論文内容の要旨

論文題目：Noble gas chronological study of brecciated meteorites: Implication for the early solar system evolution

和訳題目：希ガス同位体分析に基づく角礫岩質隕石の年代学的研究：初期太陽系の進化に関する知見

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Noble gases are the most sensitive tracer which indicates various sources of noble gas and nuclear interactions induced by high energy particles because of their unique isotopic compositions as well as ultra-high sensitive analytical method. I–Xe and K–Ar (Ar–Ar) systems are also applicable to chronological studies of the early solar system. Objectives of my PhD study were focused on the chronological study for the surface materials of the asteroids which interacted with solar wind (SW) emitted from the ancient Sun and galactic cosmic-rays (GCR). Brecciated meteorites had been located on its parent body surface. The meteorites can trace behaviors of SW, GCR, and the surface of the irradiated body in the early solar system because some of them were exposed to SW and GCR. Thus, history of the interactions can be made clear by combination of noble gas isotopic compositions from various origins and isotopic chronometers. 1) The important

event which must have occurred in the early solar system was dissipation of gas and dust from the protoplanetary disk. Timing of the gas dissipation was estimated mainly by theoretically and/or from observation of the protoplanetary disk at the period of pre-main-sequence. I present a new method to determine the timing of the dispersal by combination of I–Xe chronometer and solar-noble-gas concentrations in brecciated meteorites. 2) In the ancient Sun deuterium burning is thought to have occurred in the T Tauri stage, which produced ^{3}He from D and H. The deuterium burning produced the ^{3}He/^{4}He of ca. 3.8×10^{-4} in the outer convective zone of the present Sun, which is higher than the primordial ^{3}He/^{4}He ratios of ca. $(1.4–1.7) \times 10^{-4}$ observed in primitive meteorites and in atmosphere of Jupiter. I tried to find out a transitional change in ^{3}He/^{4}He ratios in ancient solar gases trapped in solar-gas-rich brecciated meteorites. 3) I also discovered a clear evidence of two-stage irradiation of meteorites by GCR; i.e., an eucritic inclusion in the Vaca Muerta mesosiderite was exposed to GCR for more than 60 Myr before incorporation into the bulk material.

1) Timing of the clearing of proto-solar nebula: The aim of this study was to determine the age when SW started to irradiate planetary materials after dissipation of protoplanetary gas between the Sun and the planetesimals in asteroidal belt. Concentrations and isotopic ratios of light noble gases derived from SW were precisely determined for several solar-gas-rich meteorites. The SW noble gases in Willard (b) were preserved well. The gases in Zag might have been partially degassed during the formation of light/dark structure. In contrast to these meteorites, Cook 011 had mostly degassed by thermal metamorphism at 1 Ga, which was determined by ^{39}Ar–^{40}Ar method. I–Xe dating method was applied to these meteorites to measure formation age of brecciated structures or trapping age of the SW gases. The gas-rich portions of the meteorites revealed younger I–Xe age than the gas-poor ones. The boundary between the different I–Xe ages implies the timing when nebular gas dispersed from the inner solar system (<3 AU), because SW could not reach to the asteroidal belt until the gas density was reduced to about ten orders of magnitude lower than the

initial condition of the proto-solar disk. The I–Xe ages obtained for the meteorites indicate that the nebular gas was totally dispersed between 4550 ± 2 and 4555 ± 3 Ma.

2) Ancient ^{3}He/^{4}He ratio of solar wind: The SW He and Ne compositions were analyzed for the gas-rich portions of the regolithic breccias. The SW antiquities of the samples ranged from 4.51 to 4.55 Ga, which were obtained by the I–Xe dating method. Variable SW ^{3}He/^{4}He ratios which were lower than that in the present Sun were obtained. The low ^{3}He/^{4}He ratios suggest that the old SW reflected a direct evidence for the deuterium burning in a core of the Sun or scarce mixing between the core and outer convective zone after deuterium burning was over. However, SW ^{20}Ne/^{22}Ne ratios corresponding to the ^{3}He/^{4}He were also lower than the present one, which cannot be explained by nuclear fusion in the Sun. Thus, the low ^{3}He/^{4}He and ^{20}Ne/^{22}Ne ratios observed in the gas-rich meteorites could be produced by a partial removal of outermost coat of the grains with high isotopic ratios during the gardening, compaction, and impact heating processes. The result of this work suggests that the SW ^{3}He/^{4}He was unchanged for 4.55 Gyr keep the present-day value. Consequently, the deuteron burning and a mixing process between the core and the surface layer of the Sun had totally finished before 4.55 Ga.

3) Cosmic-ray exposure history of the Vaca Muerta mesosiderite: Noble gas isotopic compositions were measured for a eucritic pebble and bulk material of a silicate–metal mixture from the Vaca Muerta mesosiderite as well as pyroxene and plagioclase separated from the eucritic pebble by total melting and stepwise heating methods. Trapped noble gases were degassed completely by a high-temperature thermal event, probably at the formation of Vaca Muerta parent body (VMPB). The presence of fissiogenic Xe isotopes from extinct ^{244}Pu in the bulk samples might be a result of rapid cooling from an early high-temperature metamorphism. High concentrations of cosmogenic noble gases enabled us to determine precise isotopic ratios of cosmogenic Kr and Xe. Spallogenic Ne from Na and unique Ar isotopic compositions were observed. The ^{81}Kr–Kr exposure age of 168 ± 8 Myr

for the silicate pebble is distinctly longer than the age of 139 ± 8 Myr for the bulk samples. The precursor of the pebble had been irradiated on the surface of the VMPB for more than 60 Myr (first stage irradiation), with subsequent incorporation into bulk materials approximately 4 Ga. The Vaca Muerta meteorite was excavated from the VMPB 140 Ma (second stage irradiation). Relative diffusion rates among the cosmogenic Ar, Kr, and Xe based on data obtained by stepwise heating indicate that Kr and Xe can be partially retained in pyroxene and plagioclase under the condition which resets the K–Ar system. This result supports the presence of fission Xe and of excess concentration of cosmogenic Kr, which could have survived the thermal event ca. 3.8 Ga.