Formation of the Sapphirine-bearing Al-rich Chondrule in the DaG 978 Carbonaceous Chondrite: Preliminary Mineralogical and Oxygen Isotopic Results. A. C. Zhang[1,2], S. Itoh[2], H. Yurimoto[2], Q. Sun[1], R.C. Wang[1]. [1]School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China (aczhang@nju.edu.cn), [2]Department of Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan.

Introduction: Refractory inclusions and ferromagnesian chondrules are the most important components in primitive chondrites. They record the formation conditions and processes in the early solar system. Aluminum-rich chondrules are mediate between refractory inclusions and ferromagnesian chondrules in mineralogy and bulk chemistry. They may provide a clue to unravel the possible relationship between refractory inclusions and ferromagnesian chondrules. Dar al Gani (DaG) 978 is an ungrouped type-3 carbonaceous chondrite found in 1999 [1]. In this chondrite, we observed a sapphirine-bearing Al-rich chondrule (abbreviated as SARC), which has complex petrographic texture. Here, we report the preliminary results of mineralogical and oxygen isotopic studies on SARC and discuss its possible origin.

Analytical methods: The petrography of SARC was mainly observed by using JEOL 7000F scanning electron microscope at Hokkaido University. Mineral chemistry of SARC was determined by using JEOL 8100 electron microprobe at Nanjing University. Oxygen isotopic compositions of minerals in SARC were measured by using the Cameca IMS-1270 ion microprobe at Hokkaido University. The analytical procedure is similar to [2]. The monocollector mode was used, with FC2 measuring ^{16}O and EM measuring ^{17}O and ^{18}O. The spot diameter is about 3 µm. A mass resolution power of ~5500 was used to separate ^{17}O from ^{16}OH.

Results: The sapphirine-bearing Al-rich chondrule has a round shape and is about 1.5 mm in size. Based on mineral assemblages, SARC has a complex core-mantle-rim texture. The core is about 700 µm in size. It is mainly characterized by the densed distribution of fine-grained and subhedral to euhedral spinel (Mg# = 59-60), which is included in Al-rich enstatite (~11 wt% Al_2O_3, Mg# = 98-99), anorthite (An87-89), and mesostasis (Fig. 1). The mesostasis in the core contains abundant prismatic sapphirine crystals ($Mg_2Al_4SiO_{10}$) and very fine-grained diopside and glass (Fig. 1). A few sapphirine grains include spinel. Sapphirine has a chemical composition close to its end-member, but contains slightly high Si (1.04-1.07 based on 10 O atoms). The mantle is about 400 µm thick and mainly composed of Al-rich enstatite (8-11 wt% Al_2O_3, Mg# = 99), anorthite (An84-87), and mesostasis. A few anhedral to subhedral olivine grains (Mg# = 68-71) and FeNi metals were also observed in the mantle. This mesostasis consists of diopside and glass, and no sapphirine grain was observed. The boundary between the core and the mantle can only be defined by the presence of spinel or not. In the rim of SARC, round-shaped olivine (Mg# = 69) and FeNi metal are included in enstatite (~1 wt% Al_2O_3, Mg# = 75-93).

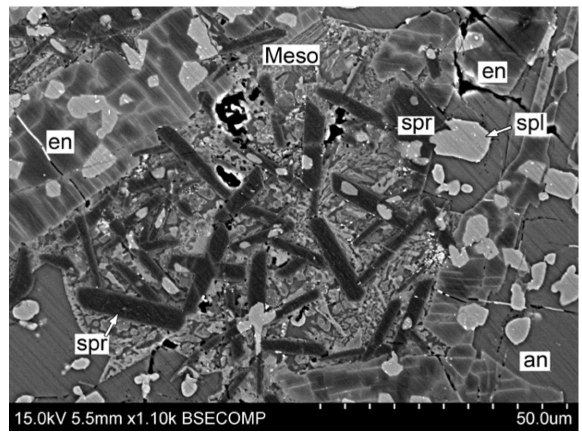

Fig. 1. BSE image of sapphirine-rich mesostasis in the sapphirine-bearing Al-rich chondrule from DaG 978.

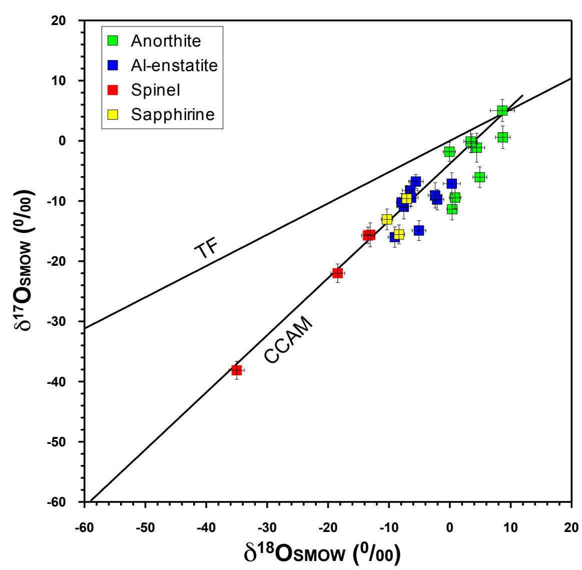

Fig. 2. Oxygen isotopic compositions of spinel and sapphirine from the core, and Al-rich enstatite and anorthite from the mantle in the sapphirine-bearing Al-rich chondrule from DaG 978.

Oxygen isotopic compositions of minerals from the core and the mantle in SARC generally lie along the carbonaceous chondrite anhydrous minerals (CCAM) line (Fig. 2). Spinel is relatively ^{16}O-enriched and has a large variation of δ^{18}O from −35 to −13.1 ‰. Sapphirine from the core has δ^{18}O varying from −10.3 to −7.1 ‰. The δ^{18}O of Al-rich pyroxene from the mantle ranges from −9.0 to 0.3 ‰. Anorthite from the mantle is ^{16}O-poor (δ^{18}O = −0.1~8.7 ‰). More analyses for oxygen isotopic compositions of minerals in this chondrule are still in process.

Discussion: The sapphirine in SARC from DaG 978 is the second report of occurrence in chondrites, which is similar in texture to USNM 3510 in the Allende chondrite [3]. Both of them are compound objects and have a fine-grained core and a coarse-grained mantle. However, no olivine was observed in the sapphirine-bearing core in SARC, distinctly differing from USNM 3510 [3]. The similar texture might indicate that they formed in a similar formation process; however, the different olivine abundance in the two sapphirine-bearing objects may imply that at least their precursors are different in bulk chemistry.

Based on the petrographic texture and chemical compositions of minerals in SARC, crystallization of SARC may include four stages. The first stage is crystallization of the spinel-rich core from the spinel-saturated Al-rich melt. In this stage, the fact that spinel was included in anorthite and Al-enstatite indicates that spinel should be the first phase crystallized from the melt. Then, anorthite and Al-enstatite may crystallize from the melt. Sapphirine should be a relatively late stage phase since it occurs mainly in mesostasis. The second stage is the crystallization of anorthite and Al-rich enstatite in the mantle from a spinel-unsaturated Al-rich melt after the formation of the core. In the late stage of crystallization of the mantle, forsterite might be saturated and crystallize from the melt. In the third stage, fragments or melts of magnesian chondrules was accreted on the margin of the partially solidized Al-rich melt. The fourth stage involves the oxidization of spinel and olivine in SARC.

The current oxygen isotopic results generally support this formation sequence proposed above. Most importantly, the large oxygen isotopic variation along the CCAM line indicates that the precursor of SARC was experiencing oxygen isotopic exchange with a ^{16}O-poor nebular gas during its crystallization. Based on the oxygen isotopic compositions of spinel in SARC, the original oxygen isotopic compositions of the precursor of SARC could be highly ^{16}O-enriched, at least having a δ^{18}O value of about −35 ‰. It is very likely that the original δ^{18}O value for the precursor of SARC is close to that of refractory inclusions [c.f., 4,5,6]. The ^{16}O-poor feature of anorthite relative to Al-enstatite could be due to the later crystallization after the enhanced degree of oxygen isotopic exchange between melt and surrounding ^{16}O-poor nebular. We are measuring the oxygen isotopic compositions of other phases in SARC, for instance, Al-rich enstatite and anorthite in the core and olivine and enstatite in the mantle and the rim. With more detailed oxygen isotopic data, we will discuss the formation process and conditions of the entire SARC in DaG 978.

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