# Fluid inclusions in ultra high-pressure eclogites from the Dabie Shan, eastern China

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Although a lot of work has been done on the ultrahigh-pressure (UHP) eclogites from the Dabie Shan, eastern China, the role of the fluid phase during eclogite-facies metamorphism is not answered yet. In order to obtain information on the physical-chemical conditions of the fluid phase during UHP metamorphism, we studied fluid inclusions in coesite-bearing eclogites from the Bixiling complex in the southern Dabie Shan. These rocks outcrop in an area of about 1 $km^2$ within foliated quartzofeldspathic gneiss. The boundary between the eclogites and country rock shows tectonic contact relations. The complex mainly consists of eclogites and elongated (1–40m) lenses of garnet peridotite. The field observations suggest that both eclogites and garnet peridotite underwent coesite-eclogite-facies metamorphism.

The eclogites from the Bixiling complex typically contain garnet, omphacite, phengite, rutile, quartz, kyanite, with minor zoisite, amphibole, plagioclase, epidote, biotite, zircon and coesite. The peak mineral assemblage for the eclogites is characterized by garnet + omphacite + phengite + rutile $\pm$ kyanite $\pm$ coesite $\pm$ zoisite $\pm$ zircon. The eclogites underwent a complex metamorphic evolution of at least five metamorphic stages (Xiao *et al.*, 1995): (a) prograde pre-eclogite-facies metamorphism at $\leqslant$ 17kb and < 700°C; (b) coesite eclogite-facies metamorphism at $\geqslant$ 27 kb and $\geqslant$ 700 °C as documented by coesite relics preserved as inclusions in garnet and omphacite; (c) quartz-eclogite-facies metamorphism at 15–20 kb and ~800 °C, characterized by coarse-grained garnet + omphacite + kyanite + quartz; (d) a retrograde symplectite stage at 9–13 kbar and 600–700 °C, represented by various symplectitic replacement assemblages of clinopyroxene, amphibole and plagioclase; and (e) a post-symplectitic stage corresponding to the amphibolite-facies metamorphism.

In the coesite-bearing eclogites from Bixiling, fluid inclusions normally are < 20 μm in diameter, rarely up to 40 μm. Four types of fluid inclusions were distinguished according to textural criteria and fluid compositions:

(1) High-salinity brines in quartz blebs in kyanite represent the oldest generation of fluid inclusions. Sometimes they occur also in kyanite itself. They are isolated or randomly distributed inclusions. They are mostly 3-phase ($LVS_{halite}$) and show rounded or negative crystal morphologies. They have filling degrees of about 80 vol%. These fluid inclusions do not show any phase transition during cooling; on subsequent warming, they show a granular texture between −65 °C and −75 °C, interpreted as a devitrification phenomenon (metastable non-crystalline to crystalline state) and hides a clear observation of the eutectic point. We asumme that the $T_e$ is slightly higher than the devitrification temperature and indicates the presence of $Ca^{2+}$ (and/or $Mg^{2+}$). Rare clathrate melting between 10 and 15 °C indicates the presence of $CO_2$.

(2) High-salinity aqueous inclusions ($\pm$ halite) in omphacite and kyanite occur as tubes that are oriented parallel to the growth zones of the host mineral suggesting primary origin. They probably contain relic metamorphic fluids of the eclogite-facies. Unlike the isolated fluid inclusions in quartz blebs, this type of high-salinity inclusions show clear freezing between −60 and −70 °C and display $T_{m\ ice}$ between −24°C and −16°C. They have eutectic temperatures between −30 and −21 °C, indicating a dominantly NaCl-bearing fluid.

(3) Carbonic inclusions were found both in omphacite and in matrix quartz. They are monophase at room temperature. They occur isolated and as clusters, and have rounded or negative crystal shapes. The $CO_2$ inclusions in omphacite display final $T_{mCO_2}$ around −58.5°C and $T_h$ (to liquid) between −31 and

$-25°C$, whereas the inclusions in quartz display $T_m$ around $-59.5$ °C and $T_h$ between $-17$ and $-4°C$. The melting temperatures are indicative for small amounts of additional $N_2$ and/or $CH_4$. The close textural relationship between high-salinity and CO2 inclusions suggests that they may have been trapped simultanously.

(4) The majority of the fluid inclusions are low-salinity aqueous inclusions trapped in matrix quartz. Most occur in healed fractures. They show large variation in size and shape, but their composition is quite consistent with ice melting temperatures of $-6$ to 0°C. Most of the inclusions are 2-phase (L + V) at room temperature with filling degrees of 80–95 vol%.

Isochore calculations show that the early fluid inclusions in quartz blebs were trapped at 5–6 kb at 600°C. The isochores of primary high-salinity aqueous inclusions in omphacite and kyanite fall into the minimum P-T conditions for the eclogite-facies metamorphism (P = ~15 kb at T = 700–800°C), i.e. at least 12 kbar below the peak metamorphic pressure estimated from the stability of coesite. The lower fluid densities are probably due to late re-equilibration of the fluid inclusions. Mismatch between pressure estimates based on mineral thermobarometry and on fluid inclusions is commonly encountered in high-grade metamorphic rocks, due to partial decrepitation by internal overpressure in fluid inclusions during uplift. The calculated trapping conditions of the $CO_2$ inclusions in omphacite and quartz are 6 kbar and 4 kbar, at 700°C, respectively, i.e. also below the UHP metamorphism. The isochores of the late low-salinity aqueous inclusions in quartz indicate maximum trapping pressure of 5kbar at 500°C, corresponding with late fluid inclusion formation during retrograde amphibolite metamorphism.

Fluid inclusions in different textural settings reflect trapping and remobilization of fluids at different metamorphic stages of the eclogites in Bixiling: The fluid inclusions in quartz blebs in kyanite are assumed to represent the earliest recognizable fluid and originated from prograde metamorphism. The fluid phase during the prograde stage was dominated by Ca-(Mg)-rich brines. Although minor amounts of $CO_2$ have been found in these fluids, $CO_2$ appeared to be not important during the prograde metamorphism, however locally present in omphacite during the eclogite-facies stage. Both the NaCl-bearing inclusions (in omphacite and kyanite) and the $CO_2$ inclusions (in omphacite and quartz) probably originated from UHP conditions but may have partly leaked during uplift. The low-salinity inclusions correlate to retrograde amphibolite-facies conditions and lower.

In conclusion, the fluid inclusions show that during the metamorphic evolution the fluids evolved from highly concentrated Ca-dominated brines $\pm$ $CO_2$ (prograde metamorphism), towards Na-dominated solutions (peak metamorphism) and low salinity aqueous fluids during retrograde uplift. A possible explanation for the decreasing salinities in time is the dehydration of hydrous minerals during prograde and peak metamorphism, and the increasing admixture of pure water derived from the surrounding quartzo-feldspathic gneisses. The role of $CO_2$, locally present as inclusions in matrix quartz and in omphacite, appeared to be limited.

## References

Xiao, Y.L., Li, S., Jagoutz, E. and Cheng, W. (1995) *Chinese Sci. Bull.*, **40**, 156–8.