



THE ORFORD NICKEL MINE

QUÉBEC, CANADA

Peter Tarasoff

91 Lakeshore Road
Beaconsfield, Québec H9W 4H8
Canada

Robert A. Gault

Research Division
Canadian Museum of Nature
Ottawa, Ontario K1P 6P4
Canada

The Orford nickel mine has been a popular collecting site for chromian grossular, terminated millerite and large diopside crystals for well over a century. Specimens from this classic locality are found in many of the world's great collections. The deposit inspired the first attempt at mining and smelting nickel in Canada, and gave birth to one of the world's largest nickel companies.

LOCATION

The Orford nickel mine is situated in Lot 7,¹ Range XII, Orford Township (lot 7, rang XII, canton d'Orford), southeastern Québec, Canada (latitude: 45°25'00"; longitude: 72°07'20"; National Topographic System, Map 31 H/8, Mont Orford). It is about 800 meters east of Nickel Mine Bay (Baie Nickel Mine) on Brompton Lake (Lac Brompton), in the Municipality of the Parish of Saint-Denis-de-Brompton (Municipalité de paroisse de Saint-Denis-de-Brompton). The village of Saint-Denis-de-Brompton is 5.6 km northeast of the Orford nickel mine.

¹St-Julien (1961) has pointed out that the mine is in Lot 7 and not Lot 6 as reported in all previous references.

Mineral specimens from the mine are often labeled as coming from Orford or Magog, Québec; these locality designations should be avoided. Orford is the modern, unofficial name of a village called Cherry River, which is located 12 km south-southwest of the mine. The town of Magog is 16 km to the south of the mine.

The mine can be reached from the junction (underpass) of Autoroute 10 and Highway 249 by proceeding 15.3 km north on Highway 249 towards Saint-Denis-de-Brompton, turning left (west) onto Chemin Bouffard, and following this road for 5.4 km to the end of the pavement. A gravel road bearing left around a pond for 500 meters leads to a house. The mine is located at the base of a rocky escarpment in a wooded area approximately 250 meters south of the house.

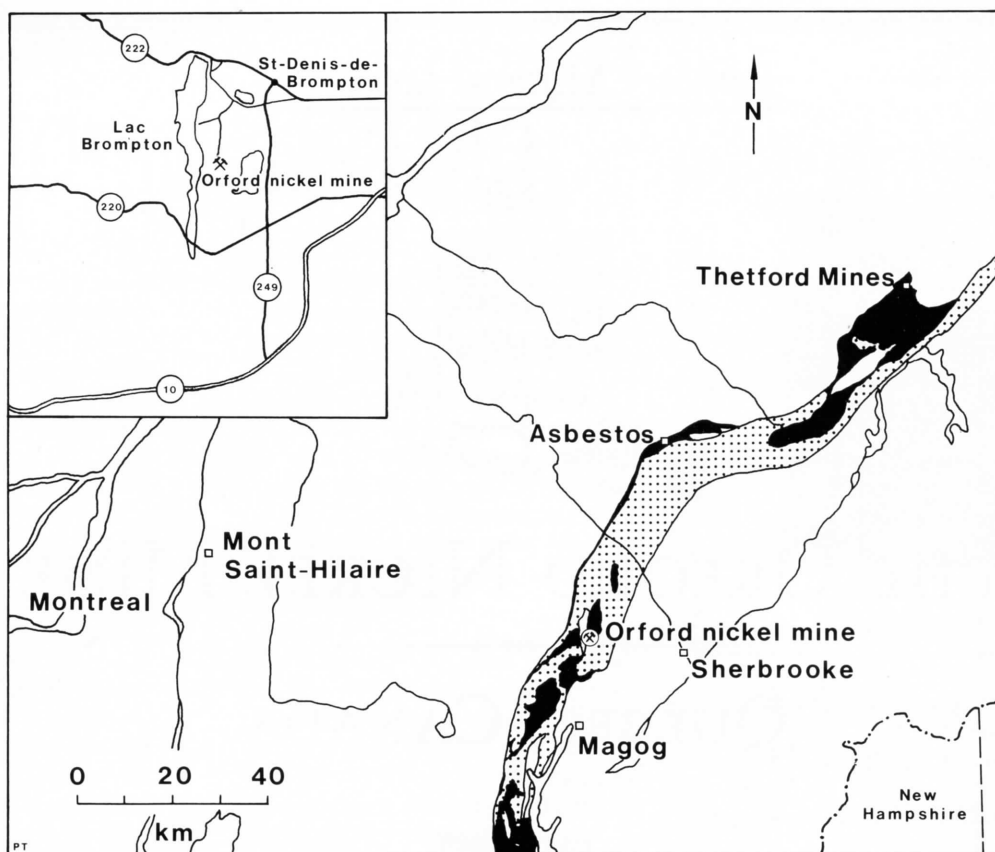


Figure 1. Location map, showing ophiolitic ultramafic complexes (black) in the Saint-Daniel Mélange (stippled). Geology after Williams and St-Julien (1982).

HISTORY

Mining and Smelting

The discovery of the Orford nickel deposit is not documented, but it seems likely that it was the result of prospecting for copper. Copper had been found in the Eastern Townships of Québec as early as 1841, and by the 1860's a major copper mining industry had developed, spurred by the demand for copper created by the American Civil War. In reporting on the Orford deposit in 1863, T. Sterry Hunt noted that "explorations were made at this place a year or two since, in the hope of obtaining copper, which was supposed to be indicated by the brilliant green of the garnet" (Hunt, 1863b). Hunt was the first to recognize the presence of the nickel sulfide, millerite at Orford (Chapman, 1888). A protégé of Professor Benjamin Silliman at Yale University, Hunt had been appointed chemist and mineralogist to the newly established Geological Survey of Canada in 1847, and has been called one of the great geochemists and mineralogists of all time (Boyle, 1971).

The Orford property came to be owned by Robert G. Leckie of Acton Vale, Québec. A graduate of the Glasgow Technical College in Scotland, Leckie became interested in mining soon after immigrating to Canada in 1856. In 1877, while attending a meeting of the American Institute of Mining Engineers in Boston, he met William E. C. Eustis, a Boston-based mining and metallurgical engineer. On hearing about the Orford property, Eustis decided to have a look at it. Accompanied by Robert M. Thompson, his Boston lawyer, he visited "the mine holed into the side of a hill" in September 1877 and, apparently impressed with what he saw, decided to purchase it (Thompson and Beasley, 1960).

Eustis then invited a Professor Whitby from Yale University to examine the deposit. "On the way to the mine, the professor was



Figure 2. T. Sterry Hunt (1826–1892), chemist and mineralogist to the Geological Survey of Canada. Hunt recognized the presence of nickel in the Orford deposit, and carried out the first mineralogical work. Geological Survey of Canada photo (GSC 69324).

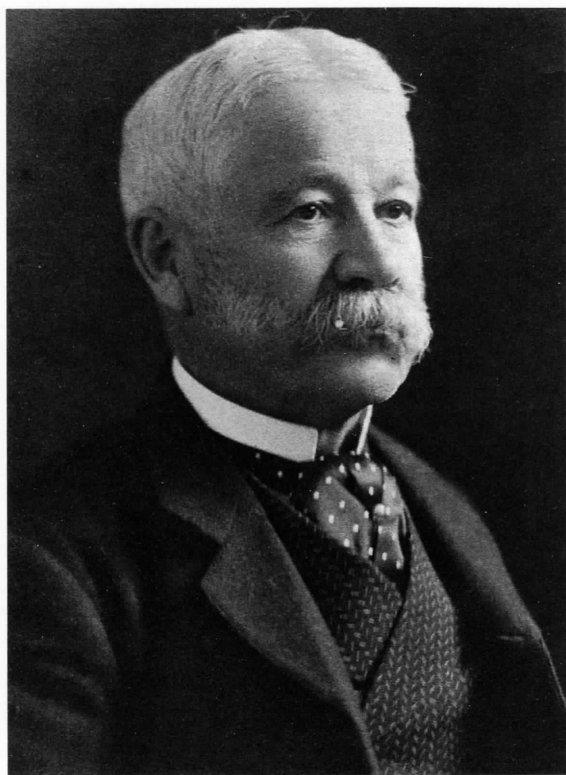


Figure 3. Robert G. Leckie (1833–1913), mining engineer. Leckie sold the Orford nickel property to W. E. C. Eustis, and became the mine manager. National Archives of Canada photo (C140333).

thrown from his buggy. With ruffled feelings, he completed the journey, made a cursory inspection, testily gave his decision: 'scratch the ground again, and then send for me'; and left" (Thompson and Beasley, 1960).

Undeterred, Eustis proceeded to develop the mine, retaining Leckie as the mine manager. By November of 1877, 20 men were at work at the mine (Harrington, 1878). Two shafts were started about 55 meters apart, and by February 1878, the No. 1 shaft had been sunk to a depth of 12.5 meters, and the No. 2 shaft to a depth of 14 meters (Eustis, 1878; Eustis, 1879a).

With mining underway, Eustis turned his attention to the smelting of the ore. At a meeting of the American Institute of Mining Engineers in Philadelphia in February 1878, Eustis (1879a) reported that, contrary to his original "grave doubts about the practicability of treating the ore," he had obtained satisfactory results, first in crucible tests, and then in a small blast furnace at the Massachusetts Institute of Technology.

On March 9, 1878, the Orford Nickel and Copper Company was incorporated in the Province of Québec with a capitalization of \$300,000. The articles of incorporation authorized the company to mine, manufacture and sell nickel, phosphate, copper and other minerals. The principal shareholders in the new company, which had its head office in Boston, were Eustis, who became president, and Thompson, who became general manager. Leckie, who also became a shareholder, was named managing director of the Orford mine.

The Orford property soon boasted "numerous substantial houses . . . a commodious store, powder-house . . . etc." (Willimot, 1882). Two furnaces were built to smelt the ore; one was a reverberatory furnace fired with gas generated from wood; the second was a small cupola operated with coke (Eustis, 1915).

Underground, the first shaft had reached a depth of approximately 30 meters, and a drift was driven to join up with the second shaft

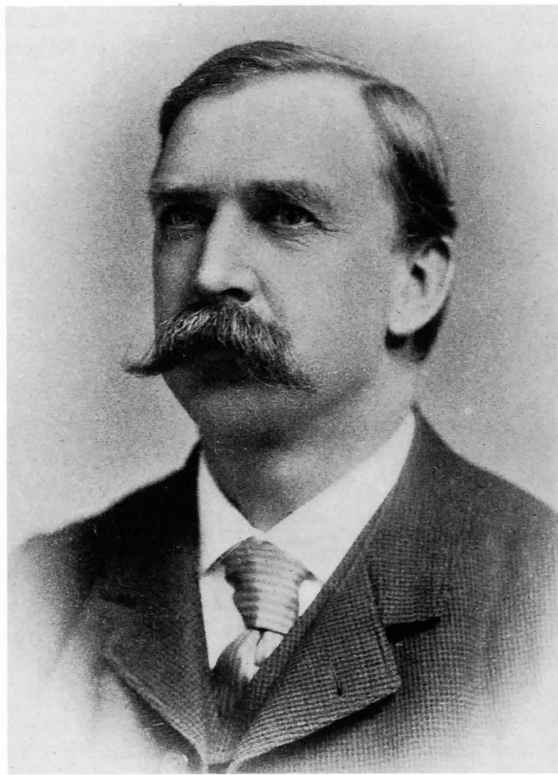


Figure 4. William E. C. Eustis (1849–1932), mining and metallurgical engineer, and president of the Orford Nickel and Copper Company. Eustis purchased the Orford nickel property in 1877 and developed the mine. Harvard University Archives photo.

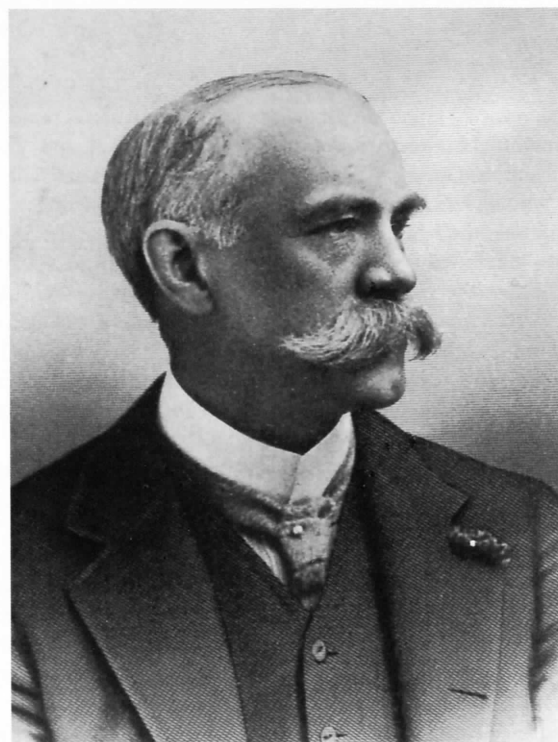


Figure 5. Robert M. Thompson (1849–1930), general manager of the Orford Nickel and Copper Company. Thompson became the first chairman of the International Nickel Company in 1902. Photo courtesy of Inco Limited.

which ultimately had a depth of some 45 meters. Ore was stoped out between the two shafts in order to provide feed for the smelting furnaces (Eustis, 1915).

To run the furnaces, Eustis obtained the services of a Scottish furnace man, James McArthur, who had been trained by Sir Henry Bessemer. Smelting the ore proved to be much more difficult than Eustis's tests had indicated. The story is told that "all that came out [of the furnace] was a pasty mass of slag, but no metal" and that "disgusted over the results, McArthur quit" (Thompson and Beasley, 1960).

Nevertheless, as attested to by the many tonnes of slag still to be found at the mine site, efforts to smelt the ore continued. Technical advice was provided by Henry M. Howe, who was later to become professor of metallurgy at Columbia University, and one of the most eminent American metallurgists of his time. Some success in smelting the nickel ore was achieved by adding pyritic copper ore as a flux (Howe, 1878). However, the resulting matte contained far more copper than nickel, and the large flux addition required was uneconomic.

In his Philadelphia paper, Eustis (1879a) had reported: "As to the per cent of nickel which [the] ore carries, and which will determine its money value, it is not easy at present [in February 1878] to speak with any certainty . . . [but] at the bottom of No. 1 shaft, pieces of ore taken to be average ones . . . show between three and four per cent nickel." This was optimistic. Hunt (1863b) had found that nickel was "sparingly disseminated" in the ore and "masses submitted to analysis did not yield more than one per cent of nickel," while the ore smelted in the test at the Massachusetts Institute of Technology had contained "not over one half of one per cent of nickel" (Eustis, 1879a). In the end, "the ore was found on the average low grade, and the gangue too refractory to make operations remunerative" (Leckie, 1900). After having invested a considerable sum of money, Eustis decided to suspend operations. Mining at Orford ceased in the spring of 1879.

When Charles W. Willmot of the Geological Survey of Canada visited the mine in August 1882, it was deserted except for a caretaker (Willmot, 1882). Willmot noted rather sardonically that "the general aspect on approaching the mine conveys some idea of the misdirected enterprise of the proprietors."

In the interim, Eustis and Thompson had leased a copper mine near Capelton, some 22 km to the southeast of the Orford nickel mine. This new venture, the Crown mine of the Orford Nickel and Copper Company, proved to be successful. In 1881 a smelter (later called the Orford Works) was built at Constable Hook (now Bayonne), New Jersey, to treat the pyritic copper ore from the Crown mine. Sulfuric acid was produced as a by-product and, in 1883, the Orford Nickel and Copper Company was renamed the Orford Copper and Sulphur Company. Four years later, in 1887, Eustis and Thompson ended their partnership, and the company was dissolved. Eustis retained the Crown mine in Quebec and formed a new company called Eustis Mining Company. Thompson took over the Orford Works, which he operated under the new name, the Orford Copper Company.

A year earlier, in 1886, the Canadian Copper Company had shipped some copper ore to the Orford Works from its major new discovery at Sudbury, Ontario. It was then discovered that the Sudbury ore also contained nickel. This eventually led to the development, at Constable Hook, of the Orford process for separating copper from nickel, and a contract for the Orford Works to refine the copper-nickel matte production of the Canadian Copper Company. In 1902, the Orford Copper Company merged with the Canadian Copper Company to form the International Nickel Company, with Thompson as the first chairman. Known today as Inco Limited, it is the Western world's largest producer of nickel. It can trace its beginnings to an unsuccessful nickel mine in Orford Township, Québec.

In a final chapter, some geophysical and diamond drill exploration was carried out on the Orford nickel property in the 1950's and 1960's. Nothing of economic significance was found.

Mineral Collecting

Although short-lived as a mining venture, the Orford nickel mine has a long history as a mineral locality. In 1862, even before mining began, a specimen of millerite was exhibited at the London International Exhibition as part of a collection of Canadian economic minerals gathered by the Geological Survey of Canada. The catalog accompanying the collection noted that the millerite was associated with "emerald-green . . . chrome garnet [grossular]" (Geological Survey of Canada, 1862). The green grossular attracted the attention of mineral collectors and museum curators. The earliest known specimens are in the Natural History Museum, London, and were presented by T. Sterry Hunt in 1862. Another specimen donated by Hunt in 1866 is in the Peabody Museum of Natural History collection at Yale University. Also in the Brush collection at Yale is a specimen of grossular which was presented by General Adams in 1867. Adams was at that time operating the copper mine at Capelton, Québec, which was later leased by Eustis and his partners in the Orford Nickel and Copper Company.

In 1878, after mining had begun, mineral specimens from the Orford nickel mine were exhibited at the Universal Exposition in Paris (Harrington, 1878). That same year, Eustis showed samples of millerite and grossular when he presented his paper on the mine to the American Institute of Mining Engineers in Philadelphia (Eustis, 1879a). This brought Eustis requests for specimens, and he obliged. In a letter to an A. Meany in Swansea, Wales, Eustis (1879b) wrote: "I have sent you today . . . a box of nickel specimens . . . I regret that I had none of our most interesting specimens in this office [in Boston]. The ore is regarded as such a curiosity by our mineralogists here that I cannot keep the specimens." One such specimen of grossular, donated by Eustis, is in the Peabody Museum collection at Yale. In Canada, Leckie was also providing specimens from the mine; two are preserved in the Redpath Museum at McGill University.

When Charles Willmot of the Geological Survey of Canada visited the Orford nickel mine in 1882 it was in the capacity of museum assistant. He was responsible for collecting rocks and minerals, and for preparing collections for the Geological Museum, the forerunner of the present Canadian Museum of Nature. A suite of specimens collected by Willmot at the Orford nickel mine and exhibited in the Geological Museum (Hoffmann, 1893) is now preserved in the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, Ottawa. One of the specimens collected by Willmot in 1882 is also in the Harvard Mineralogical Museum collection.

In 1890, R. W. Ells of the Geological Survey of Canada reported that "for the cabinet, magnificent specimens of chrome garnet [grossular], pyroxene [diopside] and calcite are here obtained, of which large quantities have been removed by collectors both from Canada and the United States" (Ells, 1890). Specimens from the mine had found their way into many important private collections in the United States, including those of *Clarence S. Bement* (1843–1923), now at the American Museum of Natural History; *Frederick A. Canfield* (1849–

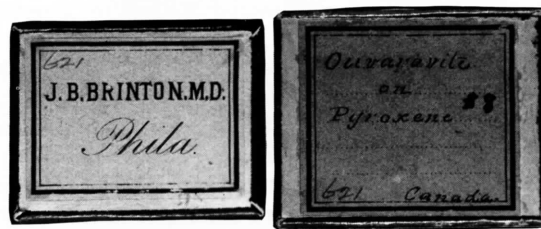


Figure 9. An early Orford micromount prepared by J. B. Brinton, Philadelphia. P. Tarassoff collection and photo.



Figure 7. Orford nickel mine specimen labels. Clockwise from upper left: A. F. Holden collection, Harvard Mineralogical Museum; W. F. Ferrier collection, Redpath Museum, McGill University; J. D. Whitney collection, Harvard; W. F. Ferrier collection, Redpath Museum; G. J. Brush collection, Peabody Museum of Natural History, Yale University; Redpath Museum collection—specimen donated by R. G. Leckie; Redpath Museum collection; J. D. Whitney collection, Harvard; C. S. Bement collection, American Museum of Natural History. Center, top: National Mineral Collection, Geological Survey of Canada. Center, bottom: Peabody Museum of Natural History collection—specimen donated in 1866 by T. Sterry Hunt, with his initials on the label. P. Tarassoff photo.

1926) and Washington A. Roebling (1837–1926), both at the National Museum of Natural History, Smithsonian Institution; and A. F. Holden (1866–1913), now at Harvard. The suite of Orford specimens in the Bement Collection was supplied in 1885 by a dealer named Townsend. Other mineral dealers who handled Orford specimens were A. E. Foote & Company, and Lazard Cahn (1865–1940). The collection of Josiah D. Whitney (1819–1896) at Harvard was the source of the Orford specimens used by Charles Palache and H. O. Wood in their classic crystallographic study of millerite (Palache and Wood, 1904).

Significant suites of Orford specimens are also in the Ferrier collections, now preserved in the Royal Ontario Museum and the Redpath Museum. These were acquired from Walter F. Ferrier (1865–1950), a geologist who assembled what was probably the most important private collection in Canada in the years up to 1913 (Stevenson, 1972). Ferrier corresponded with many contemporary mineralogists and mineral collectors, among whom were Palache and Roebling, and supplied them with specimens, mainly from Canadian localities. He was an active field collector, and it seems likely that he personally collected the “Ferrier” Orford specimens that now reside in a number of collections.

Orford specimens also appeared in important private collections in Europe, including those of Carl Bosch (1874–1940) in Germany, which is now at the Smithsonian, and Charles Trechmann (1851–1917) in England, which is now in the Natural History Museum, London. A specimen of grossular from the Trechmann collection and

now in the Royal Ontario Museum was acquired by him from the London mineral dealer Thomas D. Russell in 1888.

In 1893, an Orford specimen was again exhibited at an international exposition. This time it was part of the Smithsonian’s exhibit at the World Columbian Exposition held in Chicago. The specimen of grossular had been purchased from the Washington, D.C. mineral dealer Edwin E. Howell that same year.

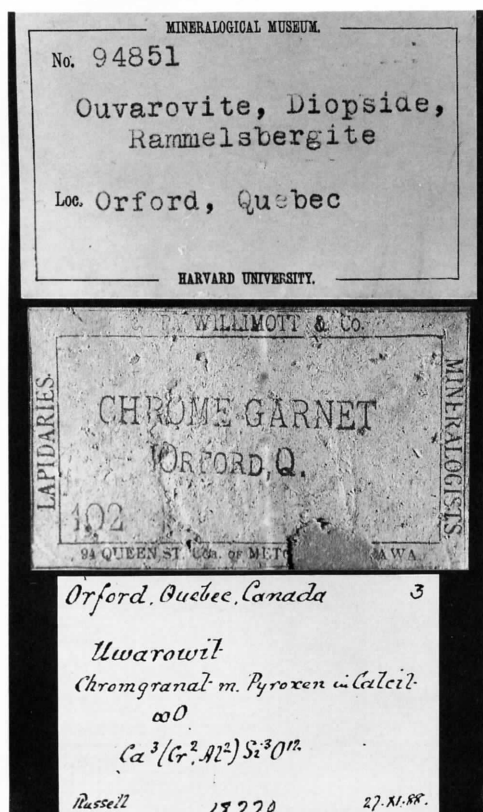


Figure 8. Orford nickel mine specimen labels. Top: Harvard Mineralogical Museum collection—the rammelsbergite was later shown to be maucherite. Center: Miller Museum collection, Queen's University—label of 19th century Ottawa dealer, C. P. Willimott. Bottom: Royal Ontario Museum collection, ex-Trechmann collection, the Natural History Museum, London. P. Tarassoff photos.

Some fifty years later, Dresser and Denis (1949) remarked that “the dump at the Orford nickel mine has long been a place of interest for mineralogists on account of the excellent specimens of the relatively rare mineral millerite, and also of uvarovite [grossular] and diopside, that may be collected there.” Today, more than a century after mining ceased, the locality continues to be an active mineral collecting site, still producing specimens which are often superior to those in old collections.

GEOLOGY

Regional Geology

The Orford nickel deposit is associated with the same belt of northeasterly trending serpentinized ultramafic rocks which hosts the Ruberoid asbestos mine at Eden Mills, Vermont; the Jeffrey mine at Asbestos, Québec (Grice and Williams, 1979); and the asbestos mines at Black Lake and Thetford Mines, Québec. The belt also hosts many chromite and base-metal sulfide deposits which have been mined at various times.

The ultramafic rocks are part of the Saint-Daniel Mélange, one of three lithologic units which make up the Dunnage terrane in the southern Québec Appalachians (Tremblay and St-Julien, 1990; Cousineau and St-Julien, 1992). The Baie Verte-Brompton Line which forms the western boundary of Saint-Daniel Mélange marks the suture

between rocks of North American continental affinity, and rocks of oceanic affinity which belong to the Dunnage terrane. The Saint-Daniel Mélange is an ophiolitic complex consisting of blocks and slices of sandstones, mafic and felsic volcanic rocks, granitoids and mafic to ultramafic rocks which are enclosed in a pebbly mudstone matrix; the ultramafic rocks consist of serpentinized harzburgite, dunite and peridotite (Slivitzky and St-Julien, 1987). All the rocks have been subjected to deformation and metamorphism. The Saint-Daniel Mélange is interpreted to represent vestiges of an oceanic domain of Cambrian age which was accreted at a subduction zone during the closure of the Iapetus (Proto-Atlantic) ocean during the Taconic Orogeny in Middle Ordovician time.

Tectonic deformation during the Acadian Orogeny in Devonian time resulted in major regional folding and faulting (Tremblay and St-Julien, 1990). Folding is complex due to superposition on earlier fold systems. The folds have steeply dipping limbs and steeply plunging axes (St-Julien, 1967).

Local Geology

The rocks in the area of the Orford nickel deposit consist of a complex assemblage of metasediments and metavolcanics which contain slices of serpentinized harzburgite, here referred to as serpentinite (Fortier, 1945; St-Julien, 1961; Slivitzky and St-Julien, 1987). This assemblage within the Saint-Daniel Mélange has been referred to as the Lac Montjoie serpentinite mélange (Williams and St-Julien, 1982). The serpentinite bodies are generally concordant with the beds of metasediments and metavolcanics which form part of a major drag fold that plunges about 50° to the northeast. The serpentinites contain veinlets of chrysotile asbestos and banded disseminations, massive lenses, veins, and pods of chromite (Fortier, 1945; Fortier, 1946).

The Orford Nickel Deposit

The Orford nickel deposit is located at the fault contact between a slice of serpentinite and black slates or phyllites of the pebbly mudstone matrix of the Saint-Daniel Mélange (Gauthier, 1985). Unfortunately, very little information about the geology of the deposit was recorded when it was being mined. The underground workings have long been inaccessible, but remnants of the deposit can be observed in the footwall serpentinite which forms a prominent escarpment.

Logan (1863) reported that “associated with the serpentine is a pale greenish pyroxene rock . . . large masses of calcareous spar [calcite], probably filling a vein, are here met with.” In most of the subsequent literature the deposit has been described as a calcite vein. Recent studies suggest that the deposit was formed by metasomatic replacement, and that the “vein” exploited by the Orford nickel mine was probably a large lense of calcite within a skarn-like calc-silicate zone. Eustis (1879a) noted that “on surface other smaller veins and branches of spar [calcite] and garnet [grossular] are visible.” The calc-silicate zone strikes north and dips about 70° to the west. It has a strike length of over 55 meters, and extends down-dip at least 45 meters. Its full width is unknown, but the “vein” itself was 3 meters wide (Eustis, 1879a).

The footwall serpentinite unit has been progressively carbonatized, grading from an essentially unaltered serpentinized harzburgite some 120 meters from the footwall, to tremolite and talc-tremolite marble on the footwall; carbonatization of the serpentinite is marked by a sharp increase in CaO and a decrease in MgO towards the footwall (Gauthier, 1986b; Trottier, 1985). Irregular patches of calcite in the serpentinite sometimes enclose relict massive chromite and serpentine (Fortier, 1946). In common with other serpentinites in the Saint-Daniel Mélange (Nickel, 1959), this serpentinite contains about 0.2% nickel (Gauthier, 1986b; Trottier, 1985); the concentration of nickel is essentially constant across the carbonatized zone.

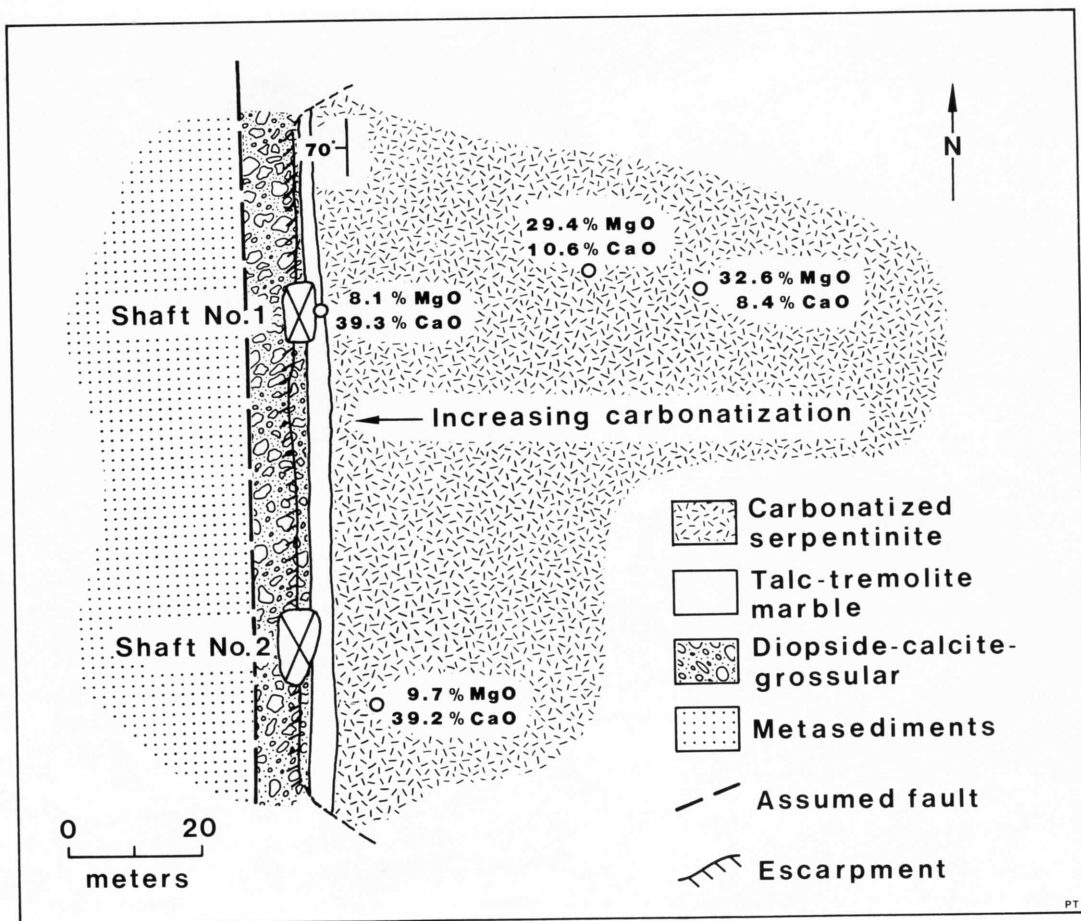


Figure 9. Geology of the Orford nickel deposit (modified after Gauthier, 1986b).

Overlying the deposit on the hanging-wall side are phyllites or slates (St-Julien, 1961) which are identified with the pebbly mudstone matrix of the Saint-Daniel ophiolitic mélange (Slivitzky and St-Julien, 1987). The true nature of the hanging-wall itself, which is not exposed at the surface, is uncertain. It has been variously described as a magnesian limestone (Eustis, 1879a), a silicic tuff or schist (Fortier, 1945; Fortier, 1946) and an acid volcanic rock (St-Julien, 1961).

According to Eustis (1879a), the "No. 2 shaft . . . was started on the vein in decomposed spar [calcite] and pyroxene [diopside], carrying occasionally small masses of chrome-garnet [grossular]," and reached "good solid nickel ore" at a depth of 14 meters. Dump material suggests that the order of abundance of the minerals is diopside > calcite >> grossular >> chromite >> millerite.

Two generations of diopside can be recognized: (1) fine-grained rock-like masses, often intergrown with grossular, and containing calcite-filled cavities lined with crystals of diopside and grossular; (2) coarsely crystallized masses, frequently enclosing angular, granular masses of grossular. Both generations of diopside are often found together, with sharp contacts, in a breccia-like mélange. In addition to filling cavities, calcite occurs as very large, coarsely cleavable masses; in the overall paragenetic sequence it is the last mineral to have been deposited. Chromite occurs as relict masses and grains, and is usually enclosed by grossular. In thin section, chromite inclusions in the grossular show fuzzy and fringed edges suggestive of their having been partially dissolved (Fortier, 1946). Millerite, and the nickel arsenide maucherite, are closely associated with grossular and diopside in calcite-filled cavities; no paragenetic priority is apparent among the minerals in the cavities (Palache and Wood, 1904), suggesting they crystallized at, or about the same time.

Textural features of the mineral assemblages, and the carbonatization

of the footwall serpentinite, are consistent with a hydrothermal origin for the Orford nickel deposit (Fortier, 1946; Gauthier, 1985; Gauthier, 1986a; Gauthier, 1986b; Gauthier *et al.*, 1989). Carbonatization of ultramafic rocks in ophiolitic complexes has been postulated to result from CO_2 -Ca metasomatism by hydrothermal solutions circulating



Figure 10. One of the open shafts at the Orford nickel mine, circa 1964. Photo from Gregory (1967), reproduced with permission of *Rocks and Minerals*.

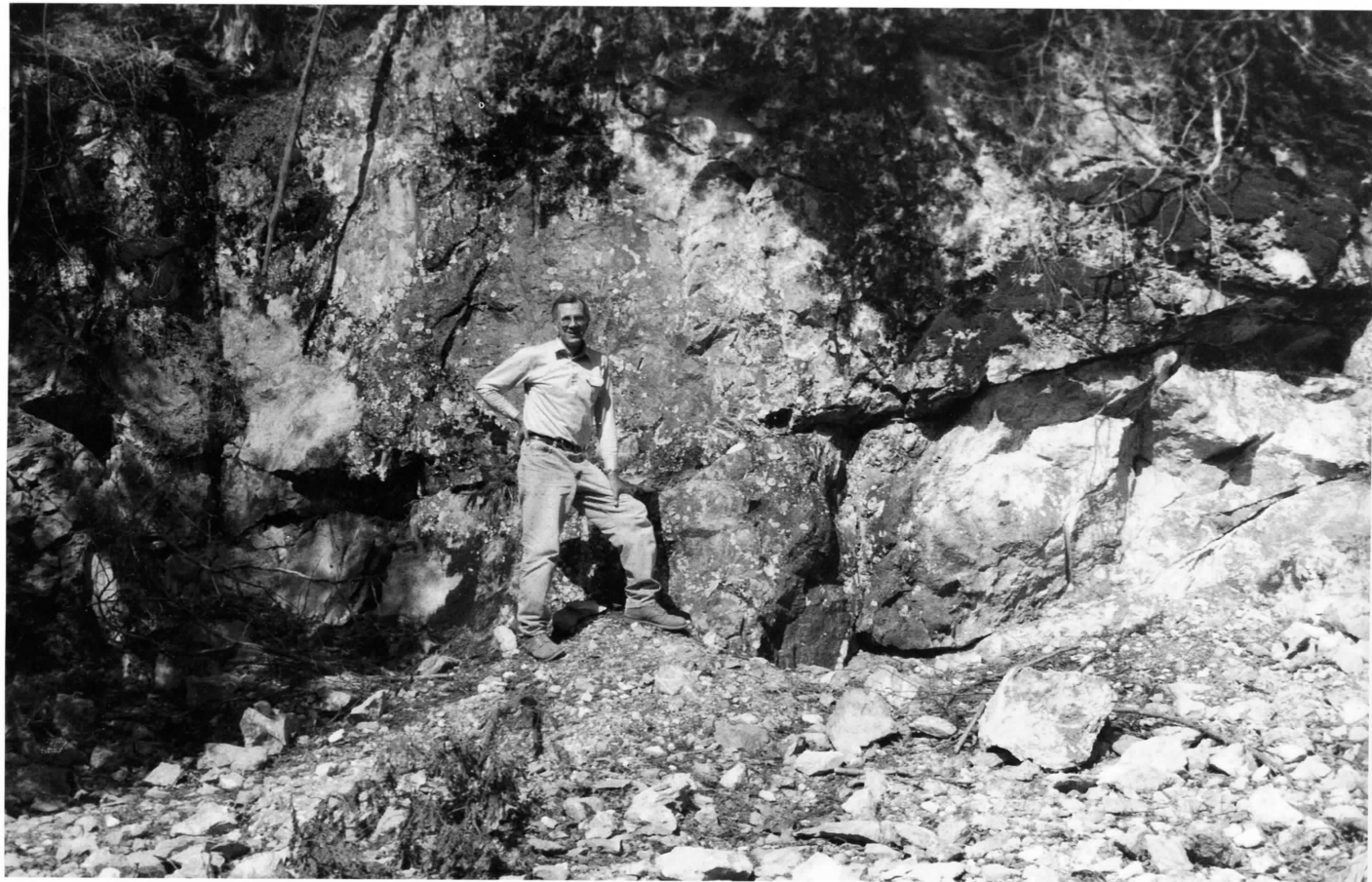


Figure 11. Footwall at the site of the no. 2 (south) shaft in 1992. A. Tarassoff photo.

along deep-seated suture zones during the late stages of their tectonic emplacement and serpentinization (Buisson and Leblanc, 1985). The end-product of this metasomatism is listwaenite, a carbonate-rich rock. As the hydrothermal system evolves, the listwaenite itself may undergo replacement. Several sulfide replacement deposits of this nature have been recognized in the Dunnage terrane of the Québec Appalachians (Gauthier *et al.*, 1989).

A tentative model is herein proposed for the genesis of the Orford nickel deposit. Following carbonatization of the serpentinite by CO_2 -Ca metasomatism and the formation of listwaenite along the fault contact, continued hydrothermal activity, probably coeval with regional metamorphism, resulted in the replacement of the listwaenite by diopside and grossular. Chromite in the listwaenite, probably derived from the protolith serpentinite, provided nucleation sites for some of the grossular. Chromium mobilized by the partial dissolution of chromite was taken up by the grossular. Nickel, already present in the listwaenite and probably derived from the protolith serpentinite, was also mobilized, and with the addition of sulfur, arsenic and possibly more nickel, was reprecipitated as millerite and maucherite. The fine-grained diopside-grossular assemblage was subsequently brecciated by fault movement. Hydrothermal solutions then invaded the fractured zone, depositing diopside, grossular and calcite in openings.

MINERALOGY

The minerals occurring at the Orford nickel mine are listed in Table 1. Species marked with an asterisk were identified in the course of the present study and have not been previously reported from this locality. Mineral identifications were made by a combination of X-ray powder diffraction, and semiquantitative (EDS) and quantitative (WDS) electron microprobe analyses.

Table 1. Minerals of the Orford nickel mine.

Sulfides	Phosphates and Arsenates
Arsenopyrite*	Annabergite*
Godlevskite*	Apatite group*
Maucherite	
Millerite	
Pentlandite*	
	Silicates
Oxides	Albite*
Chromite	Allanite-(Ce)*
Magnetite*	Andradite*
	Clinocllore*
	Diopside
Carbonates	Epidote
Calcite	Grossular
Dolomite	Microcline*
	Pecoraite*
	Prehnite*
	Tremolite

*Species whose occurrence at the Orford nickel mine is reported here for the first time.

The following mineral descriptions are based on an examination of specimens in private and institutional collections, and on the published literature.

Albite $\text{NaAlSi}_3\text{O}_8$

Albite occurs as colorless crystals to 1 mm, associated with microcrystals of green grossular on a distinctive matrix composed of jackstraw aggregates of yellow-green, striated, prismatic microcrystals

of diopside. Microcline, another member of the feldspar group, is found in the same association. The albite crystals have a blocky habit, with an obvious triclinic symmetry. The crystal faces have a slightly frosted appearance.

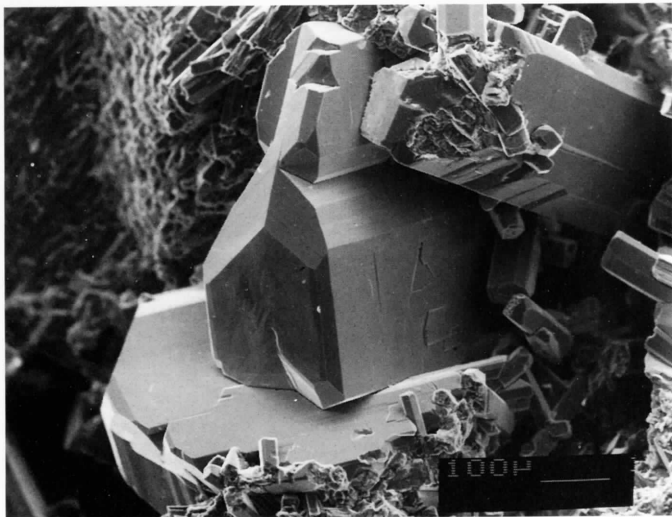


Figure 12. Allanite-(Ce), twinned tabular crystals 0.7 mm across. S. Cares collection. SEM photo by T. T. Chen.

Allanite-(Ce) $\text{Ca}(\text{Ce},\text{La})(\text{Al},\text{Fe},\text{Cr})_3(\text{SiO}_4)_3(\text{OH})$

Chromian allanite-(Ce) has been found as groups of intergrown, square, tabular, twinned crystals to about 0.7 mm, associated with microcrystals of diopside and grossular in cavities in a yellow-green fibrous diopside matrix. The morphology of the crystals suggests that the twin plane is (100). The crystals are transparent, dark brown and have a vitreous to adamantine luster.

Two crystals were examined with the electron microprobe. One showed three distinct zones due to a wide variation in Al, Cr and Fe in the Al site, and Ca and rare-earth elements (REE) in the REE site. The second crystal proved to be unzoned. Its analysis (Table 2) shows that allanite from the Orford nickel mine is unusual in having an exceptionally high chromium content.

Only a few crystals of allanite-(Ce) have been found to date.

Table 2. Analysis* of allanite-(Ce) from the Orford nickel mine.

Weight %		Formula Content***	
SiO ₂	30.90	Si ⁴⁺	3.008
Al ₂ O ₃	13.05	Al ³⁺	1.497
CaO	10.55	Ca ²⁺	1.100
Cr ₂ O ₃	7.11	Cr ³⁺	0.547
FeO	10.60	Fe ²⁺	0.863
MnO	0.25	Mn ²⁺	0.021
TiO ₂	0.31	Ti ⁴⁺	0.023
La ₂ O ₃	7.60	La ³⁺	0.273
Ce ₂ O ₃	13.48	Ce ³⁺	0.480
Pr ₂ O ₃	1.53	Pr ³⁺	0.054
Nd ₂ O ₃	3.21	Nd ³⁺	0.112
Sm ₂ O ₃	0.17	Sm ³⁺	0.006
H ₂ O**	1.54	H ⁺	1.000
Total	100.30	Cation Σ	8.984

* Microprobe analysis using Jeol 733 Superprobe with Tracor-Northern automation. Operating conditions: 15kV, 20 na, 30 μm defocussed beam. ** Determined by stoichiometry.

*** Formula content on basis of 13 anions.

Andradite $\text{Ca}_3\text{Fe}_2^{3+}(\text{SiO}_4)_3$

This member of the garnet group occurs as transparent, pale yellowish brown dodecahedrons to 1 mm associated with colorless diopside crystals in small cavities in fine-grained massive diopside and grossular.

A microprobe analysis gave CaO 33.91, MnO 0.34, Al₂O₃ 2.29, V₂O₃ 0.05, Fe₂O₃ 28.14, SiO₂ 36.59, total 101.32 weight %. No chromium was detected.

Andradite forms a series with grossular, and may be more common than the few known specimens would indicate.

Annabergite $\text{Ni}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

Annabergite is the principal component of pale bluish green encrustations occasionally found on and in weathered material in the mine dumps. Under the microscope, the encrustations are observed to be finely botryoidal. The weathered material may have come from the surface of the deposit and may predate mining.

Apatite group $\text{A}_5(\text{XO}_4)_3(\text{F},\text{Cl},\text{OH})$

Apatite has been found as tiny, transparent, very pale yellow to colorless grains associated with pecoraite, millerite, grossular and diopside. The specific apatite species has not been determined.

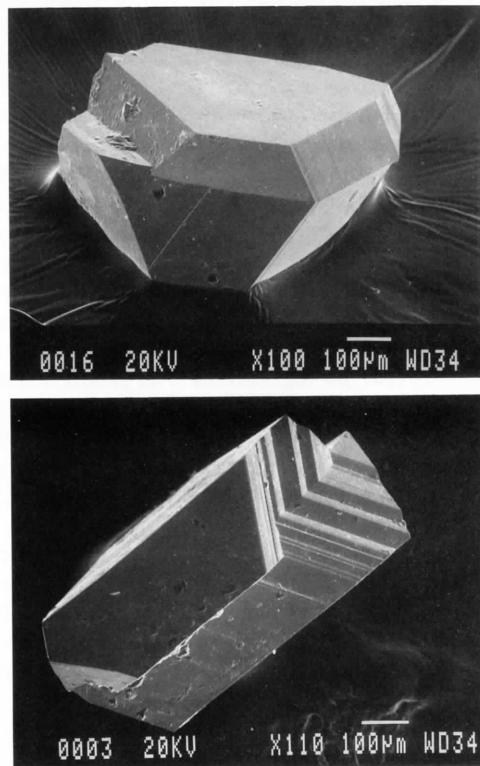


Figure 13. Arsenopyrite, twinned crystal 0.7 mm across. W. A. Henderson collection. SEM photo by T. T. Chen.

Arsenopyrite FeAsS

Arsenopyrite occurs as steel-gray, tabular, twinned crystals to 0.7 mm embedded in calcite and associated with grossular, diopside and millerite. Unequal development of the crystals has resulted in what appears to be one dominant {101} face. The crystals are apparently also twinned on (101). The prism faces are striated.

Like the other species which are found primarily as microcrystals embedded in calcite, arsenopyrite is exposed by etching the calcite with dilute hydrochloric or acetic acid. Only one specimen of arsenopyrite is currently known, but diligent search should uncover others.

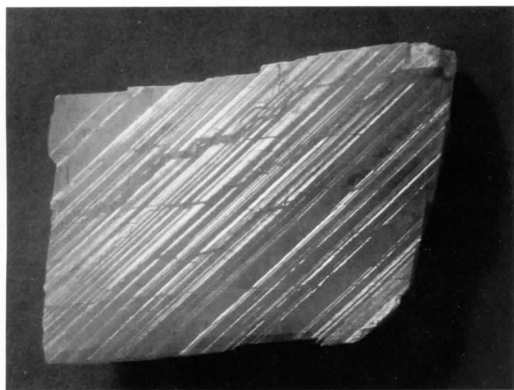


Figure 14. Calcite showing a set of $\{01\bar{1}2\}$ twin striations on a parting surface developed along a second set of $\{01\bar{1}2\}$ twin planes. The parting surface is corrugated due to displacement along the first set of twin planes. W. A. Henderson collection and photo.

Calcite CaCO_3

Coarsely cleavable massive calcite is very common in the mine dumps. Individual cleavage rhombohedrons measure up to 12 cm across. These cleavage fragments exhibit several interesting and uncommon features. They are polysynthetically twinned with the negative rhombohedron ($01\bar{1}2$) as the twin plane (Palache and Wood, 1904). This pressure-induced twinning is evidenced by parallel striations on the $\{011\}$ cleavage surfaces. All three equivalent sets of $\{01\bar{1}2\}$ twins may be observed in a single cleavage fragment, with two sets much more strongly developed than the third. Slip has occurred along the two sets, in what was apparently a second episode of plastic deformation; this causes displacement of the twin lamellae, and offsets where the twin striations cross. Parting is easily produced along the weakened twin planes, resulting in $\{1011\}$ cleavage rhombs bevelled by one or two $\{01\bar{1}2\}$ parting surfaces. The parting surfaces have pronounced parallel ridging and a dull luster. A further interesting feature of the calcite cleavage rhombs is that their surfaces are frequently twisted.

Crystals of calcite are uncommon. Small crystals, up to 3 mm in size, occur with grossular and diopside in the cavities in massive diopside. Larger crystals, up to 5 cm across, have been found in what appear to be solution cavities in massive calcite. The calcite crystals display scalenohedral, rhombohedral, and short prismatic habits, and tend to be rounded and etched. Several stages of deposition, each represented by a different crystal habit, may be observed on a single specimen.

The calcite is colorless to white, and transparent to opaque. It does not fluoresce in ultraviolet light.

Chromite $\text{Fe}^{2+}\text{Cr}_2\text{O}_4$

Chromite is relatively common in the Orford deposit. It occurs as inclusions in grossular crystals, as grains disseminated in granular grossular and diopside, and as small masses. Fortier (1946) reported finding chromite masses up to 30 cm across. Very rarely, chromite occurs as rough octahedral crystals to 0.7 mm. Both the massive chromite and the crystals are usually encrusted by grossular.

Microprobe analyses by Dunn (1978) of chromite inclusions in grossular have shown that their composition varies from $(\text{Fe}_{0.57}^{2+}\text{Mg}_{0.40}\text{Mn}_{0.02})(\text{Cr}_{1.57}\text{Al}_{0.37}\text{Fe}_{0.06}^{3+})\text{O}_4$ to $(\text{Fe}_{0.53}^{2+}\text{Mg}_{0.43}\text{Mn}_{0.02})(\text{Cr}_{1.72}\text{Al}_{0.23}\text{Fe}_{0.06}^{3+})\text{O}_4$. The magnesium content of 0.40 to 0.43 atoms per unit formula indicates a composition almost midway between chromite and magnesiochromite.

The chromite is black with a submetallic to metallic luster. Under the microscope it shows brownish red internal reflections.

Clinocllore $(\text{Mg},\text{Fe}^{2+})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$

This member of the chlorite group occurs as emerald-green foliated aggregates and thin tabular pseudohexagonal crystals to 1 cm embedded in calcite in pale yellowish green, fine-grained massive grossular and diopside. Godlevskite, maucherite, millerite and pentlandite occur in the same association.

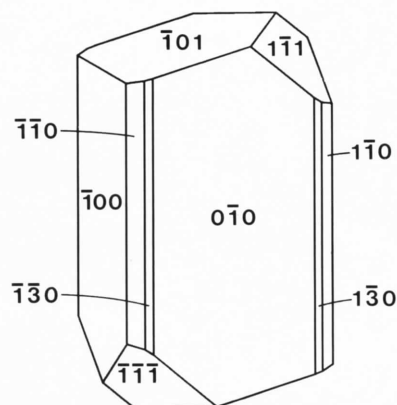


Figure 15. Idealized drawing of diopside microcrystal from a calcite-filled cavity. SHAPE drawing by L. Horváth.

Diopside $\text{CaMgSi}_2\text{O}_6$

Although an 1863 analysis indicated that the pyroxene from the Orford nickel deposit was diopside (Hunt, 1863a), the group name pyroxene continued to be used in the literature and on mineral collection labels until well into this century.

Much of the diopside is present as fine-grained masses and intergrown, subhedral prismatic to bladed crystals. Both types are often found in close association. Large masses of very coarsely crystallized subhedral crystals can be observed *in situ* in the footwall of the deposit. Columnar groups of subhedral prismatic crystals are also common in the mine dumps; groups up to 32 cm in length have been found. Elongated interstices between the crystals in the columnar

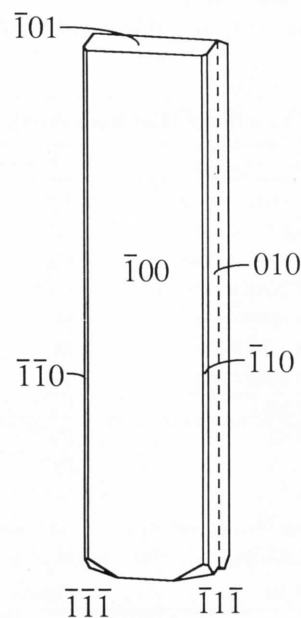


Figure 16. Bladed diopside crystal tabular on (100) and twinned on (100) . SHAPE drawing by R. P. Richards.

groups are often lined with drusy grossular. Rarely, the crystals in the columnar groups are well formed and terminated.

Large cleavage masses of calcite in contact with very coarsely crystallized diopside are often penetrated by prismatic to bladed subhedral to euhedral diopside crystals to 8 cm in length. The crystals are sometimes curved and twisted; others appear to have broken *in situ*.

Sharp, equant to tabular diopside crystals to about 1 mm, and less often prismatic, bladed and tabular diopside crystals to about 1 cm in length, usually associated with grossular, are found in cavities in the fine-grained diopside. The cavities range in size from a few millimeters to a few centimeters, and are commonly filled with calcite. These afford excellent microcrystal specimens.

Some of the best diopside specimens from Orford are the large single crystals and parallel to sub-parallel crystal groups which have been recovered from the mine dumps in recent decades. A major find of exceptionally large crystals was made in 1968, and is widely represented in institutional and private collections. It appears that these crystals were originally embedded in calcite, and that they were released when the easily cleaved calcite was fragmented during mining or by weathering. The habit of most of the crystals is thin to thick bladed; a few are prismatic with an almost square cross-section. The bladed crystals are up to 14 cm long, and 2 cm by 3.5 cm in cross-section; a length of 6 cm and a cross-section of 0.5 cm by 1.5 cm is more typical. The crystals tend to be tapered, becoming wider and thinner towards the single termination. This and the numerous offsets on the crystal faces indicate that they are composite crystals. The crystals are also twinned, as described below. Doubly terminated crystals have been found, but are very rare.

In all crystal habits, the dominant forms are the pinacoids $a\{100\}$ and $b\{010\}$; these are combined in the same zone with narrow faces of the prisms $m\{110\}$ and $i\{130\}$ (Palache and Wood, 1904). All the faces in this zone $\{hk0\}$ are lustrous, and the $\{010\}$ faces are usually striated parallel to $[001]$. The terminating forms are the second-order pinacoid $p\{101\}$ and the fourth-order prism $u\{111\}$; these faces tend to be rough, with a dull luster. Also observed, as minute faces, are the basal pinacoid $c\{001\}$ and the prism $s\{111\}$. Crystals in the tabular habit are flattened on (010) , (100) , or rarely, on (001) . Prismatic and bladed crystals are elongated parallel to $[001]$. The bladed crystals are tabular on (100) , which is an uncommon habit for diopside.

Many of the diopside crystals at Orford are twinned, with (100) as the twin plane. The twins usually interpenetrate to some extent, and commonly the only surface expression of twinning is one or more "tabs" in the terminations, each of which shows a tiny $\{100\}$ face.

The color of fine-grained masses of diopside varies from yellowish white to pale yellow to pale yellow-green. Coarsely crystallized aggregates of diopside are grayish yellow to brownish gray with yellow green areas, and are subtranslucent to opaque. Microcrystals are generally various shades of pale yellow-green, and transparent; occasionally the crystals are colorless. Larger crystals grade to deep yellow-green. The color of the large bladed to prismatic crystals ranges from grayish yellow to a rich yellow-brown, with a vitreous luster. The crystals are megascopically translucent, but under the microscope they are observed to be transparent, with numerous internal "veils." Cabochons with a distinct cat's-eye have been cut from some of these larger diopside crystals.

Single crystals of white diopside labeled as having been found in the same township lot as the Orford nickel mine are in the Ferrier Collection at the Redpath Museum, McGill University. The crystals are doubly terminated, have an equant habit, and are 1.5 cm in size. These may be the same as those described in the catalog note accompanying a specimen of Orford millerite which was displayed at the 1862 London International Exhibition: "there is, on the [same lot], a pale green pyroxenic rock, in which occur druses, lined with large twin crystals of white pyroxene, and with cinnamon-colored garnets" (Geological Survey of Canada, 1862). No other morphologically similar diopside crystals have been observed in collections or on the mine dumps.

Green diopside from the Orford mine is sometimes referred to as "chrome" diopside. Electron microprobe analyses were carried out to determine whether the green color can in fact be attributed to chromium. The analyses (Table 3) confirm the presence of chromium in some samples, but show a much higher content of iron, another transition element which can act as a green chromophore. Vanadium, also known as a green chromophore, was sought but not detected. Only one sample (analysis 1) has a Cr_2O_3 content which overlaps the compositional range of the green chromian diopside from Outokumpu, Finland (Von Knorring *et al.*, 1986). No correlation between color and the chromium content of Orford diopside is evident. These results indicate that the use of the prefix "chromian" is not justified.

Table 3. Analysis* of diopside from the Orford nickel mine.

Color	1 light yellow-green	2 yellow-green, light zone	3 yellow-green, dark zone	4 yellow-green	5 brown, light zone	6 brown, dark zone
SiO_2	54.26	54.28	55.06	55.65	53.93	54.98
CaO	25.71	25.73	25.63	26.09	25.67	25.73
MgO	14.89	14.69	15.27	16.67	13.19	15.72
MnO	0.23	0.38	0.16	0.07	0.36	0.08
FeO^{**}	4.54	5.32	4.35	2.80	7.61	3.79
Na_2O	0.19	0.07	0.10	0.00	0.05	0.11
Cr_2O_3	0.53	0.22	0.13	0.00	0.00	0.00
Al_2O_3	0.27	0.00	0.18	0.13	0.11	0.48
Total	100.62	100.69	100.88	101.41	100.92	100.89

* Microprobe analyses using Jeol 733 Superprobe with Tracor-Northern automation. Operating conditions: 15kV, 20 na, 30 μm defocused beam.

** Total iron as FeO.

(1) Grain with very faint patchy zoning; from a small transparent crystal, associated with green grossular in a calcite-filled cavity in massive fine-grained diopside. (2) Zoned grain from a large bladed crystal. (3) Same grain as in (2). (4) Grain with very faint patchy zoning; from a columnar aggregate of subhedral crystals, brown with yellow green areas. (5) Grain with pronounced zoning; same specimen as in (4).

(6) Same grain as in (5).



Figure 17. Diopside, two diverging bladed crystals 13.8 cm tall, collected in 1968. Harvard Mineralogical Museum specimen 119207. (Shown actual size.)



Figure 18. Diopside, columnar group of prismatic crystals 11 cm tall. M. Hébert collection. G. Robinson photo.

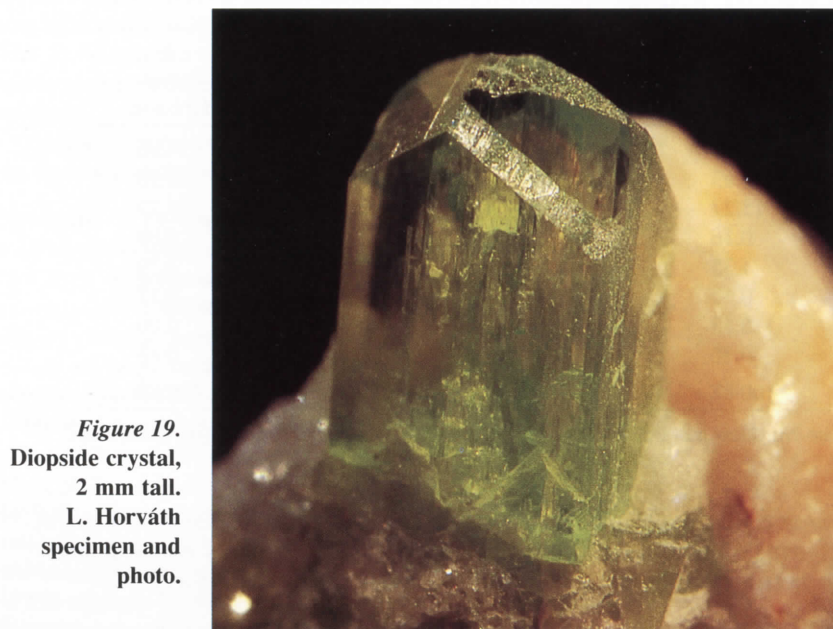


Figure 19. Diopside crystal, 2 mm tall. L. Horváth specimen and photo.



Figure 20. (Below) Diopside crystal group, 6.5 cm tall. P. Tarassoff collection. G. Robinson photo.



Figure 21. Diopside, short prismatic crystal 2 mm in length. P. Tarassoff collection. L. Horváth photo.



Figure 22. Diopside, group of tabular crystals, 6 cm across. Canadian Museum of Nature specimen 53130. G. Robinson photo.

Dolomite $\text{CaMg}(\text{CO}_3)_2$

Willmot (1882) reported that dolomite occurs with calcite in the interstices of aggregates of coarsely crystallized diopside. Its presence has not been confirmed.

Epidote $\text{Ca}_2(\text{Fe}^{3+}, \text{Al})_3(\text{SiO}_4)_3(\text{OH})$

Hunt (1879) reported that small crystals of pale green epidote occurred in calcite with green grossular, chromite and millerite. No specimens of this description were observed in any of the collections examined in the course of the present study; the occurrence of epidote has therefore not been confirmed.

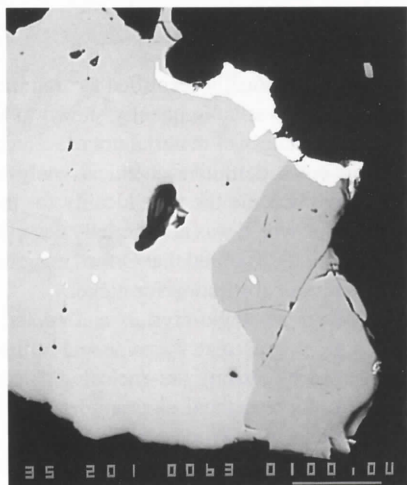


Figure 24. Back-scattered electron image of polished section of godlevskite/pentlandite crystal showing intergrowth of godlevskite (light), pentlandite (dark) and maucherite (white). 100 µm scale bar. R. Gault photo.

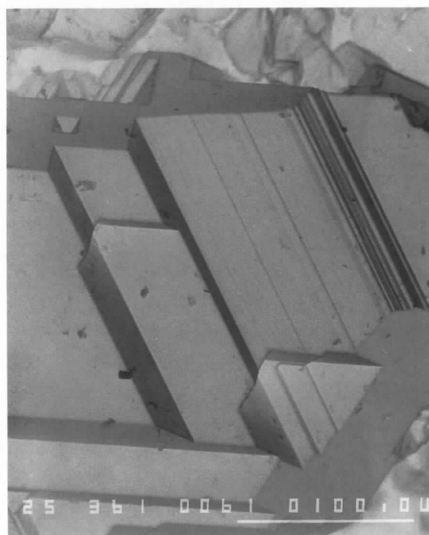


Figure 23. Godlevskite/pentlandite crystal, field of view 0.25 mm. P. Tarassoff collection. SEM photo by R. Gault.

Godlevskite $(\text{Ni}, \text{Fe})_7\text{S}_6$

Godlevskite was originally described from the Noril'sk and Talnakh nickel deposits in Russia (Kulagov *et al.*, 1969), and was later found at the Texmont nickel mine near Timmins, Ontario (Naldrett *et al.*, 1972). At these localities godlevskite occurs as anhedral grains.

At the Orford nickel mine, godlevskite has been found intimately intergrown with pentlandite as euhedral crystals to 0.5 mm. The godlevskite/pentlandite crystals occur disseminated along with maucherite, millerite, clinocllore and chromite in a pale green, massive, fine-grained granular intergrowth of grossular and diopside

impregnated with calcite. The sharpest crystals are found in small calcite-filled cavities.

The godlevskite/pentlandite crystals are equant and complex, with numerous stepped faces, some with distinctive triangular growth features. The crystals are bright, metallic, and bronze-yellow in color.

An electron microprobe analysis of the godlevskite gave Fe 3.71, Ni 64.01, Co 0.51, S 31.97, total 100.21 weight %.

Grossular $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$

For many years the green garnet from the Orford nickel mine has been incorrectly called "uvarovite." In the earliest references it was referred to simply as "chrome garnet" (Hunt, 1863a; Willmot, 1882) based on Hunt's analysis which showed $\text{Al} > \text{Cr}$. However, citing Hunt's analysis, Palache and Wood (1904) called the garnet "ouvarovite, but with a very small proportion of chromium." The name "uvarovite" has been widely applied to Orford material in the literature (Fortier, 1946; Dresser and Denis, 1949; Sinkankas, 1964; Gregory, 1967; Traill, 1983) and on mineral collection labels. The correct identity of the green garnet was demonstrated by Dunn in 1978. Dunn's microprobe analyses of 14 specimens showed the garnet to be a chromian grossular with a compositional range from $(\text{Ca}_{5.89}\text{Mn}_{0.09})\text{Al}_{3.14}\text{Cr}_{0.41}\text{Fe}_{0.37}^{3+}\text{Si}_{6.06}\text{O}_{24}$ to $(\text{Ca}_{5.89}\text{Mn}_{0.11})\text{Al}_{2.54}\text{Cr}_{1.25}\text{Fe}_{0.21}^{3+}\text{Si}_{6.00}\text{O}_{24}$.

The chromian grossular occurs as sharp crystals to 2 mm in druses on coarsely crystallized diopside, in druses lining cavities in fine-grained diopside, and as "floaters" embedded in calcite. Less commonly, grossular crystals encrust massive chromite. Grossular is also found disseminated in, and intergrown with fine-grained diopside, as fine-grained masses, and as granular intergrowths with calcite. The individual grains of grossular tend to retain a subhedral to euhedral crystal form.

The majority of the crystals are simple rhombic dodecahedrons {110}. On some crystals the dodecahedrons are modified by narrow faces of the {211} trapezohedron, sometimes in combination with small faces of the cube {100}, or a tetrahexahedron. This latter form has not been measured. Palache and Wood (1904) also observed the hexoctahedrons {358} and {459} as very narrow modifying faces; this was the first time that these forms had been reported for the garnet group. Most of the crystals have very smooth and lustrous faces.

The color of the crystals generally ranges through various shades of yellow-green to emerald-green; some appear almost black due to included chromite. Less commonly, the color is pale to dark yellow. The crystals are mostly transparent. Some crystals are color-zoned, with a green core and a yellow outer zone, or an opaque white to pale yellowish green core and a transparent emerald-green outer zone. Massive grossular is generally pale green to pale yellow-green, and translucent to opaque.

Rarely, the "hessonite" variety of grossular is found as druses of brownish orange crystals to 3 mm on fine-grained diopside and green grossular. Some of this material may be the same as the "cinnamon-colored garnets" referred to above in the description of diopside.

Magnetite $\text{Fe}^{2+}\text{Fe}_2^{3+}\text{O}_4$

Magnetite has been found as aggregates and disseminations of subhedral to euhedral crystals to 2 mm along the selvages of small masses of calcite in fine-grained diopside. It is associated with clinocllore and pale green grossular. The smallest crystals are skeletal, while larger crystals generally have rounded faces and exhibit oscillatory growth. The dominant crystal form is the dodecahedron modified by small octahedral and, occasionally, cubic faces. Magnetite also occurs as extremely small, sharp octahedrons in the tremolite marble in the footwall of the deposit.

Magnetite is far less common at Orford than chromite, from which it can be readily distinguished by its strong magnetism.

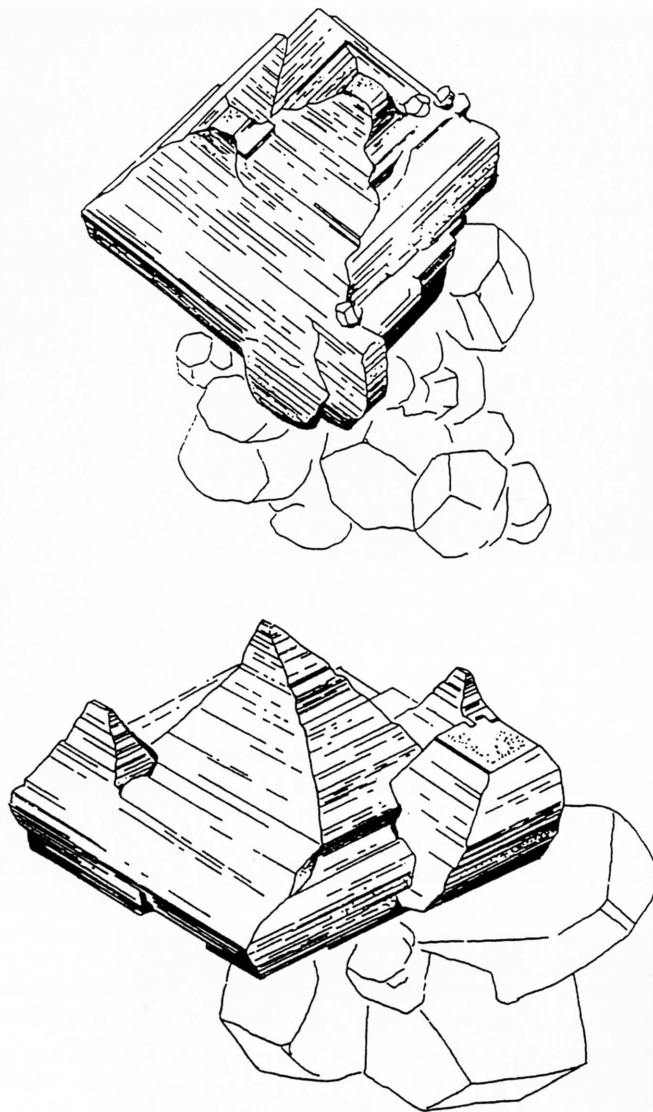


Figure 25. Maucherite crystals: (top) 1.0 mm across, S. Cares collection; (bottom) 0.4 mm across, W. A. Henderson collection. Drawing by G. Glenn.

Maucherite $\text{Ni}_{11}\text{As}_8$

A metallic mineral provisionally identified as "rammelsbergite" by Palache and Wood (1904) was subsequently shown to be maucherite (Peacock, 1940). Had a paucity of material not prevented Palache and Wood from carrying out a definitive chemical analysis, the Orford nickel mine might have become the type locality for the mineral we now know as maucherite, which was not formally described until 1913 (Grunling, 1913). Dunn (1978) found that Orford maucherite is almost pure $\text{Ni}_{11}\text{As}_8$, with no iron substitution for nickel.

The maucherite occurs as single crystals and crystal clusters to 1 mm associated with green grossular, diopside and millerite in calcite; the crystals are revealed by etching the enclosing calcite. The dominant crystal forms are the tetragonal dipyrmaid {101} and the basal pinacoid {001} (Palache and Wood, 1904; Peacock, 1940). The dipyrmaid {102} is observed as narrow faces. Palache and Wood (1904) also reported the dipyrmaids {104}, {108} and {304} and the prism {110}, but there is some uncertainty about the goniometric measurements (Peacock, 1940). The maucherite crystals are heavily striated perpendicular to the *c* axis due to oscillatory growth between

the dipyramidal forms and the pinacoid. Many of the crystals have multiple, stepped, pyramid-like terminations. The maucherite has a bronze-yellow color, often with an iridescent tarnish.

The Orford nickel mine is the only known occurrence of distinct crystals of maucherite in Canada.

Microcline KAlSi_3O_8

This member of the feldspar group occurs as thin, platy crystals to 2 mm across, associated with grossular and diopside. The microcline crystals have a corroded appearance, and are colorless to white, with a waxy luster. In the few known specimens, the associated diopside occurs as jackstraw aggregates of distinctive, yellow-green, short prismatic crystals.

A microprobe analysis of one microcline crystal gave K_2O 16.23, Na_2O 0.20, BaO 0.20, SrO 0.11, Al_2O_3 17.65, SiO_2 64.82, total 99.21 weight %.

Millerite NiS

The Orford nickel mine is noted for its terminated millerite crystals, which are illustrated in Goldschmidt's *Atlas der Krystallformen* (1920) and [labeled "Brompton Lake, Quebec"] in Dana's *System of Mineralogy* (Palache, *et al.*, 1944). The "beauty, perfection and unusual size" of the crystals led Palache and Wood (1904) to undertake a classic crystallographic study of Orford millerite.

A microprobe analysis of the millerite indicates substitution of iron (3.82 weight %) and cobalt (0.16 weight %) for nickel, and arsenic (0.16 weight %) for sulfur (Gauthier *et al.*, 1989). No copper was detected.

The millerite crystals occur either embedded in calcite or implanted on drusy grossular and diopside in calcite-filled cavities. Crystals in intimate contact with grossular and diopside are often "bent, twisted and contorted . . . as though, after formation, the crystals had been pressed down to fit all the irregularities of the uneven underlying surface" (Palache and Wood, 1904). Crystals projecting into calcite tend to be straighter and better formed. They occur as isolated crystals, as parallel to subparallel aggregates, as radiating clusters, and as randomly oriented, intergrown groups. Eustis (1879a) reported the occurrence of parallel crystals forming a flat plate. In one exceptional

specimen in the Redpath Museum collection, millerite forms a crust of intergrown, flat-lying, microcrystals completely lining a 3 by 4-cm cavity. The habit of millerite crystals varies from stubby to long prismatic, to acicular. Most crystals are less than 1 cm in length and 1.5 mm in diameter. An unusual feature of some of the crystals is that they have a hollow tubular core.

The largest crystals are wholly enclosed in calcite. Willmot (1882) reported that such crystals often exceeded 8 cm in length. Hunt (1879) reported the occurrence of tabular crystals about 1 cm in width and 2.5 cm in length. None of the larger crystals appear to have been preserved. A crystal in the Whitney collection at Harvard, and illustrated by Palache and Wood (1904), has a length of 4 cm and a diameter of 2 mm.

Many of the millerite crystals have offsets due to pressure-induced twinning or gliding on (0112). Repeated twinning along closely spaced glide planes causes the crystals to appear bent; in extreme cases, crystals exhibit V-bends. The occurrence of pressure-induced twinning in millerite was first recognized by Palache and Wood (1904) in their study of Orford millerite.

The millerite crystals exhibit a large number of forms. Palache and Wood (1904) measured nine forms, of which four were new for millerite. One or more faces of an additional 13 forms were observed but could not be identified with certainty. The dominant form is the trigonal prism $\{10\bar{1}0\}$ which is sometimes combined with the ditrigonal prisms $\{11\bar{2}0\}$ and, more rarely, $\{21\bar{3}0\}$ and $\{7290\}$. The prisms are striated parallel to $[0001]$, often heavily due to oscillatory growth of the prism faces, and tend to have a rounded hexagonal to triangular cross-section. The most common termination is the positive rhombohedron $\{10\bar{1}1\}$, which is also a direction of perfect cleavage. Other terminating forms are the negative rhombohedrons $\{02\bar{2}1\}$ and $\{50\bar{5}2\}$, and the scalenohedrons $\{2131\}$ and $\{4153\}$; these latter forms appear as very small faces. The prism faces of crystals freshly released from calcite have a bright metallic luster; their terminal faces tend to be duller and may be rough and pitted. The color of the millerite is brass-yellow and is quite distinctive from the bronze-yellow color of maucherite.

Millerite also occurs as grains disseminated in fine-grained massive grossular and diopside, and in the tremolite marble in the footwall.

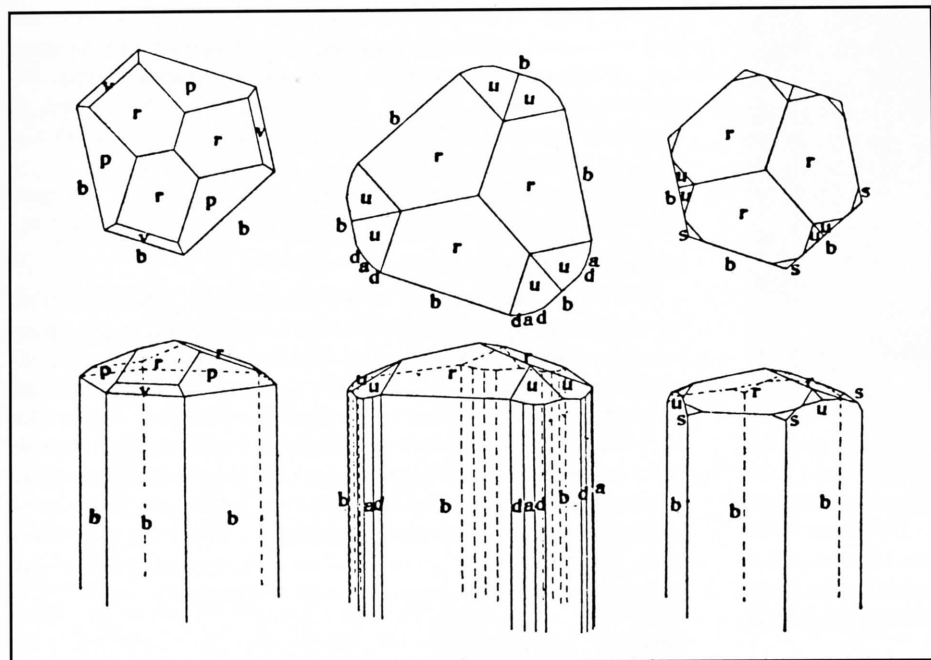


Figure 26. Crystal drawings of millerite from the Orford nickel mine (from Palache and Wood, 1904).

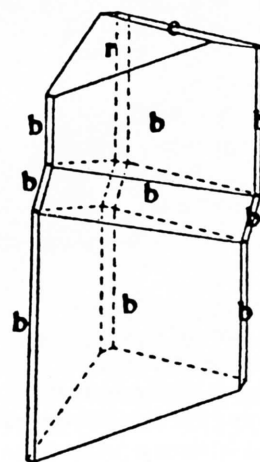


Figure 27. Drawing of millerite crystal with offset caused by pressure twinning on (0112) (from Palache and Wood, 1904).

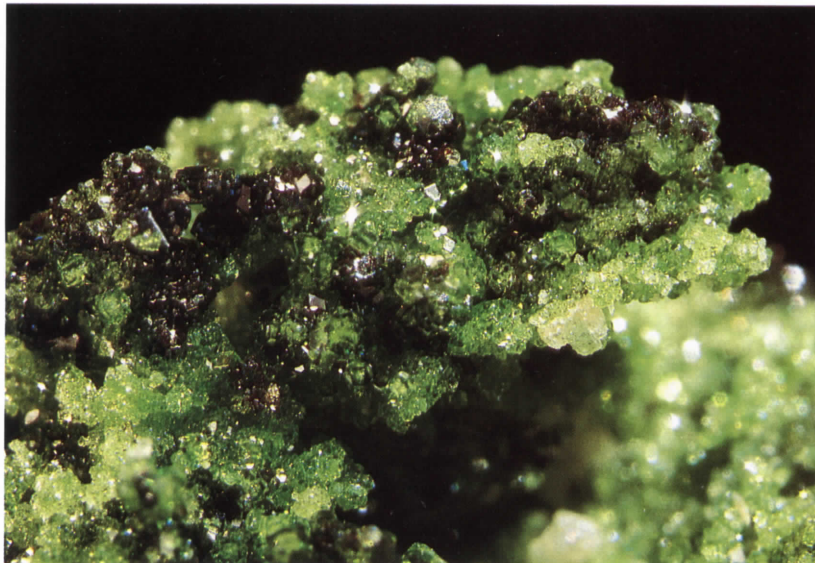


Figure 28. Grossular, druse of 1 mm crystals. L. Horváth collection and photo.



Figure 29. Andradite, drusy crystals, field of view 6 mm. P. Tarassoff collection. L. Horváth photo.



Figure 30. Grossular in typical association with diopside; length of largest diopside crystal, 7 mm. P. Tarassoff collection. L. Horváth photo.

The best clue to finding millerite crystals in the mine dumps is their association with green grossular embedded in calcite. Examination of freshly broken surfaces of the calcite will often reveal millerite if it is present. The best microcrystal specimens are obtained by etching the calcite in acid. Millerite has not been observed in direct association with coarsely crystallized diopside.

Pecoraite $\text{Ni}_3\text{Si}_2\text{O}_5(\text{OH})_4$

Pecoraite, a nickel-bearing member of the kaolinite-serpentine group, occurs at Orford as grains, coatings, partial replacements and

pseudomorphs after millerite crystals. Larger grains, to 2 mm, are cryptocrystalline. The partial replacements and pseudomorphs have a lamellar to splintery, somewhat fibrous structure. The color ranges from greenish yellow to yellow-green, with a waxy luster.

A quantitative microprobe analysis of a cryptocrystalline grain showed partial substitution of Ni by Mg, Fe, Co, Na, Mn and Ca, in descending order of atomic percentage. In total, approximately one in three of the Ni sites in the chemical formula is replaced by these elements. The mineral gives a very diffuse X-ray powder pattern similar to that reported for pecoraite in the Powder Diffraction File (22-754).

Pentlandite $(\text{Fe},\text{Ni})_9\text{S}_8$

As noted above, pentlandite occurs intimately intergrown with godlevskite. Maucherite was also observed as an intergrowth in one sample. The composite godlevskite/pentlandite crystals have sharp external faces. Although impossible to differentiate visually, the godlevskite and pentlandite are easily distinguishable through scanning electron microscopy using the backscatter image detector. No epitaxial relationship between the two species has been noted. A microprobe analysis of the pentlandite gave Fe 20.02, Ni 43.35, Co 4.84, S 31.65, total 99.86 weight %.

Pentlandite also occurs as anhedral, equant grains to 0.5 mm, associated with tiny chromite grains embedded in massive tremolite.

Prehnite $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$

Prehnite has been found as reniform masses with a platy structure, as semi-parallel aggregates of subhedral blocky crystals to 1.5 cm on a matrix of platy prehnite, and as corroded, longitudinally striated, bladed crystals to 5 mm in length. The blocky crystals are etched and have a pale yellow-brown color. The bladed crystals are colorless. The platy masses have a yellowish white to pale tan color and a vitreous luster on fresh surfaces. The prehnite is associated with green grossular and diopside.

Prehnite crystals can easily be mistaken for etched calcite crystals, while the platy masses superficially resemble diopside. Prehnite has probably been previously overlooked for this reason.

Pyrite FeS_2

A cautionary note is in order regarding the pyrite which is found in the vicinity of a foundation between the two mine shafts. This pyrite was used as a flux in smelting the ore and does not come from the Orford nickel mine.

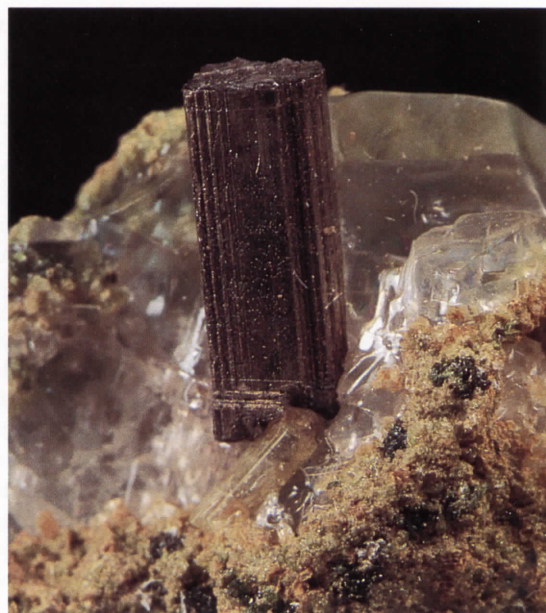


Figure 31. Millerite crystal, 5 mm. Canadian Museum of Nature specimen 50534; G. Robinson photo.

Figure 32. Millerite crystal, 1.2 mm. Canadian Museum of Nature specimen 55846; G. Robinson photo.

Figure 33. Prehnite, group of semi-parallel crystals with diopside and grossular, 6 cm. Canadian Museum of Nature specimen 55594, from the Pinch collection. G. Robinson photo.

Tremolite $\text{Ca}_2(\text{Mg}, \text{Fe}^{2+})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$

Tremolite occurs as patches of fine, silky white fibers on diopside (Sabina, 1966). It is also a component of the tremolite marble in the footwall in which it occurs as aggregates of colorless to very pale gray, fibrous microcrystals; these are revealed by etching the marble in acid.

Pale greenish gray, cryptocrystalline to very finely fibrous masses cut by cross-fiber asbestiform veinlets are occasionally found in the mine dumps. Both the matrix and the veinlets are tremolite. This material probably represents a replacement of the footwall serpentine.

Uncharacterized Species

Nickel Silicate

Dunn (1978) found "what may be a new nickel silicate mineral" as microscopic grains (3–4 μm in diameter) at the boundary between grains of chromian grossular and maucherite. Not enough of the mineral was available to permit its full characterization, and no information on its color or other physical properties was reported.

Unknown

This mineral occurs as coatings on diopside and grossular crystals, and as a filling in interstices between the crystals. It has a very fine, flaky structure. The color is pale greenish white to creamy white. An EDS analysis of a coating on diopside showed Ca, Mg, Si, and minor Fe spectral peaks; this may be from the substrate diopside. The mineral is amorphous.



PRESENT STATUS

The Orford nickel mine is on private property, but the site is currently open to collectors on a daily fee basis. The mine shafts were backfilled several years ago as a safety measure by the Québec government. Collecting can still be productive, and some excellent specimens have been found in recent years. Permission to collect

should be obtained from the owner, whose residence is on the property.

ACKNOWLEDGMENTS

We wish to extend our appreciation to the many individuals who provided valuable help during the research for the present article: Ellen Faller and Barbara Narendra (Peabody Museum of Natural History, Yale University); Joseph Peters (American Museum of Natural History); Robert Gait (Royal Ontario Museum); Paul Pohwat and Pete Dunn (National Museum of Natural History, Smithsonian Institution); Alan Criddle (Natural History Museum, London); Joan Kaylor and Louise Stevenson (Redpath Museum, McGill University); Mark Badham (Miller Museum of Geology and Mineralogy, Queen's University); Gary Ansell and Ann Sabina (Geological Survey of Canada); Michel Gauthier (Université du Québec à Montréal); W. Gillies Ross (Bishop's University); Lindsay Greenbank; and Fran and Chris Rasmussen (Alpine Valley Gem Shop).

Special thanks are due to Ron Orasi, Inco Limited, for providing archival material relating to the Orford nickel mine; to Carl Francis, Harvard University, for generously sharing his notes on the Orford mineral locality, as well as providing access to the Mineralogical Museum collection; to Peter Richards for sharing his knowledge of crystal morphology; to Gary Glenn for his skillful drawings; to George Robinson (Canadian Museum of Nature) and László Horváth for their critical reading of the text, and for photography; to Jerry Van Velthuisen (Canadian Museum of Nature), George Chao and Ron Conlon (Carleton University), T. T. Chen and John Dutrizac (CANMET) for technical assistance; and to Stephen and Janet Cares, William A. Henderson Jr. and Michel Hébert for loan of specimens for research and photography. We also wish to thank the reviewers of the manuscript, Richard C. Erd, Andrew Roberts and Wendell Wilson, for their helpful comments. A note of appreciation is also due to Carlos Mateus for allowing mineral collectors access to the Orford nickel mine site.

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