The vesuvianites of Kristiansand, southern Norway

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The city of Kristiansand lies on the southernmost tip of Norway, and despite being a small town with around 70 000 inhibitants, it is easily accessible from anywhere in Norway and abroad. The airport has direct flights to all major Norwegian cities, as well as Aberdeen, London, Amsterdam and Copenhagen (2009). In addition, the ferry trip from Denmark takes between 2-2 ½ hours.

The Eg vesuvianite locality is one of the classic European mineral localities, and was first mentioned in a manuscript by Esmark in 1818. Eg vesuvianite specimens appeared on the European mineral trade market in the 1820s when the mineral trader Nepperschmidt "....die anfanglich von Epidot gehaltenen Krystalle nach Deutschland gebracht, wo sie alsbald durch ihre ungewohnliche Grosse and ausgeziechnet schalige Textur die Aufmerksamkeit der Mineralogen auf such lenkten". This first period of finds produced some marvellous greenish brown vesuvianite crystal with lengths up to 30 cm.

The first find was not huge, and Keilhau (1840) issued the following statement: "Dersom ikke nye Anbrud aabnes ved minering, saa er dette berømte Findested for Idokrasen, der herfra haves i alle Landes Mineral-Samlinger, nu at ansee nesten som udtømt", or translated to English: "If new material will not be exposed through blasting, this famous location for idocrase, from which specimens are represented in every country's mineral collection, must now be considered as almost exhausted." From that time onwards the famous Eg location goes silent for a long time and the unusually large crystals with the scaly apparance is not even mentioned in the work "The Worlds Minerals" by Spencer (1911).

The vesuvianite, however, was still to be found in the Kristiansand rocks. Not so exposed, that is true, but finds in Kongsgårdskogen in the 1920s and from Eg and Gimlekollen in the 1960s nevertheless thrilled local collectors and museums. Even during the last couple of years both Eg and Gimlekollen have produced nice crystals. It is these recent finds that are described in this article.

Localities

All the vesuvianite locations described in this article are located within the border of Kristiansand city, west of the large Kristiansand-Porsgrunn fault.

The locations referenced in this article are:

1- Eg. This is both *the* classic locality, and the best modern locality. The exact location of the classic locality is unknown. The vesuvianite at Eg was rediscovered by T. Falkum in 1960, in a loose boulder, and later vesuvianite was found in outcrops near Falkum's discovery. Today vesuvianite is found quite frequently, and is exposed in several outcrops.

It is not very likely that the vesuvianites found today are from the same location as the classical find described by Esmark. It should be noted that some of the accessory minerals reported from the original find have not been identified in the modern locations. Most noteworthy is chondrodite and spinel that have been reported at the Eg location, but have not been found there today.

2- Kongsgårdskogen. In 1918 a small quarry was opened in Kongsgårdskogen just north of Vollevann. Several large vesuvianites were found in the 1920s. This locality

is not available anymore, as the area is developed as a residential area.

3- Gimlekollen, just north of Vollevann, a few vesuvianite bearing skarns were found during the development of a residential area in the 1960s. Several large vesuvianite crystals found their way into local collections in this period. Vesuvianite and garnet can still be found in a small outcrop in a road cut.

In addition, occasional references will be made to the skarn occurrences in Kalkheia. Vesuvianite has not been reported from these occurrences until Vang (2008) noted that vesuvianite could be found as small grains in calcite marble. Her work, as well as Tom Barth's previous work on Kalkheia, is both used for reference, due to the similarities between the Kalkheia skarns and the skarns known for the large vesuvianite crystals.

Geology

The Kristiansand area is divided by the large Kristiansand–Porsgrunn fault. This fault divides the Telemark sector and Bamble field. The fault is following the Topdalfjorden and Ålefjærsfjorden. The differences in the geology east and west of the fault are obvious to the observer in the field, but are not considered relevant for this article. Both east and west of the fault, the rocks are Precambrian metasediments and supracrustal volcanic rocks. They are metamorphosed in amphibolite facies during the Sveco-Norwegian orogeny about 1200 mill years ago.

The most common rocks are gneisses and amphibolites, but also quartzites and small pockets of marble can be found. Towards the end of the orogeny, a granitic pluton penetrated the metamorphic rocks, and granitic pegmatites are quite common. Some of the pegmatites may well be of metamorphic origin. Later activity has created a few hydrothermal veins, notably some barite and manganese bearing veins. The formation of bavenite at the expense of beryl in some granite pegmatites is evidence of later activity.

The calc-silicate rocks are believed to have originated through regional metamorphosis, which is supported by the general pressure temperature charts for the amphibolite facies compared to the onset of skarn formation. Also, pegmatite and aplite veins crossing the calc-silicate rocks show no or very limited contact reactions with the marble and skarns.

The calc-silicate rocks can roughly be divided into three zones, each with different mineral assemblages:

- An inner zone consisting of calcite marble, **the marble zone.**
- Around the marble, in contact with the gneiss body, typically, a **garnet skarn** formed,
- and finally, the **transition zone** between the garnet skarn and the marble.

It is more difficult to generalize the transition between the gneiss and the garnet skarns. Sometimes the transition is very sharp and homogenous. In other places the transition is characterized by small patches of skarn within the gneiss outside the "real" border line, whereas other times hornblende and biotite rich zones form the transition.

The marble consists almost entirely of calcite with small grains of other minerals such as pyroxene and scapolite. From Kalkheia, minerals like chondrodite, phlogopite and spinel are known. Close examination of the marble zone at the different Eg locations may reveal the presence of some of these minerals, as both chondrodite and spinel are reported from the classic occurrence. The marble zone has not been thoroughly investigated in modern time, and at the time when Barth and Falkum investigated the area, the current Eg locations were not known.

The garnet skarn consists almost entirely of garnet, with small inclusions of calcite, quartz, pyroxene, epidote and other minerals. It is in separate lenses within the garnet skarn that the large vesuvianite crystals occur.

The transition zone consists predominantly of calcite, quartz, garnet, scapolite and pyroxene. The last three minerals are sometimes observed in well developed crystals. In addition, tremolite(?) and titanite are observed within this zone. Some skarn bodies contain an outer transition zone between the garnet skarn and the gneiss rich in hornblende and/or biotite.

The skarns of Kristiansand are poor in mineral species, and some of the described species are found only as minute grains in the marble zone. Only 3-4 mineral species appears in crystals with a sufficient size and quality to be attractive for collectors.

Vesuvianite

The vesuvianite from Kristiansand typically occurs as irregular lenses or veins within the garnet skarn. These lenses consist almost exclusively of vesuvianite, and have normally a distinct borderline to the surrounding garnet. The surrounding garnet skarns are surprisingly homogenous, with the vesuvianite lenses as notable exceptions.

The vesuvianite shows a similar type of occurrence in both the current locations. The descriptions given by Nepperschmidt (Eg), Keilhau (Eg) and Barth (Kongsgårdskogen) indicate a similar type of vesuvianite occurrence in all the Kristiansand locations. It is difficult to distinguish which location an individual specimen comes from. This indicates that all the skarn pockets near Kristiansand have formed under very similar conditions at all the locations.

With a few exceptions, there is no evidence of garnet crystal development towards the vesuvianite lenses, or any general rule of one mineral replacing the other. It seems logical to assume that both the garnet and the vesuvianite are formed at the same time, and the formation of vesuvianite on the expense of garnet is due to small local differences in the chemistry within the skarn during the formation of the rock.

The vesuvianite crystals are found embedded in the massive vesuvianite and one or more crystal faces are developed. Only occasionally, crystals start their growth directly from the garnet-vesuvianite border. The degree of crystallization within each lens varies, and in highly crystallized lenses, the vesuvianite crystals crisscross and can obstruct crystal terminations. There is no alignment in the crystal growth directions. The crystals show a typical scaly appearance, as noted already from the first specimens, which were found early in the 19th century. Quite often, the crystals seem layered, one crystal being contained within another. Some crystals show a partly transparent milky surface on some of the layers. The milky appearance is purely visual, as the composition of the vesuvianite in these layers is fairly consistent with the main crystal. This is common from all known appearances, whether modern or old.

The crystals have a very similar appearance, all being prismatic. The colour ranges from brownish green to brownish, and the crystals often show banding and patterns of different colors.

There are no chemical differences between the different layers of the crystals, and no evidence of any later activity that may have casued this scaling.

In addition to these scaly crystals of uniform composition, Barth (1963) described some unusual crystals that are shaped like vesuvianite crystals, but these distinct multi-mineral "vesuvianite" crystals comprise a mixture of vesuvianite, garnet, calcite, diopside and epidote. Sometimes these crystals seem like garnet pseudomorphs after vesuvianite. However, It seems unlikely that the crystals have undergone any chemical transformation, where one mineral are formed from or at the expense of another mineral, but rather that all the different minerals have formed within the same crystal at the same time. Barth makes a point on the

seemingly simultaneous formation of vesuvianite and epidote, as the chemical conditions of their formation are different, and the chemical environment of garnet lies in-between those of vesuvianite and epidote.

The same type of crystals is found both at the Gimlekollen and Eg locations today, and also here, there is no evidence of one mineral replacing another. All these crystals show the same properties as those previously described by Barth. The modern finds from Gimlekollen are all from the transition zone. From the earlier finds, the detailed location and zone are unknown.

One possible explanation for the formation of these multi-mineral "vesuvianite" crystals is the special conditions in the transition zone. It may be that one of the vesuvianite lenses by coincident formed in the more complex chemical environment in the transition zone rather than within the homogenous garnet skarn environment, and that the chemistry of the environment changed during the formation of the crystals.

Other minerals

The skarns of Kristiansand are not particularly rich in mineral species. The main crystal forming minerals found during the last couple of years are described below:

Garnet

The garnet is in the grossular-andradite series. Most often the composition falls within the grossular composition. The iron content varies between the different skarns, and also within the individual skarn lenses. The colour is often related to the iron content. The main garnet skarns are massive garnet, and garnet crystals are found in three different areas:

1) Within calcite pockets in the massive garnet skarn. These crystals often show only a limited number of crystal faces, but are normally of quite high lustre and quality. The size ranges from a few mm to several cm.
2) On the border between the garnet skarn and the transition zone. The garnet skarn border towards the transition zone is often crystallized. The crystal size here can often be quite large. Crystals exceeding 10 cm are infrequently found. These are, however, normally covered by other minerals, such as pyroxenes and scapolite. Due to locally changing chemical environment during the formation of the garnet crystals, these have frequently an outer layer of pyroxene. Sometimes also garnet and scapolite are intergrown
3) In the transition zone, garnet crystals may form "on top" of the pyroxene and scapolite towards the calcite marble. These crystals may be of good quality and can reach sizes of several cm.

Garnet is the main component of all garnet skarns in all the skarn locations in Kristiansand, both Gimlekollen, Eg, Kalkheia and Kongsgårdskogen.

Scapolite

The scapolite is a typical mineral in the transition zone and in the marble. Analysis reported by Barth (1927) and also confirmed as a part of this paper show that the scapolite composition is within the meionite composition. Meionites from Eg, Kalkheia and Gimlekollen have been analysed, showing relative similar composition, and it should be safe to conclude that all scapolites from the Kristiansand skarns can be classified as meionite.

Meionite is found as small grains in the marble as well as fibrous layers in the skarn zone, often with quartz. It is in the transition zone that meionite can be found as crystals. The scapolite regularly forms small crystals on top of pyroxene towards the calcite marble. The crystals can range from 1 mm to 1 cm and the crystals are prismatic, rounded crystals similar to rice grains. At Kalkheia larger, white crystals exceeding 10 cm, sometimes also with end terminations are observed. Crystals up to several cm in length can frequently be found, although often embedded in marble.

In the transition zone at Eg, the crystals are of a light yellowish colour, and can be found as up to 10 cm crystals that are intertwined in bundles.

Pyroxene
Pyroxene is found in all three zones; as small grains in the marble zone and as small pockets in the garnet skarn. In the transition zone, crystals of pyroxene can be found.

There are two main types of pyroxene found, a greyish green found at all locations, and a shiny black found predominantly at Kalkheia. There are differences in the compositions of the pyroxenes as well. The black pyroxene lies within the diopside-hedenbergite series, closest to the hedenbergite end member. The greenish pyroxene has a composition within the boundaries of diopside, but contains subordinant amounts of Al, Fe, Ti and others, and the adjective augittic has been used to describe it more accurately. Pyroxene is frequently coating garnet crystals, and is rarely found in good crystals, although well developed hedenbergites can be etched out of the marble from Kalkheia.

Titanite
Titanite crystals have been found at Kalkheia and at Gimlekollen. The rounded, dark brown titanites found at Kalkheia rarely exceed 1 cm. At Gimlekollen a few larger, sharp, opaque, yellowish green crystals have been found. Vang (2008) described small, mm-sized titanite rhombs as an accessory component in both the marble and the garnet skarn.

Other minerals
In addition, the following minerals have been described from the skarn localities of Kristiansand. This is probably not a complete list of minerals from these skarns, as in particular the Eg skarns are poorly mapped for different mineral species. The current work has been focused on finding mineral specimens of interest for collectors. Overgrowth and lack of freshly blasted material have made the search for randomly occurring species more difficult. Barth's work at the Kalkheia locality has been much more thorough in its search for and identification of mineral specimens than the current search at Eg. Also the work of Vang (2008) shows that new knowledge on the minerals from the Kristiansand skarns can be obtained by systematic and tedious work. For the work done for this paper, it would simply not been possible for us to find or identify a mineral species like clinohumite, of which Barth found one single 0.7 mm grain in marble.

Mineral	Description	Location(s)	References
Molybdenite	Found in sheets in garnet skarn, rarely exceeding 1 cm.	Kalkheia	Barth (1925, 1928) Revheim, this work
Pyrrhotite	Found as massive inclusions in garnet skarn.	Kalkheia	Barth (1925, 1928) Revheim, this work
Pyrite	Found as microcrystals in the transition zone, and also macroscopically observed with amphiboles.	Eg, Kalkheia	Barth ((1925, 1928) Vang (2008) Revheim, this work
Spinel	Found as crystals in the marble zone. Crystals up to 1 cm are known.	Kalkheia	Barth (1925, 1928)
Phlogopite	Small crystalline "books" in the marble and the transition zone.	Kalkheia	Barth (1925, 1928) Revheim, this work
Chondrodite	Small crystals/grains in the marble	Kalkheia, Eg	Barth (1925, 1928)
Clinohumite	Known from a single mm sized grain in marble.	Kalkheia	Described as "titanolivine" by Barth (1925, 1928)
Amphiboles	1) Separate "hornblende skarns" with or without plagioklas. 2) Crystals in small calcite pockets. 3) Small fibrous aggregates of tremolite(?) are known from the transition zone.	Eg, Kalkheia	Barth (1925, 1928) Revheim, this work Vang (2008)
Fluorite	Unknown		Barth (1925, 1928)
Magnetite	Unknown		Barth (1925, 1928)
Zirkon	Unknown		Barth (1925, 1928)
Rutil	Unknown		Barth (1925, 1928)
Biotite	With hornblende in "hornblende skarns".	Eg, Kalkheia	Barth (1925, 1928) Vang (2008) Revheim, this work
Quartz	In the transition zone as residual silica as a result of scapolite formation. As veins in the garnet skarn.	Eg, Kalkheia, Gimlekollen	Barth (1925, 1928) Vang (2008) Revheim, this work
Plagioklas	A constituent of the gneiss border zone, in particular with amphiboles.		Barth (1925, 1928) Revheim, this work
Epidote / zoisite	Epidote/zoisite occurs mainly in the garnet skarn as small inclusion. Rarely with vesuvianite Occasionally in the transition zone with scapolite.	Kalkheia, Gimlekollen, Eg, Kongsgårdskogen	Barth (1925, 1928) Revheim, this work Vang (2008)
Apatite	Millimetre-sized crystals in marble.	Kalkheia	Barth (1925, 1928) Vang (2008)
Calcite	Main constituent in the marble and the transition zone. In small pockets in the garnet skarn.		
Graphite	?		Barth (1925)
Serpentine	?		Barth (1925)
Chlorite	?		Barth (1925)
"Limonite"	?		Barth (1925)

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