

LIQUID IMMISCIBILITY IN AN IMPACT MELT: OR WHY ARE BLUE ZHAMANSHINITES BLUE?

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INTRODUCTION: The Zhamanshin crater is the source of several different types of impact glasses: tektite-like irghizites, and zhamanshinites, which have been divided into Si-rich and Si-poor varieties, the former subdivided into normal and blue varieties [1]. The blue color of blue zhamanshinites is apparent only in reflected light, with the color being brownish in transmitted light. Koeberl [2] found that blue zhamanshinites had higher Ca and REE contents than Si-rich zhamanshinites, but did not identify the blue coloration agent. We report here the cause of the coloration of blue zhamanshinites, and suggest that liquid immiscibility may have a previously unrecognized role in impactite melt evolution (however, see also [3]).

EXPERIMENTAL PROCEDURE: Portions of blue zhamanshinites were ultramicrotomed and examined using a JEOL 2000FX STEM equipped with a LINK eXL EDX analysis system.

RESULTS: The STEM work revealed that blue zhamanshinites contain spherical inclusions of a second glass with diameters of 60-150 nm, as shown in Figure 1. Dark field imaging and electron diffraction work established that these spherical inclusions are non-crystalline. We eliminated the possibility that these inclusions could have resulted from electron-beam induced transformations. The spatial density of the spherical glass inclusions varies considerably, down to zero in some areas, on a scale less than a millimeter; Figure 1 shows a grain with the maximum observed density. Analyses of glass inclusions and host glass are given in Table 1, and are compared to the average of microprobe analyses of bulk blue zhamanshinites. The glass inclusions are considerably enriched in Ca, Mg, Fe and P relative to the host glass.

BLUE COLORATION: The 100nm size of the glass inclusions, density difference between host and inclusion glass, and color difference between transmitted (red) and scattered (blue) light indicate that Rayleigh scattering accounts for the blue coloration of these particular zhamanshinites [4].

LIQUID IMMISCIBILITY: The observation of two coexisting separate glasses, one Si-rich and the other rich in divalent cations, suggests the action of liquid immiscibility. Roedder and co-workers [5&6] have investigated an appropriate silicate system ($\text{SiO}_2\text{-FeO-K}_2\text{O-Al}_2\text{O}_3$), delineating the immiscibility volume. Figure 2 (after these investigators) shows where the immiscibility volume in the simple system mentioned above would fall in the more general system $\text{SiO}_2\text{-FeO-MgO-CaO-Na}_2\text{O-K}_2\text{O-Al}_2\text{O}_3$. We have no proof that the immiscibility volume maintains its size, shape, or position in this more general system. It is known that it is eliminated by some compositional substitutions. However, for the sake of the following brief discussion we will assume that Figure 2 is correct in general aspects. All microprobe analyses, save one (labeled A-4), of blue zhamanshinites lie just within the central two-liquid field of the general system, indicating that liquid immiscibility could have been expected to have occurred, depending upon the exact composition and cooling history. If this two-liquid field is appropriate to the compositions involved, as the blue zhamanshinite melt cooled to the two-liquid solvus and beyond the spinodal, a homogeneous melt could separate into two melts. As indicated by the tie lines across the two-liquid field, one melt would have the approximate composition indicated by point A on Figure 2, the other melt would be of approximate composition A'. Since the bulk melt has a composition very near point A, melt A should greatly predominate in the resultant immiscible mixture. Shown in Figure 2 are the compositions of blue zhamanshinite host glass and glass inclusions, which are in general agreement with the expected compositions A and A', respectively. The system shown in Figure 2 does not include P_2O_5 , but the studies of immiscibility in lunar magmas [6] show that P_2O_5 is strongly enriched in the cation-rich melt, as we observe here in zhamanshinites.

If one plots other impactite and tektite bulk compositions on the diagram in Figure 2, they also largely lie within the field described by the blue zhamanshinites. One might therefore wonder why liquid immiscibility is not a general feature of impactites and tektites? There are several possible answers to this question. (1) It is already known that the exact placement of the two-liquid field is composition dependent. Thus, the Ca-rich composition of the blue zhamanshinite melt (up to 7 wt% CaO) might have been a determining factor. No other impactites and tektites are so rich in Ca [7]. (2) All impactite and tektite compositions [7] are very near the edge of the inferred two-liquid solvus. It is possible that most impactite melts lie between the solvus and the spinodal, which would preclude separation of a second liquid. (3) A second liquid would never separate if the system were quenched at a temperature above the two-liquid solvus. It is possible that the blue zhamanshinite melt quenched at a temperature significantly lower than that of other impactites. (4) Increasing pressure may favor liquid immiscibility [8]. However, tektite melts are formed and cool under

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conditions of massive decompression, making this possibility unlikely. (5) The presence of water in impactite melts might also influence separation of a second melt, although most impactite glasses are very dry, and so this effect may not be important. (6) Since the position and size of the two-liquid fields in silicate systems are composition dependent, it is possible that the bulk composition of blue zhamanshinites lies just outside the two-liquid field, and that the second liquid separated from this specific melt through the process of metastable liquid immiscibility [9-11]. The presence of metastable liquid immiscibility is promoted by a relatively low melt cooling rate. Other tektite melts could have frozen before a second melt had the opportunity to separate. The presence of liquid immiscibility may be useful in the estimation of impact melt cooling rates [10]. (7) Few impactites have been examined in the TEM. It is possible that the role of liquid immiscibility in impact melts is more important than previously recognized. The Muong Nong tektites, with their compositionally variable layering are an obvious candidate for this phenomenon.

REFERENCES: [1] Koeberl and Storzer, Proc. Second Intern. Conf. Natural Glasses, 207-213 (1987); [2] Koeberl, GCA 52, 779-784 (1988); [3] Cassidy, Meteoritics 1, 426-437 (1956); [4] Zolensky et al., Am. Mineral. 73, 313-323 (1988); [5] Roedder, Proc. Fourth Lunar Sc. Conf., pp.681-703 (1973); [6] Roedder and Weiblen, Proc. Second Lunar Sci. Conf., 507-528 (1971); [7] Koeberl, Tectonophysics 171, 405-422 (1990); [8] Watson and Naslund, Geophys. Lab. Carnegie Inst. Yearbook 1976, pp.410-414 (1977); [9] Roedder, Contrib. Mineral. Petrol. 82, 284-290 (1983); [10] Roedder, Nature 267, 558-559 (1977); [11] Freestone and Powell, Contrib. Mineral. Petrol. 82, 291-299 (1983).

TABLE 1 BLUE ZHAMANSHINITE ANALYSES

	Glass Inclusions		Host Glass	Bulk
SiO ₂	40.28	49.13	82.23	74.0
Al ₂ O ₃	11.98	10.37	11.21	11.02
FeO	13.72	13.48	3.00	4.47
CaO	17.72	21.18	3.56	4.08
MgO	6.17	3.65	ND	1.33
K ₂ O		ND	ND	2.70
Na ₂ O		ND	ND	1.52
Ti ₂ O		ND	ND	0.58
MnO		ND	ND	0.10
P ₂ O ₅	10.13	3.19	ND	0.8
Total	100	100	100	100.60

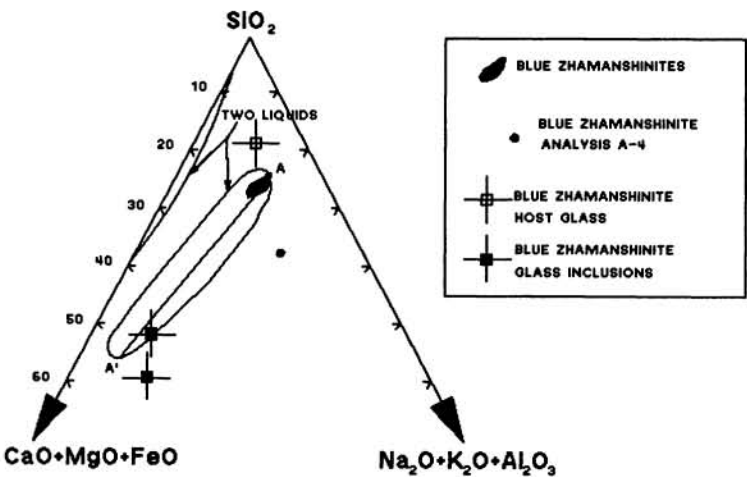


FIGURE 2

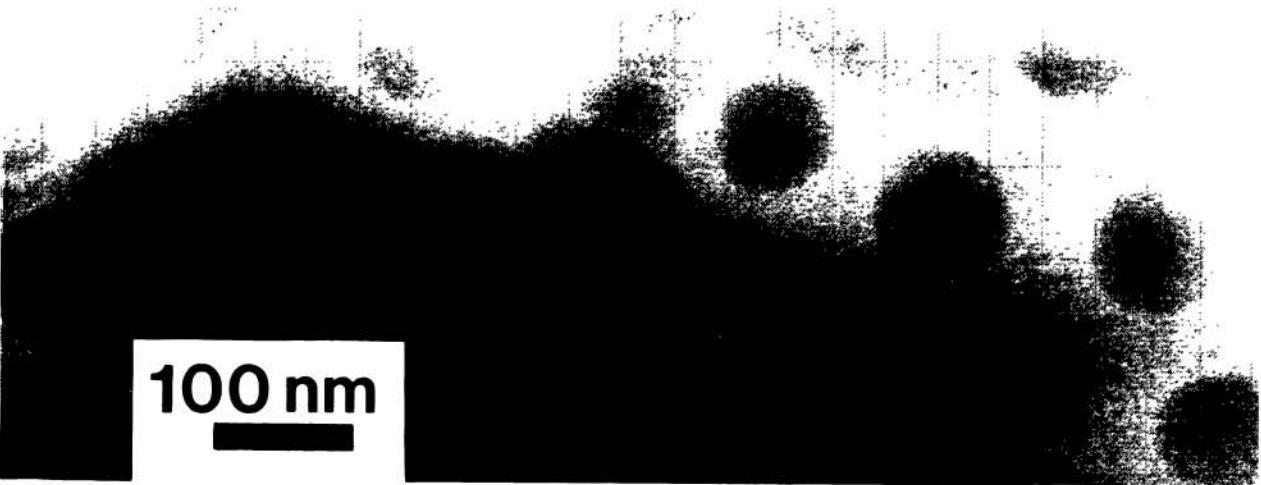


FIGURE 1