

HYPERVELOCITY IMPACT EXPERIMENTS TO STUDY METEORITE FRAGMENTATION IN THE OCEAN AND IMPACT-DERIVED PRODUCTS. M. Nishizawa¹, Y. Matsui¹, K. Suda^{1,2}, T. Saito¹, T. Shibuya^{1,3}, H. Yano^{1,3} and K. Takai¹, ¹ Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka 237-0061, Japan (m_nishizawa@jamstec.go.jp), ² National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, ³ Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Sagami-hara, Japan.

Introduction: The origin(s) of prebiotic organic materials on the early earth is closely related to chemical evolution. One proposes that biologically relevant organic materials were mostly produced through atmospheric chemistry and mineral-water interactions from simple compounds (e.g., N₂, CO₂) available in the early earth, whereas the other proposes that a significant amount of extraterrestrial organic materials, that were produced in the early solar system, protoplanetary disk, and molecular clouds, were delivered to the early earth and became key components of protocells [1]. If the latter hypothesis is correct, it is required that the considerable amounts of meteoritic organics were survived from mineralization during hypervelocity impact into the ocean. However, the fate of meteoritic organics during/after oceanic impact remains to be understood due to the lack of experimental data of the meteorite fragmentation during the hypervelocity impact to liquid water. Meteorite fragmentation during the oceanic impact is key to understand physicochemical conditions that meteoritic organics undergone. This study presents the results of hypervelocity impact experiments in an open system to better understand the meteorite fragmentation in the ocean.

Methods: Experiments were performed using the Hypervelocity Impact Facility at ISAS/JAXA (Fig. 1). The vertical type of the two-stage light gas gun was used to accelerate projectiles at velocities of 4.7-6.2 km/s. The projectiles used in the experiments were an polycarbonate sphere of 4.7 mm in diameter, a stainless steel (SUS304) sphere of 2 mm in diameter and a cylindrical column of ordinary chondrite (diameter of basal plain = 2 mm, column height = 2 mm). Ordinary chondrite used in this study is mainly composed of olivine, pyroxene, metal iron, iron sulfide and tiny material in a matrix. An iron metal block was used as a target to track the trajectory of projectile in water ("witness plate") and was placed in a transparent polyvinyl chloride (PVC) or acrylic resin container with or without liquid water.

The velocities of projectile were estimated from the time of flight measurements. The times of passage at two points of flight path were measured by using a pair of laser/detector system at two stations in the flight tube. Hypervelocity impact between projectile and water was monitored with a high speed video camera (HPV-1; Shimadzu Co., Ltd) with a time resolution of

1 μ s or 2 μ s. The 3D structure and volume of crater made on the iron target was measured by laser displacement sensor. Accuracy of displacement measurement was $\pm 10 \mu$ m in a vertical direction (Z axis), and much better than $\pm 10 \mu$ m in horizontal directions (X and Y axes).

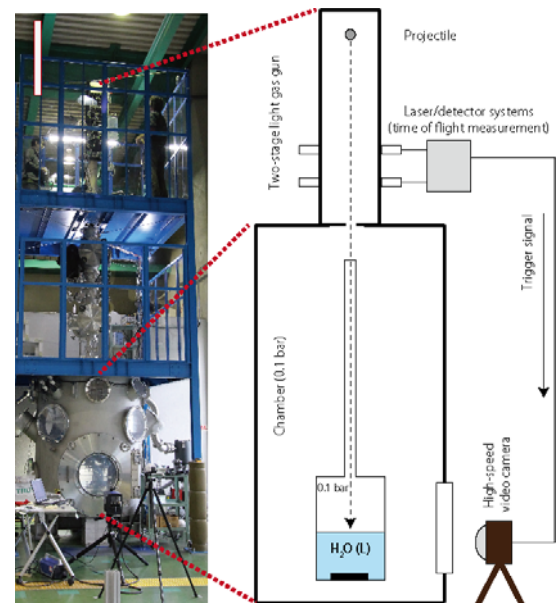


Fig. 1: Schematic illustration of experimental system. Scale bar = 1 m.

Results and Discussion: Hypervelocity impact of polycarbonate to liquid water was observed with a time resolution of 2 μ s. After the first touch of polycarbonate to water, impact flash, shock wave front and opaque hemisphere expanding to water layer were appeared. Protrusions arose radially from the expanding hemisphere when shock wave reflected from the iron target crosses the hemisphere. Solid products recovered after an experiment showed a cloud-like aggregate of fibrous structures. Those indicate that polycarbonate was initially molten/vaporized during collision with water (melting temperature: ca. 250°C) and then re-condensed as debris cluster before forming a crater to the target.

For SUS-water impact, debris cluster started to disperse before its dynamical interaction with reflected shock wave (Figs. 2b-c). Figure 3 shows top surfaces

of the iron targets recovered after the experiments with varying water depth. The crater diameter decreased as water depth normalized to projectile diameter (normalized water depth: WD/d) increased. The number of craters increased with depth if WD/d ranged from 3.5 to 12 (Figs. 3c, d). Compared to the polycarbonate experiments, large craters were made on the iron target. These suggest that the degree of melting and grain refining during the penetration of water layer were not greater for SUS projectile than for polycarbonate projectile, which is consistent with higher melting temperature (1400°C) and malleability for SUS.

Ordinary chondrite-water impact showed hybrid characteristics between polycarbonate- and SUS-water impacts. Impact flash was observed after the first touch of chondrite to water, as similar to the polycarbonate-water impact. On the other hand, debris cluster of chondrite started to disperse within the water column before dynamical interaction with reflected shock wave, as similar to SUS projectile. Multiple craters appeared on the iron target if WD/d ranged from 2 to 5 but disappeared if $WD/d > 5$. Thus, the “boundary” water depth at which craters disappear on the iron target was 5 for ordinary chondrite, which was shallower than for SUS ($WD/d = 12$) but deeper than for polycarbonate ($WD/d = 2$). Collectively, the hybrid characteristics of ordinary chondrite-water impact imply component-dependent fragmentation of chondrite during oceanic impact that metal iron grains in the chondrite selectively arrive on the ocean floor and make craters, whereas fragile and relatively volatile components in the chondrite (e.g., matrix and organic matter) are selectively dispersed within water column or vaporized/re-condensed during collision with water layer.

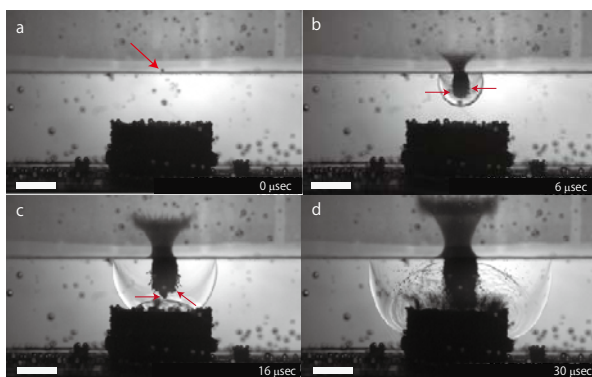


Fig. 2: Sequential photographs of hypervelocity impact of SUS and iron metal in the presence of overlying water layer. Thickness of overlying water layer before impact is 28 mm. Arrows show a stainless-steel projectile (a), protrusions aroused from the side and bottom surfaces of expanding opaque cylinder (b, c). Scale bar = 20 mm.

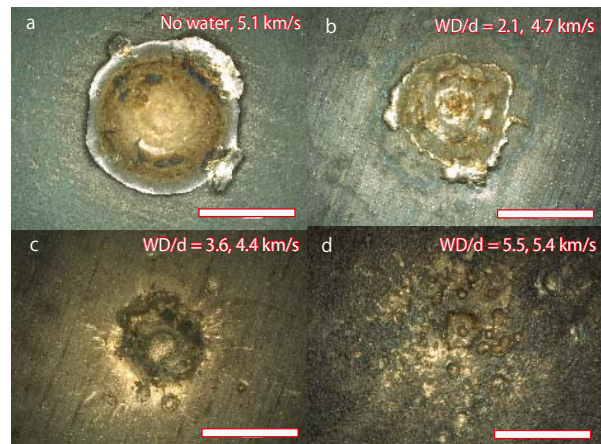


Fig. 3: Relationship between crater structure made on iron target and thickness of overlying water layer in the experiments with SUS projectile. WD/d denotes the normalized water depth. Scale bar = 5 mm.

Conclusion: Impact experiments at ca. 5 km/s showed an extensive fragmentation and dispersion of a variety of projectiles within water column as WD/d value increases. Previous laboratory experiments have shown that complex macromolecular insoluble organic matter (IOM), a major phase of organic carbon in carbonaceous chondrite, releases a sizeable suite of low molecular weight hydrophilic organic compounds under hydrothermal treatment at 300°C and 100 MPa [2]. Because the number of extraterrestrial bodies exponentially increases as their size decrease [3], aqueous alteration associated with impact-driven fragmentation and dispersion of small asteroids/comets (e.g., < 500 m in diameter) within the seawater may have been a main process as a sustainable production of low molecular weight hydrophilic organics related to chemical evolution in the early ocean.

References: [1] Chyba C. and Sagan C. (1992) *Nature*, 355, 125–132. [2] Yabuta et al. (2007) *Meteoritics & Planetary Science* 42, 37–48. [3] Kurosawa K. (2015) *EPSL*, 429, 181–190.