FORMATION OF P-RICH OLIVINE IN DAG 978 CARBONECEOUS CHONDRITE THROUGH FLUID-ASSISTED METAMORPHISM

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Introduction: Olivine in terrestrial and extraterrestrial igneous settings usually contains very low P_2O_5, due to a low olivine/melt partition coefficient for P (~0.1; [1]). However, P-rich olivine (P_2O_5>1 wt%) has also been described in a few terrestrial and extraterrestrial samples ([2], and references therein). It was suggested that P-rich olivine is a metastable phase during rapid crystallization from high-temperature melts, which has a high P activity, but low Si acitivity. Recently, during surveying the concentrations of minor elements in olivine in carbonaceous chondrites, we observed that a few lath-shaped olivine grains in a type 3.5, ungrouped carbonaceous chondrite Dar al Gani (DaG) 978 contain high P_2O_5 (up to 5.5 wt%). Here, we report the detailed texture and mineralogy of the P-rich olivine and discuss its origin.

Results: Olivine in DaG 978 has a large variation of occurrence [3]. It mainly occurs in chondrules and refractory inclusions. A few lath-shaped olivine grains, texturally replacing low-Ca pyroxene, are also observed in chondrules and chondrule fragments [3]. A few of them contain bright, submicron-sized inclusions on the BSE images. Most of the olivine grains in refractory inclusions and those included in low-Ca pyroxene of chondrules are Fe-rich (Mg# = 69-75), although a few olivine grains contain Mg-rich cores (Mg#= 89-100). They contain very low contents of P_2O_5 (0-0.03 wt%), Al_2O_3 (0.01-0.16 wt%), and Cr_2O_3 (0.02-0.10 wt%). On the contrast, the lath-shaped olivine (Mg# = 66-72) contains high P_2O_5 contents ranging from zero to 5.53 wt%. Meanwhile, the Al_2O_3 and Cr_2O_3 are 0.02-1.10 wt% and 0.05-0.91 wt%, respectively. In a chondrule fragment containing lath-shaped olivine, FeNi metal, troilite, Cr-rich hercynite, and Ca-phosphate minerals are also observed. We prepared a TEM section of lath-shaped olivine from this chondrule fragment by using FIB technique. Our TEM observations reveal that the bright, submicron-sized inclusions in the lath-shaped olivine are Cr-rich hercynite. Beside Cr-rich hercynite, the lath-shaped olivine is associated with apatite and merrillite. Some of the apatite and merrillite grains together with Cr-rich hercynite are included in plagioclase. The TEM-EDS spectra of some lath-shaped olivine grains exhibit a high peak for P while no peak for Ca is observed. The TEM elemental mapping shows that P distributes heterogeneously in different olivine grains.

Discussion and conclusions: Although P-rich olivine in previsou studies all was interpreted having formed through rapid crystallization from high-temperature melts [2,4], lack of igneous texture indicates that the P-rich olivine in DaG 978 is not a product of rapid crystallization from melts. Instead, its origin should be closely associated with the origin of lath-shaped olivine in carbonaceous chondrites, which has been extensively studied. Fluid-assisted metamorphism is the widely-accepted formation mechanism of lath-shaped olivine [5]. This interpretation is also supported by our observations. Meanwhile, our observations further indicate that the lath-shaped olivine in DaG 978 formed during the interaction between fluid and low-Ca pyroxene in chondrules. First, the petrographic feature indicates lath-shaped olivine formed through replacing low-Ca pyroxene. Second, the presence of Cr-rich hercynite could be another piece of evidence. Low-Ca pyroxene in chondrules of DaG 978 usually contains Al_2O_3 and Cr_2O_3 higher than olivine [3]. When low-Ca pyroxene is replaced by secondary olivine, Al and Cr would incorporate into oxide minerals (i.e., hercynite or chromite). The presence of Cr-rich hercynite in DaG 978 can also exclude the direct precipitation of lath-shaped olivine from an aqueous solution, because Cr is immobile element in aqueous solution. Third, FeNi metal and troilite that are associated with the lath-shaped olivine, remain intact. Therefore, the lath-shaped olivine is not formed through replacement of FeNi-metal ± sulfide nodules. In addition, the heterogeneous distribution of P among different olivine grains and coexistence with Ca-phosphate minerals indicates an unequilibrium origin from a localized high-P condition.

In summary, the P-rich olivine in DaG 978 should have formed during a thermal event while the low-Ca pyroxene was replaced by a P,Cl,Fe-rich fluid.

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