norite, DS |
| 74 | Sept-Îles layered complex | 17 ppb Pd, 30 ppb Pt max. | 0.06 % Ni, 0.21 % Cu max. | >100 000 | drill holes | Gabbro, troctolite |
| 75 | Cartouche | 13.8 g/t Pd, 14.4 g/t Pt, 30.2 g/t Au | <0.01 % Ni, 0.15 % Cu | 109 | 1 gs | Calcite vein |
| 76 | Hopes Advance 1 (N zone) | 0.26 g/t Pd, 0.35 g/t Pt | 1.90 % Ni, 2.29 % Cu | 88,100 | 2 gs | MS |
| 77 | Lac Pio (west vein) | 2.04 g/t Pd, 0.20 g/t Pt | 3.09 % Ni, 11.11 % Cu | 54,400 | 5 gs | MS |
| | | 3.05 g/t Pd max. | | | | |
| 78 | B-30 | 13 ppb Pd, 19 ppb Pt | 1.12 % Ni, 0.39 % Cu | 297,500 | 3 gs | Biotite gneiss, DS, SMS |
| 79 | Réservoir Taureau | 0.86 g/t Pt, 0.16 g/t Au | 0.46 % Ni, 0.51 % Cu | | bulk | Gabbro, gneiss |

Notes : Grades are averages when >1 sample; gs, grab sample, SF, sulfides, DS, disseminated sulfides; SMS, semimassive sulfides; MS, massive sulfides mantle are incorporated in the partial melt, e.g., ultramafic komatiite magma (Keays, 1982; Barnes ***et al***., 1997). The crystallization products of such sulfide-undersaturated magmas would be good targets for PGE exploration, if the magmas became sulfide-saturated at a late stage. Another way to generate a PGE-fertile magma is by partially remelting a zone of the mantle that had previously experienced a low to moderate degree of melting (e.g., less than 20 %). In this scenario, the first-stage, sulfide-saturated melt would have incorporated part of the available sulfide but little of the incompatible PGE, the latter having more affinity with the residual sulfides; this melt would therefore be depleted in PGE. The second-stage melt would have been able to incorporate the remaining sulfides and most of the initial incompatible PGE; this melt would be sulfide-undersaturated and fertile in PGE (Hamlyn and Keays, 1986). Boninitic magma is a possible example of a second stage melt. Such magma may have fed many of the world's major PGE-bearing, layered, mafic intrusions (Hamlyn ***et al***., 1985; Hamlyn and Keays, 1986). First-stage, sulfide-saturated melts would form poor targets for PGE exploration, while second-stage melts would provide good targets if they become sulfide-saturated just before final emplacement.

Rocks with a Cu/Pd ratio between 1000 and 10 000 are similar in this respect to the mantle (Barnes ***et al***., 1993a,b). Smaller values suggest PGE enrichment relative to the mantle, which can be caused by efficient mixing of the sulfides with a large quantity of silicate magma (high R-factor[1]) or by hydrothermal processes. Magmas that are initially sulfide-saturated, or become so early on during their ascent, are likely to lose sulfides before their final emplacement and would therefore be PGE-depleted (Keays, 1982). Rocks formed from these magmas would have Cu/Pd ratios greater than the mantle value, because of different partition coefficients for these elements. As a general indication of the PGE depletion or enrichment of Québec deposits, typical Cu/Pd ratios are given in Tables 1 and 2. However, it should be borne in mind that post-magmatic, hydrothermal remobilization, which has been observed in several important Ni-Cu-PGE deposits in Québec, can easily affect metal ratios (Farrow and Watkinson, 1999).

This review is based on published and unpublished analytical data from various sources. Where several analyses for a given deposit are available, averages have been used. However, in some cases, data are few, increasing the risk of the nugget effect or the use of non-representative analyses. These constraints, combined with the probable variability in the quality of the analyses, suggest that caution should be exercised when interpreting the present results.

## *GOOD PGE TARGETS OF MAGMATIC ORIGIN*

Based on the above criteria (particularly a mantle value for the Cu/Pd ratio–see Tables 1 and 2), geological settings in Québec that contain magmatic deposits formed from fertile, PGE-undepleted magmas are listed below, generally in order of decreasing age. These settings (with examples of deposits) are therefore considered good targets for magmatic PGE exploration. Site numbers refer to locations shown in Figure 1; the corresponding deposits are listed in Table 1.

1. Archean komatiites in the Superior Province. Examples of deposits are the Ni-Cu-dominant occurrences in the Venus greenstone belt ***(site 1)*** in the central part of the Superior Province. These include the Gagnon, Gayot, Base Line, and L showings. The Venus deposits, rich in Ni and PGE, are similar to Australian, Kambalda-type Ni-Cu-PGE deposits, which are typically located within a rift zone, in spinifex-textured ultramafic flows situated near the base of a differentiated volcanic sequence containing intercalated exhalative sediments (Naldrett, 1989). The former Marbridge mine ***(site 2)***, NW of Val d'Or, and the La Trêve II deposit ***(site 3)***, west of Chibougamau, are other possible examples.
2. Archean, mafic-ultramafic intrusions in Archean greenstone belts. Examples of Ni-Cu-dominant deposits in the Abitibi belt include the following : RM-Nickel ***(site 4)***, Lantagnac ***(site 5)***, Amos ***(site 6)***, and Trécesson ***(site 7)***. The Crête de Coq showing ***(site 8)*** is an example located in the Upper Eastmain River belt.
3. Archean, chromite-bearing, layered, mafic-ultramafic intrusions. Examples of PGE-dominant deposits are the various chromitite occurrences in the Menarik intrusion ***(site 9)*** and the Nadine showing ***(site 10)***, both in the James Bay area. These occurrences may be analogous to the PGE deposits in the Archean Bird River sill in Manitoba, in which PGE occur in peridotites and chromitites in the lower part of an Archean, differentiated, ultramafic to mafic intrusion (Scoates ***et al,***, 1988).
4. Archean, mafic-ultramafic intrusions in the Belleterre-Baby volcanosedimentary belt and vicinity. The following are examples of Ni-Cu-dominant deposits : Midrim ***(site 11)***, Lac Croche ***(site 12)***, Lac Kelly ***(site 13)***, and Lac Sheen ***(site 14)***.
5. Proterozoic mafic dikes cutting Archean rocks in the Abitibi belt. A possible example of a Ni-Cu-dominant deposit is the La Trêve I showing ***(site 3)***.

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[1] The R-factor is the ratio of the mass of the silicate magma to the mass of the sulfide melt, as defined by Campbell and Naldrett (1979).

6. Lower Proterozoic komatiites in the Cape Smith belt (or Ungava Trough). Examples are the Ni-Cu-dominant, sulfide deposits in the Raglan Formation, including the following deposits : Katinniq (minable reserves of 7.63 Mt at 2.72 % Ni and 0.75 % Cu; ***site 15***), Donaldson East and West ***(site 16)***, and Lac Cross ***(site 17)***. Picard ***et al.*** (1994) reported average grades between 2.28 and 4.87 g/t Pd+Pt for the four deposits. Falconbridge has reported (web site) geological reserves of more than 19 million tonnes grading 2.82 % Ni and 0.77 % Cu among several deposits in their Raglan property.

7. Lower Proterozoic, differentiated, mafic-ultramafic sills and dikes intruding the Povungnituk Formation in the Cape Smith belt. Examples include Ni-Cu-dominant, massive sulfide deposits near the base of certain sills, such as the D8 ***(site 18)*** and D9 ***(site 19)*** showings. Recent exploration at the Expo Ungava deposit ***(site 20)*** has revealed interesting PGE values in drill core. The Méquillon feeder dike ***(site 21)*** contains disseminated, Ni-Cu dominant sulfides. The PGE-dominant, reef-like, Delta 3 horizon ***(site 22)*** of pegmatitic gabbro is located in the upper part of a sill.

8. Lower Proterozoic, differentiated, mafic Montagnais sills with no basal sulfide concentrations in the Labrador Trough. Some sills contain reef-like, pegmatitic gabbro horizons in which showings of PGE-rich, disseminated sulfides have been discovered, e.g., Lafortune ***(site 23)*** and Gillet ***(site 24)***.

9. Middle Proterozoic, late-stage, mafic or mafic-ultramafic intrusions in the Grenville Province. Examples are the Ni-Cu-dominant lac Nadeau sulfide showing ***(site 25)*** in the Portneuf-Mauricie volcanosedimentary belt and the PGE-dominant lac Mitaine sulfide showing ***(site 26)*** on the Manicouagan Plateau.

10. Chromitite horizons in ophiolites of the Appalachian Province. Examples include the following PGE-dominant deposits : Hall ***(site 27)***, Finneth #1 ***(site 28)***, Lambly-Nadeau ***(site 29)***. The Hall and Finneth #1 deposits are located in ultramafic cumulates, and their Pt and Pd grades are greater than their Os, Ir, and Ru grades. By contrast, the Lambly-Nadeau deposit is in harzburgitic tectonites, and is characterized by an enrichment in Os, Ir, and Ru. Elsewhere in the world, ophiolites that contain PGE-bearing chromitites include Shetland (Lord ***et al.***, 1994) and Leka (Pedersen ***et al.***, 1993).

## *LESS IMPORTANT, MAGMATIC PGE TARGETS*

Although intrusions formed from PGE-depleted magma may be less important PGE targets, they may, on the other hand, contain economic Ni-Cu deposits. For example, sulfides in the "Ovoid" at Voisey's Bay (Labrador) contain, on average, 4.6 % Ni and 2.8 % Cu, but only 252 ppb Pd and 123 ppb Pt (Naldrett ***et al.***, 2000); they are PGE-depleted according to the criteria used in this review (Cu/Pd = 111 000). In addition, the presence of PGE-depleted intrusions in a given area does not mean that all intrusions in that area are necessarily PGE-depleted. Thus, Barnes ***et al.*** (1997) noted that there can be significant variations in metal enrichment among intrusions in the same geographic area. This is the case, for example, in the Belleterre-Baby and Portneuf-Mauricie belts and on the Manicouagan Plateau. Furthermore, as noted earlier, the degree of PGE enrichment or depletion in samples from a given intrusion can depend on the stratigraphic level of the sampling site. Caution is therefore required when evaluating the exploration significance of the results. In Québec, examples of settings containing magmatic sulfide mineralization with PGE-depleted characteristics are listed below; deposits and intrusions corresponding to the sites mentioned are listed in Table 2. The PGE content of individual samples varies considerably, from a few ppb to more than 1 g/t.

1. Many Archean mafic-ultramafic intrusions in the Superior Province. Examples in the Abitibi area include the Matagami Lake, Nicobi, Muscocho, Montbeillard, Lac aux Foins (these occurrences are not located in Figure 1), Cold Spring Rapids (Bell River complex, **site 30**), Doré Lake complex **(site 31)**, Lac à l'Eau Jaune **(site 32)**, and the Cummings complex **(site 33)**. Examples of Ni-Cu dominant deposits in the Belleterre-Baby belt include Laforce **(site 34)** and the former Lorraine mine (600 000 tonnes at 1.08 % Ni and 0.62 % Cu; **site 35**). The Qullinaaraaluk deposit (Minto Subprovince; **site 36**) and the Lac Rocher deposit (Frotet-Evans greenstone belt; **site 37**) are examples from other parts of the Superior Province.

2. Lower Proterozoic, differentiated, aphyric, mafic-ultramafic sills with basal sulfide concentrations in the Labrador Trough (Montagnais Sills). The Ni-Cu-dominant sulfide deposits discovered to date suggest only weakly depleted PGE concentrations, so that such occurrences can be considered targets of intermediate importance. Ni and Cu grades are rather low, suggesting a low R-factor. Examples of deposits include Blue Lake 1 ***(site 38)***, Centre and Pogo Lake ***(site 39)***, and Chance Lake ***(site 40)***.

3. Lower Proterozoic, glomeroporphyritic gabbro sills in the Labrador Trough (Montagnais Sills). The Ni-Cu deposits are generally found in sills containing a layer of pyroxenite. Examples of deposits include : Chrysler 2 ***(site 41),*** Leslie 2 ***(site 42)***, Erickson 1 ***(site 43)***, and Lepage ***(site 44)***. The Cu/Pd, Cu/Pt, and Cu/Ni ratios of massive and disseminated sulfides in glomeroporphyritic gabbro are generally greater than those of massive sulfides in the aphyric, mafic-ultramafic sills of the Trough. Massive sulfides in the latter appear to be slightly richer in PGE.

4. Many Middle Proterozoic, mafic or mafic-ultramafic intrusions in the Grenville Province. Examples of deposits include those in early gabbronorite sills and

most late mafic-ultramafic intrusions on the Manicouagan Plateau, e.g., 2EZ ***(site 45)***, Lac Mora ***(site 46)***, Lac Uniforme ***(site 47)***, Lac 108 ***(site 48)***, Réservoir ***(site 49)***, Villeray ***(site 50)***. Other examples include the pyroxenite-hosted Lac Edgar showing ***(site 51)*** in the Shabogamo Gabbro, near Fermont; deposits in mafic dykes intruding the Matamec complex, e.g., lac Volant ***(site 52)***, Ann ***(site 53)***, AB-7 ***(site 54)***; the lac Méchant showing ***(site 55)***; showings in several small, mafic-ultramafic intrusions in the Manic 3 area, e.g., Lac Louis ***(site 56)***, Millage 80 (***site 57***), B-50 ***(site 58)***; deposits in certain mafic-ultramafic intrusions in the Portneuf-Mauricie belt, e.g., the former Lac Édouard mine (160 000 tonnes grading 1.5 % Ni and 0.7 % Cu, ***site 59***), Lac Kennedy ***(site 60)***, Lac Matte ***(site 61)***, Rochette ***(site 62)***; the former Renzy Lake mine, located in an ultramafic sill (2 million tonnes grading 0.7 % Ni et 0.7 % Cu, ***site 63***); and a showing in the possibly alcalic Sainte-Véronique mafic-ultramafic intrusion ***(site 64)***.

5. Middle Proterozoic mafic to ultramafic intrusions in the marginal zones of Grenville Province anorthosite massifs. Examples include deposits, which generally contain <100 ppb PGE, in mafic to ultramafic intrusions associated with the following massifs : Havre-Saint-Pierre ***(site 65)***, Tortue ***(site 66)***, Rivière-Pentecôte ***(site 67)***, Lac-Saint-Jean [including Chute-des-Passes ***(site 68)***, Dupont (***site 69***; the value of 10,500 for Cu/Pd at Dupont is rather low for this group of deposits), and McNickel ***(site 70)***], De La Blache ***(site 71)***, Shawinigan ***(site 72)***, and Morin ***(site 73)***.

6. The Cambrian Sept-Îles layered complex ***(site 74)*** has been unsuccessfully explored for PGE-dominant, reef-type deposits. The layered rocks appear to be PGE-depleted (<50 ppb Pt+Pd) to a drilled depth of about 2 km, but it is not impossible that a PGE-rich horizon occurs at a greater depth.

## *HYDROTHERMAL PGE TARGETS*

Several examples of post-magmatic, hydrothermal PGE mineralization are known in Québec. Some are associated with Ni-Cu-PGE deposits of magmatic origin. At the Cartouche showing ***(site 75)*** in the James Bay area, high-grade, possibly Proterozoic veins of calcite, barite, and specularite intrude Archean, felsic volcanic rocks. A grab sample returned 14.4 g/t Pt, 13.8 g/t Pd, 30.2 g/t Au, and 2463 g/t Ag (Roger and Boucher, 1997). In the Donaldson East deposit (Cape Smith belt, ***site 16***), hydrothermal veins containing amphibole and biotite occur in proximity to magmatic deposits and are enriched in PGE (up to 1.7 g/t Pd), Cu, Ag, and Au (Picard ***et al,***, 1994). Near some of the deposits hosted by sills intruding the Povungnituk Formation, hydrothermal veins enriched in Pd, Pt, and Cu occur in shear zones (e.g., 17.5 g/t Pd and 3.3 g/t Pt in a shear zone affecting the footwall rocks of the sill at the D8 showing, ***site 18***; Giovenazzo, 1991). The Labrador Trough contains several magmatic Ni-Cu deposits with a post-magmatic, hydrothermal component. The massive sulfides in the Blue Lake 1 deposit ***(site 38)*** are bordered by iron-rich chloritic rock of hydrothermal origin; a bulk sample gave 3.3 g/t Pd (Clark, 1989). Chloritic rocks and quartz-chlorite-chalcopyrite veinlets of hydrothermal origin occur adjacent to the Chrysler 2 massive sulfide body ***(site 41)***, also in the Trough, and are enriched in PGE and Au (1.7 g/t Pd, 0.2 g/t Pt, and 0.3 g/t Au, on average; Ward, 1989). In the Hopes Advance 1 (north zone) deposit ***(site 76)***, a body of massive sulfides and Cu-rich veins hosted by folded and faulted metasedimentary rocks gave maximum concentrations of 14.4 g/t Pd and 4.6 g/t Pt (Wares and Goutier, 1990, and in preparation). Thick veins of massive sulfides in the Pio Lake deposit ***(site 77)*** in the Labrador Trough were probably formed by a combination of ductile remobilization and hydrothermal processes (Wares and Goutier, 1990, and in preparation). The west vein contains about 12,600 tonnes grading 3.2 % Ni and 6.6 % Cu, while the east vein is estimated at about 10,200 tonnes grading 0.3 % Ni and 6.9 % Cu. Grab samples from the veins have returned up to 3.05 g/t Pd. Sulfides from the former Lorraine mine ***(site 35)***, in the Timiskaming area, have also been strongly remobilized by multiple processes; average grades in the massive sulfides are 0.8 g/t Pd and 0.6 g/t Pt, while maximum concentrations are 0.9 g/t Pd and 2.0 g/t Pt (Barnes ***et al.***, 1993b).

Hydrothermal veins with a low PGE content are associated with many magmatic Cu-Ni deposits in Québec. In the Abitibi area, veins containing low concentrations of PGE are associated with magmatic sulfides in, for example, the Lac à l'Eau Jaune deposit ***(site 32)*** and the Cummings complex ***(site 33)*** (Barnes ***et al***., 1993a). Examples of veins containing slight amounts of PGE in the Grenville Province include the 2EZ showing ***(site 45)*** on the Manicouagan Plateau, the McNickel showing ***(site 70)*** north of lac St-Jean, and the Lac Louis showing ***(site 56)*** north of Baie-Comeau. The B-30 showing ***(site 78)***, also in the Grenville, is an example of an epigenetic, sulfide mineralization associated with silicious alteration and hosted by a sequence of brecciated biotite gneiss and amphibolite. The Réservoir Taureau showing ***(site 79)***, which resembles the vein-type mineralization at Cobalt (Ontario), distinguishes itself by the presence of Ni-Co arsenides; a bulk sample returned 0.86 g/t Pd and 0.16 g/t Au (Poirier, 1988), although more recent sampling failed to confirm these concentrations.

Although hydrothermal mineralization is often of high grade, a sufficient volume may be difficult to find. Nevertheless, significant deposits are known elsewhere (e.g., New Rambler, Rathbun Lake, Nicholson Bay), and deposits of this type can make interesting exploration targets (Hulbert ***et al***., 1988).

## LAC DES ÎLES-TYPE TARGETS

The potential in Québec for the discovery of PGE-dominant deposits similar to those at Lac des Îles (NW Ontario) requires serious consideration, because exploration for this type of mineralization is relatively new. The Archean, Lac des Îles deposit, termed "supersolidus, intrusion breccia" type by Barrie (1995), shows chemical characteristics suggesting a strong enrichment in PGE (Cu/Pd = 450, according to data from Sweeny and Edgar, 1987, 1988). The small quantity of sulfide in the Lac des Îles deposit makes it highly possible that similar mineralizations elsewhere have previously gone unnoticed. The discovery of a similar deposit in Québec would therefore require careful observation of the physical characteristics of the intrusion and, in particular, the evidence for multiple intrusive events, breccias, and the action of volatiles (pegmatitic textures and deuteric, hydrothermal alteration). In Québec, some of these characteristics are present, for example, at the RM-Nickel showing (up to 5.8 g/t Pd and 0.9 g/t Pt, Barnes ***et al.***, 1993a, ***site 4***) in the Rouyn-Noranda area; at the Crête de Coq showing (up to 0.6 g/t Pd and 0.3 g/t Pt, SIGÉOM database, MRN, ***site 8***) in the Upper Eastmain River greenstone belt; and at the Réservoir showing (up to 110 ppb Pd and 112 ppb Pt, SIGÉOM database, MRN, ***site 49***) on the Manicouagan Plateau.

## TARGETS ASSOCIATED WITH LATE-STAGE INTRUSIONS

The late Archean, PGE-bearing intrusions in the Sudbury area, e.g., East Bull Lake, are thought to represent second-stage, rift-related magmatism; they are considered to have relatively high PGE potential (Peck ***et al***., 1993). The tectonic zone hosting the deposits may extend eastward into Québec, parallel to the Grenville Front. The zone may encompass Archean rocks both in the Superior Province to the north of the Front and in the Grenville Province parautochthonous terrain to the south of the Front.

Elsewhere in Québec, late-stage intrusions in areas where a major degree of previous mantle melting may have occurred should be considered for PGE exploration. Late Archean or Proterozoic intrusions in the Superior Province, possibly derived from second-stage melts, are good targets. An example is the late tectonic, PGE- and chromitite-bearing Menarik intrusion ***(site 9)***. The Proterozoic, PGE-bearing dike at La Trêve I ***(site 3)***, west of Chibougamau, may be another example. The Qullinaaraaluk intrusion ***(site 36)*** in the Minto Subprovince and the Lac Rocher intrusion ***(site 37)*** in the Frotet-Evans belt are also examples of late Archean magmatism, but these intrusions appear to be PGE-depleted. In the Manicouagan Plateau area, voluminous, Lower to Middle Proterozoic mafic magmatism was followed by later mafic magmatism. At least one late intrusion, Lac Mitaine ***(site 26)***, is fertile in PGE. Another, the Réservoir intrusion ***(site 49)***, was probably formed from multiple injections of volatile-rich, mafic magma, but this magma appears to have been PGE-depleted. The Portneuf-Mauricie volcanosedimentary belt of Middle Proterozoic age contains several mafic plutons whose emplacement may have been considerably more recent than the regional volcanism; one of them, at lac Nadeau ***(site 25)***, contains PGE-undepleted sulfide mineralization.

## CONCLUSIONS

It is clear from the above discussion that Québec boasts a great diversity of geological environments containing Ni-Cu-PGE and PGE mineralizations. Many of these settings have characteristics indicating highly favorable exploration potential. However, much exploration work remains to be done before this potential can be fully evaluated.

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