BIOMASS CAPTURE AND SURVIVAL IN METEORITE IMPACTS.

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Introduction: In [1] we reported carbonaceous inclusions inside of Darwin impact glass. Pyrolysis gas chromatography mass spectrometry (PY-GCMS) revealed that the inclusions contained a suite of organic compounds, including cellulose, lignin, aliphatic biopolymer and protein remnants [1]. These are remains of the ecosystem that existed at Darwin crater when the impact took place. Survival of organics in the inclusions is surprising, the host melt that they are trapped in reached temperatures >1700 °C and organics should be destroyed at temperatures ≥600 °C [1]. Here we attempt to explain the mechanisms of capture and survival of biomass during impact. Capture processes can be inferred from petrographic observations, survival is evaluated with simple heat flow calculations.

Impact at Darwin. Darwin crater is a 1.2 km diameter structure in the remote wilderness of west coast Tasmania, Australia [2]. All lines of evidence indicate that it is the source of Darwin glass [2,3,4]. Based on Ar/Ar age dating of the glass, the impact occurred ca. 800 000ka [5]. At the time of impact, the crater site was a swamp, surrounded by rainforest [1,3].

Petrography of inclusions and host glass: Inclusions in a thin section of Darwin glass are shown in Fig. 1. This is the first *in situ* scanning electron microscope (SEM) observation of an inclusion in a thin section, previous examples were imaged in glass fragments by X-ray micro tomography. Gross compositional heterogeneity in the host glass is denoted by variations in gray scale. Bright regions are higher in SiO_2 and depleted in FeO, relative to the darker regions. The flow banding is clearly orientated, indicating stretching of the viscous glass during cooling.

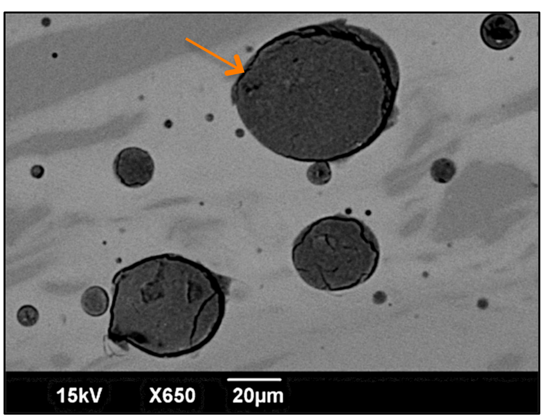

Fig. 1. SEM image of a Darwin glass thin section. An example of an inclusion is indicated.

Previously [1], we reported only spherical inclusions. We have now discovered irregular shaped inclusions too (Fig. 2), these provide additional insights into the formation mechanisms. The pictured inclusion shows evidence for deformation that we interpret to have resulted from compression and shear, as the host glass quenched around it.

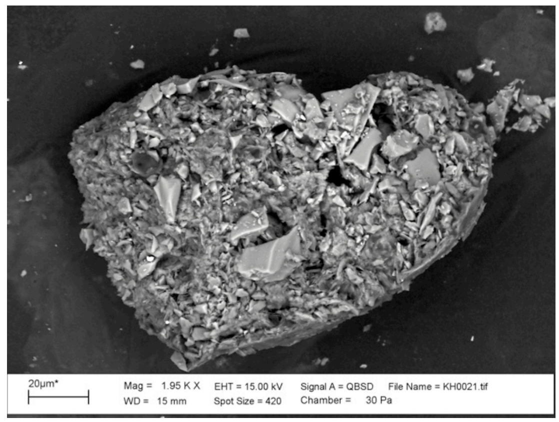

Fig. 2. SEM image of non-spherical, carbonaceous inclusion, extracted from Darwin glass.

Mechanism of capture: Darwin glasses were produced at the point of impact, from melting of the upper most target rocks [4,6]. Prior to ejection of melt from the crater site, the receiving environment will be scorched by radiation from the impacts fireball [7,8]. The fireball is short-lived, lasting a few seconds. Although extremely hot inside, it is primarily thermal radiation and will rarely induce complete combustion [7,8]. Outside of the range of the fireball, an impacts blast wave propagates extreme winds into the receiving environment [7,8]. Seismic shock waves may also accompany the impact [7,8]. We suggest that the blast wave and seismic shaking ripped up the swamp, stripped vegetation from the ground surface and launched these materials into the air.

The melt bearing plume follows the blast wave, expanding outwards and upwards. Inside of the plume, liquid glass melts exist out to distances well beyond the range of blast and thermal effects. This means that the melt bearing plume advances across the debris of scorched biomass, while soil and other organic particles may also be falling out of the atmosphere. By turbulent convection, organic particles are drawn into the plume. Inside of the plume these encounter liquid melt droplets. Trapped inside of the melt, the organic material underwent rapid heating. Subsequent de-gassing produced gas-melt froth, rich in CO, CO_2 and hydrocarbons, this immiscible froth expanded rapidly into spheroidal shapes, then froze suddenly as the Darwin glass melt solidified.

Mechanism of survival: The main variables that determine the likelihood of preserving organics during heating are peak temperatures and the duration of exposure [e.g. 9, 10]. Experiments have shown organics to be resilient to prolonged low temperature exposures [10]. For complex organic signatures to be preserved, peak temperatures are considered to be the limiting factor, since even short-lived exposure to very high temperatures will break organic bonds [1]. This is the basis for the following calculations, which consider peak temperatures reached during transport of organic material, in this case peat, captured inside of impact glass melt. We choose peat, as this is consistent with the composition of biomarkers in the inclusions [1].

Our model sets a boundary layer temperature and tracks diffusion into a spherical peat particle (using a thermal conductivity value (*k*) for peat of 0.25 Wm^{-1}/K^{-1}). We take this boundary layer temperature from the cooling profile suggested for a tektite particle with a radius of 1.3 cm, by another model developed to explain production of the Moldavite tektites from the Ries Crater [11]. The model result indicates that peat particles with radii ≤1 cm are too small to buffer heat diffusion sufficiently to prevent core temperatures from quickly exceeding 500-600 °C and breaking organic bonds (Fig. 3). In peat particles with radii of ≥1 cm, core temperatures remain <500-600 °C during the time that the host melt takes to quench (~1.5 seconds).

Compression of trapped peat during quenching of the melt, bubble collapse and violent particle collisions will shatter the peat particles into smaller fragments. Melt droplets themselves will also be segregating as blasted from the crater, with fine droplets detaching from larger blebs. Therefore, melt in the plume will be a chaotic mixture of different sized droplets at various stages of solidification and a range of size dependent temperatures. The observed inclusions likely formed when fine fragments of shattered peat were re-captured in smaller droplets. On recapture the fine fragments continued de-gassing, but by this point in time the host melt is below 600 °C and organic components are 'safe'.

Implications: Peak temperatures and pressures do not differ during large and small impacts [8], but the duration of effects increases with increasing impact size. In our calculations, we have used the temperature profile of tektite melt, from a large (100MT) impact event [11]. Therefore our observations of organic survival in the small (20MT) Darwin impact, suggest that organics may survive in larger events too, by the same mechanisms.

Much has been made about the potential astrobiological implications of biomarkers being preserved in impact melt ejecta [1,12]. This potential rests on demonstrating that biomass survival in impact melt is common on Earth. Our proposed mechanism of capture does not require an unusual set of circumstances, it should apply to any impact onto a fecund surface. Ultimately, for impact glasses to be prospective targets in the search for extinct extraterrestrial life, organic inclusions need to be discovered in tektites.

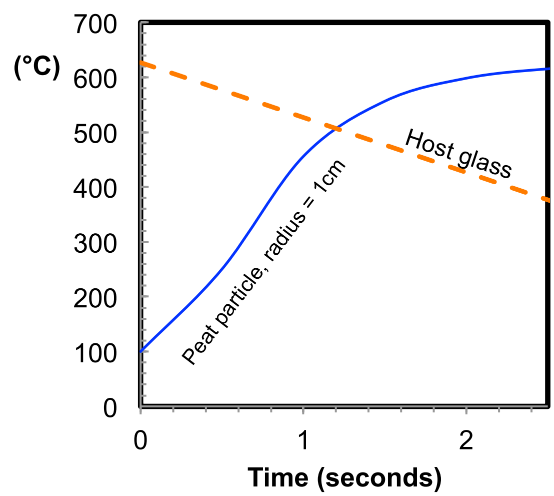

Fig. 3. Thermal evolution of a peat particle (blue line). The particle is exposed to boundary layer temperatures indicated by the orange line, this is the cooling profile for tektite melt from [11]. The blue line is for a peat particle with a 1 cm radius, smaller particles (not shown) rapidly reach temperatures >600 °C.

References: [1] Howard K.T. (2013) *Nat. Geosci.* 6, 1018-1020. [2] Howard K.T. & Haines P.W. (2007) *EPSL* 260, 328-339. [3] Howard K.T. (2009) *Met. & Planet. Sci.* 44, 115-129. [4] Howard K.T. (2008) *Met. & Planet. Sci.* 43, 473-496. [5] Loh C. H. (2002) *Met. & Planet. Sci.* 37, 1555–1562. [6] Koeberl, C. (1986) *Ann. Rev. Earth and Planet. Sci.* 14, 323-350. [7] Collins G. S. et al. (2005) *Met. & Planet. Sci.* 40, 817-840. [8] Melosh H. J. (1989) *Impact Cratering A Geologic Process*. 245 pp. [9] Bowden S. A. et al. (2009), *Astrobiology* 8, 19-25. [10] Parnell et al. (2011) *Icarus* 212, 390-402. [11] Stoffler D. et al. (2002) *Met. & Planet. Sci.* 37, 1893-1970. [12] Schultz P. et al. (2013) *Geology* 42, 515-518.