Fe-rich olivine in brecciated eucrite Northwest Africa 2339: petrography and mineralogy.

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Introduction:

Olivine is an important mafic mineral in planetary basaltic rocks (e.g., those from Earth, Moon, and Mars). However, in the howardite - eucrite - diogenite (HED) meteorites that are thought to be derived from asteroid 4 Vesta, olivine is not very common. To date, olivine was mainly observed in diogenite meteorites and a few howardite meteorites; however, it is very rare in eucrite meteorites [e.g., 1-10]. Northwest Africa (NWA) 2339 was classified as a monomict eucrite breccia recovered in 2004 [11]. In the classification description [11], olivine was not observed. However, during our study on this eucrite, olivine is more common than previously thought, although the amount is not high compared to those of pyroxene and plagioclase. In this study, we report the petrography and mineralogy of olivine in NWA 2339 and discuss their possible origins and significances.

Petrography and Mineralogy:

Petrographic observations on NWA 2339 were mainly performed by using the the JEOL 8100 EPMA at Nanjing University and the JEOL JSM-7000F FE-SEM at Hokkaido University. Mineral compositions were measured by using the JEOL 8100 EPMA at Nanjing University.

NWA 2339 is composed mainly of mineral fragments of pyroxene and plagioclase. Most pyroxene grains are pigeonite and contain no exsolution lamellae or chemical zoning. However, a few pigeonite fragments contain augite lamellae up to 10 μm in width. The Fe/Mn values of pyroxene in NWA 2339 are about 30, although a few pyroxene fragments with anomalous Fe/Mn values (~20) were also observed. Plagioclase fragments are anorthite (An=84-97). A few ophitic or subophitic lithic clasts, consisting of pyroxene and plagioclase, were also observed.

Olivine was observed in more than 25 lithic clasts and mineral fragments from a thin section of ~0.55 cm^2. These lithic clasts and polymineral fragments exhibit a large variation in texture and mineral assemblage.

In a few clasts (e.g., 2339C-03, -09, -10, and -23), olivine grains are relatively coarse (up to ~500 μm) and associated with coarse-grained pyroxene with exsolution lamellae (up to 20 μm in width) and silica. Other associated minerals include plagioclase, ilmenite, Ti-rich chromite, troilite, and K-feldspar, which occur in different clasts. Olivine grains in these relatively coarse-grained clasts are fayalitic (Fa=73-83). The CaO contents in these olivine grains are close to or below detection limit.

In a few lithic clasts (e.g., 2339C-02, -06, -12, -13, -20, -22, and -37), olivine forms a symplectite texture with ferroaugite ($En_{12-25}Fs_{29-52}Wo_{36-45}$) and/or silica. Some symplectites are individual fragments; whereas a few occur along the margin of coarse and zoned pyroxene grains. The size of these olivine grains ranges from 2 μm to ~50 μm. Olivine in symplectites at the margin of coarse-grained pyroxene is Fe-richer (Fa=83-84) than that in individual symplectite fragments (Fa=73). The CaO contents in these olivine grains range from 0.12 wt% to 0.32 wt%.

Olivine was also observed in a few subophitic lithic clasts of pyroxene and anorthite (e.g., 2339C-01, -07, -11, and -26). These olivine grains are anhedral to subhedral and a few of them are included by zoned pyroxene grains. They are also fayalitic in composition (Fa=75-79) and contain 0.12-0.41 wt% CaO. Most pyroxene grains in these lithic clasts are Mg-rich (Mg#=48-70). Pyroxene is Fe-rich at grain boundary and cleavages, and pyroxene rim has an Mg# value low to 17.

Olivine in a few lithic clasts and pyroxene fragments (e.g., 2339C-15, 24, and -36) occurs as small inclusions (<10 μm) with silica. The olivine inclusions have a Fa component of 75-76. Pyroxene grains enclosing olivine show exsolution lamellae of various widths (from submicron to 3 μm). High-Ca pyroxene grains are $En_{23-26}Fs_{34-37}Wo_{40}$ and low-Ca pyroxene grains are $En_{36}Fs_{58}Wo_{6}$.

In a few coarse low-Ca pyroxene grains ($En_{47-55}Fs_{38-46}Wo_{7}$), Fe-rich olivine (Fa=74-75) occurs as veins, associated with troilite and high-Ca pyroxene. Most veins are <10 μm in width; however, in one fragment, olivine vein is up to 20 μm.

In 2339C-05, olivine was observed in melt inclusion of anorthite fragment (An=84-85) as a daughter mineral. The melt inclusion consists of two mineral assemblages. One is relatively coarse-grained (3-12 μm) mineral assemblage, which includes olivine, ilmenite, apatite, merrillite, plagioclase ($An_{69}Ab_{23}Or_{8}$), and troilite. The other is a very fine-grained (<2 μm) assemblage of silica, K-feldspar, and ilmenite. Olivine has a small chemical variation (Fa=72-77) and contains 0.17-0.30 wt% CaO.

One clast (2339C-08) containing olivine is fine-grained with olivine, Al-rich hedenbergite

($En_{0-3}Fs_{49-50}Wo_{49-50}$, 6.24-7.83 wt% Al_2O_3), ferrosilite ($En_{35-37}Fs_{56-61}Wo_{2-8}$), and ilmenite grains in matrix of plagioclase, Si-dominant glass, and troilite. The fayalite components of olivine are 80-81 and the CaO contents are 0.12-0.27 wt%.

Discussion and conclusion:

Our petrographic observations reveal that Fe-rich olivine is very common in NWA 2339 and has a large variation in texture. This feature implies that NWA 2339 is a unique eucrite. And it is very likely that NWA 2339 is a polymict eucrite breccia rather than a monomict breccia as suggested previously [11]. This conclusion is also consistent with the large chemical variation of pyroxene and the presence of various lithic clasts in NWA 2339.

All olivine grains observed in NWA 2339 are fayalitic in chemistry, distinctly differing from that those in diogenite meteorites [7]. At the same time, most pyroxene grains associated with olivine in NWA 2339 are not orthopyroxene. Thus, it is impossible that olivine in NWA 2339 was derived from rocks at depth in eucrite parent body, such as diogenite or olivine diogenite.

In the literature [1-6, 8-10], four main processes were proposed to interpret the origin of fayalitic olivine in howardite and eucrite meteorites. (1) Olivine could be the result of a solid state decomposition of Fe-rich pyroxene. (2) Some vein-like olivine in pyroxene was interpreted to have formed during shock fracturing. (3) Fayalitic olivine could be a magma phase. (4) Barrat and coauthors [8] interpreted that fayalitic olivine could be the result of fluid-rock interactions on eucrite parent body.

These above processes could explain the petrographic features of some fayalitic olivine grains in NWA 2339. For instance, solid state decomposition of Fe-rich pyroxene could account for the symplectite of olivine with ferroaugite and/or silica and olivine and silica inclusions in pyroxene. The fluid-rock interaction theory by [8] could also interpret the fayalitic olivine vein in low-Ca pyroxene fragments, although other interpretations were also proposed to interpret olivine veinlets in pyroxenes [4, 6]. Although we prefer that other fayalitic olivine in NWA 2339 could also be of magmatic origin, various textures of olivine-bearing clasts may reflect different sources or different formation stages.

Coarse-grained olivine could have crystallized at depth in the eucrite layer on eucrite parent body because the following two reasons. 1) It is impossible that the coarse olivine up to 500 μm formed by later processes, such as decomposition of Fe-rich pyroxene or fluid-rock interaction. The textures also argue against the origins of decomposition and fluid-rock interaction. 2) That the associated pyroxene grains show very thick exsolution lamellae also supports the clasts formed at depth.

Olivine grains in those lithic clasts with ophitic to subophitic textures should also be primary phase. The main evidence is that some olivine grains were included by pyroxene and a few olivine grains have straight crystal faces, indicating olivine crystallized from melt. At the same time, the olivine grains have much lower Mg# values than associated pyroxene grains in same clasts, which could be the result of later oxidation. The Fe-rich features at grain boundary and cleavage of pyroxene support this interpretation. This interpretation is also consistent with the different diffusion rates of Mg-Fe in olivine and pyroxene. Compared to coarse-grained olivine and pyroxene with thick exsolution lamellae, the lithic clasts with ophitic to subophitic texture might have formed at relatively shallow depth.

2339C-05 is a very important clast because olivine is located in melt inclusion of anorthite fragment and it has bulk chemistry similar to KREEPy rocks from the Moon. The texture indicates that olivine crystallized from melt. On the other hand, two mineral assemblages in 2339C-05 might be the result of silicate liquid immiscibility.

In 2339C-08, that fayalitic olivine is included by Al-rich hedenbergite may indicate the melt these two minerals formed could be extremely Fe-rich and Al-rich. The different mineral assemblage from common eucrite clasts may imply that it was derived from a Fe-rich source region.

In summary, the common presence of fayalitic olivine in NWA 2339 might indicate that it was derived from an iron-rich, olivine-rich, and highly differentiated region on the surface of eucrite parent body. It may also have significance to interpret future high-spatial-resolution spectroscopic data on the surface of asteroid 4 Vesta from Dawn mission.

References:

[1] Ikeda Y. and Takeda H. (1985) *JGR (Supplement)*, 90, C649-C663. [2] Treiman A.H. and Drake M.J. (1985) *JGR (Supplement)*, 90, C619-C628. [3] Kozul J.M. and Hewins R.H. (1989) *Meteoritics*, 24, A289. [4] Takeda H. et al. (1994) *EPSL*, 122, 183-194. [5] Buchanan P.C. et al. (2000) *MAPS*, 35, 1321-1331. [6] Beck P. et al. (2001) *MAPS* (Supplement), 36, A17. [7] Beck A.W. and McSween H.Y. (2010) *MAPS*, 45, 850-872. [8] Barrat J.A. et al. (2011) *GCA*, 75, 3839-3852. [9] Patzer A. and McSween H.Y. (2011) Workshop for Formation of the First Solids in the Solar System, Abstract#9002. [10] Beck A.W. et al., (2011) *MAPS*, 46, 1122-1151. [11] Connolly H.C. et al. (2007) *MAPS*, 42, 413-466.

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