THE ROLE OF ALKALI FELDSPAR IMPACT EJECTA IN THE ORIGIN AND DISSEMINATION OF EARLY LIFE. M. R. Lee[1] and A. Pickersgill[1], [1]School of Geographical and Earth Sciences, University of Glasgow. Glasgow G12 8QQ, U.K. (Martin.Lee@Glasgow.ac.uk)

Introduction: Meteorite impacts may have been pivotal to the origins of life on Earth. For example, impactors could have introduced and/or generated bioessential chemicals, and early life may have evolved and flourished within impact structures [1, 2]. Although less attention has been paid to ejecta deposits, they could have been biologically highly significant because the most energetic impacts would have distributed fragments of the impactor and target rock over large areas of the Earth's surface.

One of the most abundant mineral constituents of ejecta from impacts on continental crust is K-rich alkali feldspar [3]. As an example, the target rocks of 18 the 44 Phanerozoic impact structures >16 km in diameter have an average of 22–32 vol. % K-feldspar [4]. This mineral would also have been an important component of ejecta from pre-Phanerozoic impacts because significant volumes of K-feldspar were available at 3.0–2.5 Ga with the development of granite in the upper crust [3]. The oldest dated impact structure, Yarrabubba in Australia, has an age of 2229 ± 5 Ma and its main target rock is a monzogranite [5].

Hypervelocity impacts into alkali feldspar rich target rocks would have had significant effects on Earth's climate because alkali feldspar aerosols are highly effective in nucleating ice and making clouds, and much more so than any other common mineral [6]. The reason why alkali feldspars are so disproportionately important in atmospheric ice nucleation is probably due to the microtopography of grain surfaces, which is in turn largely controlled by the geometry of perthite exsolution microtextures thatcontrol how grains break [6]. Here we have sought to evaluate whether alkali feldspar impact ejecta could have had other effects on the Earth system, and specifically in the dissemination and creation of life.

Materials and Methods: In order to understand the likely nature of alkali feldspar ejecta we have studied two Phanerozoic impact structures whose target rocks have abundant K-rich alkali feldspar: Rochechouart (30–32 % K-feldspar) and Chicxulub (15–30 % K-feldspar) [4]. The alkali feldspars studied were in a shocked granite from a depth of 1199.6 m in drillcore from Chicxulub IODP-ICDP Expedition 364, Hole M0077A (sample 259-R3_2.5-4.5), and unshocked granite from Champagnac Quarry in Rochechouart. The microstructures of the alkali feldspars in polished thin sections were characterized at the University of Glasgow using a Zeiss Sigma SEM. In order to understand how the alkali feldspar ejecta could have behaved at the Earth's surface, alkali feldspars in regoliths that have formed by the weathering of lower Devonian Shap granite in northwest England were also studied by SEM. This granite is not associated with an impact structure, but the regolith is an analogue for the response of alkali feldspar ejecta to subaerial exposure.

Results: Alkali feldspars in samples of the target rocks of the Rochechouart and Chicxulub structures are microperthitic. They comprise albite lamellae (films) in K-feldspar (orthoclase with subordinate microcline), and these 'strain-controlled' exsolution microtextures are cross-cut by veins and patches of albite that are collectively referred to as patch perthites. Chicxulub feldspars are more coarsely microperthitic than those from Rochechouart. The Shap alkali feldspars are also microperthites consisting of films, veins and patches of albite within orthoclase. They are similar to the Chicxulub alkali feldspars with respect to the proportions of albite and orthoclase, and the relatively coarse scale of the microtextures.

The surfaces of alkali feldspars from the Shap granite regolith have very high density etch pits and channels (Fig. 1a). Individual etch pits occur at the sites where dislocations intersect the grain surface (Fig. 1b). These defects are present along the interface between albite films and orthoclase and have developed to minimize elastic strain resulting from the misfit between albite and orthoclase lattices. Dislocation etch pits also occur within the patches and veins of albite that cross-cut the exsolution microtextures. The etch pits enlarge mainly by dissolution of albite, and eventually coalesce to produce channels at the grain's surface that extend into the interior.

Discussion:

Nature of alkali feldspar ejecta. Approximately a third of the ejecta from the Rochechouart and Chicxulub impact events would have been alkali feldspar, and a mixture of unshocked and variably shocked grains. As they are microperthites, the unshocked crystals would have been highly effective in ice nucleation [6]. The effects of shock on grain surface topography and ice nucleation properties are however unknown. The highest intensity of shock (>~30 GPa) would have resulted in melting and concomitant loss of exsolution microtextures whereas lower pressures (~10–30 GPa) would have produced planar shock microtextures such as planar fractures (PFs) and planar deformation features (PDFs) [7]. These planar elements will have affected how the grains fracture and therefore the microtopography of their surfaces.

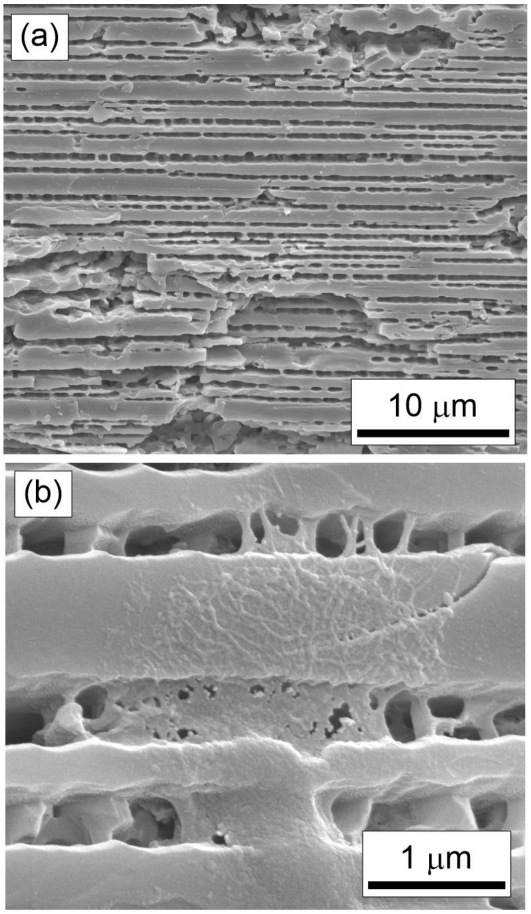

Figure 1a,b. Secondary electron SEM images alkali feldspars from the Shap regolith. The etch pits and channels have formed by dissolution of albite such that most feldspar exposed at the surface is orthoclase.

Significance of alkali feldspar ejecta for early biology. The Shap granite regolith samples show that in addition to determining grain surface microtopography and ice nucleating properties, perthite microtextures control how these minerals decay during subaerial exposure. Processes and products of this weathering may have several important implications for early life.

As shown by [8], the etch pits that are so abundant on alkali feldspar grain surfaces are the surface expression of three-dimensional networks of sub-micrometer wide tubes that can penetrate many tens of micrometers into grain interiors. These etch tubes could have served several biologically important purposes including: (i) providing access to mineral inclusions within the feldspars that could have been a source of bioessential elements including phosphorous and transition metals; (ii) helping to concentrate prebiotic molecules and protect them from UV radiation; (iii) operating as rudimentary cell walls. Although the crystallographic relationships between shock-formed planar microtextures and exsolution microtextures are poorly known, images of shocked alkali feldspar ejecta from Chicxulub [9] suggests that they would have served as planes of enhanced dissolution and so added to the networks of intragranular etch tubes. The role of alkali feldspar ejecta as catalytic biological microreactors may have been enhanced by chemical leaching of the feldspar to make organophilic silica-rich surfaces [10].

In addition to containing unshocked and shocked grains that had not been previously weathered, alkali feldspar ejecta would also contain fragments of the target rock that had been altered by groundwater prior to the impact. In common with the regolith grains, alkali feldspars from the weathered target rock would have the networks of etch tubes that could have hosted microbial communities. Impact-ejection of these alkali feldspars would have distributed the endoliths over large areas, thus disseminating early life. This possibility is supported by experiments showing that microorganisms can survive shock of tens of GPa [11].

Conclusions: The unique microtextures of microperthitic alkali feldspars mean that the ejecta from large impacts into continental crust could have been important both to the Earth's climate, and possibly also the origin and dissemination of early life. Crucial to further evaluation of these ideas will be to understand how shock microstructures affect the microtopography of grains, their ice nucleating properties, and their behavior during natural weathering.

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References: [1] Cockell C. S. (2006) *Phil Trans Roy Soc London B. 361,* 1845–18656. [2] Osinski G. R. et al. (2020) *Astrobiology, 20,* 1121–1150. [3] Pankhurst M. J. (2017) *Geology 45,* 379–382. [4] Coldwell B. C. and Pankhurst M. J. (2019) *J Geol Soc 176*, 209–224. [5] Erickson T. M. et al. (2020) *Nat Comms 11,* 300. [6] Harrison A.D. et al. (2016) *Atmospheric chem and phys 16,* 10927–10940. [7] Stöffler D. et al. (2018) *Met. Planet. Sci. 53,* 5–49. [8] Parsons I. et al. (1999) *PNAS 95,* 15173–15176. [9] Schulte P. et al. (2009) *Geochim. Cosmochim. Acta 73,* 1180–1204. [10] Smith, J. V. et al. (1999) *PNAS 96,* 3479–3485. [11] Stöffler D. et al. (2007) *Icarus 186,* 585–588.