Suevites and Tagamites of Zhamanshin Astrobleme: Distribution in the Crater and Petrographic Features

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Abstract. The study of impact glasses from the Zhamanshin meteorite crater has a long history extending back to early 1970ies. Most attention is paid to unique impact-related rocks known as zhamanshinites (bombs) and irghizites (lapillii). But, as first shown by V.L. Masaitis, other, more common types of impactites, suevites and massive melts (tagamites), are also present in Zhamanshin. We study the distribution in the crater, structure and composition of these particular rocks using powder X-ray diffraction and scanning electron microscopy. It is shown that all impact glasses from the Zhamanshin crater are genetically related and derive from the impact event, while the observed petrographic differences between them reflect the conditions of their formation. Individual varieties of studied impactites (suevites and tagamites) are spatially separated and, as a rule, do not intersect. This points to the absence of global mixing of the target material as a result of the impact event, as well as to the complex nature of the impactor.

1. Introduction
The Zhamanshin impact structure (Aktobe region, Kazakhstan, N 48.37° E 60.94°) has attracted the attention of researchers for several decades, primarily due to its unique association of impact glasses. Glasses of impact origin in the Zhamanshin crater are widespread and unevenly distributed over the ground surface. They are commonly found in the form of bombs, fragments (zhamanshinites), and lapillii (irghizites) eroded from loose masses of allochthonous breccias. These formations attracted great interest and have been described in numerous publications [1-9].

However, back in 1990-1991 V.L. Masaitis has shown that lenticular suevites and massive beds of impact melts (tagamites) are also present in the Zhamanshin crater, both within the crater and in wells at depths down to several hundred meters [10, 11].

According to the existing classification [12] main characteristics of these impact-related rocks are as follows. Impact melt rock (tagamite) is a massive glassy rock of impact origin with allochthonous bedding. Tagamites crystallize from the melt that forms at the time of impact. They form lenticular and dyke-like bodies cutting authigenic and allochthonous breccias, as well as flows that overlap breccias. The thickness of molten rocks ranges from several to hundreds of meters. In terms of chemical composition, tagamites are close to the average bulk composition of target rocks which underwent
melting upon the impact. Suevites are clastic rocks of impact origin which form allogenic breccia and consist of unsorted rock fragments and solidification products of the impact melt in the form of drops, lapilli and bombs. They typically contain over 10-15 vol. % of melt glass.

At the Zhamanshin crater, tagamites and suevites remain insufficiently studied. This hampers the efforts to construct a model of the impact event and to explain the complex genesis, diversity, and distribution of impactites in the crater. This work contributes to the study of the structure and phase composition of suevites and tagamites.

2. Samples and methods
Samples of suevites, massive impact melts (tagamites) and, for comparison, zhamanshinites (bombs) were collected during two field trips to the Zhamanshin meteorite crater in 2018 and 2019 (Figure 1). Suevites outcrop in the northern and northeastern sectors of the crater and are localized in areas up to hundreds of meters across. They occur as polymictic allogenic breccia consisting of deformed blocks and rubble of rocks of the Paleogene, Mesozoic and Paleozoic age, as well as of fragments of impact glass. The content of the latter reaches 30-50 vol. %, which classifies the rock as a vitroclastic suevite.

Tagamites were found as a massive (several meters thick) sheet-like body, and as fragments (up to tens of centimeters in size) in the southern sector of the crater. They have pronounced traces of flowing. Zhamanshinites are distributed everywhere in the crater, but unevenly, as bombs and their debris. They are especially numerous on the inner slope of the outer crater rim. For this study, samples of zhamanshinites were selected according to morphological differences: massive black, banded, slag-like (pumice).

![Figure 1](image.png)

**Figure 1.** Natural occurrence and separate fragments of suevites (a, b, c) and tagamites (d, e, f) at the Zhamanshin astrobleme.

Texture and structural features of the samples have been visualized using scanning electron microscopy and the chemical composition determined with microanalysis. A system with focused electronic and ion probes QUANTA 200 3D (FEI, Netherlands) with the analytical complex Pegasus 4000 (EDAX, USA) and a tabletop scanning electron microscope-microanalyzer TM 3000 (Hitachi, Japan) were used. Mineralogical composition was investigated using X-ray powder diffractometry (Bruker D2 Phaser, Germany).

3. Results
The results of X-ray phase analysis are given in the Table. Phase compositions are listed without taking into account an X-ray amorphous phase which is present in all samples. It is not possible to estimate the content of the latter by this method. Massive bed-like impact melts (tagamites) are characterized by the highest homogeneity and simplicity of composition; in addition to the X-ray amorphous phase, only a small amount of quartz was found. Zhamanshinites, apart from quartz, also contain iron oxides, plagioclase, cristobalite and pyroxene, as well as secondary minerals of the chlorite group. Suevites appear the most complex. In addition to minerals found in zhamanshinites, they contain clay minerals, minerals of the mica group, microcline, amphibole, chlorites, etc.
Table 1. Phase composition of impactites, quantitative estimates by Rietveld method, wt. %.

| Phase Composition | Tagamites | Zhamanshinites massive black | Zhamanshinites porous (pumice) | Suevites |
|-------------------|-----------|-----------------------------|-------------------------------|----------|
| X-ray amorphous phase | +         | +                           | +                             | +        |
| Quartz            | +         | 0–5<sup>a</sup>             | 5–8<sup>a</sup>               | up to 20<sup>b</sup> |
| Magnetite         | —         | 0–5                         | 8–10<sup>a</sup>              | 0–6<sup>b</sup> |
| Hematite          | —         | 0–5                         | up to 21<sup>a</sup>          | 5–16<sup>b</sup> |
| Plagioclase       | —         | up to 78                    | up to 62<sup>a</sup>          | 6.5–48<sup>a</sup> |
| Cristobalite      | —         | —                           | up to 6<sup>a</sup>           | up to 4.7<sup>b</sup> |
| Pyroxene          | —         | 0–14                        | up to 18<sup>b</sup>          | 5.8–15<sup>b</sup> |
| Amphibole         | —         | —                           | —                             | up to 4<sup>b</sup> |
| Mica (muscovite)  | —         | —                           | —                             | 1–26.6<sup>b</sup> |
| Microcline        | —         | —                           | —                             | up to 3.5<sup>b</sup> |
| Kaolinite, chlorite, calcite, goethite | — | — | — | up to 31<sup>b</sup> |

<sup>a</sup> neo-formed minerals  
<sup>b</sup> relict minerals

SEM observations show no visible inclusions in the tagamite glass. Zhamanshinites are represented by a matrix of aluminosilicate porous glass with a large number of inclusions of relict pyroxene grains and neo-formed minerals such as quartz, plagioclase, iron oxides (Figure 2a) and other minerals in minor quantity. Glass is chemically heterogeneous within a single sample (Figure 2b). Iron oxides, magnetite and hematite, form both skeletal forms and aggregates of full-faceted crystals (Figure 2c, d). Similar grains are found in irghizites but in a smaller amount [13]. The voids are often filled with aggregates of secondary minerals (Figure 2e). Light areas are pumices with numerous tortuous pores (Figure 2f).

In suevites, glass is enclosed in a polymineral fine- and microcrystalline matrix consisting of target rock fragments cemented with clay minerals (Figure 3a, b). The size of the glass fragments ranges from several microns up to 5 mm. Typical forms are angular, drop-like, tortuous. Glass is heterogeneous and porous, with segregations of pure quartz according to X-ray analysis (Figure 3c), iron oxides, plagioclase. The pores are often filled with fine-grained target material. Iron oxides in suevites are found both in glass and cement. In cement these are large grains or crystals of magnetite (martite), possibly relic (Figure 3d), or small spherules, often showing a skeletal structure (Figure 3d). In glass, iron oxides occur as skeletal and full-faceted forms, some of these two-phase, with hematite central parts and magnetite shell (Figure 3f).
Figure 2. Electronic images of zhamanshinites. (a) general view; (b) heterogeneous glass, light areas having high iron content; (c, d) skeletal forms and aggregates of full-faceted magnetite crystals; (e) aggregates of gypsum in the voids; (f) pumice. Reflected electrons.

Figure 3. Electronic images of suevites. (a, b) glass fragments with traces of flowing; (c) internal structure of glass: gray – SiO₂ segregations, black – pores, white – iron oxides; (d) magnetite (martite) crystal; (e) magnetite spherule; (f) skeletal crystals and a two-phase grain of iron oxides within glass. Reflected electrons.
4. Discussion and conclusions

4.1. Distribution in the crater
Field observations on the Zhamanshin astrobleme have been carried out for several decades, starting with the expeditions of E.P. Izokh, P.V. Florenskii, A.I. Dabizha, Ya. I. Boyko. Main attention has been drawn to unique impactites, primarily irghizites and zhamanshinites [14-17]. Masaitis et al. [18, 19] were the first to identify suevites and massive melts (tagamites) as separate objects at this meteorite crater. During the expeditions of St. Petersburg University in 2018 and 2019, the presence of these types of impact-related rocks in the crater was confirmed and their distribution areas were determined more precisely. A characteristic feature is their restricted distribution in the crater. Particular types of impactites are spatially separated and, as a rule, do not outcrop together.

In most astroblemes, internal structure of the coptogenic complex is lenticular-banded, represented by alternating bodies of different rocks [19]. Tagamites commonly form separate geological bodies in within allogenic breccia and suevites. Different structure of Zhamanshin astrobleme may then indicate absence of global mixing of target material at the impact event implying a peculiar impact scenario. Characteristic features of the impactor (e.g. multiple collisions) may have played a role as well.

4.2. Petrography of suevites and tagamites
Study of the mineral composition revealed the following. Massive lenticular impact melts of Zhamanshin are the most homogeneous at the microinclusion level. They are mainly X-ray amorphous with a small amount of crystalline quartz. These are the varieties of impact rocks that have undergone melting at the highest temperatures. No relic minerals have been found, while dense glass, without cracks and pores, remained practically unchanged.

Zhamanshinites are represented by glass of various degrees of melting. Some interlayers contain many inclusions of various mineral phases, others are homogeneous. In addition to an X-ray amorphous phase, they contain quartz, plagioclase, pyroxene in appreciable amounts (> 5-10 wt %), as well as magnetite (likely cation-substituted [20]) and hematite. A high degree of fracturing and porosity of zhamanshinites resulted to their changes in the post-impact period.

The polymineral composition of suevites results primarily from the style of their formation. Molten glass (irghizites, microirghizites, zhamanshinites) and its fragments fell into destroyed but unmelted target rocks, while post-impact changes has likely been relatively minor. A characteristic feature of Zhamanshin suevites is a very heterogeneous glass content and weak cementation. Bombs and glass flecks amount to more than 30% by volume, which allows to classify the rock as a litho-vitroclastic lapillan/ agglomerate suevite [12].

In summary, all impact glasses of the Zhamanshin crater appear genetically related, deriving from the impact event. Petrographic differences between them are primarily due to the conditions of their formation.

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