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Projectile-Target Interaction and Liquid Immiscibility in Impact Glass from the Wabar Craters, Saudi-Arabia

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Abstract

High-resolution microchemical studies on Wabar glass suggest that meteoritic iron was selectively mixed with high silica target melt at high temperatures. During cooling, liquid immiscibility caused unmixing of a high-Fe basaltic melt. Variation in the composition of Wabar glass largely depends on the volume ratio between immiscible basaltic melt, high-silica melt, and remains of meteoritic FeNi-melt spheres.

1. Introduction

The processes of projectile-target interaction and associated inter-element fractionation are still poorly understood. The pristine impact glass of the ~300 year old Wabar meteorite craters (Saudi Arabia) represents suitable material to study these processes. Wabar impact melt rocks are the result of mixing iron meteorite (IIIAB medium octahedrite with on average ~92 wt% Fe, ~7.3 wt% Ni, and ~0.22 wt% Co [3]) with a strongly quartz-dominated dune sand target, which contains some limited amounts of feldspar, calcite, and perhaps clay minerals (on average ~96.3 wt% SiO_2, ~2.6 wt% Al_2O_3, ~1 wt% CaO, ~1 wt% K_2O, and ~0.4 wt% FeO [3]). These materials are very similar in composition to those used in recent impact cratering experiments [1] facilitating comparison of experimental results with nature. Wabar glass has been investigated by several authors in the past (e.g., [2, 3], and references therein). They have recognized two different types of impact melt, called “white melt” and “black melt” with meteoritic contamination of <1% and ~4%, respectively [3], as well as ubiquitous disseminated metallic FeNi-Spheres [2]. This study is aimed to improve our knowledge on Wabar impact glass heterogeneity by means of microanalytical techniques of high spatial resolution.

2. Samples and analytical methods

Two samples were prepared from one specimen of Wabar glass derived from the Ries Crater Museum collection (Nördlingen, Germany) in the MfN sample preparation facility, and were characterized by optical and electron microscopy. Imaging and major element analysis were done with a JEOL JXA-8500F electron microprobe equipped with a field emission cathode and operated at 15 kV and ~60 nA. For chemical analysis, beam diameters of mostly ≤1 µm for metal phases and 5 µm for glass phases were used. Standardization was done on pure elements for Fe, Co, and Ni, and on international mineral reference standards for Na, Mg, Al, Si, P, S, K, Ca, and Ti.

3. Petrography and Microchemistry

The specimen we studied is of a very pristine, unweathered nature and is composed of a highly siliceous, vesicular glass that shows numerous flow bands and schlieren of Fe-poor (in transmitted light tan colored) to Fe-rich (brown to dark brown colored) glass which resembles the black melt variety of [3], and several µm- to mm-sized inclusions of partially or completely molten target sand. In our specimen, we can distinguish several different melt types that coexist heterogeneously on a mm- to µm-scale. The specimen shows local crystallization of very fine grained clinopyroxenes, but is—as a result of rapid cooling or quenching—generally of hyaline nature.

Target melts: Mostly uncontaminated target melts occur in form of partially molten quartz grains; completely molten and essentially monomineralic, homogenous bodies of lechatelierite or diaplectic quartz glass; radial-formed bodies of ballen silica, which mostly show local crystallization of very fine grained, Fe-rich clinopyroxenes (i.e., ferro-hedenbergite) along the margins; and partial melts within target rock clasts that represent a compositional mixture of quartz and the other rock forming minerals (e.g., feldspars).

Black melt: Differently colored flow bands of black melt show variable amounts of SiO_2 (77-91 wt%, 87.5 wt% on average), FeO (3.5-14 wt%, 6.3 wt% on average), and CaO (0.7-2.3 wt%, 1.2 wt% on average), while amounts of Al_2O_3 (~2.3 wt%), NiO (<0.6 wt%), and Na_2O (~0.4 wt%) remain on a very constant level, regardless of coloration. The color intensity of a given set of black melt flow bands correlates positively with FeO and negatively with SiO_2 content, i.e., in transmitted light, dark brown schlieren contain more FeO than tan colored ones. In detail (insert Fig. 1), the black melt is composed of an emulsion of three different melts. It is dominated by a very siliceous melt (on average ~87 wt% SiO_2, ~5 wt% FeO, ~3.6 wt% Al_2O_3, ~1.7 wt% K_2O and ~0.7 wt% CaO) that contains numerous droplets of a Fe- and Ca-rich basaltic melt (labeled FeCa-melt, Fig. 1). The FeCa-melt consist on average of ~44 wt% SiO_2, ~40 wt% FeO, ~5.8 wt% CaO, ~2.5 wt% Al_2O_3, ~1 wt% MgO and ~0.9 NiO. The diameter of FeCa-melt droplets mostly ranges from the µm- to nm-scale. The size of FeCa-melt droplets and schlieren increases significantly around larger FeNi-spheres (Fig. 1).

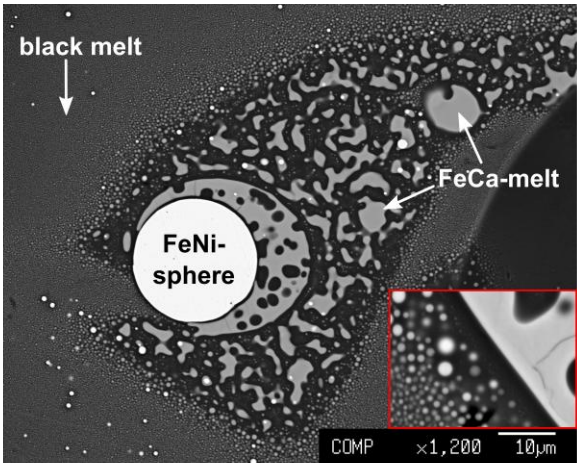

Figure 1: BSE-image of emulsion-like textured FeCa-melt around a large FeNi-sphere in black melt. Insert shows contact between FeCa-melt (right) and black melt (left); insert width is ~12 µm.

Projectile remnants: Projectile remnants occur as FeNi-spheres in black melt, but also wrapped around clasts of partially or completely molten target material. The metallic FeNi-spheres show varying diameters mostly between ~1-100 µm. In general, with decreasing spherule size the Ni (and Co) content is successively enriched over Fe.

4. Discussion and Conclusions

It is suggested that the metallic projectile melt has mechanically entered the target, thereby preferentially partitioning meteoritic iron into the siliceous target melt, probably due to selective oxidation (see [2]). While loosing iron and size, the meteoritic spheres get more and more enriched in Ni (and Co) in accordance to previous studies [2] and recent experiments [1]. At rather high temperatures, the meteoritic iron likely was completely dissolved in the siliceous target melt. Successive cooling, however, induced liquid immiscibility and numerous droplets of Fe-rich basaltic melt (FeCa-melt) nucleated. Compositional variation of Wabar black melt largely depends on the volume ratio between the Fe-poor siliceous and the Fe-rich basaltic melt. Adjacent to large FeNi-spheres that represent the Fe-supply, the relative amount of the FeCa-melt significantly increases, until the siliceous melt nucleates within the FeCa-melt. Liquid immiscibility has also been described for other impact glasses (e.g., blue zhamanshinites, [5]). Natural occurrences and experiments (e.g., [4], and references therein) show growing evidence that liquid immiscibility could play a major role in the formation of impact melt rocks.

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