

# EFFECT OF COLLISIONS ON DEHYDRATION OF HYDROUS MATERIALS IN ASTEROIDS. S. Wakita<sup>1</sup> and H. Genda<sup>1</sup>, <sup>1</sup>Earth-Life Science Institute, Tokyo Institute of Technology, Japan (shigeru@elsi.jp).

**Introduction:** Based on spectral observation, there are relationship between carbonaceous chondrites and C-type asteroids [1, 2], such as Ryugu and Bennu where space mission Hayabusa2 and OSIRIS-REx visit. Those C-type asteroids may have hydrous minerals on their surface. Carbonaceous chondrites also contain hydrous minerals [3], which would form during thermal evolution of planetesimals [4, 5, 6]. Planetesimals which contain ice and rock are heated by decay heat of short-lived radionuclides (e.g., <sup>26</sup>Al), and increase in temperature causes melting of ice followed by aqueous alteration. Asteroids less than 100 km in diameter would have been experienced some impact events from their birth to now [7, 8]. Thus, it is important to see the effect of impacts to internal of asteroids/planetesimals.

Impact can excavate interior of asteroids. Thus, surface materials on the asteroids might originate from their inside [9]. On the other hand, impact can heat up internal asteroid which can contain hydrous minerals. Then, there is possibility that impact heating can provoke dehydration reaction. In that case, impact eventually erase feature of hydrous minerals and we cannot detect hydrous mineral on the surface of asteroid. Some of CM and CR carbonaceous chondrites contain dehydrated minerals [10, 11, 12]. Peak temperature of carbonaceous chondrites is low for dehydration reaction [13]. This means that their parent body does not reach high temperature globally and some local heating event is the key for the dehydration reaction. Impact is one procedure to generate heats locally. Here, we report how planetesimal collision effects on internal of target planetesimal with hydrous core. As a first step, we examine planetesimal collisions by a shock physics code. We investigate the amount of dehydrated materials in the hydrous core and fate of materials after the collisions.

**Methods:** We numerically perform head-on planetesimal collisions using iSALE-2D shock physics code [14, 15, 16]. The target planetesimals are assumed to be 100 km in radius with 90 km sized core of hydrous materials and 10 km anhydrous layer. When the initial planetesimal has water/rock ratio of 0.3, such kind of planetesimal with hydrous core would form via internal heating (i.e., <sup>26</sup>Al) and aqueous alteration. As a material for hydrous core, we choose serpentine, which is one of major products by aqueous alteration. We choose dunite as material of anhydrous layer and impactor, because it is similar to ordinary chondrite [17]. In our numerical calculations, we vary the size of impactor which does not contain hydrous materials ( $R_{\text{imp}} = 10, 20, \text{ and } 40 \text{ km}$  in radius) and impact velocity ( $v_{\text{imp}} = 2.5, 5, 10 \text{ km/s}$ ). Note that the typical impact velocity in current main

asteroid belt is 5 km/s [18, 19]. In this study, we focus on occurrence of dehydration reaction in hydrous core triggered by planetesimal collisions. For this purpose, we assume the dehydration reaction occurs at 600 °C based on experimental works [11, 20, 21]. We define dehydrated part where specific entropy ( $S$ ) exceeds critical value ( $S_{\text{dehyd}}=3.2$ ), which corresponds to specific entropy for 600 °C of serpentine.

**Results & Discussions:** We first show our result of fiducial case of  $R_{\text{imp}} = 20 \text{ km}$  and  $v_{\text{imp}} = 5 \text{ km/s}$ . Figure 1 shows the snapshots of  $3.0 t_s$  ( $t_s$  is a characteristic time of projectile penetration defined as  $t_s = 2R_{\text{imp}}/v_{\text{imp}}$ ) after the collisions with color contours of velocity (left half) and entropy (right half). We can see small portion of hydrous core exceeds  $S_{\text{dehyd}}$ . This means that only small amount of hydrous materials experiences dehydration reaction. The correlation of pressure and entropy in hydrous core is shown in Figure 2 with Hugoniot curve of serpentine. We also can see large amount of hydrous minerals avoids from dehydration reaction (i.e.,  $S < S_{\text{dehyd}}$ ). Trajectories of tracer particles are also shown in Figure 2 (blue and red dash-dotted lines). When the shock wave passages, their entropy and pressure increase. Even after pressure releases, their entropy gradually increases until the pressure settles down. These features can be seen when we consider material strength and these are consistent with previous work on impact physics [22].

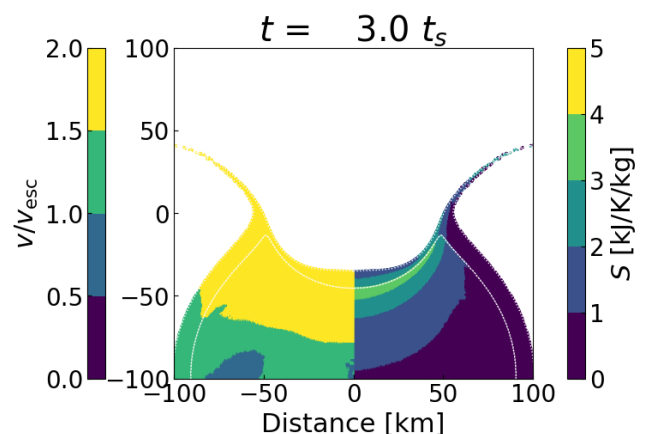


Figure 1: Snapshot of a planetesimal collision between anhydrous impactor and target of 100 km in radius with 90 km hydrous core for the fiducial case ( $R_{\text{imp}} = 20 \text{ km}$  and  $v_{\text{imp}} = 5 \text{ km/s}$ ) at  $3.0 t_s$ . Velocity ( $v$ ) normalized by escape velocity ( $v_{\text{esc}}$ ) at each position are shown on left half and specific entropy ( $S$ ) is on right half. White dotted lines denote surface position of impactor and target, and material boundary in the target.

Next, we compare the amount of dehydrated materials in each model with various size of impactor and impact velocity. The mass ratios of dehydrated material at  $10t_s$  ( $M_{\text{dehyd}}^{10t_s}$ ) to the initial mass of hydrous core ( $M_{\text{hyd}}^0$ ) are plotted in Figure 3 as a function of specific impact energy. The specific impact energy is defined as  $Q_R = 0.5v_{\text{imp}}M_{\text{imp}}M_{\text{tar}}/M_{\text{total}}^2$  [23,24], where  $M_{\text{imp}}$ ,  $M_{\text{tar}}$ , and  $M_{\text{total}}$  are mass of impactor, target, and sum of them, respectively. In our fiducial case (blue circle in Figure 3), dehydrated materials form only 3% of initial hydrous materials. When the impact energy increases (because of large  $v_{\text{imp}}$  and/or  $R_{\text{imp}}$ ), it is much easier to provoke the dehydration reaction. On the contrary, impact velocity of 2.5 km/s cannot always produce dehydration materials (see black symbols in Figure 3), and only the case with large impactor ( $R_{\text{imp}} = 40$  km) can produce dehydrated minerals. Accordingly, we can say that most of hydrous materials inside asteroids can avoid from dehydration reaction with typical collision events in current asteroid belt.

Now, we see velocity of hydrous and dehydrated materials after the planetesimals collisions. The velocity of materials normalized by escape velocity of planetesimals ( $v_{\text{esc}} = (2GM_{\text{total}}/(R_{\text{imp}}+R_{\text{tar}}))^{1/2}$ ) is shown in Figures 1 (left half) and 2 as color contours. It is clear that all dehydrated materials ( $S > S_{\text{dehyd}}$ ) escape from the planetesimals. We also found that hydrous materials ( $S < S_{\text{dehyd}}$ ) have larger velocity than escape velocity ( $v > v_{\text{esc}}$ ). Thus, the ejecta from impacts contains both of dehydrate materials and hydrous ones. This indicates that current surface materials on the asteroids may originate from other asteroids.

Recently, it is reported that current on-going space mission OSIRIS-REx found hydrated minerals on Bennu. C-type asteroid Ryugu target of Hayabusa2 spacecraft may contain hydrous minerals in its inside. Therefore, our understandings of the collisional effects onto the asteroids can lead the better understanding of the surface conditions and history of those asteroids.

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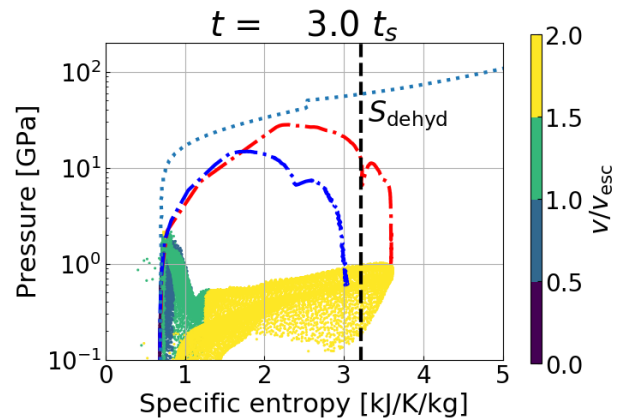


Figure 2: Correlation between pressure and absolute specific entropy in the hydrous core of fiducial case (see Figure 1). Color contour depicts velocity which is normalized by escape velocity ( $v_{\text{esc}}$ ) as in Figure 1. The Hugoniot curves of serpentine (dotted line), the critical specific entropy of dehydration  $S_{\text{dehyd}}$  (vertical dashed line), and trajectory of tracer particles (dash-dotted lines) are also shown.

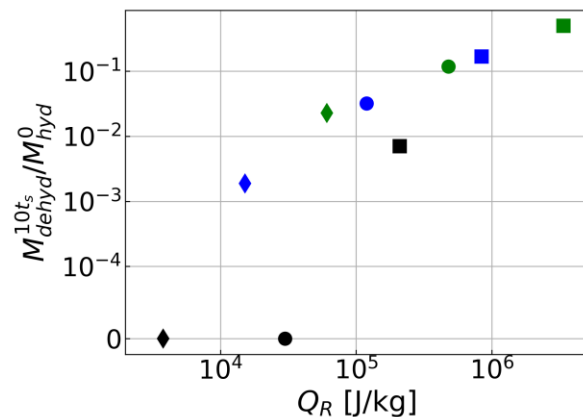


Figure 3: The ratio of dehydrated mass to initial hydrous mass,  $M_{\text{dehyd}}^{10t_s}/M_{\text{hyd}}^0$  as a function of specific impact energy  $Q_R$ . Color represents each impact velocity ( $v_{\text{imp}} = 2.5$  km/s as black, 5 km/s as blue, and 10 km/s as green) and the symbol represents the size of impactor ( $R_{\text{imp}} = 10$  km as diamond, 20 km as circle, and 40 km as square).