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Shock induced melting of chondrite-like materials: implication on the origin of pallasite

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Differentiation of metal and silicate from primitive chondrite-like source material is the most important chemical differentiation process in the early evolution of terrestrial planets. How and when the metal-silicate separation took place, however, is not fully understood. Chemical differentiation between metal and silicate in the deep magma ocean has been discussed based on high-pressure experiments by many workers. However, metal-silicate separation may have taken place much earlier than global magma ocean stage, judging from the frequent occurrence of iron meteorites.

In order to understand the dynamic melting process during the planet accretion stage, we carried out shock melting experiments on chondrite-like starting materials, mixture of Fe-metal and peridotite KLB-1 (Takahashi, 1986) with various proportion of Fe metal sponge (Fe : peridotite = 30:70, 40:60, 50:50, 60:40 in weight). Six shock experiments were carried out using a propellant gun (30 mm bore) at the NIMS (Nishio, 2008). Samples were encapsulated in stainless steel (SUS304) containers. The target container is 30 mm in diameter and 30 mm in height. The sample space in the container is 18 mm in diameter and ca. 2 mm in height. The impact velocity (1.9-2.0km/s) was measured in each shot to calculate the shock pressure (45-50GPa) by the impedance match method (Sekine et al., 1987). In shock recovered samples, melting took place only locally and numerous metal droplets were formed in molten part of the sample. Large Fe-droplets is up to 50 micron in diameter which indicates that growth of Fe-metal droplets took place in less than 1/100 sec (Fog.1a). The instantaneous growth of Fe-metal droplets must be due to the large surface energy of molten Fe relative to molten peridotite. In the shock melted samples with Fe-globules, degree of partial melting in the peridotite matrix is about 50 vol%. The volume of Fe-metal droplets may represent the volume of Fe-metal clusters that had been three dimensionally connected prior to shock melting. It is implied that size of the metal grains formed in each shock melting process in planet building stage may depends on the connectivity of Fe-metal phase in the source materials. It follows that very large Fe-metal globes may have formed by single shock event if the source materials were rich in Fe grains with high 3D connectivity. In order to test the above hypothesis, we carried out more than 40 experiments using a non-end loaded piston-cylinder apparatus at the Magma Factory, Tokyo Institute of Technology using the same starting materials (mixture of Fe-metal sponge and peridotite KLB-1). In the piston-cylinder experiments, pressure was kept constant at 1 GPa. The starting materials were encapsulated in graphite (1.2 mm inner diameter and 2.5 mm long). Sample temperatures were raised quickly to 1300C and then hold for 10 min (just above the solidus of peridotite KLB-1 at 1 GPa, Takahashi, 1986). Temperature was raised very quickly from 1300 to 1600C and quenched. Sample temperature was controlled so that the total time for melting of Fe (above1550C) to be 10 to 1800 sec. MgO capsule was used in longer experiments (longer than 60sec). Textures of the melted samples are similar to those by the propellant gun experiments at iron poor sample (Fe:KLB-1=30:70wt%). In iron rich samples, however, up to millimeter scale very large Fe-grains were formed even in shortest runs (Fig.1b, 1600C 10 sec). Based on these experiments, we propose that size of the metal grains formed in each shock melting process in planet building stage may depends on the connectivity of Fe-metal phase in the source materials. Very large (up to km size?) Fe-metal globes could have been formed by single shock event if the source materials were rich in Fe. Pallasite (stony-iron meteorite) may represent the products of local melt pockets formed after impacts.