THERMAL EVOLUTION OF CV-LIKE CARBONACEOUS CHONDRITE ASTEROID. S. Wakita, K. Jogo, and A. N. Krot, HIGP/SOEST, University of Hawai'i at Manoa. E-mail: shigeru@higp.hawaii.edu.

Introduction: The parent asteroids of most groups of carbonaceous chondrites (CC) experienced aqueous alteration, most likely as a result of melting of ice that accreted together with largely anhydrous silicates. The CI, CM, and CR chondrites experienced relatively low temperature aqueous alteration, which resulted in formation of hydrous silicates, carbonates, magnetite, and Fe,Ni-sulfides. In contrast, CV chondrites, currently subdivided into three subgroups, oxidized Bali-like (CV_{OxB}), oxidized Allende-like (CV_{OxA}), and reduced (CV_R), experienced diverse styles of alteration (low-temperature aqueous and high-temperature metasomatic) and subsequent thermal metamorphism to varying degrees. The commonly observed secondary minerals in CV chondrites include ferroan olivine, salite-hedenbergite pyroxenes, andradite, nepheline, sodalite, wollastonite, grossular, monticellite, magnetite, Ni-rich metal, and Fe,Ni-sulfides. Short-lived isotope chronology (^{26}Al-^{26}Mg, ^{53}Mn-^{53}Cr, and ^{129}I-^{129}Xe) of secondary minerals in CV chondrites suggests that alteration started ~3 Myr after CV CAIs and lasted for at least 10 Myr [e.g., 1]. The estimated temperature of alteration and subsequent thermal metamorphism of CV chondrites varies from <350 K for aqueously altered Kaba (CV_{OxB}) to ~750K for largely anhydrous Allende, to ~1100 K for heavily-metamorphosed clasts in Mokoia and Y-86009 [2–8]. If all subgroups of CV chondrites and heavily-metamorphosed clasts in Mokoia and Y-86009 formed in a single CV parent body, the core of this body was probably heated to at least ~1100 K [2].

There are several theoretical studies on thermal history of the CR, CI, and CM chondrite parent bodies [9–11]; a comprehensive thermal model of the CV chondrite parent asteroid is currently absent. The goal of our study is to construct a thermal model of the CV-like parent body which would be consistent with the mineralogical and isotopic constraints on physico-chemical conditions and chronology of CV alteration and thermal metamorphism. Here we report numerical simulations of thermal evolution of a CV-like parent body using different initial conditions (e.g., water/rock ratio, size of asteroid, and time of accretion). We also considered formation of a rocky core due to ice melting [12].

Methods and Initial Parameters: We assume that the original CV chondrite parent asteroid consisted of anhydrous rocky material and water ice. The H_2O in the solar nebula could condense as water ice if the partial pressure of H_2O exceeds the saturated pressure over water ice. In the minimum mass solar nebula [13], condensation of water ice occurs at ~ 3.2 AU. The initial water/rock mass ratio used in our calculations ranges from 0 to 0.92; the latter represents the highest value for a gas of solar composition [14]. These water/rock ratios correspond to a region in the protoplanetray disk from 3.2 to 4.5 AU. Temperature in this region is estimated to be ~150K, which is considered to be the initial temperature of CV parent asteroid used in our calculations. In this region, H_2O is completely condensed as water ice, whereas the abundance of other gases condensed (e.g., NH_3 and CO) is negligible. ^{26}Al ($t_{1/2}$ = 0.72 Myr) is assumed to be the main heating source of the CV-like asteroid [9–11]. The initial ^{26}Al/^{27}Al ratio in the CV-like asteroid is assumed to be between the canonical value of 5×10^{-5} and 5×10^{-7} (4.8 Myr after CAIs; close to the upper limit of life time of the protoplanetary disk). The abundance of Al, 1.75 wt%, is inferred from bulk chemical compositions of CV chondrites [15].

The phase transitions of water ice, its melting and vaporization are considered. The melting temperature of H_2O ice is assumed to be 273K. After complete melting of water ice, rock would settle toward the center of the parent bodies and form a rocky core if the initial H_2O ice volume exceeds rock volume (corresponding to the initial water/rock mass ratio > 0.34). We assume that the rocky core would retain some amount of liquid water; the water/rock ratio in the rocky core is assumed to be ~0.1, which is smaller than that of the cores of the CM and CI chondrite parent asteroids (0.1–0.2 [16]). If vapor pressure of water exceeds lithostatic pressure, liquid water would vaporize. The latent heat of phase transition of water is considered. The reaction heats of aqueous alterations have not been considered yet and will be added later. The flow of water in the CV chondrite parent body might occur [11], but has not been considered here: if permeability is low, the flow scales would be short (less than a meter [17]) and won't affect significantly thermal evolution of a parent body. Numerical simulations are performed using radius of the parent body between 10 and 100 km, which may represent the initial sizes of planetesimals [18].

Results and Discussion: Figure 1 shows the results of thermal modeling of the CV-like parent bodies 50 km in radius which accreted with different initial ^{26}Al/^{27}Al ratios and various initial water/rock mass ratios; only the parent body with water/rock ratio of 0.92 would form a rocky core [12]. We infer that CV parent body that accreted at 1.4–1.8 Myr after formation of CAIs with the canonical $^{26}Al/^{27}Al$ ratio could reach peak metamorphic temperature of ~1100K; chondrite parent bodies which accreted later could not have reached such high temperatures. The estimated accretion times of the CV-like parent asteroids predate those estimated for CI and CM parent asteroids (~ 3 Myr after CAI formation [9, 10]) and put an upper limit on time of CV chondrule formation (assuming the uniform distribution of ^{26}Al in the protoplanetary disk).

According to our calculations, melting of water ice and evaporation of water occur 0.2–0.3 Myr and 0.3–0.4 Myr after accretion of CV asteroid, respectively. The evaporation temperature of water is estimated to be between 470 and 500K (Fig. 1). This temperature increases with radius increase and decrease of water/rock ratio. If rocky core formation could occur, the parent body could reach 1100K regardless of the initial water/rock ratio.

Figure 2 shows the temperature profile in the parent body that accreted 1.86 Myr after CAIs and had the initial water/rock ratio = 0.11. We find that the temperature in a thin layer near the surface of this parent body (~1 km thickness at ~48 km) is between the melting temperature of water ice and evaporation temperature of water, suggesting that water could be retained in this layer and be responsible for aqueous alteration over 10 Myr after accretion as inferred from short-lived isotope chronology of secondary minerals in CV chondrites. Two other models illustrated in Fig. 1 could also retain water in a surface layer.

Additional simulations with different initial parameters will be presented at the meeting.

References: [1] Krot A. N. et al. (2006) in *Meteorites and the Early Solar System II*, Univ. Arizona Press. [2] Brealey A. J. and Krot A. N. (2010) in *Metasomatism and Metamorphism: The Role of Fluids in Crustal and Upper Mantle Processes*, eds. D. E. Harlov and H. Austrheim, submitted. [3] Cohen R. E. et al. (1983) *Geochim. Cosmochim. Acta, 47*, 1739–1757. [4] Krot A. N. and Hutcheon I. D. (1997), *LPS, XXVIII*, 1347. [5] Krot A. N. et al. (1998) *Meteoritics & Planet. Sci, 33*, 1065–1085. [6] Jogo et al., (2008) *Meteoritics & Planet. Sci., 71*, A5188. [7] Jogo K. and Nakamura T. (2009) *Meteoritics & Planet. Sci., 72*, A5188. [8] Jogo K. and Krot A. N. (2010), *Meteoritics & Planet. Sci, 73*, A5073. [9] Grimm R. E. and McSween H. Y. Jr. (1989) *Icarus, 82*, 244–280. [10] Cohen B. A. and Coker R. F. (2000) *Icarus, 145*, 369–381. [11] Young E. D. (2001) *Phil. Trans. R. Soc. Lond., 359*, 2095–2110. [12] Wakita S. and Sekiya M. (2010) *LPS, XLI*, 1291. [13] Hayashi, C. (1981) *Progr. Theor. Phys. Suppl., 70*, 35–53. [14] Lodders K. (2003) *Astrophys. J., 82*, 244–280. [15] Hutchison R. (2007) in *Meteorites: A Petrologic, Chemical and Isotopic Synthesis*, Cambridge Univ. Press. [16] Clayton R. N. and Mayeda T. K. (1999), *Geochim. Cosmochim. Acta, 63*, 2089–2104. [17] Bland P. A. et al. (2009) *Earth Planet. Sci. Lett., 296*, 235–243. [18] Chamber J. E. (2010) *Icarus, 208*, 505–517.

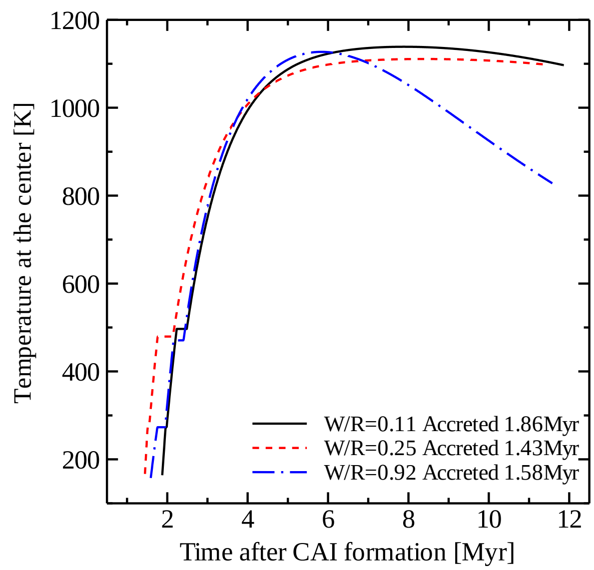

Fig. 1. Temperature evolution at the center of the chondrite parent bodies with 50 km in radius. Solid black line, dashed red line and dot-dashed blue line represent thermal evolution of parent bodies that accreted 1.86, 1.43 and 1.58 Myr after CAI formation and had water/rock (W/R) ratio of 0.11, 0.25 and 0.92, respectively. All three parent bodies could have reached peak metamorphic temperature ~ 1100K.

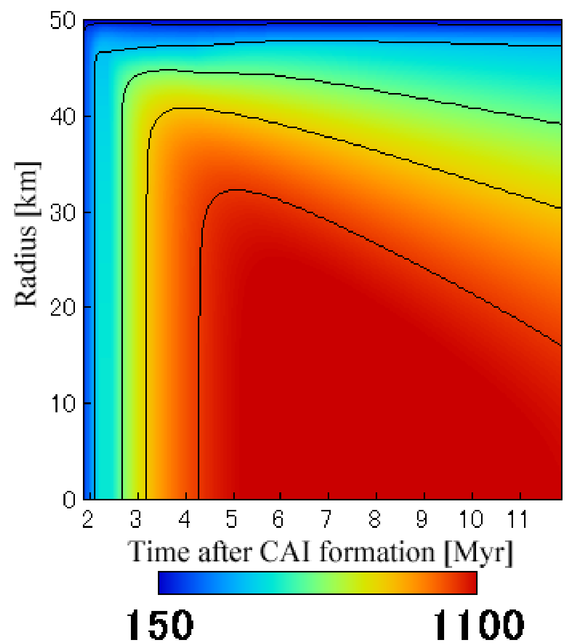

Fig. 2. Temperature profile in a parent body, 50 km in radius that accreted 1.86 Myr after CAI formation and had water/rock ratio of 0.11. Red and blue colors correspond to 1100K and 150K, respectively. The isothermal lines are drawn every 200K.