Mn-Cr age of aqueous alteration in a parent body of the Vigarano CV3 chondrite

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At the early stage of the solar system formation, asteroids had formed from the gas and dust in the solar nebula. Afterwards, asteroids were heated by the decay of the short-lived radionuclide and the collisions between asteroids. There has been abundant water together with rocky particles in the asteroids and therefore aqueous alteration, the hydrothermal reaction between rocks and water, has commonly taken place. Aqueous alteration is the earliest chemical reaction that has taken place in hydrous asteroids because of low reaction temperatures. Thus it predates thermal metamorphism that ubiquitously occurred in any kind of asteroids. In order to obtain a better understanding for the evolution of the early solar system, it is important to elucidate the effects of aqueous alteration on materials that form primitive asteroids. Vigarano meteorite, classified to reduced subgroup of CV3 chondrite, is one of the most primitive solid material in the solar system, because it experienced very weak aqueous alteration in a primitive asteroid. During aqueous alteration fayalite up to 50 µm in size formed in matrix. Based on the abundance of short-lived radionuclide 53Mn in fayalite, I determined the age when the aqueous alteration had taken place in a primitive asteroid.

For this purpose, first, I observed thin sections of the meteorite using a polarizing optical microscope with reflected and transmitted light. Next, I observed, identified and analyzed secondary minerals in the meteorite using a scanning electron microscope (SEM), an electron probe micro analyzer (EPMA). Finally, I analyzed Mn and Cr isotopic ratios of fayalite using a secondary ion mass spectrometer (SIMS). To determine relative sensitivity factors of SIMS analysis for 55Mn/52Cr ratio, we measured San Calros olivine, whose 55Mn/52Cr ratio was analyzed using inductivity coupled plasma (ICP).

SEM observations showed that fayalite exhibits a train of grains forming vein-like structure and replaces pre-existing magnetite. The composition of Fayalite was determined to be Fa# = 94.6 with a high Mn/Cr ratio, so these fayalite grains are suitable for the Mn-Cr dating. SIMS measurement revealed that the Mn-Cr evolution diagram of fayalite defines an initial 53Mn/55Mn ratio of (2.19+/-0.53)x10-6. This ratio indicates that Vigarano fayalite formed 3 Ma before Angrite that formed in a differentiated asteroid. An absolute age was also determined to be 4561+/-3 Ma relative to that of Angrite.

The observations that the fayalite exhibits a train vein-like structure indicate that aqueous alteration occurred in situ in an asteroid and the fayalite formation age corresponds to the time of aqueous alteration. Next, CV3 chondrites are divided into two groups: the oxidized subgroup and the reduced subgroup. The alteration age of Vigarano meteorite (the reduced subgroup) is identical within errors to that of Mokoia meteorite (the oxidized subgroup: Hutcheon et al. 1998). This time indicates that the reduced subgroup and the oxidized subgroup may constitute a single asteroid, although I cannot rule out the possibility of the presence of two separate bodies. Finally, the fayalite formation time indicates the upper limit of the formation age of CV chondritic asteroids, because the Vigarano chondrite asteroids had already accreted when fayalite was formed.