Formation age of mesosiderites

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Mesosiderites are composed of roughly equal amounts of silicates and Fe-Ni metal. This meteorite group has been thought to have formed by mixing of crustal and core materials without including much of the mantle materials. Although several scenarios for the formation of mesosiderites have been proposed, the mechanism and timing of the metal-silicate mixing are still open questions. In the previous works, the Sm–Nd and Mn–Cr ages of mesosiderites have indicated that the metal-silicate mixing likely occurred 20–150 Ma after solar system formation (Stewart et al., 1994; Wadhwa et al., 2003). However, the ages still have a large range more than 100 million years. In order to determine a more precise age of the metal-silicate mixing event, it is necessary to analyze the minerals which formed during the mixing event and have remained closed systems for chronometers throughout the later impact events. Rutile and zircon have strong resistance to mechanical and chemical breakdown over long periods and suitable for ^{92}Nb-^{92}Zr and U-Pb dating, respectively. In addition, the previous works have suggetsed that these minerals formed during the mixinf event (e.g., Haba et al., 2017). In this study, we will report the new ^{92}Nb-^{92}Zr and U-Pb ages of mesosideritic rutiles and zircons, respectively, to determine the age of the metal-silicate mixing event.

Four mesosiderites having different metamorphic grades, Vaca Muerta (1A), NWA 1242 (2A), A 882023 (2/3A), and Estherville (3/4A), were used in this study. Rutiles and zircons were separated from residual samples after dissolving the Fe-Ni metal and silicate parts with concentrated acids. Subsequently, a few hundreds of rutile grains which were handpicked from residual samples were dissolved in HNO_3-HF using Parr®bombs. The Nb/Zr ratio and Zr isotope measurements were performed using a quadrupole ICPMS and a Neptune Plus MC-ICPMS, respectively, at ETH Zurich. 16 individual zircons from Vaca Muerta, NWA 1242, and Estherville (40–200 μm in diameter) were spiked with 3–5 mg of EARTHTIME ^{202}Pb-^{205}Pb-^{233}U-^{235}U tracer solution and dissolved in concentrated HF using Parr® bombs. U and Pb were separated using a HCl-based column chemistry and measured using a TRITON Plus TIMS at ETH Zurich.

Three zircon grains from Vaca Muerta and Estherville yielded a weighted mean ^{207}Pb-^{206}Pb age of 4558.5 ± 1.6 Ma (2σ). Other four grains from Vaca Muerta, four grains from NWA 1242, and five grains from Estherville yielded weighted mean ^{207}Pb-^{206}Pb ages of 4528.0 ± 1.4 Ma (2σ), 4525.1 ± 2.5 Ma (2σ), and 4526.8 ± 2.7 Ma (2σ), respectively. The younger ages from three mesosiderite samples show an overlapping within the errors. The weighted mean ^{207}Pb-^{206}Pb age of all younger zircons is 4527.2 ± 1.1 Ma (2σ). According to Haba et al. (2017), mesosiderites have two kinds of zircons: (I) magmatic zircons that crystallized before the metal-silicate mixing event, and (II) secondary zircons that formed through the mixing event. The older age is in good agreement but significantly more precise than the previously reported age for the magmatic zircon from Vaca Muerta, whose age is 4563 ± 15 Ma (2σ) (Ireland and Wlotzka, 1992). Therefore, these zircons are considered to be relict zircons that formed in the silicate parts before the metal-silicate mixing event. The new ^{207}Pb-^{206}Pb age of the magmatic zircons of mesosiderites indicates that the magmatic zircons in mesosiderites formed during the very early stage of the parent body history. On the other hand, the younger age is consistent with the recently reported ^{207}Pb-^{206}Pb age of zircons from Estherville (4521 ± 26 Ma, Haba et al., 2017). The young age has been interpreted as the timing of the metal-silicate mixing event or later impact event. The ^{207}Pb-^{206}Pb ages of zircons in this study indicate two distinct populations (Fig. 1). In addition, the older ages were obtained from relatively small zircon grains (30−50 μm in a diameter), while the younger ages were from the zircons which have various sizes up to 200 μm. If the younger age is attributed to the resetting of U and Pb decay system during the later impact event, the ^{207}Pb-^{206}Pb age of a relatively small zircon should yield the younger age. However, this estimation conflicts with the observation where the older ages are all from relatively small zircons. Therefore, the younger age is considered to correspond to the metal-silicate mixing event that formed mesosiderites.

The Nb-Zr data of rutiles from four mesosiderites are plotted on a single line in the Nb-Zr isochron diagram. The ^{92}Nb/^{93}Nb ratio obtained from the rutile data is $(7.5 \pm 0.7) \times 10^{-6}$, which is in good agreement with the ^{92}Nb/^{93}Nb ratio for mesosiderites reported in Schönbächler et al. (2002). The data plotted on the single line indicate that the ^{92}Nb-^{92}Zr decay system of mesosideritic rutiles has not been disturbed by later impacts after they formed. Since the rutiles in mesosiderites have been considered to form during the metal-silicate mixing under reducing condition (e.g., Yamaguchi et al., 2001), the ^{92}Nb-^{92}Zr age of rutiles should correspond to the timing of the mixing event. Using the initial ^{92}Nb/^{93}Nb ratio of rutiles and the solar system initial ^{92}Nb/^{93}Nb ratio ($(1.7 \pm 0.6) \times 10^{-5}$, Iizuka et al., 2016), the ^{92}Nb-^{92}Zr age of rutiles was calculated to be 41 ±

15 Myr after CAI formation. This age corresponds to the absolute age of 4527Ma, which is consistents with the ^{207}Pb-^{206}Pb age of secondary zircons of mesosiderites. The ^{92}Nb-^{92}Zr age of rutiles strongly supports that the metal-silicate mixing that formed mesosiderites occurred at 4527.2 ± 1.1 Ma.

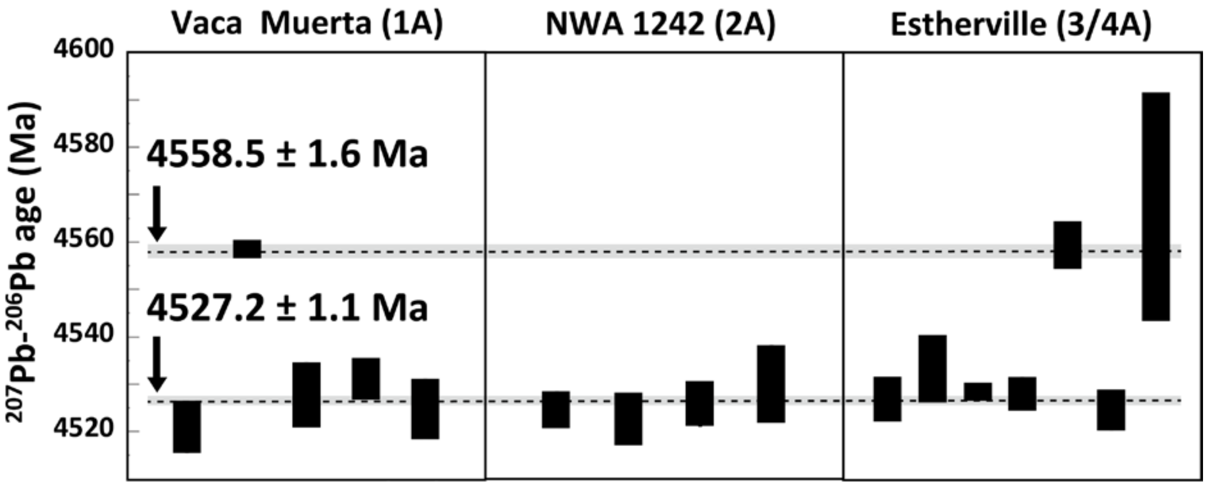

Fig. 1. $^{207}Pb/^{206}Pb$ age data for 16 zircons from Vaca Muerta, NWA 1242, and Estherville. The weighted mean age of younger zircons is 4527.2 ± 1.1 Ma (n = 13), and that of older zircons is 4558.5 ± 1.6 Ma (n = 3). Data error are 2σ.

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