Skarn type grandite garnet in oceanic lower crust of the Troodos Ophiolite, Cyprus. Grandite growth from a new view?

Anna Hagen[1], Romain Bousquet[1], Colin Devey[2], Thor Hansteen[2]

[1] Institute of Geoscience, Kiel University, Kiel - Germany [2] GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel - Germany

C A U Christian-Albrechts-Universität zu Kiel
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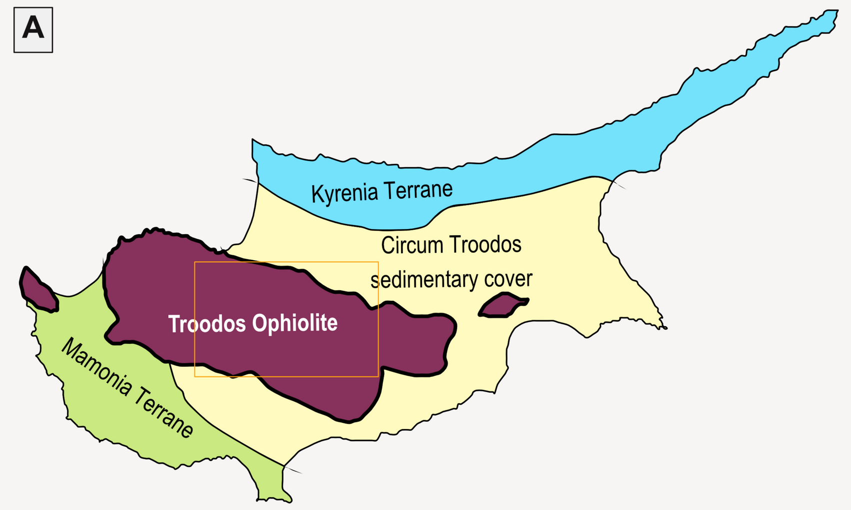
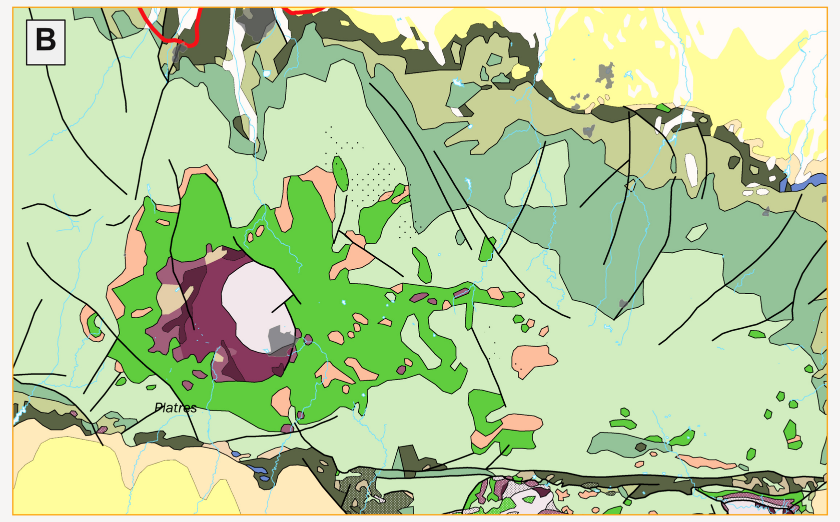
(1) Troodos Ophiolite - Cyprus



The Troodos ophiolite on Cyprus offers a detailed view into the stratigraphy of a late cretaceous oceanic lithosphere, as this oceanic floor, including a former spreading axis (mid oceanic ridge), has been rotated and uplifted since then. Both structurally and petrologically, the Troodos ophiolite is a valuable study area to describe and understand former magmatic processes during the formation of new oceanic crust, as well as for the comparison with today's spreading ridges.



Ophiolite complex (Troodos)

- Upper pillows
- Lower pillows
- Basal group (pillows & dykes)
- Sheeted dyke complex
- Plagiogranite
- Gabbro-Gabbronorite
- Sepentinite
- Websterite
- Wehrlite
- Harzburgite
- Dunite

Fig. 1: A Geological overview map of Cyprus. Orange rectangle marks the detailed map section. B Geology of the central Troodos Ophiolite. (*Bousquet, redrawn after Constantinou 1995*).

(2) stratigraphy of oceanic crust

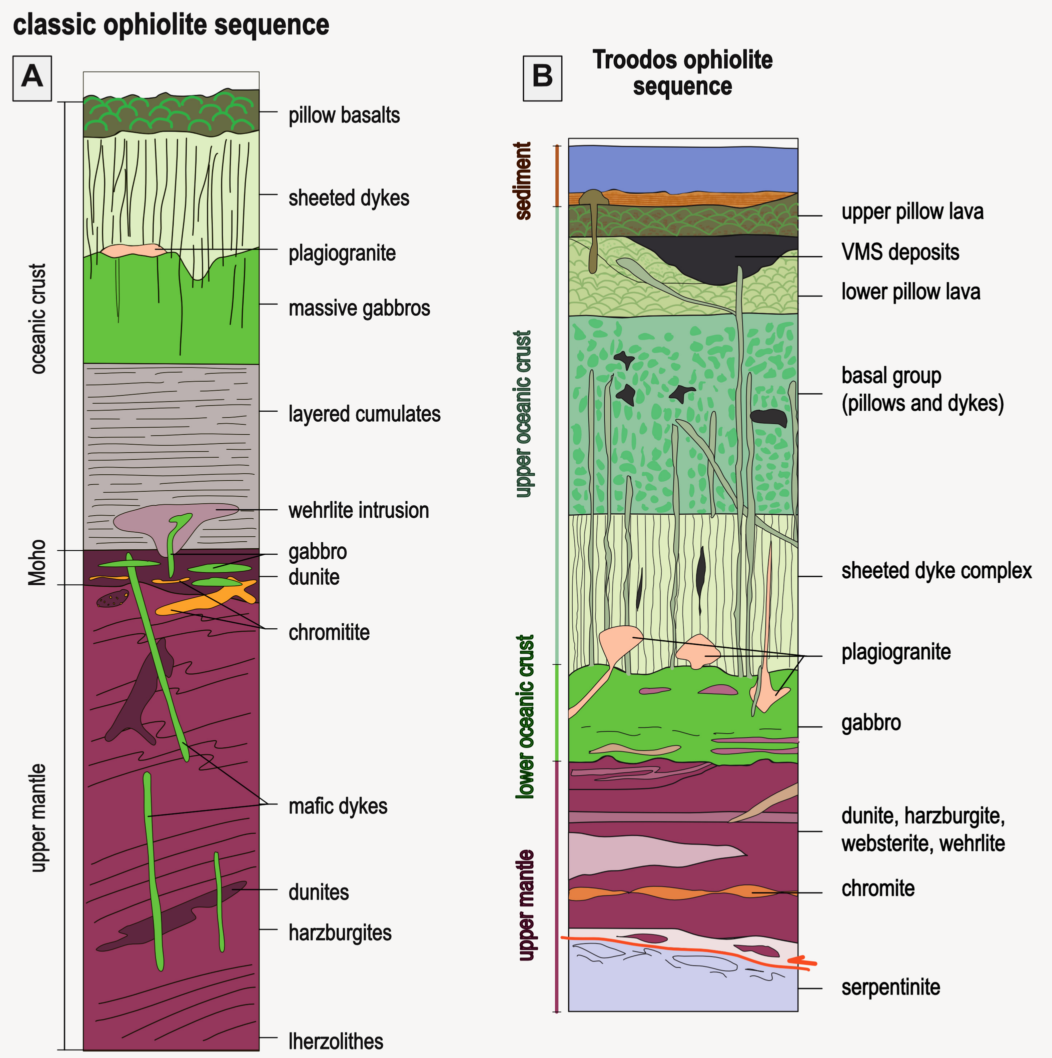


Fig. 2: A Typcial ophiolite sequence as can be observed in ophiolites in Oman, Turkey, Albania. (*redrawn after Yang et. al 2001, original from Boudier and Nicolas 1985*). B Troodos ophiolite sequence. (*redrawn after Bousquet*).

Within the stratigraphy of oceanic crust as found in the Troodos ophiolite, several sequences of plagiogranites occur, from the lower crustal gabbroic complex to the sheeted dyke complex. In addition to these known and described plagiogranites, we now find a single plagiogranite complex situated in the upper gabbro sequence, incorporating a large amount of epidote and grandite; the latter one up to fist size, that has not been described yet.

Epidote and grandite crystals in this special type of plagiogranite show partially intergrown patterns.

Plagiogranites =
felsic igneous rock type, rich in plagioclase and quartz with minor mafic minerals (amhibole, epidote)

Plagiogranites are a common integral part of oceanic crust and generally occur near the contact between gabbros and sheeted dyke complex. They are documented in many ophiolites as well as in present oceanic crust (associated with spreading ridges).

(3) Grandite garnet in oceanic plagiogranite

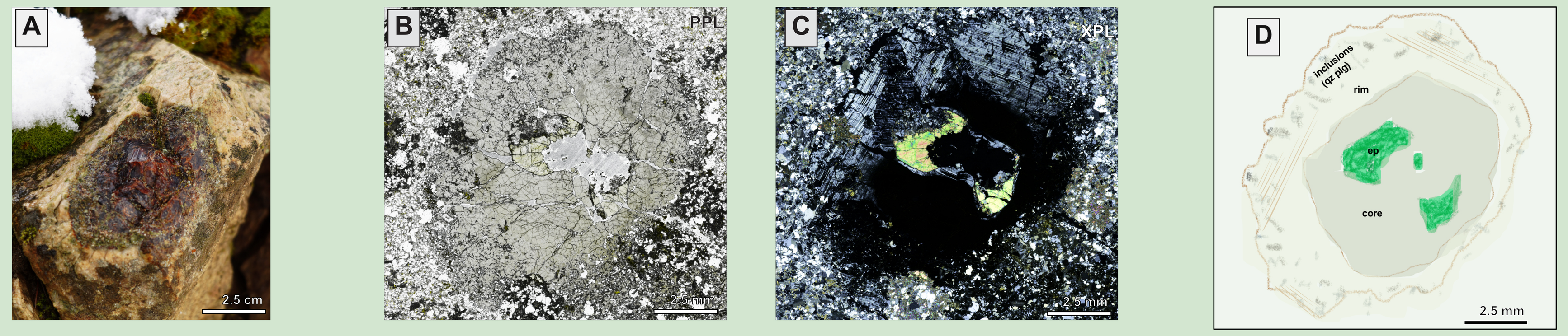


Fig. 3: A Large grandite type garnet in plagiogranite, Troodos ophiolite, Cyprus. B Thin section of euhedral grandite crystal with inclusion of twinned epidote in center, PPL. C Thin section of grandite, XPL, showing anisotropic lamellae in outer rim and around epidote inclusions in center. D Illustration of grandite with homogenous core and sieve textured rim with lamellae. Epidote inclusions in center.

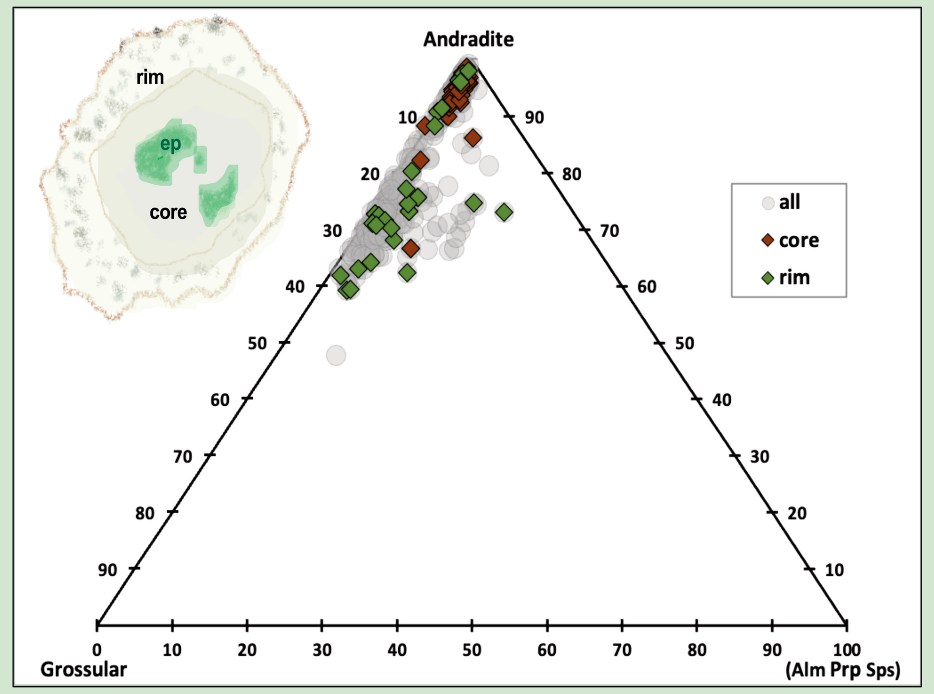


Fig. 4: Composition of grandite garnet in the plagiogranite, Troodos Ophiolite. The core of the grandite is of Andradite composition, whereas the rim is less homogenous in composition and shows partly higher grossular component.

The grandite-type garnets show features similar to other known skarn-associated grandites, including an onion-like, very fine and sharp oscillatory chemical zoning, as well as both isotropic and anisotropic features when investigated under polarized light. The sieve texture observable at the outer rim of the grandite minerals is made up of mainly quartz and plagioclase inclusions. The quartz inclusions themselves show highly salinary fluid inclusions. Due to the high content of Ca and Fe^{3+} in both epidote and grandite, we assume a highly oxidizing environment with a high involvement of fluids.

At a certain point, boiling and thus the phase separation of fluids might enhance the mobility of Fe and other involved elements during the evolution of the system.

Skarn =
coarse-grained rock type, formed by contact metamorphism of carbonate rocks, typically containing garnet, pyroxene and wollastonite

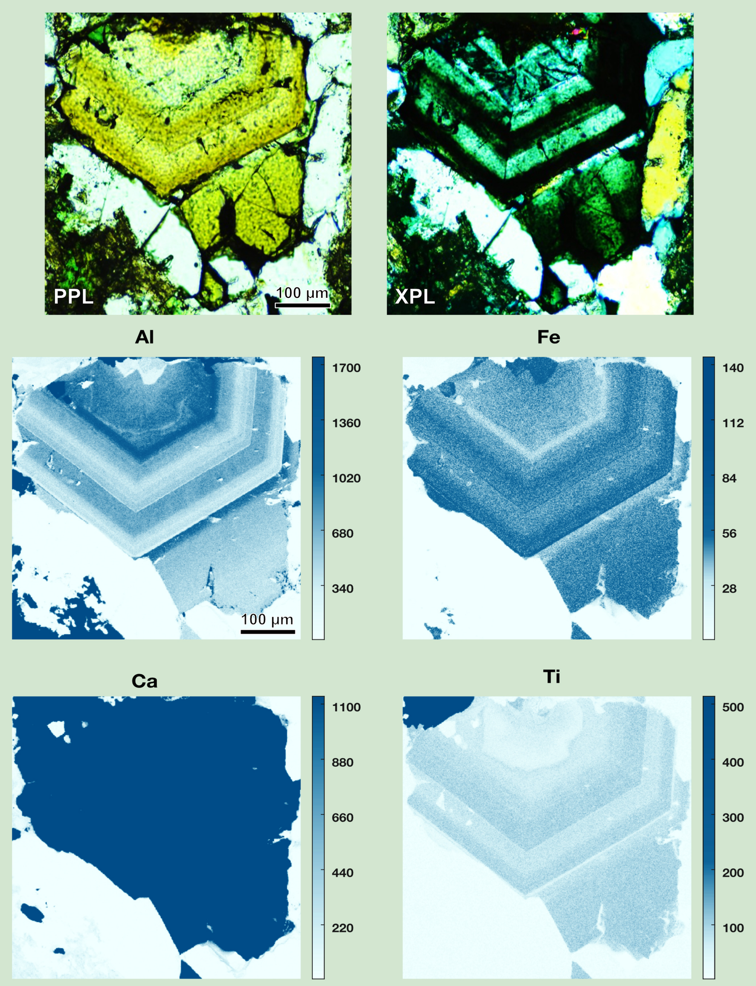


Fig. 5: Element distribution of an exemplary grandite crystal showing sharp lamellaer features in Al, Fe and Ti content. Al and Fe distribution show opposite pattern indicating a distinctive exchange between Al and Fe. Please note different scales! Scale displays microprobe counts.

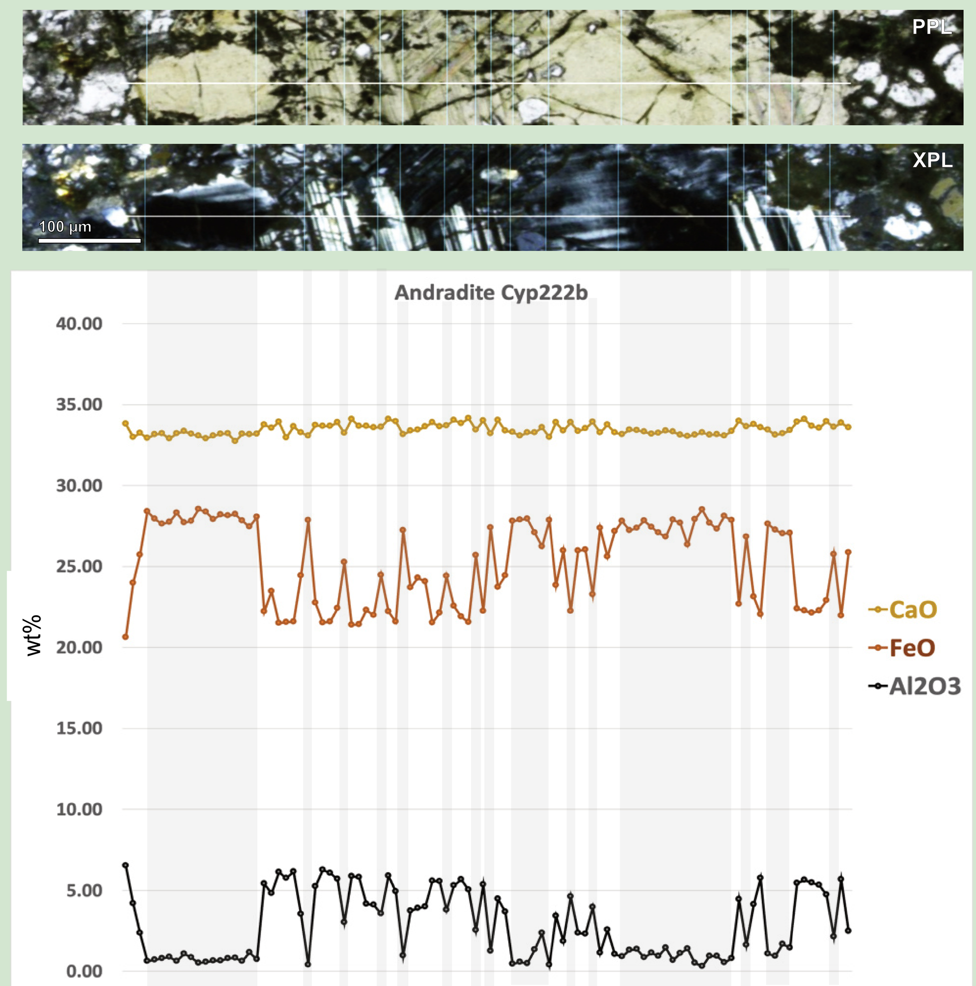


Fig. 6: Element profile of exemplary grandite. Al and Fe content show distinctive exchange in the sharp osciallatory lamellae in the rim (osciallatory anisotropic) while the core shows homogenous composition and isotropic behaviour. High Al content results in anisotropic behaviour of grandite lamellae.

(4) Hydrothermal or magmatic process?

As we find the grandites in a plagiogranitic rock body, which has clearly experienced a high degree of hydrothermal alteration typical for subseafloor alteration of oceanic crust, it is difficult to distinguish whether these grandites have grown during a magamtic or hydrothermal stage. Euhedral growth and the large size of the grandites, as well as the magmatic texture of the grandite bearing plagiogranite, indicate a magmatic origin.
Epidotes, on the other hand, show two different patterns within the plagiogranite. One favours a rather magmatic origin, as we find euhedral, zoned epidotes as inclusions in the large grandites, the other a rather hydrothermal origin, by showing patchy, recrystalized features.

Highly salinary fluid inclusions (salt crystal and vapor bubble) found in quartz inclusions in the sieve textured rim of the grandite crystals indicate boiling of involved fluids. The resulting brine was then, at some point, trapped in the inclusions. Situated in the outer rim of the grandites, these inclusions also point to a participation of hydrothermal fluids, at least in a late magmatic stage.

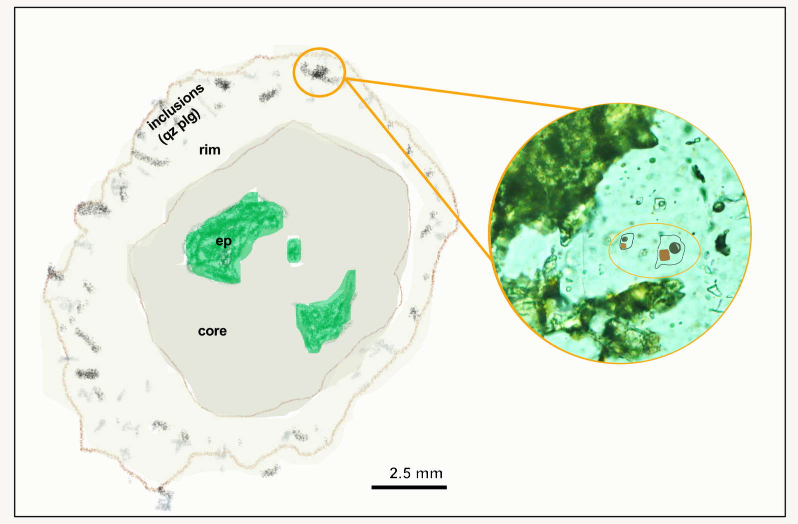


Fig. 7: Higly salinary (brine) inclusions in quartz included in the sieve textured rim of the grandite crystal. Inclusions consist of vapor bubble and salt crystal.

(5) conclusion

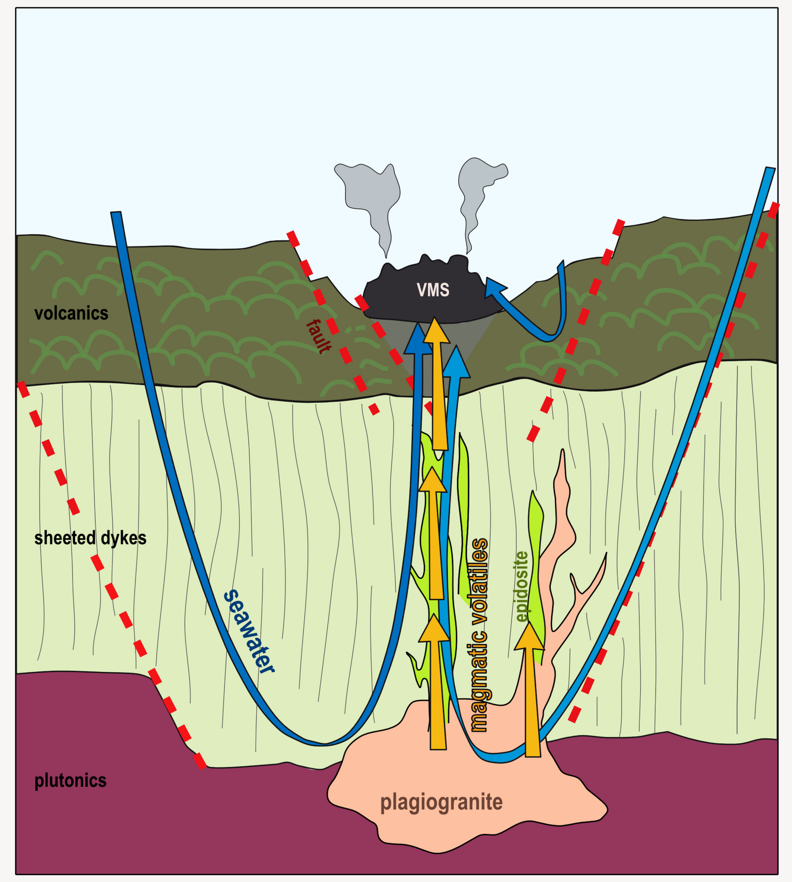


Fig. 8: On-axis magmatic and hydrothermal system. Pulses of seawater infiltrating the system and magmatic volatiles released from cooling plagiogranite body control oscillatory element availability and exchange in the system. Alternating influx and mixing of both types of volatiles probably lead to oscillatory growth of epidote and grandite and results in unique growth patterns of grandite in the Troodos plagiogranite. (*after Fox et. al 2020*).

In conclusion, we can state that the grandite we find here in this plagiogranite in the Troodos ophiolite complex, looks like other skarn-type associated grandite, yet here, no sedimentary rock type is included in the forming process. Further, we assume the growth of this grandite to be associated with very high volatile activity, either during hydrothermal alteration or metasomatic processes, or even earlier, in a magmatic stage close to subsolidus condition. We further assume that the activity of several pulses of magmatic and/or infiltrating saline volatiles in a system with very unique chemical composition, probably even a system experiencing the transition from a magmatic to a hydrothermal system, is what forms these uniquely patterned grandites in the oceanic crust.

Anna Hagen
Institute for Geoscience
Kiel University
anna.hagen@ifg.uni-kiel.de

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