

# Evolution of the Minerals of Beryllium

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## Introduction

The elements beryllium and scandium are Roy Kristiansen's favorites and he has devoted much of his mineralogical activities to study of minerals containing Be or Sc as essential constituents. Roy has contributed to the discovery of several new Be and Sc minerals and of new localities for existing minerals. To celebrate Roy's 70<sup>th</sup> birthday, we have written this overview of the 111 species containing essential beryllium from the perspective of mineral evolution, an extension of material presented earlier (Grew and Hazen 2009, 2010).

This perspective is relatively new to mineralogical science – it envisages the critical role played by time (Zhabin 1979; Hazen et al 2008), that is, “mineral evolution frames mineralogy in a historical context” (Hazen and Ferry 2010). Mineral evolution addresses

questions such as: Were the minerals we find today present on the early Earth, over 3400 million years ago? Are some minerals that formed on early Earth no longer present? And What do changes in Earth's near-surface mineralogy through 4.5 billion years of history reveal about our planet's evolving geosphere and biosphere?

Beryllium minerals are relative late comers on Earth – the oldest reported occurrence in the geologic record is 3000 million years for beryl and emerald (Figs. 1, 2), over 1500 million years after formation of Earth, a marked contrast with several minerals of scandium: thortveitite ( $\text{Sc}_2\text{Si}_2\text{O}_7$ ), davisite ( $\text{CaScAlSiO}_6$ ) and eringaite ( $\text{Ca}_3\text{Sc}_2\text{Si}_3\text{O}_{12}$ ), which formed in the solar system before Earth (Ma et al 2011; Ma 2012).

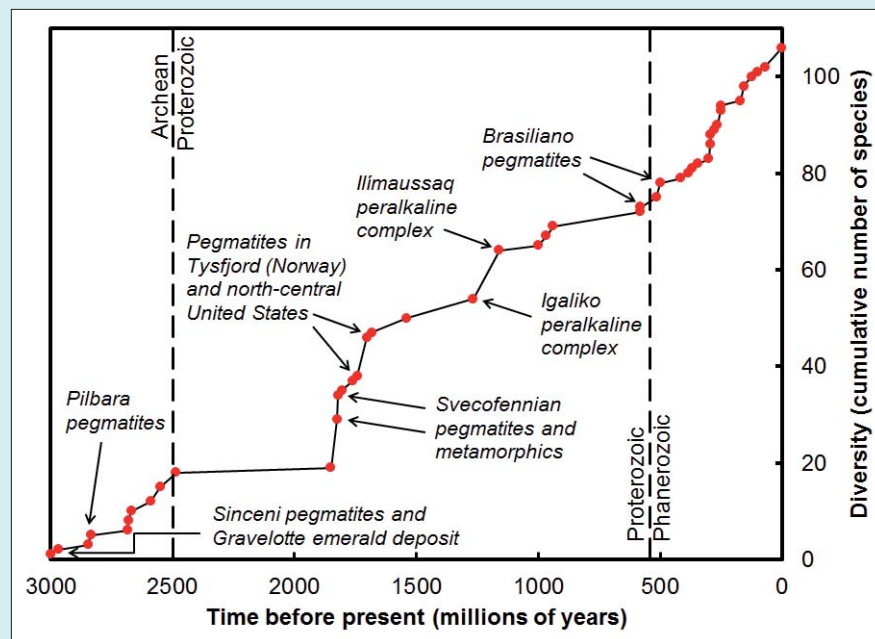


Figure 1. Plot of 106 Be minerals for which geo-chronological data are available (Grew and Hazen, unpublished data).

## The minerals of beryllium

Table 1 lists in alphabetical order the 112 minerals containing essential Be that are considered valid by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (CNMNC IMA), together with their formulae, which are largely taken from the 2012 CNMNC IMA list (the list can be downloaded from the CNMNC IMA website or the RRUFF website). We question the validity of two of the approved species, and thus we have not included them in our count. Bohseite may not be distinct from bavenite given the results reported by Lussier and Hawthorne (2011). Krivovichev et al. (2004) found that clinobaryllite could

be considered the 10-polytype of  $\text{BaBe}_2\text{Si}_2\text{O}_7$ , for which baryllite is the 20-polytype, in which case these minerals are not distinct species, but polytypes of a single species. Vinogradovite is also listed by the CNMNC IMA as a valid mineral containing essential Be,  $(\text{Na,Ca,K})_5(\text{Ti,Nb})_4(\text{Si}_6\text{BeAl})\text{O}_{26}\cdot 3\text{H}_2\text{O}$ . However, we do not consider Be an essential constituent of vinogradovite, because there is no evidence for significant Be in the type material (Semenov et al. 1956). Significant Be substitutes for Si and Al at the Si(2) site in several samples of vinogradovite from the Ilímaussaq complex (Greenland), but it is not dominant at this site, i.e.,  $\text{Si} \approx 6$ ,  $\text{Al} \approx 1.2$ , and  $\text{Be} \approx 0.8$  out of 8 atoms total at the Si(2) site (Kalsbeek & Rønsho 1992), and thus the Ilímaussaq vinogradovite would not qualify as a mineral species distinct from type vinogradovite.

None of the valid unnamed minerals (Smith & Nickel 2007) in the list updated in 2011, which is also available at the CNMNC IMA website, appears to be distinct from an approved mineral. However, there are three additional minerals included in Table 1, bringing the total to 111 valid Be minerals in our view, including IMA 2012-039 (Grice et al. 2013). Pršek et al. (2010) reported a hingganite in which Nd is dominant among the rare earth elements + yttrium, which is potentially a new species, hingganite-(Nd). Hawthorne (2002) suggested that yttrian milarite approaching the end-member  $\text{K}(\text{CaY})\text{Be}_3\text{Si}_{12}\text{O}_{30}$  in composition could be a distinct mineral. Group assignment is

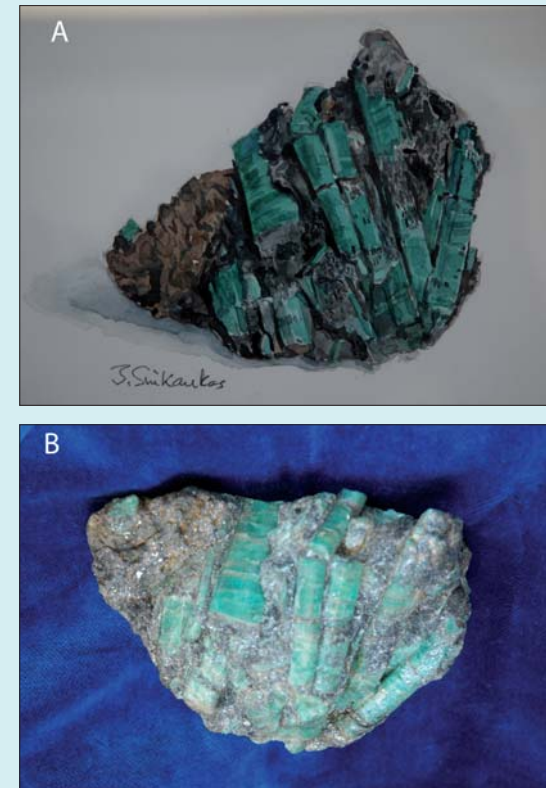


Figure 2. Emerald in mica schist matrix from Murchison greenstone belt, South Africa; 90 x 75 mm. A. Photograph of the painting by John Sinkankas, which was also published as Figure 5 of the colored section in Sinkankas (1981). B. Photograph of the specimen itself in nearly the same orientation. Both photographs are © Peter Lyckberg. The painting and specimen are in the collection of Peter Lyckberg.



Figure 3. Bertrandite,  $\text{Be}_4\text{Si}_2\text{O}_7(\text{OH})_2$ , in pseudo-hexagonal prisms from the Golconda mine, Governador Valadares, Minas Gerais, Brazil. Photograph of sample R060800 reproduced with permission from the RRUFF Project (Downs 2006).

based largely on Back and Mandarino (2008) and Mills et al. (2009).

Beryllium minerals include 66 silicates (e.g., Figs. 3-4), 27 phosphates (e.g., Figs. 5-6), 2 arsenates, 11 oxides and hydroxides (e.g., Fig. 7), 1 carbonate (Fig. 8) and 4 borates (e.g., Fig. 9).

### Some basics of mineral evolution

Zhabin (1979) was among the first to raise the possibility of mineral evolution, suggesting some parallels with biological evolution. He gave three stages of mineral formation: (1) meteoritic, (2) basaltic and (3) crustal, and noted that the succession of minerals in a given deposit repeated the succession overall on the planet. Zhabin (1979) introduced the concepts of “panchronous” minerals, which have been forming from the earliest era until the present time, “monochronous” minerals, which formed only once in the history of the Earth, and “polychronous” minerals, which formed more than once.

Hazen and his colleagues (e.g., Hazen et al 2008, 2009, 2011, 2012; Hazen and Ferry 2010) have taken the conceptualization of mineral evolution much further, emphasizing the co-evolution of minerals and life forms and



Figure 4. Chiavennite,  $\text{CaMn}^{2+}(\text{BeOH})_2\text{Si}_5\text{O}_{13} \cdot 2\text{H}_2\text{O}$ , in aggregate of pale yellow to orange spearhead-shaped blades associated with orthoclase and analcime from Tvedalen, Larvik, Vestfold, Norway. Photograph of sample R070349 reproduced with permission from the RRUFF Project (Downs 2006).

the relationship between increasing mineral diversity and the “Great Oxidation Event” and growth of supercontinents from tectonic plate movements. The mineral kingdom can be considered as an example of a nonliving system that becomes increasingly diverse with the passage of time due to three mechanisms: (1) progressive separation and concentration of elements by physicochemical processes; (2) an increase in the range of intensive variables, such as pressure, temperature, and the activities (effective concentrations) of  $\text{H}_2\text{O}$ ,  $\text{CO}_2$  and  $\text{O}_2$ ; and (3) biological activity (Hazen and Eldredge 2010). There are three eras that followed the formation of prenebular “ur-minerals” over 4600 million years ago: (1) Planetary Accretion, which extended up to 4550 million years, (2) Crust and Mantle Reworking from 4550 to 2500 million years



Figure 5. Beryllonite,  $\text{NaBe}(\text{PO}_4)_2$ , in columnar aggregate from Kunar Province, Afghanistan and in glassy fragments from the type locality of Stoneham, Maine, U.S.A. Coin diameter is ~1 cm. E.S. Grew samples and photo.

and (3) Biologically Mediated Mineralogy, from 2500 million years to the present. The eras are further divided into 10, partially overlapping stages, for example, two stages of meteorite formation at the dawn of Earth’s history 4500-4560 million years before present, whereas other stages, such as granite and pegmatite formation and plate tectonics, began on the Early Earth, most likely after 4000 million years ago and continue to the present day.

### Background on beryllium

Beryllium is a quintessential crustal element: it is highly enriched in the upper continental crust compared to other reservoirs, i.e., 2.1 parts per million vs. 1.4 parts per million in the lower crust and 70 parts per billion in primitive mantle (Rudnick and Gao 2005; Palme and O’Neill 2004). However, less than 10 parts per million are rarely sufficient to stabilize a mineral of which Be is an essential constituent (e.g., Grew 2002). Normally further enrichment by at least an order of magnitude is necessary for the more common Be minerals, notably beryl, to appear, for example, 70 parts per million in granitic pegmatites (Evensen and London 2002; London and Evensen 2002). Consequently, important factors in the formation of Be minerals and the analysis of their occurrence in geologic time are:

- 1) With very rare exception Be in crustal material must be concentrated by processes such as fractionation and hydrothermal activity in order for Be minerals to form.
- 2) Formation of diverse suites of new Be minerals has been realized by processes such hydrothermal reworking and metamorphism of preexisting Be minerals, in some cases after a substantial time interval.
- 3) Analysis of the occurrence of Be minerals in geologic time must take into account issues of preservation, biases in sampling, and the fact that Be minerals may be forming in certain environments today that cannot be currently observed.

### Some caveats in interpreting the geologic record

In reporting the first occurrences of Be minerals in the geologic record, we are dealing with sample bias problems similar to those faced by paleontologists. Most importantly, the geologic record is incomplete. As pointed out by Barton & Young (2002), deposits of Be minerals formed on or near the Earth’s surface would be lost to erosion, i.e., beryllium minerals could have formed in these environments in the Proterozoic or earlier, but did not survive.



Figure 6. Väyrynenite,  $\text{BeMn}^{2+}\text{PO}_4(\text{OH})$ , forming pink mass with defined cleavage planes from the Viitaniemi pegmatite, Eräjärvi, Orivesi, Finland. Photograph of sample R050243 reproduced with permission from the RRUFF Project (Downs 2006).



Figure 7. Magnesiotaaffeite-6N’3S,  $\text{BeMg}_6\text{Al}_6\text{O}_{12}$ , as a greyish purple flattened tabular hexagonal crystal from Ratnapura District, Sri Lanka. Photograph of sample R090019 reproduced with permission from the RRUFF Project (Downs 2006).

Geological and mineralogical investigations are not evenly spread over the globe, and this also is a source of potential bias into the reported distributions. For example, the presence of numerous centers of mineralogical research and mining activity in Scandinavia undoubtedly played a role in stimulating the many discoveries of Be minerals in the Svecofennian province, Oslo igneous province, and Neoproterozoic pegmatites in Norway.

#### Beryllium minerals in the Archean eon (4000 to 2500 million years)

Pegmatites are the primary sources of Be minerals found in Archean rocks. The two oldest reported Be minerals are beryl and phenakite from southern Africa. Beryl is reported in pegmatites coeval with the Sinceni pluton, Swaziland, and thus dated at  $3000 \pm 100$  Ma using Rb-Sr isotopes (Trumbull 1993); an older age for the Sinceni Pluton suggested by a  $3074 \pm 4$  Ma  $^{207}\text{Pb}/^{206}\text{Pb}$  zircon evaporation age (Maphalala & Kröner 1993) needs confirmation (Trumbull 1993). Emerald and phenakite occur in biotite schist associated with "albitite pegmatoid" and phenakite in the pegmatoid in the Gravelotte emerald deposit (Figs. 1; 2), Murchison greenstone belt, South Africa (Robb & Robb 1986; Grundmann & Morteani 1989) for which the zircon age of  $2969 \pm 17$  Ma on the Discovery Granite (Poujol



Figure 8. Niveolanite,  $\text{NaBeCO}_3(\text{OH}) \cdot 2\text{H}_2\text{O}$ , as a fibrous aggregate 1.5 cm across, part of type specimen, from Mont Saint-Hilaire, Rouville, Montérégie, Québec, Canada. Horváth Collection HC11128. Photo © László Horváth. Reproduced with permission courtesy of László Horváth.

2001) probably best dates crystallization of this "pegmatoid." Granitic pegmatites ranging in age from 2850 to 2550 million years associated with greenstone belts in the Pilbara (Fig. 1) and Yilgarn Cratons, Western Australia (e.g., Sweetapple & Collins 2002; Jacobson et al. 2007) and the Superior Province, Ontario and Manitoba, Canada (e.g., Breaks et al. 2005; Černý 2005) contain 7 silicate and 3 phosphate Be minerals, evidence that the differentiation of granitic melts was more than sufficient to enrich resulting pegmatites to give a diversity of Be minerals in Archean orogenic belts.

Peralkaline rocks are very rare in Archean complexes, and there are only two reports of Be minerals in peralkaline rocks of that era – meliphanite and behoite as metasomatic minerals associated with nepheline syenite of the Sakharjok complex, Keivy Alkaline Field, Kola Peninsula, Russia (Bel'kov & Denisov 1968; Batiyeva & Bel'kov 1984; Lyalina et al. 2009), which was dated at  $2682 \pm 10$  Ma (Zozulya et al. 2005).

Metamorphic Be minerals are also reported from just one locality in strictly Archean rocks: chrysoberyl in a granulite-facies plagioclase-biotite-quartz gneiss 2640–2649 million years in age, Yilgarn craton, Australia (Downes & Bevan 2002). However, two Be silicates and one Be oxide are found in granulite-facies anatectic



Figure 9. Rhodizite,  $\text{KBe}_4\text{Al}_4(\text{B}_{11}\text{Be})\text{O}_{28}$ , pale yellow crystal with pink tourmaline (rúbellite) from Manjaka, Sahatany Pegmatite Field, Antananarivo Province, Madagascar. Coin diameter is ~1 cm. E.S. Grew sample (gift of François Fontan) and photo.

veins of earliest Paleoproterozoic age (2485 million years) in the Archean Napier complex: khmaralite (and beryllian sapphirine, Fig. 10), surinamite (Fig. 11) and magnesiotaaffeite-6N'3S (Grew et al. 2000, 2006).

Based on reported occurrences, by the earliest Paleoproterozoic, there were 18 Be minerals (Fig. 1), 16% of the total known. Fifteen of these minerals have been reported in rocks as young as 0.15–33 million years; largely in the Alpine-Himalayan belt, and could be forming today (see below).

#### Beryllium minerals in the Proterozoic eon (2500 to 542 million years)

Reported first occurrences in the geologic record of Be minerals suggest four periods of marked increases in species diversity generally separated by more extended periods of modest increases (Fig. 1):

1. Metamorphic and metasomatic rocks and granite pegmatites both between ~1800 and ~1850 million years in age in the Svecofennian province of Sweden and Finland (e.g., Holtstam and Langhof 1999; Jonsson 2004; Holtstam and Andersson 2007; Nysten and Gustafsson 1993; Lahti 1989; Lindroos et al. 1996).



Figure 10. Beryllian sapphirine (dark blue, Spr) separated from quartz (gray, Qtz) by selvages of sillimanite (white) and garnet (pink, Grt). With increasing Be content, beryllian sapphirine acquires the superstructure characteristic of khmaralite,  $\text{Mg}_4(\text{Mg}_3\text{Al})\text{O}_4[\text{Si}_5\text{Be}_2\text{Al}_3]\text{O}_{36}$ . From pegmatite in Casey Bay, Enderby Land, Antarctica. Coin diameter is ~1 cm. E.S. Grew sample and photo.

2. Pegmatites associated with the Tysfjord granite, 1742 Ma, Nordland, Norway (Husdal 2008, 2011) and Harney granite, Black Hills, South Dakota, USA, 1700 Ma (e.g., Campbell and Roberts 1986; Norton and Redden 1990; Dahl and Foland 2008), plus the Animilie Red Ace pegmatite, Penokean Orogen, Wisconsin, USA, 1760 Ma (e.g., Falster et al. 2001; Sirbescu et al. 2008).
3. Ilímaussaq and Igaliko peralkaline complexes, Gardar Province, southwest Greenland, 1160 Ma and 1273 Ma, respectively (e.g., Petersen and Secher 1993; Krumrei et al. 2006; McCreath et al. 2012)
4. Pegmatites associated with the late Neoproterozoic-Cambrian Brasiliano orogeny, Minas Gerais, Brazil, 585–500 Ma (e.g., Atencio 2000; Morteani et al. 2000; Pedrosa-Soares et al. 2011).

The Svecofennian province is unrivaled in its diversity of reported Be minerals: 17 are first reported in the geological record from this province and a total of 30 species are reported in all (e.g., väyrynenite, Fig. 6). A major contributor to this diversity is Långban and similar deposits in the Bergslagen ore region of central Sweden. Their history began with submarine volcanic-hydrothermal

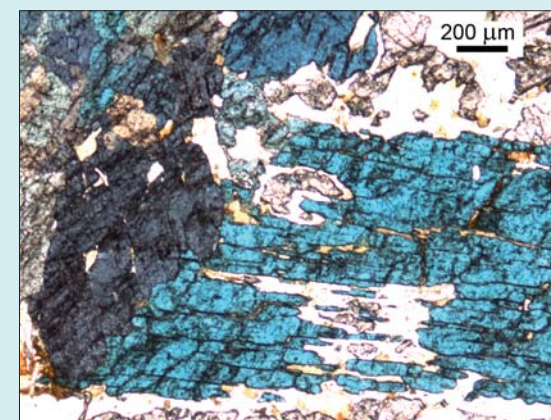


Figure 11. Surinamite,  $\text{Mg}_3\text{Al}_3\text{O}(\text{Si}_3\text{BeAlO}_{15})$ , showing purple, blue and greenish pleochroism in plane-polarized light under the microscope. Surinamite formed from breakdown of beryllian sapphirine and khmaralite during high-grade metamorphism of pegmatite. From Casey Bay, Enderby Land, Antarctica. E.S. Grew sample and photomicrograph.

exhalation and precipitation in a back-arc setting at 1890 Ma followed first by regional amphibolite-facies metamorphism and vein formation through remobilization at about 1850-1800 Ma (Svecofennian event) and then by brittle deformation possibly at about 1000 Ma. Multiple reworking of an unusual mix of constituents in an oxidizing environment where the chalcophile elements Pb, Sb, As and Sn combined with Be in oxides and silicates resulted in several minerals that are “endemic” (“monochronous” of Zhabin 1979) – not reported elsewhere (e.g., welshite, Fig. 12).

Pegmatites in Nordland, South Dakota and Wisconsin are combined in this analysis because of their unusual Be minerals and their age of 1700-1760 million years. Many of the new minerals are secondary, derived from the alteration of primary Be minerals, in most cases, beryl.

Pegmatites associated with the Late Proterozoic-Cambrian Brasiliano orogeny also carry a diverse Be mineral assemblage, e.g., moraesite (Fig. 13), in part due to an addition of 7 reported new minerals, 4 of which are secondary phosphates of the roscherite group.

The Ilímaussaq and Igaliko peralkalic intrusions constitute another premier locality for Be minerals, both in new minerals introduced and in overall diversity. However, in contrast to Långban, few of the minerals are “monochronous” (Zhabin 1979) such as sørensenite (Fig. 14). Instead, many of the most unusual minerals (e.g., tugtupite, Fig.

15) have been reported in younger peralkaline complexes, notably Khibiny and Lovozero on the Kola Peninsula (362-370 Ma) and Mont Saint-Hilaire, Quebec (124 Ma) – examples of “polychronous” minerals (Zhabin 1979).

#### Beryllium minerals in the Phanerozoic eon (542 million years to the present)

The reported number of Be minerals increases steadily and relatively steeply in the Phanerozoic (Fig. 1). Granitic pegmatites, metasomatic deposits and peralkaline intrusions all contributed to the steady increase. However, the proportion of new minerals relative to the total number of Be minerals reported is significantly lower at localities rich in Be minerals, e.g., Mont Saint-Hilaire (2 new, e.g., niveolanite, Fig. 8, 19 total) vs. Ilímaussaq and Igaliko peralkaline intrusions (14 new, 19 total). Adding to the increase are (1) reworking of older Be deposits – høgtuvaite formed by Caledonian metamorphism (414 Ma) of a Be-rich precursor of Proterozoic age (1800 Ma, Grauch et al. 1994; Skår 2002) and (2) a geologic environment not reported previously, volcanic rocks in the Eifel district, Germany (e.g., Schminke 2007, Lengauer et al. 2009) and the Roman volcanic province (e.g., Della Ventura et al. 1992).

Bearsite, glucine and jeffreyite are the only Be minerals of the 112 in the 2012 CNMNC IMA list for which a date could not be assigned, even approximately. The first two are supergene minerals. Bearsite formed in the zone of

oxidation of the Bota-Burum uranium deposit (Kazakhstan) hosted by Devonian volcanic rocks (Kopchenko and Sidorenko 1962; Pekov 1998), but it is unlikely the supergene minerals in this deposit are Devonian. Glucine formed where weathering had penetrated a highly fractured and brecciated beryl-fluorite deposit in the Boevskoye ore field, central Urals, Russia (Ginzberg et al. 1966, Pekov 1998), and like bearsite, would be much younger than the Paleozoic rocks hosting it. As regards jeffreyite, did it form in a rodingitized granite dike cutting an Ordovician ophiolite (Wares and Martin 1980), a unique occurrence for a Be mineral, as Grice and Robinson (1984) reported? Or could introduction of Be into the rodingitized granite be related to later alkaline intrusives (R. F. Martin, personal communication 2009)?

#### Could any beryllium minerals be forming now?

Beryllium minerals formed by geologic processes that are in progress at the present time are probably forming now, for example, in continental collision zones and volcanic provinces associated with cooling plutons and magma chambers. This includes most if not all of the 20 Be minerals reported in granitic pegmatites in the Alpine and Himalayan orogenic belts (e.g., beryllonite, Fig. 5), some of which formed as recently as 7 Ma (Pakistan Himalaya, Laurs et al. 1998). Collision is ongoing in the Himalayan belt, so that pegmatites with Be minerals could be

forming at depth. Although quiescent today, the Roman volcanic province was active up until 40 000 years ago (e.g., Della Ventura et al. 1992), so the 5 minerals from this province could also be considered as candidates for minerals that could be forming now.

Among the less obvious candidates is surinamite (Fig. 11), a metamorphic mineral restricted to relatively deep-seated rocks (> 8 kbar, e.g., Grew 2002). It is reported in rocks no younger than 1050 Ma (Chimwala, Chipata district, Zambia, de Roever and Vrána 1985; Johnson et al. 2006). If surinamite were forming today, it is unlikely it would be exposed any time soon.

The least obvious candidates for potential new discoveries would be a subset of the 37 Be minerals that have been reported from only one locality, for example, the Långban deposit. Although similar deposits with minerals of Be, Sb, As, Pb are known elsewhere, e.g., Franklin and Sterling, New Jersey; Kombat Mine, Namibia; and Starlera, Val Ferrera, Switzerland (Brugger and Gieré 1999), none have produced the diversity in Be minerals for which Långban is famous. The Tip Top mine in the Black Hills, South Dakota, is another such locality. Well-studied granitic pegmatites with secondary Be minerals are too numerous to enumerate, but there are five Be minerals at the Tip Top mine that have not been reported from any of them. In summary there are Be minerals for which the chances are relatively low that they are forming now, even at depth.



Figure 12. Welshite,  $\text{Ca}_2[\text{Mg}_6(\text{Sb}^{5+})_3]\text{O}_{10}[\text{Si}_2\text{Be}_3\text{Al}(\text{Fe}^{3+})_2\text{O}_7]$ , crystal 3.5x2 mm, from Långban, Sweden. Photograph by Erik Jonsson. Reproduced with permission courtesy of the Swedish Museum of Natural History.

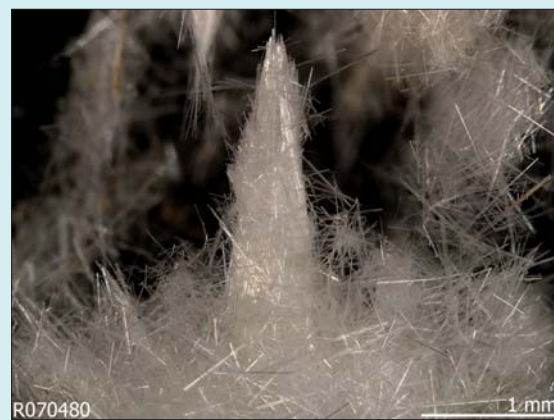


Figure 13. Moraesite,  $\text{Be}_3(\text{PO}_4)_3(\text{OH}) \cdot 4\text{H}_2\text{O}$ , needles, from Itinga, Minas Gerais, Brazil. Photograph of sample R070480 reproduced with permission from the RRUFF Project (Downs 2006).



Figure 14. Sørensenite,  $\text{Na}_2\text{Be}_2\text{Sn}(\text{Si}_2\text{O}_7)_2 \cdot 2\text{H}_2\text{O}$ , pink, columnar masses from Kvaneffjeld, Ilímaussaq complex, West Greenland. Coin diameter is ~1 cm. E.S. Grew sample (gift of Ted Johnson) and photo.



Figure 15. Tugtupite,  $\text{Na}_2\text{BeAlSi}_2\text{O}_{12}\text{Cl}$ , from Kvaneffjeld, Ilímaussaq, Greenland. Photograph of sample R050562 reproduced with permission from the RRUFF Project (Downs 2006).

## Conclusion

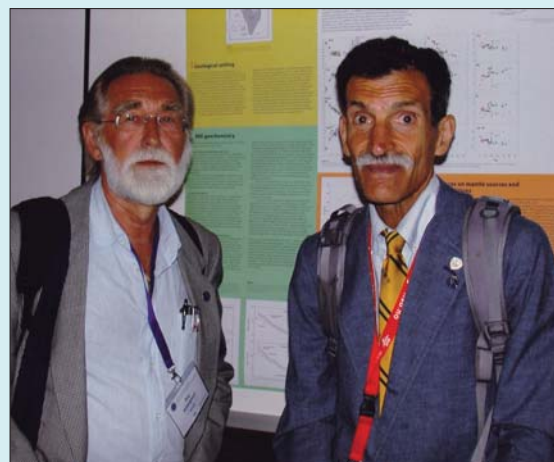
Beryllium minerals result from a variety of processes that concentrate Be and combine it with other constituents under favorable conditions. Diversity in Be mineral assemblages appears to require special circumstances. For example, diversity in granitic pegmatites depends not only on degree of fractionation, but also on alteration and reworking of pre-existing Be minerals, commonly beryl, to create a host of secondary minerals. Diversity in deposits such as Långban depends not only on combining elements such as Be with Sn, As, Sb and Pb, but also on a relatively oxidizing environment in which the latter four form oxides and silicates instead of sulfides and sulfosalts. Currie et al. (1986) suggested that the diversity of rare minerals in the Mont Saint-Hilaire intrusive might be due to the interaction of magma with Cl brines, i.e., again an appeal to special circumstances to explain mineralogical diversity.

The reported first occurrences of Be minerals in the geologic record show an episodic distribution. This feature is particularly marked in the Proterozoic, with spikes at 1800-1850 Ma, 1715-1760 Ma, 1160 Ma and 560 Ma, but the stepwise aspect of the cumulative curve is also evident in the Phanerozoic and Archean (Fig. 1). Many of the spikes are due to Be minerals found in association with orogenic events, notably Svecofennian, Penokean, Brasiliano, and Appalachian, whereas others are associated with major peralkaline intrusions, most notably the Ilímaussaq. However, it must be emphasized that there is considerable diversity in Be minerals in younger orogenic belts (Alpine-Himalayan – mostly Cenozoic) and peralkaline complexes (Khibiny and Lovozero in the Devonian; Chilwa and Mont Saint-Hilaire in the Cretaceous), although relatively few new minerals have been reported from the younger occurrences. This might be taken to mean that the possibilities for forming new Be compounds in geologic systems were pretty much exhausted by the end of the Cretaceous, and the increase in recent time is simply due to the addition of Pleistocene volcanic occurrences to the rock record that is available for sampling. But taking the longer view, the Cenozoic may simply have been too short a time period for the rare combination of special circumstances that would be needed to produce another

Långban, Ilímaussaq or Tip Top Mine: a time interval of 65.5 Ma for the Cenozoic vs. nearly 2000 Ma for the Proterozoic.

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Table 1. List of beryllium minerals

Number	Mineral name	Formula	Supergroup or Group
Be1	Alflarsenite	NaCa <sub>2</sub> Be <sub>3</sub> Si <sub>4</sub> O <sub>13</sub> (OH)·2H <sub>2</sub> O	
Be2	Almarudite	K(□,Na) <sub>2</sub> (Mn,Fe,Mg) <sub>2</sub> [(Be,Al) <sub>3</sub> Si <sub>12</sub> ]O <sub>30</sub>	Milarite
Be3	Aminoffite	Ca <sub>3</sub> (BeOH) <sub>2</sub> Si <sub>3</sub> O <sub>10</sub>	
Be4	Asbecasite	Ca <sub>3</sub> TiAs <sub>6</sub> Be <sub>2</sub> Si <sub>2</sub> O <sub>20</sub>	
Be5	Atencioite	Ca <sub>2</sub> (Fe <sup>2+</sup> ) <sub>3</sub> Mg <sub>2</sub> Be <sub>4</sub> (PO <sub>4</sub> ) <sub>6</sub> (OH) <sub>4</sub> ·6H <sub>2</sub> O	Roscherite
Be6	Babefphite	BaBePO <sub>4</sub> F	
Be7	Barylite	BaBe <sub>2</sub> Si <sub>2</sub> O <sub>7</sub>	
Be8	Bavenite	Ca <sub>4</sub> Be <sub>2</sub> Al <sub>2</sub> Si <sub>9</sub> O <sub>26</sub> (OH) <sub>2</sub>	
Be9	Bazzite	Be <sub>3</sub> (Sc,Fe <sup>3+</sup> ,Mg) <sub>2</sub> Si <sub>6</sub> O <sub>18</sub> ·Na <sub>x</sub> ·nH <sub>2</sub> O	Beryl
Be10	Bearsite	Be <sub>2</sub> (AsO <sub>4</sub> )(OH)·4H <sub>2</sub> O	
Be11	Behoite	Be(OH) <sub>2</sub>	
Be12	Berberite	Be <sub>2</sub> (BO <sub>3</sub> )(OH)·H <sub>2</sub> O	
Be13	Bergslagite	CaBeAsO <sub>4</sub> (OH)	Herderite
Be14	Bertrandite	Be <sub>4</sub> Si <sub>2</sub> O <sub>7</sub> (OH) <sub>2</sub>	
Be15	Beryl	Be <sub>3</sub> Al <sub>2</sub> Si <sub>6</sub> O <sub>18</sub>	Beryl
Be16	Beryllite	Be <sub>3</sub> (SiO <sub>4</sub> )(OH) <sub>2</sub> ·H <sub>2</sub> O	
Be17	Beryllonite	NaBe(PO <sub>4</sub> )	
Be18	Bityite	CaLiAl <sub>2</sub> (Si <sub>2</sub> BeAl)O <sub>10</sub> (OH) <sub>2</sub>	Mica
	Bohseite	Ca <sub>4</sub> Be <sub>3</sub> AlSi <sub>9</sub> O <sub>25</sub> (OH) <sub>3</sub>	Cf. bavenite
Be19	Bromellite	BeO	
Be20	Bussyite-(Ce)	(Ce,REE) <sub>3</sub> (Na,H <sub>2</sub> O) <sub>6</sub> MnSi <sub>9</sub> Be <sub>5</sub> (O,OH) <sub>30</sub> F <sub>4</sub>	
Be21	Chiavennite	CaMn <sup>2+</sup> (BeOH) <sub>2</sub> Si <sub>5</sub> O <sub>13</sub> ·2H <sub>2</sub> O	Zeolite
Be22	Chkalovite	Na <sub>2</sub> BeSi <sub>2</sub> O <sub>6</sub>	
Be23	Chrysoberyl	BeAl <sub>2</sub> O <sub>4</sub>	
	Clinobarylite	BaBe <sub>2</sub> Si <sub>2</sub> O <sub>7</sub>	Cf. barylite
Be24	Clinobehoite	Be(OH) <sub>2</sub>	
Be25	Danalite	Be <sub>3</sub> (Fe <sup>2+</sup> ) <sub>4</sub> (SiO <sub>4</sub> ) <sub>3</sub> S	Cancrinite-Sodalite
Be26	Ehrleite	Ca <sub>2</sub> ZnBe(PO <sub>4</sub> ) <sub>2</sub> (PO <sub>3</sub> OH)·4H <sub>2</sub> O	
Be27	Eirikite	Kna <sub>6</sub> Be <sub>2</sub> (Si <sub>15</sub> Al <sub>3</sub> )O <sub>39</sub> F <sub>2</sub>	Leifite
Be28	Epididymite	Na <sub>2</sub> Be <sub>3</sub> Si <sub>6</sub> O <sub>15</sub> ·H <sub>2</sub> O	
Be29	Euclase	BeAlSiO <sub>4</sub> (OH)	
Be30	Eudidymite	Na <sub>2</sub> Be <sub>3</sub> Si <sub>6</sub> O <sub>15</sub> ·H <sub>2</sub> O	
Be31	Faheyite	Be <sub>2</sub> Mn <sup>2+</sup> (Fe <sup>3+</sup> ) <sub>2</sub> (PO <sub>4</sub> ) <sub>4</sub> ·6H <sub>2</sub> O	
Be32	Ferrotaaffeite-2N'2S	Be(Fe <sup>2+</sup> ,Mg,Zn) <sub>3</sub> Al <sub>8</sub> O <sub>16</sub>	Högbomite
Be33	Ferrotaaffeite-6N'3S	Be(Fe <sup>2+</sup> ) <sub>2</sub> Al <sub>6</sub> O <sub>12</sub>	Högbomite
Be34	Footemineite	Ca <sub>2</sub> (Mn <sup>2+</sup> ) <sub>5</sub> Be <sub>4</sub> (PO <sub>4</sub> ) <sub>6</sub> (OH) <sub>4</sub> ·6H <sub>2</sub> O	Roscherite

Be35	Fransoletite	$\text{Ca}_3\text{Be}_2(\text{PO}_4)_2(\text{PO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$	
Be36	Friedrichbeckeite	$\text{K}(\square\text{Na})\text{Mg}_2(\text{Be}_2\text{Al})\text{Si}_{12}\text{O}_{30}$	Milarite
Be37	Gadolinite-(Ce)	$\text{Ce}_2\text{Fe}^{2+}\text{Be}_2\text{O}_2(\text{SiO}_4)_2$	Gadolinite-Datolite
Be38	Gadolinite-(Y)	$\text{Y}_2\text{Fe}^{2+}\text{Be}_2\text{O}_2(\text{SiO}_4)_2$	Gadolinite-Datolite
Be39	Gainesite	$\text{Na}_2(\text{Be},\text{Li})(\text{Zr},\text{Zn})_2(\text{PO}_4)_4 \cdot 1.5\text{H}_2\text{O}$	Gainesite
Be40	Genthelvite	$\text{Be}_3\text{Zn}_4(\text{SiO}_4)_3\text{S}$	Cancrinite-Sodalite
Be41	Glucine	$\text{CaBe}_4(\text{PO}_4)_2(\text{OH})_4 \cdot 0.5\text{H}_2\text{O}$	
Be42	Greifensteinite	$\text{Ca}_2(\text{Fe}^{2+})_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$	Roscherite
Be43	Gugiaite	$\text{Ca}_2\text{BeSi}_2\text{O}_7$	Melilite
Be44	Guimarãesite	$\text{Ca}_2\text{Zn}_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$	Roscherite
Be45	Hambergite	$\text{Be}_2\text{BO}_3(\text{OH})$	
Be46	Harstigitite	$\text{Ca}_6\text{Be}_4\text{Mn}^{2+}(\text{SiO}_4)_2(\text{Si}_2\text{O}_7)_2(\text{OH})_2$	
Be47	Helvite	$\text{Be}_3(\text{Mn}^{2+})_4(\text{SiO}_4)_3\text{S}$	Cancrinite-Sodalite
Be48	Herderite	$\text{CaBePO}_4(\text{F},\text{OH})$	Herderite
Be49	Hingganite-(Ce)	$\text{BeCe}(\text{SiO}_4)\text{OH}$	Gadolinite-Datolite
Be50	“Hingganite-(Nd)”	$\text{BeNd}(\text{SiO}_4)\text{OH}$	Gadolinite-Datolite
Be51	Hingganite-(Y)	$\text{BeY}(\text{SiO}_4)\text{OH}$	Gadolinite-Datolite
Be52	Hingganite-(Yb)	$\text{BeYb}(\text{SiO}_4)\text{OH}$	Gadolinite-Datolite
Be53	Høgtuvaite	$\text{Ca}_4[(\text{Fe}^{2+})_6(\text{Fe}^{3+})_6]\text{O}_4[\text{Si}_8\text{Be}_2\text{Al}_2\text{O}_{36}]$	Sapphirine
Be54	Hsianghualite	$\text{Li}_2\text{Ca}_3\text{Be}_3(\text{SiO}_4)_3\text{F}_2$	Zeolite
Be55	Hurlbutite	$\text{CaBe}_2(\text{PO}_4)_2$	
Be56	Hyalotekite	$(\text{Pb},\text{Ba},\text{K})_4(\text{Ca},\text{Y})_2(\text{B},\text{Be})_2(\text{Si},\text{B})_2\text{Si}_8\text{O}_{28}\text{F}$	
Be57	Hydroxylherderite	$\text{CaBePO}_4(\text{OH})$	Herderite
Be58	Jeffreyite	$(\text{Ca},\text{Na})_2(\text{Be},\text{Al})\text{Si}_2(\text{O},\text{OH})_7$	
Be59	Joesmithite	$\text{Pb}^{2+}\text{Ca}_2(\text{Mg}_3\text{Fe}^{3+})_2(\text{Si}_6\text{Be}_2)\text{O}_{22}(\text{OH})_2$	Amphibole
Be60	Khmaralite	$\text{Mg}_4(\text{Mg}_3\text{Al}_9)\text{O}_4[\text{Si}_5\text{Be}_2\text{Al}_5\text{O}_{36}]$	Sapphirine
Be61	Kyzylkumite	$\text{Be}(\text{V}^{3+})_2\text{TiO}_6$	
Be62	Leifite	$\text{Na}_7\text{Be}_2(\text{Si}_{15}\text{Al}_3)\text{O}_{39}(\text{F},\text{OH})_2$	Leifite
Be63	Leucophanite	$\text{NaCaBeSi}_2\text{O}_6\text{F}$	
Be64	Liberite	$\text{Li}_2\text{BeSiO}_4$	
Be65	Londonite	$\text{CsBe}_4\text{Al}_4(\text{B}_{11}\text{Be})\text{O}_{28}$	
Be66	Lovdarite	$\text{K}_2\text{Na}_6\text{Be}_4\text{Si}_{14}\text{O}_{36} \cdot 9\text{H}_2\text{O}$	
Be67	Magnesiotaaffeite-2N'2S	$\text{BeMg}_3\text{Al}_8\text{O}_{16}$	Högbomite
Be68	Magnesiotaaffeite-6N'3S	$\text{BeMg}_2\text{Al}_6\text{O}_{12}$	Högbomite
Be69	Makarochkinite	$\text{Ca}_4[(\text{Fe}^{2+})_8(\text{Fe}^{3+})_2\text{Ti}_2]\text{O}_4[\text{Si}_8\text{Be}_2\text{Al}_2\text{O}_{36}]$	Sapphirine
Be70	Mariinskite	$\text{BeCr}_2\text{O}_4$	
Be71	Mccrillsite	$\text{NaCs}(\text{Be},\text{Li})\text{Zr}_2(\text{PO}_4)_4 \cdot 1-2\text{H}_2\text{O}$	Gainesite
Be72	Meliphanite	$\text{Ca}_4(\text{Na},\text{Ca})\text{Be}_4\text{AlSi}_7\text{O}_{24}(\text{F},\text{O})_4$	
Be73	Milarite	$\text{Kca}_2(\text{Be}_2\text{AlSi}_{12})\text{O}_{30} \cdot \text{H}_2\text{O}$	Milarite
Be74	Minasgeraisite-(Y)	$\text{CaBe}_2\text{Y}_2\text{Si}_2\text{O}_{10}$	Gadolinite-datolite

Be75	Moraesite	$\text{Be}_2(\text{PO}_4)(\text{OH}) \cdot 4\text{H}_2\text{O}$	
Be76	Mottanaite-(Ce)	$\text{Ca}_4(\text{CeCa})\text{AlBe}_2(\text{Si}_4\text{B}_4\text{O}_{22})\text{O}_2$	Hellandite
Be77	Nabesite	$\text{Na}_2\text{BeSi}_4\text{O}_{10} \cdot 4\text{H}_2\text{O}$	Zeolite
Be78	Niveolanite	$\text{NaBeCO}_3(\text{OH}) \cdot 2\text{H}_2\text{O}$	
Be79	Odintsovite	$\text{K}_2\text{Na}_4\text{Ca}_3\text{Ti}_2\text{Be}_4\text{Si}_{12}\text{O}_{38}$	
Be80	Oftedalite	$\text{KSc}_2(\text{Be},\text{Al})_3\text{Si}_{12}\text{O}_{30}$	Milarite
Be81	Pahasapaite	$\text{Li}_8(\text{Ca},\text{Li},\text{K})_{10}\text{Be}_{24}(\text{PO}_4)_{24} \cdot 38\text{H}_2\text{O}$	Zeolite
Be82	Parafransoletite	$\text{Ca}_3\text{Be}_2(\text{PO}_4)_2(\text{PO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$	
Be83	Pezzottaite	$\text{CsLiBe}_2\text{Al}_2\text{Si}_6\text{O}_{18}$	Beryl
Be84	Phenakite	$\text{Be}_2\text{SiO}_4$	Willemite
Be85	Rhodizite	$\text{Kbe}_4\text{Al}_4(\text{B}_{11}\text{Be})\text{O}_{28}$	
Be86	Roggianite	$\text{Ca}_2\text{BeAl}_2\text{Si}_4\text{O}_{13}(\text{OH})_2 \cdot n\text{H}_2\text{O}$ (n < 2.5)	Zeolite
Be87	Roscherite	$\text{Ca}_2(\text{Mn}^{2+})_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$	Roscherite
Be88	Ruifrancoite	$\text{Ca}_2(\square, \text{Mn}^{2+})_2(\text{Fe}^{3+}, \text{Mn}^{2+}, \text{Mg})_4\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$	Roscherite
Be89	Samfowlerite	$\text{Ca}_{14}(\text{Mn}^{3+})_3\text{Zn}_3\text{Be}_2\text{Be}_6\text{Si}_{14}\text{O}_{52}(\text{OH})_6$	
Be90	Selwynite	$\text{NaKBeZr}_2(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$	Gainesite
Be91	Semenovite-(Ce)	$(\text{Na},\text{Ca})_9\text{Fe}^{2+}\text{Ce}_2(\text{Si},\text{Be})_{20}(\text{O},\text{OH},\text{F})_{48}$	
Be92	Sørensenite	$\text{Na}_4\text{Be}_2\text{Sn}(\text{Si}_3\text{O}_9)_2 \cdot 2\text{H}_2\text{O}$	
Be93	Sphaerobrandite	$\text{Be}_3\text{SiO}_4(\text{OH})_2$	
Be94	Stoppaniite	$(\text{Fe}^{2+})_2\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$	Beryl
Be95	Strontiohurlbutite	$\text{SrBe}_2(\text{PO}_4)_2$	
Be96	Surinamite	$\text{Mg}_3\text{Al}_3\text{O}(\text{Si}_3\text{BeAlO}_{15})$	Sapphirine
Be97	Sverigeite	$\text{NaBe}_2(\text{Mn}^{2+})_2\text{SnSi}_3\text{O}_{12}(\text{OH})$	
Be98	Swedenborgite	$\text{NaBe}_4\text{Sb}^{5+}\text{O}_7$	
Be99	Telyushenkoite	$\text{CsNa}_6\text{Be}_2(\text{Si}_{15}\text{Al}_3)\text{O}_{39}\text{F}_2$	Leifite
Be100	Tiptopite	$\text{K}_2(\text{Li},\text{Na},\text{Ca})_6(\text{Be}_6\text{P}_6)\text{O}_{24}(\text{OH})_2 \cdot 1.3\text{H}_2\text{O}$	Cancrinite-Sodalite
Be101	Trimerite	$\text{CaBe}_3(\text{Mn}^{2+})_2(\text{SiO}_4)_3$	
Be102	Tugtupite	$\text{Na}_4\text{BeAlSi}_4\text{O}_{12}\text{Cl}$	Cancrinite-Sodalite
Be103	Tvedalite	$\text{Ca}_4\text{Be}_3\text{Si}_6\text{O}_{17}(\text{OH})_4 \cdot 3\text{H}_2\text{O}$	
Be104	Uralolite	$\text{Ca}_2\text{Be}_4(\text{PO}_4)_3(\text{OH})_3 \cdot 5\text{H}_2\text{O}$	
Be105	Väyrynenite	$\text{BeMn}^{2+}\text{PO}_4(\text{OH})$	
	Vinogradovite	Not a Be mineral – see text	
Be106	Wawayandaite	$\text{Ca}_6\text{Be}_9(\text{Mn}^{2+})_2\text{Bsi}_6\text{O}_{23}(\text{OH},\text{Cl})_{15}$	
Be107	Weinebeneite	$\text{CaBe}_3(\text{PO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$	Zeolite
Be108	Welshite	$\text{Ca}_4[\text{Mg}_9(\text{Sb}^{5+})_3]\text{O}_4[\text{Si}_6\text{Be}_3\text{Al}(\text{Fe}^{3+})_2\text{O}_{36}]$	Sapphirine
Be109	Zanazziite	$\text{Ca}_2\text{Mg}_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$	Roscherite
Be110	Ferrochiavennite	$\text{Ca}_{1-2}\text{Fe}[(\text{Si},\text{Al},\text{Be})_5\text{Be}_2\text{O}_{13}(\text{OH})_2] \cdot 2\text{H}_2\text{O}$	Zeolite
Be111	Unnamed	$\text{K}(\text{CaY})\text{Be}_3\text{Si}_{12}\text{O}_{30}$	Milarite