

Water Rock Interaction [WRI 14]

High-salinity seawater-derived fluids and lower-crust
hydrothermal mineralization at the Vema Lithospheric
Section, Central Atlantic

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Abstract

We reconstructed a magmatic-hydrothermal transition in gabbros spatially associated with mantle peridotites from the Vema Lithospheric Section. The presence of titanian pargasite suggests the reaction of an early augite-plagioclase assemblage with a highly evolved residual melt and/or high-temperature magmatic fluid. The overprinting hydrothermal event occurs as fracture patterns with cracks filled by Cl-rich ferropargasite and olivine ($\text{Fe}_{0.96}\text{Mg}_{1.04}\text{SiO}_4$) locally formed by reaction between igneous orthopyroxene and magnetite. Calculations based on the olivine-forming reaction and fluid inclusions suggest cooling of the lower-crust basic bodies down to 580-610°C and the ingress of fluids with salinity of 20-22% (NaCl eq.) under lithostatic pressure. The reducing nature of the fluids ($\log f_{\text{O}_2} = -19.6$ to -18.8) results from relatively low-temperature ($< 315^\circ\text{C}$) interaction of the fluids with peridotites prior to being heated up to about 600°C in the gabbro zone.

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1. Introduction

Since MORB-type magmas are generally very poor in H_2O [1], the sub-seafloor hydrothermal activity at mid-ocean ridges is conventionally ascribed to the deep-seated reaction zones, where seawater-derived fluids approach the magmatic heater and experience extensive interaction with the surrounding rocks [2].

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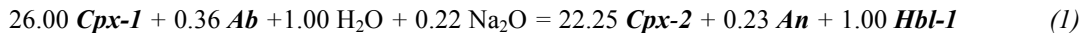
This hydrothermal reaction zone is difficult to observe in modern oceanic setting and its mineralogy is still poorly understood. Studies of hydrothermal mineralization of the middle- [2, 3] and lower-crust [4–6] reaction zones from ODP holes, crustal rocks exposed at transform faults, and ophiolites provide wide temperature ranges (320-1000°C) and highly variable composition of fluid inclusions. Even distinguishing between the products of magmatic and hydrothermal mineralization needs a complex approach (e.g., [7, 8]). In this work, we attempt to reconstruct a specific lower-crust reaction zone in gabbros spatially associated with mantle peridotites from the Vema Lithospheric Section (VLS).

2. Geology and sampling

The VLS is a flexured and uplifted sliver of oceanic lithosphere exposed south of the Vema fracture zone at 11°N in the Central Atlantic [9]. Dredging at site L2612 at depths 5195 to 4620 m yielded about 150 kg samples of mantle peridotite (95%), gabbro (4%), and basalt (1%) [10]. The L2612 gabbro collection in particular has important mineralogical features that are the subject of this study.

3. Igneous features

The early igneous stage of the L2612 gabbros is represented by coarse-grained plagioclase-pyroxene aggregates. At a later stage the gabbros suffered ductile shearing in the presence of highly evolved residual melts. The late igneous stage resulted in porphyroclastic textures and crystallization of Fe-Ti oxides, titanian pargasite and apatite. Clinopyroxene and plagioclase were partly re-crystallized and enriched in incompatible elements. The magmatic titanian pargasite (**Hbl-1**) is formed by the following reaction calculated by Si, Al, (Mg+Fe), and Ca mass balancing with the H₂O and Na₂O ingress:

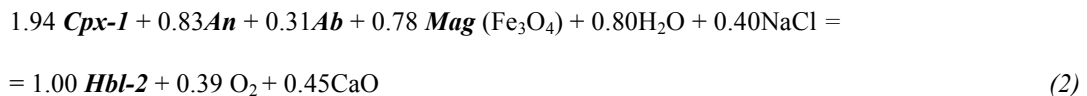


where **Ab**=NaAlSi₃O₈; **An**=CaAl₂Si₂O₈; **Cpx-1** and **Cpx-2** – early and late igneous augite clinopyroxenes, respectively.

The local plagioclase anorthitization and Zr contents of **Cpx-1**, **Cpx-2**, and **Hbl-1**, suggest two possible modes of reaction (1): (i) interaction with an extremely differentiated residual melt (Zr increment exceeding 100%, low plagioclase anorthitization) and (ii) interaction with a high-temperature magmatic fluid (insignificant Zr income, high plagioclase anorthitization).

4. Hydrothermal features

The overprinting hydrothermal event is associated with brittle deformation – fracture patterns with cracks filled by Cl-rich ferropargasite (Cl up to 1.7 wt.%). The main hydrothermal process can be simplified as a reducing reaction that produces ferropargasite (**Hbl-2**) of average (n=39) composition. The reaction, calculated by Si, Al, Mg, and Fe mass balancing with the rock/fluid exchange of mobile components H₂O, Na, Cl, Ca, and O₂, is the following:



Another reducing reaction – local olivine Fe_{0.96}Mg_{1.04}SiO₄ (**Ol**) development between magmatic orthopyroxene (**Opx**) and magnetite (**Mag**) – spatially relates to the **Hbl-2**. With the use of a

thermodynamic database [11], the *Opx-Mag-Ol* assemblage allows to determine T- and fO_2 conditions of the system (Fig. 1a).

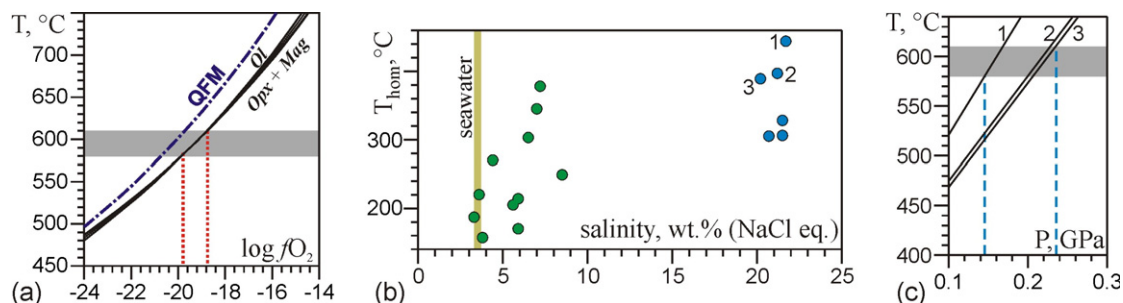


Fig. 1. (a) Temperature and $\log fO_2$ conditions calculated from the *Opx-Mag-Ol* assemblage; (b) Plot of homogenization temperature vs. salinity for the low- (green circles) and high-salinity (blue circles) fluid inclusions in plagioclase; (c) isochors of the highest-temperature inclusions of the high-salinity group and the evaluation of pressure range. Gray fields in (a) and (c) – temperature range constrained from the *Opx/Ol* Mg-Fe exchange. Numbered isochors in (c) correspond to the inclusions 1, 2, and 3 in (b).

Two contrast groups of fluid inclusions have been observed in plagioclase at the contact with *Hbl-2* (Fig. 1b). We regard the group of high-salinity inclusions as genetically linked to the Cl-rich *Hbl-2*. The second group of inclusions, instead, shows seawater-like to moderately higher salinities and can be attributed to a late low-pressure process associated with the tectonic exposure of the VLS at the seafloor. This late hydrothermal event is not considered here.

5. Discussion

The T-range, 580-610°C, obtained from the *Ol+Opx* assemblage corresponds to a realistic lithostatic pressure range of 0.14 to 0.24 GPa for trapping the highest-temperature fluid inclusions of the high-salinity group (Fig. 1c). The high-salinity fluid might derive from a low-temperature seawater/rock interaction process like epidotization, serpentinization, etc. [12]. The reducing nature of the fluid suggests that it could be involved in serpentinization of the spatially associated peridotites at relatively low temperature (< 315°C [13]) prior to being heated to about 600°C in the gabbro zone.

We note here that in higher-temperature (800-840°C) reaction zones the interaction of seawater-derived fluids with gabbros might result in the formation of plagiogranite melts [12, 14]. Relatively lower-T conditions of the studied reaction zone can be attributed to the overall colder regime of the area at a ridge-transform intersection. Higher-temperature reaction zones are probably more typical of ridge axis segments faraway from transform faults or of oceanic core complexes affected by off-axis magmatism.

6. Conclusions

The L2612 VLS gabbros show evidence of a lower-crust interaction with high-salinity seawater-derived fluids.

The transition from magmatic to hydrothermal conditions corresponds to the cooling of the lower-crust basic bodies down to 610-580°C and the ingress of fluids with salinity of 20-22% (NaCl eq.) through the system of brittle deformations under lithostatic conditions.

The mineralogical features of the lower-crust hydrothermal reaction zone are consistent with local reducing reactions producing Cl-rich ferropargasite and (locally) olivine. The reducing nature of the fluid ($\log f_{O_2} = -19.6$ to -18.8) is probably due to relatively low-temperature ($< 315^\circ\text{C}$) interaction of the fluids with mantle peridotite prior to heating up to about 600°C in the gabbro zone.

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