

JOHN RAKOVAN  
 Department of Geology  
 Miami University  
 Oxford, Ohio 45056  
 rakovajf@muohio.edu

## Nelsonite and Kiruna-type Deposits

As a mineral collector, I was first captured by the innate appeal of beautiful crystals and mineral specimens. However, I soon became interested in how minerals form and the environments where they are found. For field collectors, such information is critical to success in finding specimens. It wasn't until I was a geology student that I realized that this interest in how and where minerals form is the basis for the study of rocks and rock-forming environments.

Those minerals that make up the vast majority of rocks are appropriately called the rock-forming minerals. Of the roughly four thousand known minerals, only a handful fall into this category. This may seem surprising, but it is a simple outcome of the abundance of different elements in the earth. More than 99 percent of the earth is made of only eight elements (O, Si, Al, Fe, K, Na, Ca, and Mg). Thus, the majority of minerals and the rocks that they form are composed of some combination of these elements. For example, because O and Si are the two most abundant elements in the mantle and crust (O = 46 percent and Si = 28 percent of the crust by weight), it is not surprising that most igneous rocks are made of silicate minerals. In terms of abundance, the vast majority of minerals in igneous rocks are olivines, pyroxenes, amphiboles, micas, feldspars, and quartz; they compose the common rock types such as peridotite, basalt, gabbro, andesite, granite, and so forth.

There are, of course, rocks whose mineralogies do not follow the norm. These rock types are exotic in comparison to "normal" types. Moreover, not only does their formation usually involve uncommon chemical and physical processes that make them of great interest to scientists, but their unusual mineral assemblages also make them interesting to mineral collectors. Two igneous examples are carbonatites and kimberlites. In another unusual class of igneous rocks we find iron oxides (ilmenite, magnetite, or hematite) and apatite as the major constituents. There are several different types of rocks with this basic mineralogy, including *nelsonites* and *Kiruna-type deposits*. The former is named for an unusual deposit in Nelson County, Virginia, and the lat-



Figure 1. Fluorapatite, 5.3 cm high, Cerro Mercado, Durango, Mexico. Kerith Graeber specimen, Jeff Scovil photo.

ter for the Kiruna district in northern Sweden. Differences between nelsonites and Kiruna-type deposits include the Ti content of the iron oxides (thus the type of oxide in some cases) and the proportion of apatite in the rock, as well as their minor mineral constituents, associated rock types, geological setting, and probably their modes of formation.

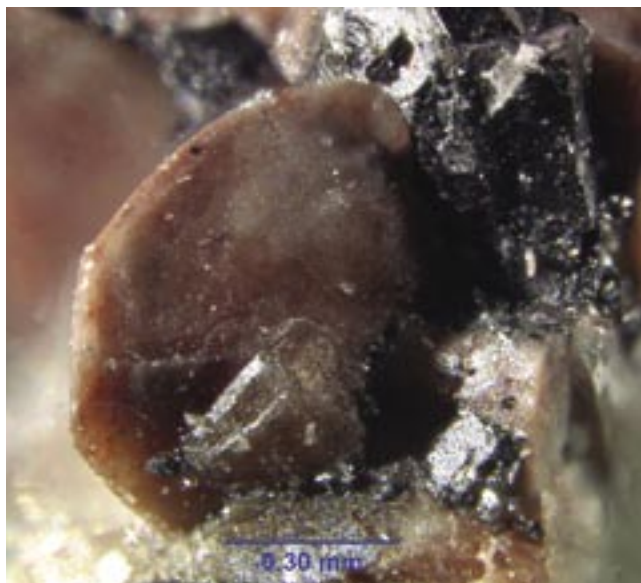
Nelsonites have a characteristically high concentration of Ti, which results in the formation of ilmenite, Ti-rich magnetite, or both. They are also apatite rich, often with 30–50 percent of this mineral. In addition, they are usually associated with anorthosites\* (intrusive igneous rocks that are almost entirely plagioclase feldspar, usually labradorite). Nelsonites are magmatic in origin. It is believed that the iron-titanium-phosphorous-oxide magmas from which they crystallize result from liquid immiscibility within a silicate magma, intense fractionation of some parent magma, or partial melting of Fe- and P-rich rocks in the earth's crust (Philpotts 1967; Kolker 1982; Barton and Johnson 1996;

---

Dr. John Rakovan, an executive editor of *Rocks & Minerals*, is a professor of mineralogy and geochemistry at Miami University in Oxford, Ohio.

---

\*Anorthosites, such as the Nain Anorthosite in Labrador and the Ahvenisto Anorthosite in Finland, are some of the best sources of large labradorite specimens and are commonly used as decorative facings on the exteriors and interiors of buildings.

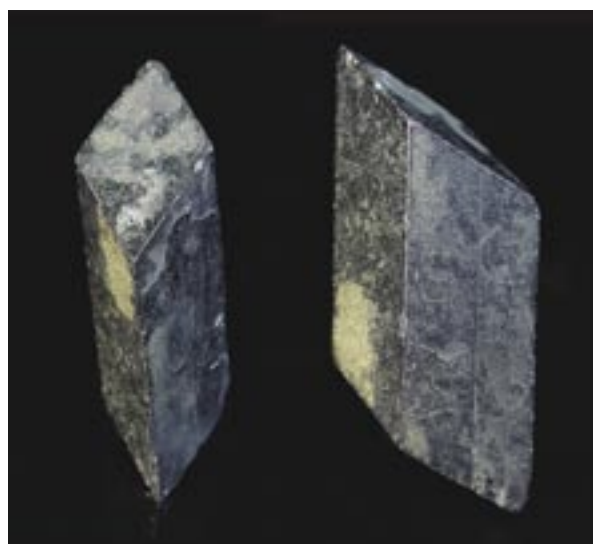


**Figure 2.** Stillwellite-(Ce), Mineville, New York. New York State Museum specimen, Marian Lupulescu photo.



**Figure 3.** Fluorapatite crystals, 1.3 cm long, with magnetite, Cedar City, Iron County, Utah. Seibel Minerals specimen, Jeff Scovill photo.

Naslund et al. 2000). In most cases where nelsonites are associated with anorthosites, there is good geological and experimental evidence that liquid immiscibility was the mechanism for generating the Fe- and P-rich magma. In this process the composition of some parent magma evolves to the point where it is chemically more stable to separate into two magmas, of very different compositions, rather than to remain as a single magma. The resulting two magmas are immiscible, meaning that they will not mix—similar to oil and water. Experiments show that, at high temperatures, large amounts of iron can dissolve readily in silica-rich melts, but as an iron-rich silicate magma is cooled, immiscible silica-rich and iron-rich liquids will separate (Philpotts 1967; Naslund 1983). In anorthosite rock suites, nelsonites are sometimes found with other rock types that are rich in iron oxides and apatite but have other major mineral constituents. One such example is oxide-apatite gabbronorites that contain ilmenite ± magnetite, apatite, orthopyroxene + clinopyroxene, and plagioclase (Dymek and Owens 2001).

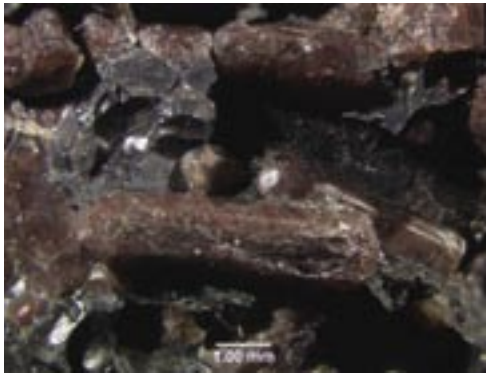


**Figure 4.** Magnetite crystal (unusual morphology),  $4.7 \times 1.5 \times 1.5$  cm, Mineville, New York: two views of the same specimen. New York State Museum specimen 12258, Barbara and George Gerhardt photo.

These minerals may also be found in nelsonites but only in minor or trace amounts.

In this issue of *Rocks & Minerals*, Lupulescu and Pyle (page 242) describe the mineralogy of a Kiruna-type iron, phosphorous, rare-earth-element deposit in Mineville, New York (Buddington 1966; Foose and McLelland 1995). In contrast to nelsonites, Kiruna-type deposits have much lower Ti contents; thus, they contain magnetite or hematite but no ilmenite. They also exhibit variable amounts of apatite. The type deposit in Kiruna, Sweden, contains about 30 percent apatite (Nyström and Henriquez 1994), and the orebed at Mineville, New York, is about 50 percent apatite. Others have very small amounts of apatite. Geologically, they are usually associated with calc-alkaline to alkaline volcanic igneous rocks (Frietsch 1978; Naslund et al. 2000) and hydrothermally altered (metasomatic) or precipitated rocks. Many have coarse textural features that suggest a volcanic origin, but some investigators suggest that the iron oxides and apatite have hydrothermally replaced what were originally silicate volcanics, while retaining the original textures. Hence, the origin of Kiruna-type deposits has been controversial, with both magmatic and hydrothermal origins proposed (Frietsch 1978; Henriquez and Martin 1978; Nyström and Henriquez 1994; Barton and Johnson 1996; Rhodes, Oreskes, and Sheets 1999; Rhodes and Oreskes 1999). Different deposits show varying evidence for these two hypothesized mechanisms of formation, and ultimately it may be found that both can result in the same deposit type.

Although commonly mined for iron ore, as was the Mineville deposit, Kiruna-type deposits are of significant economic interest for commodities other than iron. Many Kiruna-type deposits are also rich in Cu, Au, U, or REE (e.g., Hauck 1990; Einaudi and Oreskes 1990; Marikos, Nuelle, and Seeger 1990; Vivallo, Henriquez, and Espinoza 1993; Foose and McLelland 1995; Barton and Johnson 1996; Hitzman 2000). The orebody at Mineville, New York, is



**Figure 5.**  
Apatite and magnetite from the orebed at Mineville, New York. New York State Museum specimen, Marian Lupulescu photo.



**Figure 6.**  
Magnetite crystal (dodecahedral morphology), 1 cm, Barton Hill mine, Mineville, New York. New York State Museum specimen 499, Barbara and George Gerhardt photo.

particularly rich in REE, which reside in the apatite as well as in REE-minerals such as stillwellite-(Ce). For specimen production, one of the best known Kiruna-type deposits is that found at Cerro de Mercado, Durango, Mexico (Megaw 1999). Here, the iron oxide, apatite-rich rocks are hosted by volcanics (rhyolitic air-fall tuffs of the Cacaria Formation [Lyons 1988]). The iron oxide precipitated as magnetite, but most has subsequently oxidized to form “martite,” a pseudomorphic replacement of magnetite by hematite. Although it has produced many nice martite specimens, Cerro de Mercado is famous for its abundant, gemmy, yellow-green apatite crystals. The crystals are usually sharp and lustrous and range in size from a few millimeters to more than 12 cm. Although the origin (magmatic or hydrothermal) of the Cerro de Mercado iron oxide deposit is under debate (e.g., Lyons 1988; Barton and Johnson 1996)—as is the case for other Kiruna deposits—there is a clear hydrothermal component to it, and the gemmy-yellow apatites from here are certainly hydrothermal in their origin, forming in open breccias where they can grow unrestricted.

#### ACKNOWLEDGMENTS

I thank Bob Cook, Kendall Hauer, Yun Luo, and Marian Lupulescu for their reviews of this manuscript and for their helpful suggestions.

#### REFERENCES

Barton, M. D., and D. A. Johnson. 1996. An evaporitic-source model for igneous related Fe-oxide(-REE-Cu-Au-U) mineralization. *Geology* 24:259–62.  
Buddington, A. F. 1966. The Precambrian magnetite deposits of New York and New Jersey. *Economic Geology* 61:484–510.

Dymek, R. F., and B. E. Owens. 2001. Petrogenesis of apatite-rich rocks (nelsonites and oxide-apatite gabbronorites) associated with massif anorthosites. *Economic Geology* 96:797–815.  
Einaudi, M. T., and N. Oreskes. 1990. Progress towards an occurrence model for Proterozoic iron oxide deposits—A comparison between the ore provinces of South Australia and southeast Missouri. In *The midcontinent of the United States—Permissive terrane for an Olympic Dam-type deposit*, ed. W. P. Pratt and P. K. Sims, 58–69. U. S. Geological Survey bulletin 1932.  
Foose, M. P., and J. M. McLelland. 1995. Proterozoic low-Ti iron-oxide deposits in New York and New Jersey: Relation to Fe-oxide (Cu-U-Au-rare earth element) deposits and tectonic implications. *Geology* 23:665–68.  
Frietsch, R. 1978. On the magmatic origin of iron ores of the Kiruna type. *Economic Geology* 73:478–85.  
Hauck, S. A. 1990. Petrogenesis and tectonic setting of middle Proterozoic iron oxide-rich ore deposits—An ore deposit model for Olympic Dam-type mineralization. In *The midcontinent of the United States—Permissive terrane for an Olympic Dam-type deposit*, ed. W. P. Pratt and P. K. Sims, 4–39. U.S. Geological Survey bulletin 1932.  
Henríquez, F., and R. F. Martin. 1978. Crystal growth textures in magnetite flows and feeder dykes, El Laco, Chile. *Canadian Mineralogist* 16:581–89.  
Hitzman, M. W. 2000. Iron oxide-Cu-Au deposits: What, where, when, and why. In *Hydrothermal iron oxide copper-gold and related deposits: A global perspective*, vol. 1, ed. T. M. Porter, 9–25. Adelaide: PGC Publishing.  
Kolker, A. 1982. Mineralogy and geochemistry of Fe-Ti oxide and apatite (nelsonite) deposits and evaluation of the liquid immiscibility hypothesis. *Economic Geology* 77:1146–58.  
Lyons, J. I., Jr. 1988. Volcanogenic iron oxide deposits, Cerro de Mercado and vicinity, Durango. *Economic Geology* 83:1886–1906.  
Marikos, M. A., L. M. Nuelle, and C. M. Seeger. 1990. Geologic mapping and evaluation of the Pea Ridge iron ore mine (Washington County, Missouri) for rare-earth-element and precious metal potential—A progress report. In *The midcontinent of the United States—Permissive terrane for an Olympic Dam-type deposit*, ed. W. P. Pratt and P. K. Sims, 76–81. U.S. Geological Survey bulletin 1932.  
Megaw, P. K. M. 1999. The geology and minerals of Cerro de Mercado, Durango, Mexico. *Rocks & Minerals* 74:20–29.  
Naslund, H. R. 1983. The effect of oxygen fugacity on liquid immiscibility in iron-bearing silicate melts. *American Journal of Science* 283:1034–59.  
Naslund, H. R., R. Aguirre, F. M. Dobbs, F. J. Henríquez, and J. O. Nyström. 2000. The origin, emplacement, and eruption of ore magmas. *Ninth Congreso Geológico Chileno Actas* 2:135–39.  
Nyström, J. O., and F. Henríquez. 1994. Magmatic features of iron ores of the Kiruna type in Chile and Sweden: Ore textures and magnetite geochemistry. *Economic Geology* 89:820–39.  
Philpotts, A. R. 1967. Origin of certain iron-titanium oxide and apatite rocks. *Economic Geology* 62:303–15.  
Rhodes, A. L., and N. Oreskes. 1999. Oxygen isotope composition of magnetite deposits at El Laco, Chile: Evidence for formation from isotopically heavy fluids. In *Geology and ore deposits of the central Andes*, ed. B. Skinner, 333–51. Society of Economic Geologists special publication 7.  
Rhodes, A. L., N. Oreskes, and S. Sheets. 1999. Geology and rare-earth-element geochemistry of magnetite deposits at El Laco, Chile. In *Geology and ore deposits of the central Andes*, ed. B. Skinner, 299–332. Society of Economic Geologists special publication 7.  
Vivallo, W., F. Henríquez, and S. Espinoza. 1993. Hydrothermal alteration and related mineralization at El Laco mining district, northern Chile. *Low-temperature Metamorphism, Processes, Products and Economic Significance, Symposium IGCP Project 294*, 142–46. □