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**MINERALOGY AND GEOLOGY OF THE POUDRETTE QUARRY,
MONT SAINT-HILAIRE, QUÉBEC**

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INTRODUCTION

The Poudrette quarry located in the East Hill suite of the Mont Saint-Hilaire alkaline complex is one of the world's most prolific mineral localities, with a species list exceeding 365. No other locality in Canada, and very few in the world have produced as many species. With a current total of 50 type minerals, the quarry has also produced more new species than any other locality in Canada, and accounts for about 25 per cent of all new species discovered in Canada (Horváth 2003). Why has a single quarry with a surface area of only 13.5 hectares produced such a mineral diversity? The answer lies in its geology and its multiplicity of mineral environments.

INTRODUCTION

La carrière Poudrette, localisée dans la suite East Hill du complexe alcalin du Mont Saint-Hilaire, est l'une des localités minéralogiques les plus prolifiques au monde avec plus de 365 espèces identifiées. Nul autre site au Canada, et très peu ailleurs au monde, n'ont livré autant de minéraux différents. Son total de 50 minéraux type à ce jour place non seulement cette carrière au premier rang des sites canadiens pour la découverte de nouvelles espèces, mais représente environ 25% de toutes les nouvelles espèces découvertes au Canada (Horváth 2003). Pourquoi une seule carrière couvrant une aire de seulement 33.36 acres a-t-elle produit une telle diversité minéralogique? La réponse vient d'un contexte géologique ayant favorisé une multiplicité d'environnements minéraux.

REGIONAL GEOLOGY

Mont Saint-Hilaire is a small, roughly circular composite igneous intrusion rising some 375 meters above the surrounding Saint-Lawrence peneplain and measuring 3.6 kilometers in its widest part (O'Neil 1914; Clark 1955; Currie 1976, 1983; Greenwood & Edgar 1984; Globensky 1985). The intrusion, physically a monadnock, is part of a series of Lower Cretaceous age intrusions collectively known as the Montereian Hills (Adams 1903). In addition to the more prominent hills, numerous dikes, sills, plugs and pipes composed of various types of alkaline rocks, which also form part of the Montereian Hills Province, have been documented. Some of these sills and dikes have yielded rare mineral species similar to those occurring in the Poudrette quarry (Horváth *et al.* 1998; Tarassoff *et al.* 2006).

The Montereian Hills form a linear trend extending from the St-André carbonatite complex intruded in Proterozoic rocks of the Ottawa Valley-Bonnechère graben 60 km west of Montreal, to Mont Mégantic in Palaeozoic rocks of the Appalachians about 200 km west of Montreal. The composition of the intrusive rocks varies strongly, from carbonatitic in the east through silica-saturated rocks at Mont Mégantic, with silica-undersaturated gabbroic and syenitic rock types comprising the bulk of the intrusions in between. Economic concentrations of metals have been identified only from the Oka carbonatite complex where niobium has been extracted from pyrochlore (Gold *et al.* 1986).

The Montereian Hills are related both temporally and chemically to partial melting of lherzolitic mantle by a rising thermal plume (see Eby 1984a, 1985a) during the late Cretaceous period. Based on $^{40}\text{Ar}/^{39}\text{Ar}$ data, Foland *et al.* (1986) suggested that the Montereian Hills were emplaced during a single episode at about 124 ± 1 Ma. Alignment of the intrusions along an E-W trend suggests a structural control of emplacement from

deep seated faults, whereas lateral and punctual variation in rock types is attributed to differences in the chemical evolution of rising magma and level of interaction with units through which the latter moved (Foland *et al.* 1988).

The origin of the strongly undersaturated and peralkaline rocks at Mont Saint-Hilaire is poorly understood. Attempts to attribute their origin to a single source using fractionation models of mantle-derived parental melts have failed to reproduce simultaneously the chemical and isotopic compositions observed. While there seems to be agreement that some mixing process was involved in forming these rocks (Currie *et al.* 1986; Foland *et al.* 1988), hypotheses on their origin remain few and unconfirmed. For example, Currie *et al.* (1986) favour a mixing origin through interaction of magma with a chloride-rich component (evaporites or brine) at shallow levels of the crust to explain the elevated peralkalinity and $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic signatures of the most evolved units.

LOCAL GEOLOGY

Igneous rocks that form Mont Saint-Hilaire (Fig. 1) are in sharp intrusive contact with calcareous shale, siltstone and limestone of the Upper Ordovician, Utica-Lorraine Group and rarely display chilled zones (Clark 1955; Currie 1983). In the first 15 meters from the contact with the intrusion, the sedimentary units tilt inwards and locally dip up to 70° . Further away, they remain essentially horizontal. According to Currie *et al.* (1986), the inward dip of the sedimentary rocks and the presence of down-dropped xenoliths of sedimentary rocks may be evidence for passive emplacement of the pluton.

A narrow contact metamorphic aureole of less than 150 meters formed in the sedimentary rocks surrounding the mountain. Very little has been reported in the literature on the mineralogy and metamorphism of these rocks. Rajasekaran (1966a) described albite-epidote hornfels facies in contact with nepheline syenite and a metasomatized variety (a fenite) containing arfvedsonite, narsarsukite and neptunite (Rajasekaran 1966b). Currie (1983) reported comparatively low grades of hornfels metamorphism from the biotite to albite-chlorite zones on the eastern side of Mont Saint-Hilaire. Large blocks of hornfels also occur enclosed by the intrusive rocks.

The igneous rocks of Mont Saint-Hilaire have been described in detail first by O'Neil (1914), and, most recently, by Currie (1983), Greenwood & Edgar (1984) and Currie *et al.* (1986). The mountain is separated into two major units. The western half of the mountain is composed of a concentric succession of a variety of gabbroic rocks which were emplaced first. These rocks comprise leucogabbros rich in feldspar and nepheline, foliated gabbros, kaersutite-biotite gabbros, kaersutite gabbros and a gabbro-melagabbro series of rocks rich in olivine, clinopyroxene and opaque minerals. The eastern half of the mountain, which represents the youngest part of the intrusion, comprises various types of peralkaline syenitic rocks and igneous breccias. Currie (1983) named this unit the East Hill suite.

Differentiation of the gabbros, both pre- and post-emplacement, was estimated by Greenwood & Edgar (1984) to have taken place at depths between 3.5 and 8 km. Gilbert & Foland (1985) estimated that all the units forming the intrusion were emplaced within less than 0.5 My. By extension, it can be reasonably assumed that the depth of emplacement of the peralkaline rocks, as they are presently exposed, was probably the same as that for emplacement of the earlier gabbroic rocks at a minimum of 3.5 km. Greenwood & Edgar (1984) suggested that the intrusion is funnel-shaped based on the

concentric nature and inward dip of the foliation in the gabbros, whereas Currie *et al.* (1986) interpreted the contact to be essentially vertical. Based on gravity measurements, Feininger & Goodacre (1995) proposed that the intrusion filled a breccia pipe originating from a laccolith at depth. Diatreme-type breccias developed during the later phase of the intrusion. However, it is not clear if magma reached the surface at the time.

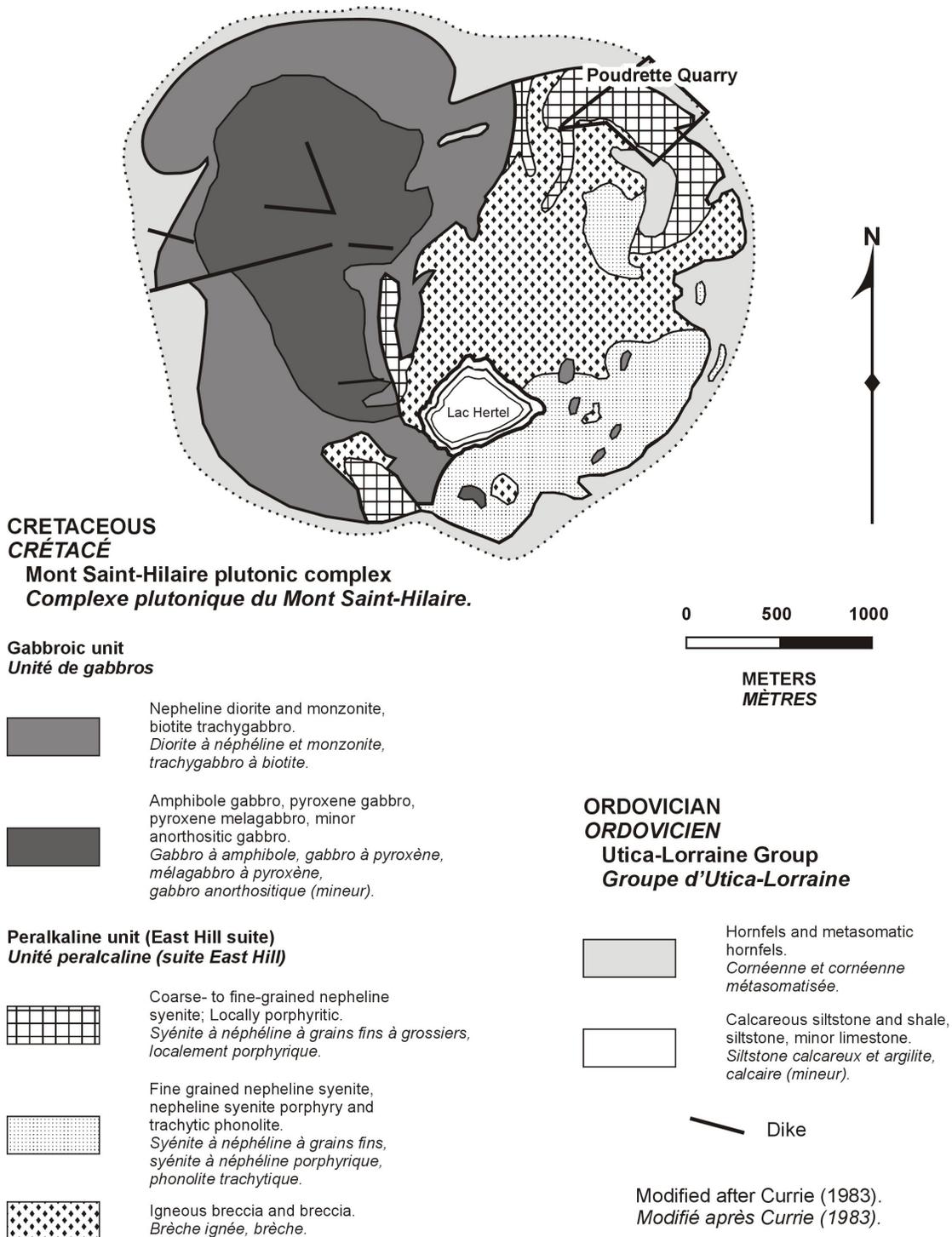
GEOLOGY OF THE POUDRETTE QUARRY

The Poudrette quarry is located at the northern end of the eastern half of Mont Saint-Hilaire (Fig.1). Quarrying operations have exposed: (1) the sedimentary country rocks and hornfels at the contact with the intrusion to the north; (2) a dense, grey, coarse- to fine-grained, frequently porphyritic variety of nepheline syenite; (3) igneous breccias containing angular fragments of a wide variety of lithologies; (4) hybrid nepheline syenites and (5) coarse-grained, sodalite-rich syenites in which grey-coloured sodalite crystals are poikilitically enclosed in large feldspar crystals and smaller proportions of clinopyroxene (Annex I).

In the quarry, the most important rock type, volume wise, is dense, grey nepheline syenite, which is exposed over a large area of the southwest quarry walls. Pouliot (1969) reported porphyritic, equigranular, fine-grained and trachytic varieties of this syenite. Alkali-feldspar and albite are the most abundant minerals present (40-70%). According to Currie *et al.* (1986), some of the phenocrysts are sanidine with the composition $Ab_{43}Or_{57}$, and none of the feldspars contain Ca detectable by electron microprobe analysis. Nepheline (20-30%), sodalite (0-15%) and aegirine (10-20%) are the other major rock-forming minerals reported by Pouliot (1969), while amphibole-group minerals, fluorite, cancrinite, eudialyte-group minerals, zircon, magnetite, ilmenite, apatite, titanite, biotite, astrophyllite-group minerals, pyrite and chalcopyrite occur as accessory minerals. The composition of the mafic minerals reflects the highly evolved nature of the rocks, showing a distinct enrichment in Mn. Currie *et al.* (1986) reported that the ilmenite contained up to more than 40 mol % of pyrophanite in solid solution, magnetite up to 0.16 apfu of Mn, and biotite up to 0.32 apfu of Mn. The nepheline syenites locally contain relatively high concentrations of miarolitic cavities. Where the cavities are flattened, they are aligned parallel to flow textures in the rock, which can dip very shallowly to the north. The heterogeneous distribution of the miarolitic cavities may be explained either through a local variation in the amount of fluid dissolved in the magma, or to local variations in temperature.

Igneous breccias consist of a syenitic matrix and mostly angular fragments of older gabbroic rocks, and sedimentary country rocks, now metamorphosed, that originate from both higher and lower stratigraphic levels than the present level of exposure. The proportion of fragments in the breccia varies widely, up to a point where a syenitic matrix may be almost absent. Some of the more interesting fragments in the breccia consist of a green-coloured fenitized precursor, which may be fine-grained and massive or coarse-grained and highly porous. The original texture and composition of these fragments has been for the most part obliterated. Although the texture and colour of some of the fragments resemble the fine-grained fenitized margins of the large hornfels blocks, it is not clear if they represent a similar sedimentary protolith. The most remarkable fragments included in the nepheline syenite consist of the large, isolated blocks of marble, hornfels and sodalite xenoliths (described in detail below).

**Figure 1. Geological map of Mont Saint-Hilaire.
Carte géologique du Mont Saint-Hilaire.**



Locally associated with the igneous breccia, or at the interface between nepheline syenite and hornfels, or between nepheline syenite and poikilitic sodalite syenite are some hybrid types of nepheline syenite.

Poikilitic sodalite syenites are coarse-grained, and often light coloured or white where they are rich in analcime, and blue where they are rich in secondary sodalite. They occur in the quarry in close spatial association with an extremely large block of hornfels exposed in the southern part of the quarry. The hornfels in this block is locally fenitized and brecciated near its margins, and takes on a characteristic green colour due to the abundance of clinopyroxene.

MINERAL ENVIRONMENTS

The minerals for which Mont Saint-Hilaire is famous are found in a large variety of environments dictated by petrology, petrogenesis, structure and mineral assemblages. The classification of these environments or modes of occurrence has changed over the years partly as a result of field observations and partly as quarrying has revealed new environments e.g. sodalite xenoliths. Unfortunately, the environments have received much less attention than the minerals themselves and very few have been investigated in any detail.

In common with other alkaline complexes, the primary reason for the large number of species found in the quarry is the algaicity of the rocks in the East Hill suite. The highly alkaline environment is characterized by the presence of sodium-rich feldspathoids, feldspars, pyroxenes, amphiboles and zeolites as primary minerals, and complex silicates containing titanium, zirconium, niobium and rare-earth elements (REE). Algaitic rocks also tend to be enriched in volatiles which give rise to unusual carbonate and halide minerals. Added to the mineralogical complexity is the fact that during the emplacement of the East Hill suite, fragments and large blocks of the older intrusive rocks in the Mont Saint-Hilaire pluton, and of the surrounding sedimentary rocks were incorporated into the magma. Metasomatic reactions between these inclusions and magmatic fluids resulted in a host of micro environments each often with its distinct mineral assemblage. Of particular note in the quarry is the huge block of hornfels that was engulfed by the magma and is spatially associated with the largest and most diverse concentration of mineral environments in the quarry (Van Velthuisen 1990; Wight & Chao 1995). Van Velthuisen (1990) suggested that this hornfels block acted as a heat sink after its incorporation in the intrusion, resulting in magma devolatilization and a concomitant increased viscosity, and that this may account for the high concentration of various xenoliths and pegmatite vugs and pipes near its margins.

Before turning to the description of the various environments in which minerals occur in the Poudrette quarry, it is interesting at this point to refer to some of the published ideas regarding magma evolution in the East Hill suite. Based on pyroxene chemistry from the various mineral-forming environments, Piilonen *et al.* (1998) suggested that the peralkaline magma quickly evolved from reducing to oxidizing conditions during its evolution. The pyroxenes did not become enriched in the hedenbergite component but evolved directly from diopside-rich to essentially aegirine. Piilonen *et al.* (1998) showed that, in addition to being enriched in the diopside component, early-crystallized pyroxene incorporated substantial Zr, while later crystallized pyroxene was more aegirine and Ti-rich. According to these authors, Zr

would have been sequestered by the pyroxenes under reducing conditions during the early stages of magma crystallization. At a later stage, minerals such as eudialyte would have crystallized under more oxidizing conditions as coordination of Zr in the melt changed to form complexes structurally compatible with those of zirconosilicates. Perhaps this peculiar trend in changing physico-chemical conditions reflects an episode of devolatilization (accompanied by brecciation?) or mixing with an oxidized component (brine?).

Pegmatites and hydrothermalites

Pegmatites and hydrothermalites are the most visible and striking features commonly encountered in the quarry. They are the major source of fine, well-crystallized mineral specimens. In the mineralogical literature on Mont Saint-Hilaire the pegmatites have commonly been classified as “unaltered” and “altered” (Chao *et al.* 1967; Perrault & Mandarino 1972; Mandarino & Anderson 1989; Horváth & Gault 1990). Most of the pegmatites have in fact been subject to hydrothermal and/or supergene alteration. It is probably more useful to classify the pegmatites associated with late-stage magmatism on the basis of their mineralogy as syenitic pegmatites and carbonate pegmatites, and to distinguish the pegmatites from hydrothermalites which appear to be entirely the result of hydrothermal deposition.

The pegmatites are considered to be fractionation products of the magma from which the syenites crystallized (Piilonen *et al.* 1998). They display some of the classical features of pegmatites: very large grain or crystal size, the presence of rock-forming minerals, and internal zoning. The pegmatites take a variety of forms: veins a few centimeters in thickness to dike-like bodies up to 3 meters in thickness; irregular, tabular, pipe-like or ovoid bodies up to a few meters in maximum dimension; and pegmatitic segregations. The veins frequently swell and pinch along their lengths. Some of the pegmatites form systems of interconnected veins.

The primary minerals in the syenitic pegmatites are typically perthitic microcline, albite, aegirine, nepheline, analcime, kentbrooksit and kupletskite, with local concentrations of catapleiite, sérandite, rhodochrosite, arfvedsonite and polyolithionite. The pegmatites are usually zoned, with a narrow fine-grained selvage of aegirine and microcline followed by an intermediate zone of coarse-grained aegirine and feldspar, and an inner zone of coarsely crystallized aegirine, microcline and other minerals. Crystal-lined cavities or “pockets” are often present in the core of the larger pegmatites. Aegirine and microcline crystals in the inner zone are usually aligned perpendicular to the contacts and project into the central cavities which are either open or filled with a compact to loose mass of sérandite, natrolite, polyolithionite and other species. In the largest known pegmatite in the quarry, named the Poudrette pegmatite, the chill zone is replaced by a meter-wide band of aplitic line rock.

Virtually all the syenetic pegmatites have been subjected to some degree of hydrothermal activity. In the earliest stages this is manifested by the deposition of second-generation albite and fibrous aegirine (Piilonen *et al.* 1998) and Ti, Zr, Nb and Be silicates, and REE carbonates, such as nenadkevichite, gaidonnayite, leifite, genthelvite, epididymite, elpidite, niobokupletskite and ancylite-(Ce). In later stages, some of the primary as well as second-generation minerals are partially or completely replaced, often as pseudomorphs. Examples of such pseudomorphs include ancylite-(Ce) after a

burbankite group mineral, albite after natrolite, albite after aegirine, catapleiite after eudialyte, and burbankite-(Ce), synchysite-(Ce) and petersenite-(Ce) after unknown precursor REE minerals. Donnayite-(Y) is a commonly a very late-stage mineral. Some pegmatites have undergone extensive oxidation by supergene processes. Lemoynite, the first new mineral species described from Mont Saint-Hilaire, was found in such a highly altered pegmatite in association with microcline, pyrite and hisingerite.

Carbonate pegmatites are less common than the syenitic pegmatites. They include the “carbonate” cavities or vugs of Chao *et al.* (1967) and later investigators. The carbonate pegmatites have been observed only in the eastern section of the quarry, often associated with sodalite syenite. The principal minerals are microcline, albite, and carbonates, especially siderite and calcite. Also common in these carbonate-rich pegmatites are rutile, zircon, quartz, synchysite-(Ce) and sulphides such as pyrite and sphalerite. Other minerals, typical of the syenitic pegmatites, are absent, and there is no evidence that pyroxenes such as aegirine, and amphiboles, were ever present.

Hydrothermalites refer to uncommon vein-like bodies and coarse-grained segregations which appear to be entirely of post-magmatic hydrothermal origin. Feldspars and other rock-forming minerals are typically absent. Examples include a vein of coarsely crystallized natrolite with associated behoite, and a body of coarsely crystallized sodalite with dawsonite, both in sodalite syenite.

Miarolitic cavities in nepheline syenite

Miarolitic cavities *sensu stricto* occur exclusively in the porphyritic nepheline syenite. In the early literature on Mont Saint-Hilaire they are referred to as “silicate vugs” (e.g. Chao *et al.* 1967). The crystal-lined miarolitic cavities tend to be concentrated in zones, often proximal to contacts between the porphyritic nepheline syenite and other rock types. They are spheroidal to irregular in shape, and average from two to 15 centimeters across. Very rarely, the miarolitic cavities contain fluid under pressure, which escapes with a popping sound when the cavities are opened. A thin selvage of a smectite group mineral or an iron-rich vermiculite commonly underlies the crystal lining of the cavities. These clay minerals have been interpreted to be the result of the alteration of earlier iron-rich phyllosilicate minerals by late residual deuteric (autometasomatic) fluids (Lalonde & Kodama 2001). The minerals within the cavities probably also crystallized from autometasomatic fluids during the subsolidus stage, or from later metasomatic fluids. In common with other mineral environments in the quarry, the mineral assemblage in the miarolitic cavities reflects an enrichment in incompatible elements in the late-stage fluids.

Typically, the cavities are lined with crystals of analcime, together with calcite, feldspar and a biotite series mineral. Some cavities are lined with crystals of natrolite much of which has an epitactic overgrowth of paranatrolite which dehydrates to gonnardite. The minerals lining the cavities provide a substrate for a large suite of minerals occurring as millimeter-sized crystals. Relatively common species include aegirine, ilmenite, pyrophanite, zircon, fluorapatite, pyrrhotite, donnayite-(Y), burbankite, sodalite and ewaldite. Among a suite of very rare minerals, barylite, wöhlerite, hiortdahlite, bonshtedtite, bradleyite, and the new eudialyte-group species khomyakovite and manganokhomyakovite have been found only in the miarolitic

cavities. These cavities also provided some of the type material used in the description of hilairite and gaidonnayite.

Sodalite xenoliths

Variously called sodalite xenoliths or inclusions (Mandarino & Anderson 1989; Van Velthuisen & Chao 1989), and sodalite syenite xenoliths or inclusions (Chao & Ercit 1991; McDonald *et al.* 1991), they constitute the most alkaline environment in the East Hill suite and are mineralogically similar to the unusual hyperagpaitic pegmatites and hydrothermalites of the Khibiny and Lovozero alkaline complexes in the Kola Peninsula in Russia (Khomyakov 1995). Their occurrence is restricted to the south end of the quarry in close proximity to the massive block of hornfels; the majority were exposed during quarrying operations from 1982 to 1992. They vary in size from a few centimeters to 2 meters across, and tend to have angular shapes. Their main constituent, up to 90 volume %, is coarse-grained sodalite. A composition of 75% sodalite, 15% analcime, and 10% microcline is probably typical (Chao & Ercit 1991). The origin, evolution, and relationship of the sodalite xenoliths to other rock types in the quarry are presently poorly understood. They may represent a cumulate rock that formed at some level of the intrusion and was subsequently brecciated during continued igneous activity. Piilonen *et al.* (1998) suggested that the magma from which the sodalite syenite xenoliths crystallized may have been an exsolved, volatile-rich phase of the magma.

The sodalite in the xenoliths fluoresces an intense orange under ultraviolet radiation. It is also photochromic: in sunlight, freshly fractured surfaces rapidly fade in colour from violet to gray or white. A large number of very rare minerals occur only in the xenoliths, including the type species griceite, rouvilleite, silinaite, nalipoite, abenakiite-(Ce), gaultite, and martinite. More than 72 minerals have been recorded from a single xenolith (Chao *et al.* 1991). Villiamite is a characteristic mineral. Other common minerals include cancrinite, aegirine, eudialyte, sérandite, steenstrupine-(Ce), vuonnemite, and a lovozerite group mineral. The highly peralkaline nature of the sodalite xenoliths is demonstrated by the presence of an array of unstable, sodium-rich, and water-soluble minerals (Table 1).

Marble and other xenoliths

A conspicuous feature of the quarry walls are large, white to pale green marble xenoliths. Their bulk composition ranges from coarse-grained calcite to a fine-grained mixture of calcite and diopside (McDonald & Chao 2004). The xenoliths are angular to somewhat rounded in shape, and range up to about five meters in maximum dimension, with an average of one to two meters. Much smaller fragments occur in the igneous breccias. The large calcite-diopside xenoliths are found only in the eastern section of the quarry in close proximity to the massive block of hornfels where they are included in both nepheline and sodalite syenites and in an intervening zone of breccia. Two different origins have been proposed for the marble xenoliths. Based on their thorough recrystallization, granoblastic texture, and apparent lack of fossils, Mandarino *et al.* (1986) considered that the xenoliths probably originated as Grenville marble in the Proterozoic Grenville Province basement through which the Mont Saint-Hilaire pluton was intruded. In support of a Grenvillian origin, Horváth & Gault (1990) also noted the presence of relict bedding and folding in some xenoliths. Although very rare, fossils have

in fact been recovered from the marble xenoliths (McDonald & Chao 2004). This and other evidence led McDonald & Chao (2004) to conclude that the marble xenoliths were more likely derived from the Palaeozoic sedimentary country rock surrounding the intrusion. The variable mineral assemblages found in the xenoliths probably reflect varying lithologies in the sedimentary precursor.

The marble xenoliths commonly contain spheroidal to irregular-shaped cavities, averaging 5-15 cm across. These are sometimes interconnected and aligned along relict bedding planes. A large suite of minerals has been recorded from the xenoliths, either as crystals and masses embedded in the marble or as crystals in the cavities. Pectolite is ubiquitous. It commonly forms fibrous intergrowths around cavities and protrudes into the cavities as well-formed crystals. Other common minerals in the cavities are calcite, vesuvianite, fluorapophyllite, richterite and other sodium amphiboles, feldspars, phlogopite, fluorite, sodalite, and quartz. Molybdenite and sphalerite are the most common sulphides. Rare species include steacyite, thaumasite, makatite, and the REE minerals ancylite-(Ce), monteregianite-(Y), stillwellite-(Ce) and cerite-(Ce). A number of very rare minerals occur exclusively in the marble xenoliths, among them sugulite, penkvilksite, bavenite, and götzenite. A narrow contact metasomatic aureole is present in some xenoliths. This typically contains vesuvianite, grossular, sodalite, meionite and miserite. Five new mineral species have been discovered in the marble xenoliths: carletonite, poudretteite, sheldrickite, haineaultite and johnsenite-(Ce). Of these, only carletonite is relatively common. With its often intense blue colour, it is also the most spectacular mineral found exclusively in the marble xenoliths.

Late-stage alteration has resulted in unique mineral assemblages in some marble xenoliths, and may obscure their true nature. The new mineral haineaultite (type 1) was found in such an environment (McDonald & Chao 2004). In the second type occurrence of haineaultite (type 2), in an altered marble xenolith, the distribution of REE in calcite which forms the bulk of the xenolith was found to differ markedly from that in calcite associated with haineaultite in cavities, suggesting that there were significant geochemical differences in the earlier and later mineralizing fluids (McDonald & Chao 2004). The new mineral sheldrickite was discovered in what appears to be a late-stage hydrothermal infilling in a marble xenolith (Grice *et al.* 1997). The assemblage includes minerals typical of the marble xenoliths such as pectolite, microcline, polyolithionite, arfvedsonite, calcite and fluorite, and a suite of minerals with a paragenesis much closer in affinity to sodalite xenoliths, including shortite, thernardite, thermonatrite and kogarkoite. Vaterite, natron, and trona have also been identified in this assemblage (Horváth. & Horváth-Pfenninger 2000a).

Of unknown origin are rare large xenoliths composed predominantly (up to 90%) of a biotite series mineral. One such xenolith in nepheline syenite yielded the new mineral petarasite (Chao *et al.* 1980).

Hornfels

The enormous block of hornfels exposed in the southeast face of the quarry extends northward in the quarry floor for a distance of about 260 m. Two features can be observed: bedding planes preserved in the hornfels are now tilted almost vertically, and a pegmatite vein cutting across the bedding planes is truncated at the contact with nepheline syenite. The block is composed of metamorphosed, late Ordovician, Utica-

Lorraine Group sediments (Globensky 1985). A hornfels sample from this unit was estimated to contain 40% quartz, 30% cordierite, 15% biotite, 10% muscovite and 5% andesine plagioclase (Van Velthuisen 1990).

In peripheral areas near its contacts with nepheline and sodalite syenites the hornfels block is crisscrossed by mineralized, often open, fissures up to a few centimeters in width where hydrothermal fluids have penetrated the joints and bedding planes. A narrow bleached zone of hornfels borders the fissures. Locally, the hornfels are brecciated. A distinctive assemblage of relatively common minerals predominates in the fissures, including calcite, siderite, dolomite, strontianite, quartz, feldspars, rutile, anatase, fluorite, fluorapatite, the zeolite gmelinite-Na, and the sulphides pyrite, pyrrhotite, sphalerite, molybdenite and chalcopyrite. The sulphides also occur as massive veins. Gypsum is relatively common in the fissures. Occurring sparsely is a large number of rarer species including the beryllium minerals eudidymite, epididymite and beryllonite. The latter occurs exclusively in the hornfels, as does the tourmaline group mineral dravite. Among REE minerals, the hornfels have yielded notably large (up to 1 cm) crystals of cordylite-(Ce). Unlike in the other mineral environments in the quarry, amphiboles and pyroxenes are almost absent.

Small blocks and fragments of hornfels occur in the igneous breccias. Many of these have been completely metasomatized and are distinguished by a greyish green colour. Euhedral crystals of narsarsukite commonly occur embedded in such xenoliths. Some of the xenoliths are cut by veinlets of quartz associated with narsarsukite, lorenzenite and carletonite. The new species kukharenkoite-(Ce), one of four known Ba-REE fluorocarbonates, was found in a hornfels xenolith in igneous breccia (Zaitsev *et al.* 1995).

Cavities in igneous breccia

Localized zones of igneous breccia occur throughout the quarry. The fine-grained matrix in some of the breccias contains irregular cavities with well-crystallized, often rare minerals. The size of the cavities is constrained by the surrounding rock inclusions and seldom exceeds a decimeter. Except for hornfels and marble, discussed under xenoliths, the rock fragments included in the breccia are of little mineralogical interest.

The breccia cavities are usually lined with albite or microcline. Common minerals present include aegirine, calcite, quartz, fluorapatite, fluorapophyllite, harmotome, titanite, richterite and several sulphides. The cavities have yielded a large suite of rare minerals. Leucosphenite is a characteristic species found almost exclusively in the cavities. Other Ti silicates commonly occurring in the cavities include lorenzenite, narsarsukite, and notably, labuntsovite-Mn. REE silicates are represented by allanite-(Ce), ashcroftite-(Y), stillwellite-(Ce) and the extremely rare joaquinite-(Ce) and kainosite-(Y) which are known only from the breccia cavities. Such cavities yielded the type monteregianite-(Y) and manganokukisvumite. REE carbonates are much rarer in occurrence in the breccia cavities than in any other mineral environment in the quarry.

Anatectic granites

Granitic rocks of apparently anatectic origin can be observed along the hornfels collar at the north end of the quarry. In one area at the contact with the hornfels, nepheline syenite grades into an approximately 2-m thick zone of granitic rock composed

of fine-grained microcline and quartz with almandine and hercynite. A dike of similar rock has been observed cutting the hornfels. It is composed of coarse-grained microcline, quartz and a biotite mica, with euhedral crystals of almandine-spessartine, corundum and hercynite.

Rock-forming minerals

Several rock-forming minerals are found as macroscopic specimens of mineralogical interest. Kaersutite, anorthoclase and andesine feldspar all occur as large, up to 5 cm, phenocrysts (or xenocrysts) in porphyritic nepheline syenite. The andesine (WDS microprobe analysis) occurs as polysynthetically twinned, translucent, greasy, dark grayish green individuals to about 3 cm in nepheline syenite. They display colour banding under short-wave u.v. light, suggesting some compositional zoning. Translucent, polysynthetically twinned glassy plagioclase phenocrysts (or xenocrysts) of very pale greenish gray colour and measuring about 5 cm in length were also observed. The latter have intermediate composition between oligoclase and andesine. Locally, the sodalite syenite consists largely of euhedral to subhedral crystals of sodalite whose dodecahedral form is evident as hexagonal sections in fractured surfaces.

MINERALS

To date, about 365 mineral species have been found in the quarry. They are listed by chemical group in Table 2. The minerals first described from Mont Saint-Hilaire, currently numbering 50, are listed in Table 3. About 45 other minerals have been partially characterized. Many of these, designated with UK (“unknown”) numbers, are potentially new species. The number of minerals containing Ti, Zr, Nb and Be as major constituents is notable. Remarkably, of the 200 or so recognized REE minerals, about 60 occur at Mont Saint-Hilaire.

For descriptions of the minerals found at Mont Saint-Hilaire, the reader is referred to the extensive literature. Comprehensive overviews can be found in Mandarino & Anderson (1989), Horváth & Gault (1990), and Horváth & Horváth-Pfenninger (2000a, b, c). Mandarino & Anderson (1989) include physical, optical and crystallographic data, and a compilation of chemical analyses, most of which have not been published elsewhere.

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Table 1. Unstable and water-soluble minerals found in the sodalite xenoliths.

Mineral	Chemical Formula
Sulphides	
Rasvumite	KFe_2S_3
Erdite	$NaFeS_2 \cdot 2H_2O$
Halides	
Villiaumite*	NaF
Halite*	NaCl
Carbonates	
Natrite*	Na_2CO_3
Thermonatrite*	$Na_2CO_3 \cdot H_2O$
Natron*	$Na_2CO_3 \cdot 10H_2O$
Trona*	$Na_2H(CO_3)_2 \cdot 2H_2O$
Shortite*	$Na_2Ca_2(CO_3)_3$
Rouvilleite	$Na_2Ca(Mn,Ca)(CO_3)_3F$
Sidorenkite	$Na_3Mn(CO_3)(PO_4)$
Sulphates	
Kogarkoite*	Na_3FSO_4
Phosphates	
Natrophosphate*	$Na_7(PO_4)_2F \cdot 19H_2O$
Phosinaite-(Ce)	$Na_3(Ca,Ce)SiPO_7$
Nahpoite*	Na_2HPO_4
Dorfmanite*	$Na_2HPO_4 \cdot 2H_2O$
Silicates	
Natrosilite*	$Na_2Si_2O_5$
Revdite*	$Na_2Si_2O_5 \cdot 5H_2O$
Vuonnemite	$Na_{11}TiNb_2P_2Si_4O_{25}F$
Parakeldyshite	$Na_2ZrSi_2O_7$
Silinaite	$NaLiSi_2O_5 \cdot 2H_2O$

*Minerals soluble in water

Table 2. Mont Saint-Hilaire minerals by chemical groups.

List compiled by László Horváth, 2006-01-14. Species for which MSH is the type locality are underlined.

<i>Elements</i>	<i>Carbonates</i>	<i>Sulfates</i>	<i>Silicates</i>	<i>Silicates</i>	<i>Silicates</i>
ANTIMONY	<u>ADAMSITE-(Y)</u>	ANGLESITE	CLINOPTILOLITE-K	MALINKOITE	TREMOLITE
BISMUTH	ANCYLITE-(Ce)	BARITE	CORDIERITE	MANGAN-NEPTUNITE	TSEPINITE-Na
GRAPHITE	ANKERITE	BEUDANTITE	DATOLITE	<u>MANGANOKHOMYAKOVITE</u>	TUGTUHITE
LEAD	ARAGONITE	BROCHANTITE	DIOPSIDE	<u>MANGANOKUKISVUMITE</u>	TUMCHAITE
SULFUR	BASTNÁSITE-(Ce)	CELESTINE	DRAVITE	<u>MARTINITE</u>	TUNDRITE-(Ce)
	BONSHEDTITE	GYPSUM	EDENITE	MAZZITE-Na	TUPERSSUATSIAITE
	<i>Sulfides</i>	HALOTRICHITE	EDINGTONITE	MEIONITE	USSINGITE
ACANTHITE	BRADLEYITE	JAROSITE	EKANITE	MICROCLINE	VERMICULITE
ALABANDITE	BURBANKITE	KOGARKOITE	ELPIDITE	MILARITE	VESUVIANITE
ARSENOPYRITE	CALCIO-ANCYLITE-(Ce)	LANGITE	ENSTATITE	MISERITE	VINOGRADOVITE
CHALCOPYRITE	<u>CALCIOBURBANKITE</u>	MELANTERITE	EPIDIDYMITE	<u>MONTEREGIANITE-(Y)</u>	VUONNEMITE
DIGENITE	CALCITE	MOHRITE	EPIDOTE	MONTMORILLONITE	WADEITE
DJURLEITE	CARBOCERNAITE	POSNJAKITE	EPISTOLITE	MOSANDRITE	WILLEMITE
ERDITE	<u>CARESITE 3T</u>	ROZENITE	EUDIALYTE	MUSCOVITE	WÖHLERITE
GALENA	CERUSSITE	SCHAIERITE	EUUDIDYMITE	NARSARSUKITE	WOLLASTONITE
GERSDORFFITE	CHALCONATRONITE	SHIGAITE	FAUJASITE-Na	<u>NATROLEMOYNITE</u>	YOFORTIERITE
GREIGITE	CORDYLITE-(Ce)	SZOMOLNOKITE	FERROCELADONITE	NATROLITE	ZAKHAROVITE
LÖLLINGITE	DAQINGSHANITE-(Ce)	THENARDITE	FERRO-ECKERMANNITE	NATROSILITE	ZEOPHYLLITE
MARCASITE	DAWSONITE		<u>FERROKENTBROOKSITE</u>	NENADKEVICHITE	ZIRCON
MILLERITE	DOLOMITE	<i>Phosphates & arsenates</i>	FERRONYBOÏTE	NEOTOCITE	ZIRCOPHYLLITE
MOLYBDENITE-2H & 3R	<u>DONNAYITE-(Y)</u>	BROCKITE	FLUORAPOPHYLLITE	NEPHELINE	ZIRSLITE-(Ce)
NICKELINE	EWALDITE	CARBONATE-FLUORAPATITE	<u>FLUORBRITHOLITE-(Ce)</u>	NEPTUNITE	
PYRITE	*HORVÁTHITE-(Y)	DORFMANITE	FLUORO-MAGNESIO-ARFVEDSONITE	<u>NIPOKUPLETSKITE</u>	
PYRRHOTITE	HYDROCERUSSITE	ERYTHRITE	<u>GAIDONNAYITE</u>	NONTRONITE	
RASVUMITE	HYDROZINCITE	FLUORAPATITE	GANOPHYLLITE	NORDITE-(Ce)	
SPHALERITE	<u>KUKHARENKOITE-(Ce)</u>	MIMETITE	GARRONITE	<u>NORMANDITE</u>	
TENNANTITE	KUTNOHORITE	MONAZITE-(Ce)	<u>GAULTITE</u>	OLIGOCLASE	
TETRAHEDRITE	LANTHANITE-(Ce)	NAHPOITE	GENTHELVITE	<u>ONEILLITE</u>	
THALCUSITE	<u>LUKECHANGITE-(Ce)</u>	NALPOITE	GISMONDINE	ORTHOJOAQUINITE-(Ce)	
WURTZITE-2H, 4H & 8H	MAGNESITE	NATROPHOSPHATE	GMEILINITE-Na	PARAKELDYSHITE	
	MANGANOTYCHITE	RHABDOPHANE-(Ce)	GOBBINSITE	<u>PARANATROLITE</u>	
	MICHELVEYITE-(Y)	RHABDOPHANE-(La)	GONNARDITE	PARAUMBITE	
	<u>MICHELSENITE</u>	STRUVITE	GÖTZENITE	PECTOLITE	
	NATRITE	VITUSITE	GROSSULAR	PENKVIKSITE	
ANATASE	NATRON	WAGNERITE	<u>HAINAULTITE</u>	<u>PERRAULTITE</u>	
BEHOITE	PARISITE-(Ce)-18T & 72 T	XENOTIME-(Y)	HALOTRICHITE	PHILOPOTITE	
BIRNESSITE	<u>PETERSENITE-(Ce)</u>		HARMOTOME	PHILLIPSITE-K	
BROCKITE	PIRSSONITE		HEDENBERGITE	PHILLIPSITE-Na	
CHLORMAGALUMINITE	<u>QUINTINITE-3T</u>	<i>Silicates</i>	HELVITE	PHLOGOPITE	
CORUNDUM	<u>REEDERITE-(Y)</u>	<u>ABENAKIITE-(Ce)</u>	HEMMORPHITE	PHOSINAITE-(Ce)	
CRYPTOMELANE	REMONDITE-(Ce)	ACTINOLITE	HIBSCHITE	POLYLITHIONITE	
DOYLEITE	REMONDITE-(La)	AEGIRINE	<u>HILAIRITE</u>	<u>POUDRETTEITE</u>	
FERROCOLUMBITE	RHODOCHROSITE	ALBITE	HINGGANITE-(Ce)	PREHNITE	
FRANCONITE	RÖNTGENITE-(Ce)	ALLANITE-(Ce)	HINGGANITE-(Y)	RAITE	
GIBBSITE	<u>ROUVILLEITE</u>	ALMANDINE	HIORTDAHLITE	REVDITE	
GOETHITE	SABINAITE	ANALCIME	HISINGERITE	RICHTERITE	
HEMATITE	<u>SHELDRIKITE</u>	ANDESINE	HYDROXYAPOPHYLLITE	RIEBECKITE	
HERCYNITE	SHOMIOKITE-(Y)	ANDRADITE	JOAQUINITE-(Ce)	ROSENBUSCHITE	
<u>HOCHLAGAITE</u>	SHORTITE	ANNITE	KAERSUTITE	SANIDINE	
ILMENITE	SIDERITE	ANORTHOCLEASE	KAINOSITE-(Y)	SAZHINITE-(Ce)	
ILMENORUTILE	SIDORENKITE	ARFVEDSONITE	KAOLINITE	SAZHINITE-(La)	
LEPIDOCROCITE	SMITHSONITE	ASHCROFTINE-(Y)	KELLYITE	SAZYKINAITE-(Y)	
LOPARITE-(Ce)	STRONTIANITE	ASTROPHYLLITE	KENTBROOKSITE	SCHORL	
LUESHITE	SYNCHYSITE-(Ce)-12T & 24 T	AUGITE	<u>KHOMYAKOVITE</u>	SEARLESITE	
MAGNETITE	THERMONATRITE	BAILEYCHLORE	KOROBITSYNITE	SEPIOLITE	
MANGANOCOLUMBITE	<u>THOMASCLARKITE-(Y)</u>	BARYLITE	KUPLETSKITE	SERANDITE	
NORDSTRANDITE	THORBASTNÁSITE	BARYTOLAMPROPHYLLITE	LABUNTSOVITE-Mn	SIDEROPHYLLITE	
OPAL	TRONA	BAVENITE	<u>LALONDEITE</u>	<u>SILINAITE</u>	
PYROCHLORE	VATERITE	BERTHIERINE	LAMPROPHYLLITE	SMECTITE grp.	
PYROPHANITE	WELOGANITE	BERYL	LÄVENITE	SODALITE	
QUARTZ		BERYLLOINITE	LEIFITE	SPESSARTINE	
RANCIËITE	<i>Molybdates</i>	<u>BOBTRAILLITE</u>	<u>LEMOYNITE</u>	STEACYITE	
RUTILE	WULFENITE	BRITHOLITE-(Ce)	LEUCOPHANITE	STEENSTRUPINE-(Ce)	
SENAITE		CALCIOHILAIRITE	LEUCOSPHEINITE	STILLWELLITE-(Ce)	
SPERTINIITE	<i>Tungstates</i>	CANCRINITE	LINTISITE	SUGILITE	
TODOROKITE	SCHEELITE	<u>CARLETONITE</u>	LORENZENITE	TAINIOLITE	
		CATAPLEIITE	LOVOZERITE	TERSKITE	
<i>Halides</i>		CERITE-(Ce)	MAGADIITE	THAUMASITE	
CRYOLITE	<i>Tellurides</i>	CHABAZITE-Ca	MAGNESIO-ARFVEDSONITE	THOMSONITE-Ca	
FLUORITE	HESSITE	CHABAZITE-Na	MAGNESIOHORNBLÉNDE	<u>THORNASITE</u>	
<u>GRICEITE</u>		CHAMOSITE	MAKATITE	THOROGUMMITE	
HALITE		CHKALOVITE		TITANITE	
NEIGHBORITE		CLINOCHLORE			
VILLIAUMITE					

Table 3. New mineral species discovered in the Poudrette quarry.

Lemoynite	Perrault <i>et al.</i> (1969)
Carletonite	Chao (1971)
Hilairite	Chao <i>et al.</i> (1974)
Gaidonnayite	Chao & Watkinson (1974)
Yofortiérite	Perrault <i>et al.</i> (1975)
Donnayite-(Y)	Chao <i>et al.</i> (1978)
Monteregianite-(Y)	Chao (1978)
Paranatrolite	Chao (1980)
Petarasite	Chao <i>et al.</i> (1980)
Steacyite	Perrault & Szymanski (1982)
Doyleite*	Chao <i>et al.</i> (1985)
Hochelagaite*	Jambor <i>et al.</i> (1986)
Thornasite	Ansell & Chao (1987)
Poudretteite	Grice <i>et al.</i> (1987)
Griceite	Van Velthuizen & Chao (1989)
Rouvilleite	McDonald <i>et al.</i> (1991)
Perraultite	Chao (1991)
Silinaite	Chao <i>et al.</i> (1991)
Nalipoite	Chao & Ercit (1991)
Fluorbritholite-(Ce)	Gu <i>et al.</i> (1994)
Petersenite-(Ce)	Grice <i>et al.</i> (1994)
Abenakiite-(Ce)	McDonald & Chao (1994)
Gaultite	Ercit & Van Velthuizen (1994)
Reederite-(Y)	Grice <i>et al.</i> (1995)
Calcioburbankite	Van Velthuizen <i>et al.</i> (1995)
Kukarenkoite-(Ce)**	Zaitsev <i>et al.</i> (1996)
Sheldrickite	Grice <i>et al.</i> (1997)
Horváthite-(Y)	Grice & Chao (1997a)
Normandite	Chao & Gault (1997a)
Lukechangite-(Ce)	Grice & Chao (1997b)
Caresite-3T	Chao & Gault (1997b)
Charmarite	Chao & Gault (1997b)
Quintinite-3T	Chao & Gault (1997b)
Thomasclarkite-(Y)	Grice & Gault (1998)
Khomyakovite	Johnsen <i>et al.</i> (1999)
Manganokhomyakovite	Johnsen <i>et al.</i> (1999)
Oneillite	Johnsen <i>et al.</i> (1999)
Niobokupletskite	Piilonen <i>et al.</i> (2000)

Table 3. Continued.

Adamsite-(Y)	Grice <i>et al.</i> (2000)
Micheelsenite***	McDonald <i>et al.</i> (2001)
Natroleymoynite	McDonald & Chao (2001)
Ferrokentbrooksit	Johnsen <i>et al.</i> (2003)
Haineaultite	McDonald & Chao (2004)
Manganokukisvumite	Gault <i>et al.</i> (2004)
Bobtraillite	McDonald & Chao (2005)
Johnsenite-(Ce)	In press (2006)
Lalondeite (UK57)	IMA CNMMN approved 2002-026
Martinite (UK92)	IMA CNMMN approved 2001-59
UK19-1	IMA CNMMN approved 2005-030
UK99	IMA CNMMN approved 2003-19

* Co-type locality with Francon quarry, Montréal

** Co-type locality with Khibiny and Vuorijärvi massifs, Kola Peninsula, Russia

*** Co-type locality with Nanna pegmatite, Narsaarsuup Qaava, South Greenland

**Annex I. Geology of the Poudrette quarry, Mont Saint-Hilaire .
Géologie de la carrière Poudrette, Mont Saint-Hilaire.**

