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CAUGHT IN AMBER: GEOCHEMISTRY AND PETROGRAPHY OF UNIQUELY PRESERVED CHICXULUB MICROTEKTITES FROM THE TANIS K-PG SITE FROM NORTH-DAKOTA (USA).

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Introduction: The Chicxulub meteorite impact is the only recognized impact event on Earth that produced and preserved an ejecta layer still traceable today on a global scale [1]. Therefore, it is possible to directly compare, both texturally and compositionally, the material from the crater in Mexico with its deposits worldwide. This approach provides vital constraints on the dynamic processes within the Chicxulub impact plume and the incorporation of different target lithologies as well as a potential meteoritic component within the ejecta.

Well-preserved glassy impact spherules smaller than 1 mm, found at proximal marine Cretaceous-Paleogene (K-Pg) sites around the Gulf of Mexico (Beloc [2] and Arroyo El Mimbral [3]) have shown to exhibit a striking similarity with the Chicxulub in-crater melt sheet in terms of geochemistry and age [4]. Here we describe a K-Pg site from a terrestrial setting ~3050 km from the crater [5], that documents the first occurrence of uniquely preserved Chicxulub microtektites, which are embedded in fossilized amber. In this study, we report the petrography, oxidation state, and major and trace element composition of these glassy impact spherules and compare the results with data from other K-Pg sites to interpret their formational mechanisms and link with the Yucatán target lithologies.

Site, samples & methodology: The characterized spherules originate from the Tanis K-Pg site at the transition between the fluvial Hell Creek and Fort Union Formation from SW North Dakota, USA [5]. This 1.3 m thick event deposit is interpreted as a seismically induced onshore surge (seiche) deposit triggered by the Chicxulub impact [5]. It preserves a unique mixed marine/terrestrial mass-death assemblage together with impact ejecta, including altered and seemingly unaltered spherules (dated to 66 Ma by $^{40}Ar/^{39}Ar$), shocked minerals, and a bulk rock iridium anomaly of 3.8 ppb [5].

Four glassy spherules, extracted from amber inside a fossilized tree within the event deposit, were cut in half and polished. These particles were studied for their microtexture using optical microscopy and SEM-EDS. The major and trace element composition of the particles was quantitively mapped using high-resolution (>15 µm) synchrotron radiation based micro X-ray Fluorescence (S-µXRF), complemented with maps and spot analyses by means of Laser Ablation ICP-MS (LA-ICP-MS). In addition, X-ray Absorption Near Edge Spectroscopy (XANES) of Fe was performed at the ESRF BM14-DUBBLE beamline to provide constraints on the oxidation state of these ejecta, which sheds light on alteration and atmospheric transport pathways [6].

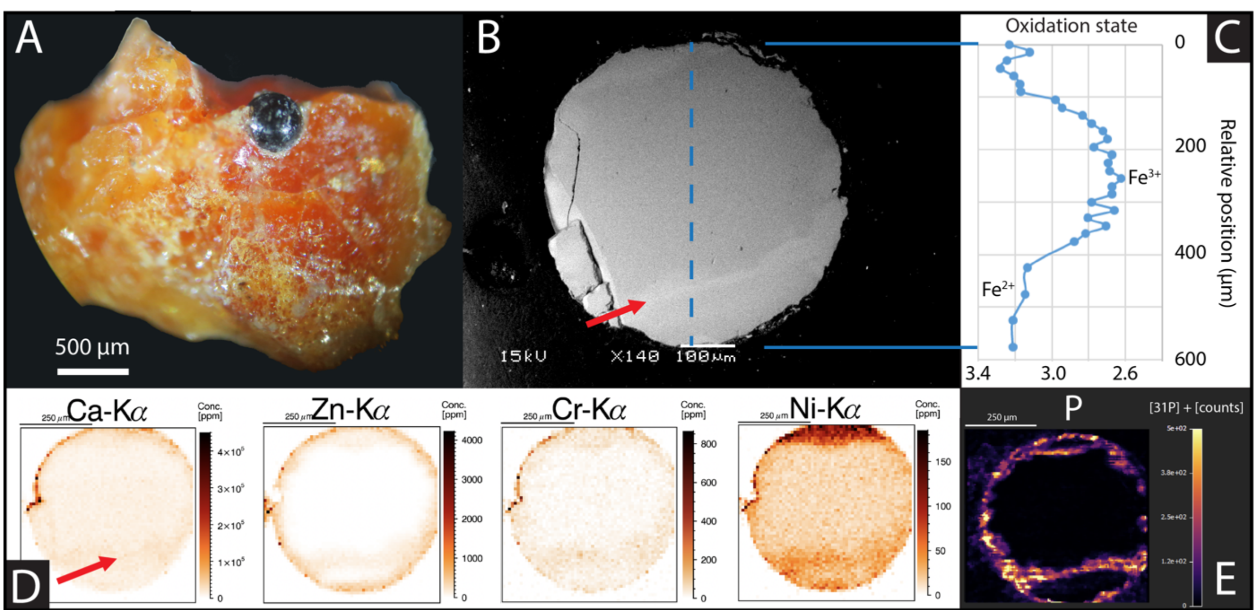

Fig. 1. A Tanis K-Pg amber microtektite (A), showing schlieren textures under the SEM (B, in red) and variations in oxidation state and selected trace element composition by means of Fe-XANES profiles (C) and S-µXRF (D) and LA-ICP-MS (E) mapping.

Results: Fig. 1 summarizes the results obtained for particle MDZ11. Petrographic screening showed that the spherules display a glassy nature with no clear visual signs of palagonitization, smectitization or dissolution [7]. Faint schlieren textures have been observed (Fig. 1B), typical for well-preserved impact-glass [7], and this compositionally distinct flow-banding is linked to enriched Ca and P contents (Fig. 1D-E). In addition, inside the glassy matrix, several ~50 µm long skeletal and dendritic melilite-like crystals can be recognized, indicating that these spherules might not be microtektites *sensu stricto* as they do contain some microlites [8].

The S-µXRF compositional maps (Fig. 1D) provide further constraints on the preservation state of these spherules. The glassy cores show little chemical variation, except for the schlieren textures, suggesting a relatively well melt homogenization. However, at the outer rim, an enrichment can be found in elements such as Zn and P, indicating the presence of an alteration rim, albeit very thin (<50 µm). The Fe-XANES profiles (Fig. 1C) throughout two particles (MDZ11 and MDZ32) display variations in oxidation state from 3.3 at the rim to 2.6 in the center, indicating that the spherule core is more reduced (higher Fe^{2+} contribution) relative to the rim (more Fe^{3+}). In contrast, two other spherules (MDZ39 and MDZ49) display relative homogeneous Fe oxidation states, with Fe^{3+}/Fe^{2+} values around 3.2.

The LA-ICP-MS spot analysis data shows that the characterized particles are silicate glasses (50.8 – 71.9 wt% SiO_2) with more variation in CaO content (5.2 – 24.2 wt%), than previous work on the Tanis site has documented (5.1 – 5.9 wt% CaO) [5]. These observed ranges are fully consistent with those determined for K-Pg glassy spherules from Beloc, Mimbral and Gorgonilla Island [7, 9]. It shows that the Tanis dataset covers a wide range including values of both the black glass subgroup and the yellow glass subgroup (Fig. 2).

Bulk trace element spider diagrams show quite homogenized values throughout the Tanis spherules, displaying REE values similar to yellow and black glass from Beloc [7], with the exception of one spot-analysis near a spherule rim. Lastly, Ni and Cr values (Fig. 1D) from the Tanis site display a ratio that is 1.5 to 4 times higher than Beloc and Mimbral spherules (Ni/Cr ratios of 0.69 and 0.27, respectively). Elevated Ni/Cr ratios have been used in Australasian tektites to infer a possible meteoritic contribution [10]

Discussion and conclusions: The petrography, geochemistry, size and age [5] of the Tanis glassy spherules implies that they represent impact melt droplets derived from the Chicxulub crater, that were quenched in flight and then caught inside resin from a tree that subsequently was transported inland by means of a seiche event. The paleodistance from Tanis to the Chicxulub crater is ~3050 km and ejecta models predict an arrival time of 12 – 25 min after impact for these spherules [11].

The delicate microtextures present inside these spherules together with their trace element composition (e.g. fluid-immobile Nb/Ta vs Zr/Hf values) suggest that the glassy cores are uniquely preserved and that only the very outer rim shows minor alteration. Fourier-transform infrared spectroscopy (FTIR) is planned to fully confirm these first observations, as it is able to map H_2O content. Pure impact glass should yield very low H_2O concentrations (0.002-0.02 wt%) [12].

The extraordinary impact glass preservation at Tanis allows for a comprehensive study of the original geochemical variations in these ejecta materials. The major element data suggest a wide range of target rock contributions similar to both black and yellow glass [7], which have been attributed to a granitic basement and a carbonate and evaporite sedimentary cover target [2]. Additional bulk trace element and isotopic analyses may further constrain the compositional heterogeneities within these K-Pg ejecta. This approach will record target rock and impactor contributions in these ejecta and sheds light on the emplacement mechanisms of ejecta material from large impact structures.

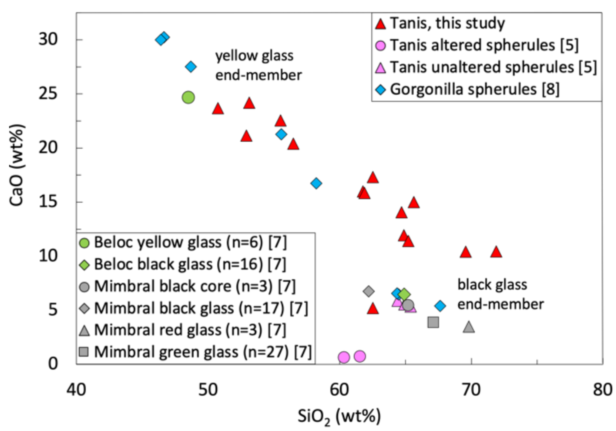

Fig. 2. Harker diagram showing a large variation in SiO_2 and CaO within the Tanis microtektite-like spherules from this study and [5], compared to glassy impact spherules from Beloc [7], Mimbral [7] and Gorgonilla Island, Colombia [9].

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