THE COOLING RATE OF THE SIOUX COUNTY EUCRITE; M. Miyamoto, P. H. Warren, and H. Takeda, Mineralogical Institute, Graduate School of Science, University of Tokyo, Hongo, Tokyo 113, Japan.

We computed the cooling rate and burial depth of a coarse-grained leucocratic clast from the Sioux County eucrite to gain information on the evolution of eucritic crust of the HED parent body. We determined the best-fit cooling rate or burial depth by closely matching the calculated width of augite and Ca gradients of both augite and the host pyroxene to the observed profiles measured by electron microprobe. Pyroxene initially having the uniform bulk Ca content of 9.4 mol% and mg#= 38 begins to exsolve at 920 °C and cools down to 570 °C at a rate of 0.01 °C/yr, forming an augite lamella about 4.2 μm in width. The best-fit burial depth is about 800 m in a rock-like sheet and is about 40 m in a hot regolith deposit.

Introduction: The Sioux County eucrite is generally considered to be a noncumulate, crystallized from a basaltic lava on the surface of the HED parent body [e.g., 1]. On the basis of the chemical zoning and texture of pyroxenes in noncumulate eucrites (subophitic basalts), Takeda and Graham [2] classified noncumulate eucrites into six types according to different degrees of thermal metamorphism: from the most primitive type 1 to highly equilibrated type 6. In this classification, Sioux County belongs to annealing grade of type 5. However, this eucrite is a texturally heterogeneous, and very possibly polymict breccia. Based on the coarse and blocky texture of the silicates in a leucocratic clast from Sioux County, Warren and Kallemeyn [3] inferred that this clast formed as an orthocumulate. We have estimated the cooling rate and burial depth of this clast based on a study of its pyroxene [4].

Results: A 7-mm pyroxene crystal in the subject clast contains augite lamellae up to about 6 μm in width with an interval of about 20 μm. The bulk composition of this pyroxene is $Ca_{9.4}$ $Mg_{34.8}$ $Fe_{55.8}$. The chemical composition of exsolved augite is $Ca_{43.6}$ $Mg_{29.9}$ $Fe_{26.5}$ and that of host low-Ca pyroxene is $Ca_{2.3}$ $Mg_{35.8}$ $Fe_{61.8}$.

Pyroxene initially having the uniform bulk Ca content of 9.4 mol% and mg# (=100 x Mg/(Mg+Fe)) of 38 begins to exsolve at 920 °C when pyroxene of that composition meets the solvus [5]. Using diffusion coefficients of pyroxene reported by Fujino et al. [6], we obtained the best fit between observed and calculated profiles (Fig. 1) when the pyroxene cools down to 570 °C at a rate of 0.01 °C/yr, forming an augite lamella about 4.2 μm in width. Cooling time at 0.01 °C/yr from 920 to 570 °C to form the lamella is about 10^4 yrs. The best-fit burial depth is about 800 m in a sheet having a thermal diffusivity of 0.004 cm^2/s, a typical value for solid rock [e.g., 7]. For a thermal diffusivity of 0.00001 cm^2/s which is a value for regolith-like material with ~50% porosity [e.g., 7, 8], the best-fit burial depth is about 40 m. However, on the Moon, compaction within the regolith causes diffusivity to increase to 0.0001 cm^2/s at a depth of only about 0.1 m (on asteroid Vesta the analogous depth for the same pressure is 2 m)[8]. For a thermal diffusivity of 0.0001 cm^2/s [8], the best-fit burial depth is about 130 m.

Discussion: At the cooling rate of 0.01 °C/yr obtained for the lamella growth, Mg-Fe zoning in pyroxene is homogenized because the diffusion coefficient of Fe in pyroxene is larger than that of Ca in pyroxene [9]. This result is consistent with the observation that Sioux County belongs to type 5 eucrites which show no Mg-Fe zoning in pyroxene. The cooling rate may be too slow for initial crystallization in a surface lava. However, the burial depth of 800 m is much shallower than those of adcumulate eucrites, which are 3-8 km obtained by a similar method [10].

A question is when pyroxene equilibration occurred in the parent body. The Rb-Sr and Sm-Nd ages of eucrites show that initial crystallization is about 4.55 Ga ago, whereas the ^{39}Ar-^{40}Ar age of almost all eucrites are reset [e.g., 11]. Takeda et al. [12] suggested that

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individual shock events cause the resetting of Ar ages and that a prolonged period of pyroxene annealing probably occurred much earlier in the history of the HED parent body on the basis of the textural observations and the wide distribution of ^{39}Ar-^{40}Ar age for eucrites of various grades of pyroxene annealing. The ^{39}Ar-^{40}Ar age of the Y75011 noncumulate eucrite, which preserves the pristine nature and is annealing grade of type 1, is largely reset (about 3.95 Ga)[12]. On the other hand, the presence of significant pyroxene annealing in the Ibitira noncumulate eucrite, which is unbrecciated and annealing grade of type 5, suggests that this annealing is not directly related to later impact metamorphism and brecciation. Bogard and Garrison [13] reported that if pyroxene equilibration occurred during burial at significant depths or in a large impact deposit, then the ^{39}Ar-^{40}Ar age of 4.495 Ga for Ibitira may date this event.

If equilibration of Sioux County pyroxene occurred during initial crystallization, Sioux County located at the burial depth of 800 m. Taking cooling time of 10^4 yrs into consideration, this event may have had no relation to the ^{39}Ar-^{40}Ar age of 4.495 Ga of Ibitira [13], because the difference (0.065 Ga) from the reported the Pb-Pb formation age of 4.560 Ga for Ibitira is much larger than the cooling time [13]. The duration of 0.065 Ga is comparable with heating time by the decay of ^{26}Al [e.g., 14].

Yamaguchi et al. [15] proposed that thermal metamorphism of noncumulate eucrites is due to either impact heating, extrusion of a second lava flow, or a global thermal event. Annealing beneath a hot lava of 800 m in thickness may be possible [15]. However, it is difficult to envision the hot lava of 800 m in thickness by successive lava flows, because many lava flows have to be produced in a short time to keep the total lava sheet hot. It is also difficult to envision that a large impact produced a deep magma pond of 800 m in depth at the basin.

If pyroxene equilibration occurred at the same time when isotopic chronometers reset, it is possible that the Sioux County clast was located at the depth of 40 m beneath a hot regolith deposit produced in an impact. We cannot exclude the possibility that equilibration of Sioux County pyroxene occurred at the time when the Rb-Sr age of Sioux County [16, 11] reset at 4.1 Ga probably due to heavy bombardment, although the Pb isotopic age is 4.526 Ga [17].

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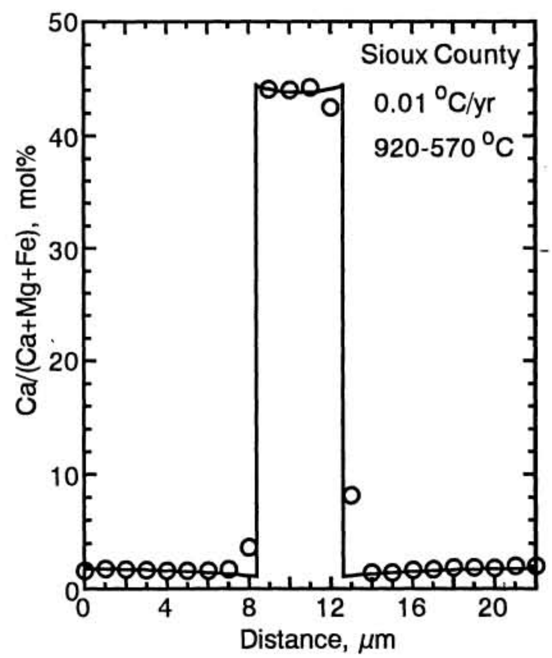

Fig. 1. Observed (open circles) and computed (solid line) Ca compositional profiles in augite and low-Ca pyroxene in the Sioux County eucrite.