Impact-induced (?) Cr-diffusion in the metallic phase in chondrites and achondrites

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Shock-induced metamorphism recorded on meteorites has been extensively studied by petrographic observations and experimental studies since the dawn of the meteorite study, and yet they are still an important topic today. Recently, shock metamorphisms have been revisited and summarized by [1]. It is widely recognized that impacts can induce localized heating (up to melting); the impact heating has been considered one of the significant driving forces of the thermal metamorphism on the asteroids by some workers [e.g., 2]. Because of the wide range of the meteorite's mineral compositions, individual meteorite groups have various materials with the combinations of different shock impedances. Also, the individual meteorite groups likely came from different sizes of parent bodies and experienced various thermal histories. Therefore, observed "impact-induced" signatures in meteorites can broadly vary. Even only among equilibrated ordinary chondrites, numerous shock-related features are reported, and the most widely recognized features include shock metamorphism: undulose extinction, planar features, mosaicism, and planer deformation features in olivine; undulose extinction in low-Ca px, polysynthetic twin lamellae parallel to (100), mosaicism and planar deformation features in low-Ca clinopyroxene; undulose extinction, becomes partially isotropic, develops planner deformation features, and transform into maskelynite in plagioclase [3]. However, those silicate features are not robust against annealing conditions caused by heat induced by subsequent or during the shock events [4,5]. Rubin 2004 extensively investigated shock features across the ordinary chondrites, including minor features that had been reported as following shock features: silicate darkening [6,7], chromite veinlets [6], chromite-plagioclase assemblages [4], metal and sulfide veins [3], narrow silicate melt vein [8], large metal and/or sulfide nodules [9], polycrystalline troilite [10], irregularly shaped troilite grains within Fe-Ni metal [11], martensite and various type of plessite [12], rapidly solidified metal-sulfide intergrowths [13], metallic Cu grains [11], glassy melt pockets [14] and large regions of silicate melt [15]. Mobilization of metal-sulfide melts and subsequent secondary phase formation, such as the occurrence of metallic Cu grains, are sufficient indicators of the shock heating above the Fe-FeS eutectic (988 °C). They can be useful indicators. Such occurrence of secondary minerals, however, are not versatile shock indicators due to the high temperature requirement. For example, the temperature range of such features is higher than that of normal equilibrated temperatures recorded in the olivine-spinel thermometry in ordinary chondrites (H4: 600–700 °C [16]). It would be helpful to have chemical evidence that robustly recorded the shock features within or under the olivine-spinel equilibrium temperature to fully understand the shock records on the parent bodies; elemental mobilization within opaque minerals can be more utilized to understand the lower temperature phenomena. Kessel et al. 2004 [17], revisited the H chondrite's metamorphic temperature and f_{O2} conditions. They concluded that the low concentrations of Cr in the taenite grains are due to their lower closure temperatures relative to silicates. We found that their results imply a possible robust record of elemental mobilization at low temperatures recorded within the chromite/metal chemical composition. In our study, we revisited the phase compositions of chromite/metal, which are ubiquitously located in chondrites and achondrites. We investigated whether trace element distributions between chromite/metal can be used to indicate the parent bodies' shock features and/or thermal histories at a relatively lower temperature range.

Sample and Method:

We have primarily studied equilibrated ordinary chondrite NWA13458, H5 (Shock stage S2 defined based on shock metamorphic features in silicates) chondrite, and shock recovery experimental products of this chondrite. The shock recovery experiments were conducted with a two-stage light gas gun at Planetary Exploration Research Center (PERC) at Chiba Institute of Technology, Japan [18]. We used NWA13458 as targets and applied the experimental method [19] with three different heating conditions: ambient temperature, 350 °C, and 650 °C. Also, we compare the petrographic observations of our sample to the other meteorite groups, including mesosiderites, two primitive achondrites (Tafassasset, N3250), one Iron (Miles: IIE), and one chondrite (Forest Vale: H4).

We analyzed samples using the scanning electron microscope (SEM, JEOL JSM-6510LA) at PERC Chiba Institute of Technology. Energy dispersive X-ray spectroscopy (EDS) was used for the observation of trace elemental diffusion profiles in the different meteorite groups.

Preliminary Results:

We located chromite grains up to a few tens of microns in size next to Fe-metal (kamacite or taenite) grains. The texture of chromites is euhedral, subhedral, anhedral, and rounded. These selected chromite grains often occur adjacent to the silicate as well. Inside the kamacite grains, we found that Cr concentrations vary. As it was reported before in ordinary chondrite metal [17], in NWA13458, Cr concentrations in the middle of kamacite grains are very low. However, Cr diffusion profiles across the grains indicate that some of kamacite grains show a zoning profile; the Cr concentrations increased towards the edge of the chromite kamacite interface. The zoning profiles are not apparent in taenite that occurs next to chromite. The similar Cr diffusion profiles into metal from chromite grains are found in mesosiderites, two primitive achondrites (Tafassasset, N3250), one Iron (Miles: IIE), and one chondrite (Forest Vale: H4). Furthermore, zoning profiles are also common within chromite grains. A center of chromite (Cr-spinel) grain is more Mg-Al-rich, but the edge of the chromite becomes closer to the end member composition, $FeCr_2O_4$.

Discussion:

The Cr zoning profiles in metals are common in chondrites, primitive achondrites, and achondrites. These profiles are not associated with their cooling rates estimated by the Ni-diffusion profile, and some samples have different cooling histories: Miles and Forest Vale were shock-heated and then cooled rapidly to low temperatures. Mesosiderites were heated to solidus temperatures (~1200 °C) and subsequently cooled rapidly but cooled very slowly through ~500 °C. Therefore, it appears to be true that the Cr zoning is not simply caused by the same mechanisms with Ni diffusion in the FeNi metal. This separation appears to be puzzling because both elements' diffusion coefficients are relatively fast in FeNi metal (and $D_{Cr} > D_{Ni}$ [20]) if one thinks that both zonings are simply caused by self-diffusion. However, this Cr up-hill diffusion profile may seem natural to explain by the interdiffusion with considering the free energy of forming chromite. Kessel et al. 2004 reported low Cr concentrations in the Fe metal in H chondrites, which implies that the Cr concentration in FeNi metal was initially higher and lost by sub-solidus diffusion. It is natural to consider the Cr in the metal-formed chromite grains. Forming chromite requires oxygen provided through the oxide, and it can be controlled over the formation of chromite overgrowth and Cr diffusion profiles in the metal grains. We will further investigate the oxygen fugacity of the H chondrites after the closure temperature of the silicate and oxides. Also, we plan to investigate the possible effects on Cr diffusion in metals by understanding oxygen fugacity and local temperature changes caused by impact shock events.

References:

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