HETEROGENEITIES OF IMPACT MELTS FROM THE ZHAMANSHIN CRATER: A TWO-STAGE MIXING SCENARIO?

A. Esau[1,2], C. Hamann[1], F. E. D. Kaufmann[1], E. Sergienko[3], S. Yanson[3], V. Karpinsky[3], and L. Hecht[1,2], [1]Museum für Naturkunde Berlin, Invalidenstr. 43, 10115 Berlin, Germany (alexander.esau@mfn.berlin), [2]Institut für Geologische Wissenschaften, Freie Universität Berlin (FUB), Malteserstr. 74–100, 12249 Berlin, Germany, [3]Earth Physics Department, Saint Petersburg State University (SPSU), 7/9 Universitetskaya Emb., 199034, St. Petersburg, Russia.

Introduction: The 13.5-km diameter Zhamanshin impact structure in Kazakhstan (48°24‘N/60°58‘E) is one of the youngest impact craters on Earth (~1 Ma). Two major types of impact melt rocks are associated with the structure (e.g., [1–4]): irghizites (aerodynamically shaped impact glasses containing a distinct projectile signature) and zhamanshinites (larger impact-glass bodies typically lacking a distinct projectile component). In addition, small glass spherules termed 'microirghizites' with compositions similar to irghizites exist [5]. The origin of the different impact melts that gave rise to the zhamanshinites, irghizites, and microirghizites has long been debated (cf., e.g., [2,5,6]). Many details regarding admixture and dissemination of projectile material into the shocked target remain unresolved. Here, we present first results of a microchemical study of target rocks, zhamanshinites, irghizites, and microirghizites (1) to constrain projectile–target interaction processes in a lithologically complex impact structure and (2) to reconstruct the stratigraphy of the crater's melt zone.

Results and Discussion: Samples of target rocks, zhamanshinites, irghizites, and microirghizites were collected during a field campaign in 2019 and analyzed by light microscopy, XRF, SEM, electron microprobe analysis, and Raman spectroscopy. Here, we summarize and discuss petrographic and compositional data collected from 31 irghizites, 15 microirghizites, and 55 zhamanshinites to reconstruct formation and chemical evolution of the different impact melts at Zhamanshin.

Zhamanshinites. In agreement with previous studies, zhamanshinites investigated here are compositionally diverse, microscopically highly heterogeneous, vesicular impact glasses that vary in size from centimeters to decimeters. Although intermediate varieties exist among our sample suite, most samples can be subdivided into Si-rich (~73–78 wt% SiO_2) and Si-poor (~50–55 wt% SiO_2) varieties (cf. [3]).

Irghizites. Irghizites investigated here are typically black, aerodynamically shaped, tektite-like, highly vesicular, compositionally heterogeneous, clast-poor to clast-free, schlieren-rich impact glasses of centimeter size (Fig. 1a,b). In agreement with previous studies (e.g. [1,2]), they can be classified into two major types: SiO_2-poor, basic splash forms (~56 wt% SiO_2) and acidic irghizites (~70-76 wt% SiO_2). Lechatelierite inclusions are abundant in almost every sample and rare occurrences of planar deformation features in quartz as well as coesite in silica-rich melts are documented in our samples. Many irghizites studied here consist of smaller glass droplets agglomerated together to a single glass body (Fig. 1a,b; cf. [1]). In those cases, the smaller glass droplets are often, but not exclusively, rimmed by a dark brown (transmitted light) or bright (BSE images), compositionally distinct rim.

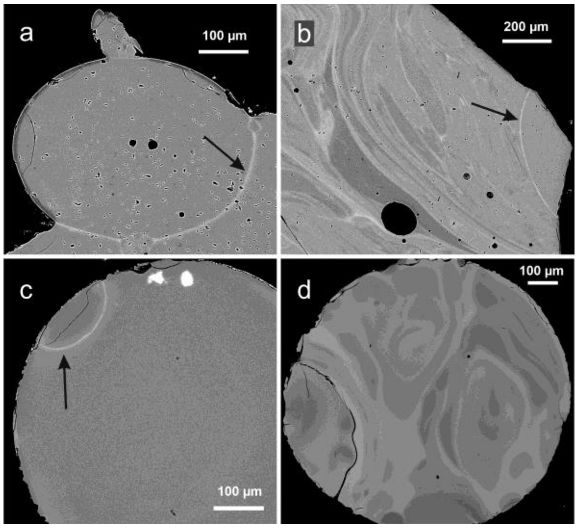

Fig. 1 Representative BSE images: (a) margin of homogeneous irghizite with attached melt droplet (microirghizite?), (b) heterogeneous irghizite, (c) rather homogeneous microirghizite, (d) heterogeneous miroirghizite, arrows indicate projectile enrichment at the surface of agglomerated melt droplets.

Microirghizites. Microirghizites are microscopic glass spherules of <10 to 1000 µm in size and of either homogeneous or heterogeneous internal structure and composition (Fig. 1c,d). They are mostly perfectly round, but teardrop-shaped as well as elongated forms and other shapes also exist (see also [5]. Petrographically, the microirghizites studied here are quite similar to the irghizites (e.g., existence of schlieren within and compositionally distinct rims around individual spherules), albeit on a smaller scale (cf. Figs. 1c,d and 1a,b). Additionally, some samples show a very bright region (BSE images) along the outer rim, sometimes with small, nanometer-sized crystallites.

Geochemical Similarities and Differences. As evident from Fig. 2, the zhamanshinite whole-rock compositions as well compositions of individual glasses and schlieren can predominantly be explained by melting and mixing of the target components (cf. [1,6]). The same holds true for the basic splash forms, which are compositionally very close to the Si-poor zhamanshinites. However, the acidic irghizites as well as most microirghizites studied here have compositions that cannot be entirely explained by melting and mixing of the target components alone (cf. [1,6]). Typically, the following compositional trends were observed (Fig. 2a,b): (1) Schlieren are typically enriched in MgO, FeO, NiO, and Cr_2O_3 and depleted in SiO_2 compared to the host glass. This trend is accentuated at the rims around individual sub-droplets (arrows in Fig. 1a,b). (2) If an average carbonaceous chondrite [7,8] is considered in either SiO_2–MgO or Cr–Ni space (Fig. 2a,b), acidic irghizite compositions fall onto mixing lines spanned between the stratigraphically uppermost, Si-rich target lithologies and the average carbonaceous chondrite. The glassy rims shown in Fig. 1a,b have a higher projectile component than the schlieren, which themselves have a slightly higher projectile component than the host glass. (3) The microirghizites are chemically highly diverse and either reflect the target-dominated mixing trend defined by the zhamanshinites (e.g., specimen shown in Fig. 1d) or mimic and often exceed the projectile–target mixing trend defined by the irghizites (up to 1.3 wt% NiO was detected in individual microirghizite microprobe analyses). Projectile enrichment at droplet surfaces (Fig. 1c) may be enhanced. In addition, some microirghizite compositions are consistent with heterogeneous admixture of FeNi metal/kamacite from the chondrite projectile (Fig. 2b).

Conclusions: The presence of non-homogenized schlieren and distinct compositional trends in both microirghizites and irghizites suggest that these impact melts originated at the initial projectile–target interface and represent melt mixtures between the uppermost target materials and a chondritic impactor. Subsequent ejection and aerodynamic transport of material resulted in formation of irghizites and agglomeration of single microirghizites into larger melt bodies. In a second step, (micro)irghizites were variably affected by accretion of impactor-rich material that partially forms micro- to nanoscale crystallites and/or vapor condensates. The data from this study reinforces the model of [2], who previously described a two-step scenario for the development of irghizites. In addition, our results illustrate the complex interactions that take place between the target and the projectile.

Acknowledgments: We are grateful to K. Knizhnik and P. Kharitonskii for support during the 2019 field campaign in Kazakhstan. Laboratory support by K. Krahn, K. Born, H. Knöfler and R.-T. Schmitt and seed funding by FUB and SPSU are greatly acknowledged.

References: [1] Jonášová Š. et al. (2016) *GCA*, *190*, 239–264. [2] Mizera, J. et al. (2012) *J. Radioanal. Nuclear Chem.*, *293*, 359–376. [3] Gornostaeva T. A. et al. (2017) *Petrology*, *25*, 1–22. [4] Gornostaeva T. A. et al. (2016) *Petrology*, *24*, 1–20. [5] Glass B. P. et al. (1983) *JGR*, *88(S01)*, B319–B330. [6] Schulz T. et al. (2020) *GCA*, *268*, 209–229. [7] Wasson J. T. and Kallemeyn G. W. (1988) *Philos. Trans. R. Soc.*, *325*, 535–544. [8] Braukmüller N. et al. (2018) *GCA*, *239*, 17–48.

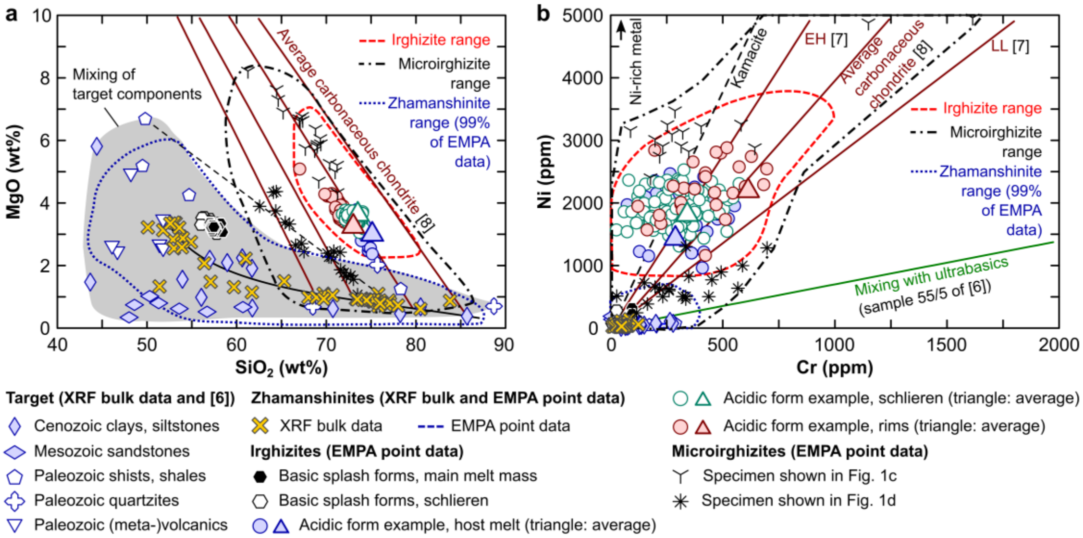

Fig. 2 Chemical composition of target lithologies, zhamanshinites, irghizites, and microirghizites in (a) SiO_2–MgO and (b) Cr–Ni composition space. Chondrite compositions used to calculate mixing lines derived from [7,8]; target rock compositions from [6] and own XRF whole-rock data.