A REVIEW OF SHOCK-METAMORPHIC FEATURES IN APATITE FROM TERRESTRIAL IMPACT STRUCTURES AND POSSIBLE IMPLICATIONS FOR EXTRA-TERRESTRIAL PHOSPHATES.

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Introduction: Despite the wide utility of apatite in the geosciences, we know little about how this mineral responds to the extreme temperatures and pressures associated with impact cratering. This has hampered interpretation of U-Pb and other data for extra-terrestrial apatite grains. For example, U-Pb analysis of lunar phosphates has been used to constrain the timing of impacts (e.g., [1] and [2]) but it is uncertain whether some of these dates represent actual impact ages or are dates intermediate between the time of apatite crystallization and shock metamorphism [2]. Here we review apparent shock-metamorphic features observed in apatite at terrestrial impact craters and present new observations of shock-recrystallised apatite from the Paasselkä impact structure, Finland, with the aim to aid our interpretation of data from extra-terrestrial phosphates.

Published data: Apatite with apparent shock-related features has been documented at a number of impact craters on Earth. For example, multiple sets of planar microstructures were observed in apatite at the Santa Fe impact structure in New Mexico, USA [3]. These are distinct from known cleavage orientations in apatite and are generally spaced at 5-10 µm intervals [3]. Planar fractures and arrays of micro-vesicles were recently documented in U-Pb-age-reset apatite at the Nicholson Lake impact structure in the Northwest Territories, Canada [4], and possible impact-induced recrystallisation of apatite was reported at the Carswell impact structure in Saskatchewan, Canada [5]. In addition to observations of naturally shocked grains, experimentally shocked apatite has also been shown to display planar microstructures (e.g., [6]).

Despite our limited knowledge of the effects of shock metamorphism on apatite, the mineral has been used to date impacts on Earth. (U-Th)/He, U-Pb and fission track geochronology of apatite grains chronometrically reset by impact-related heat and/or pressure has been applied at a number of sites (e.g., [4], [7], [8], and [9]).

New observations: Despite the documentation of planar microstructures and impact-induced age-resetting in shocked apatite, unequivocally shock-recrystallised apatite has not previously been reported at a terrestrial impact structure. Here we present the first such study.

Sample. A sample of clast-rich impact melt rock was collected from a gravel quarry near the southeastern shore of the eponymous lake filling the Paasselkä impact structure, Finland. This crater is approximately 10 km in diameter and $^{40}Ar/^{39}Ar$ dating indicates that it formed in the late Triassic, at 231 ± 2 Ma [10] [11].

Methods. Apatite grains were separated from the whole rock sample by crushing, milling, and heavy liquid and magnetic separation techniques. Eight apatite grains were identified and mounted on sticky carbon tabs so that their exteriors could be imaged in BSE mode on an FEI Quanta FEG 650 scanning electron microscope (SEM) at the Swedish Museum of Natural History, Stockholm. After external imaging, the grains were mounted in epoxy and polished in order to expose their mid-sections. Imaging and microstructural analysis by electron backscatter diffraction spectroscopy (EBSD) were then carried out on the interior surfaces on the same SEM.

Results. All eight apatite grains identified in the sample display granular textures on their exteriors (e.g., Fig. 1). However, granular textures are less readily visible on polished grain interiors (Fig. 2A) and under the petrographic microscope. Each apatite grain is composed of several thousand neoblastic crystallites that have a modal long axis length of ~5 µm (and maximum of ~20 µm) and a modal short axis length of ~2 µm (maximum of ~4 µm). The neoblasts tend to be oriented in one preferential direction (Fig. 1).

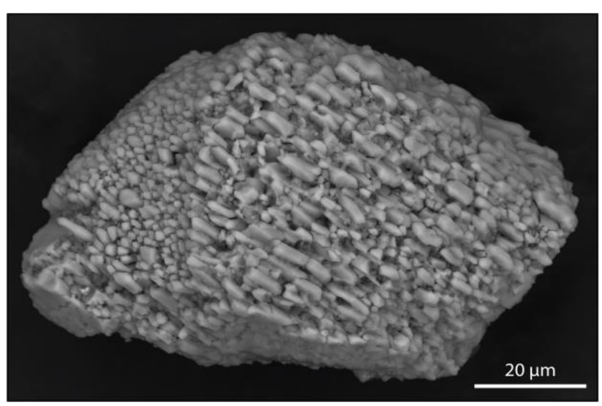

Fig. 1. Backscattered electron (BSE) image of the exterior of a shock-recrystallized apatite grain from the Paasselkä impact crater, Finland.

EBSD analysis shows that most of the analyzed apatite grains appear to be entirely granular. However, there is an oval-shaped, non-granular region in the center of the otherwise granular grain Paasselkä-ap103 (Fig. 2B-C). Neither this domain nor the granular texture of the rest of the grain is visible in BSE (Fig. 2A).

Individual granules in all grains, and the non-granular core domain in grain Paasselkä-ap103, are relatively strain-free (Fig. 2C). Relative misorientation between granules commonly reaches ~15° and the non-granular core in Paasselkä-ap103 is misoriented from the neoblast mode by ~15° (Fig. 3C).

Discussion: The first discovery of shock-recrystallised apatite at a terrestrial impact structure offers new opportunities for studies of impact cratering and shock metamorphism on Earth and elsewhere in the solar system. It is significant that partial recrystallisation textures revealed by EBSD were not visible in BSE images (Fig. 2) and we urge the application of EBSD to extra-terrestrial grains. Targeting relict and shock-recrystallised domains in extra-terrestrial apatite may refine our interpretation of, for example, lunar apatite U-Pb data (cf. [2]). Identifying shock recrystallisation textures in lunar, Martian and other extra-terrestrial phosphates might also indicate how shock metamorphism may have affected volatile abundances and isotopic compositions in such grains.

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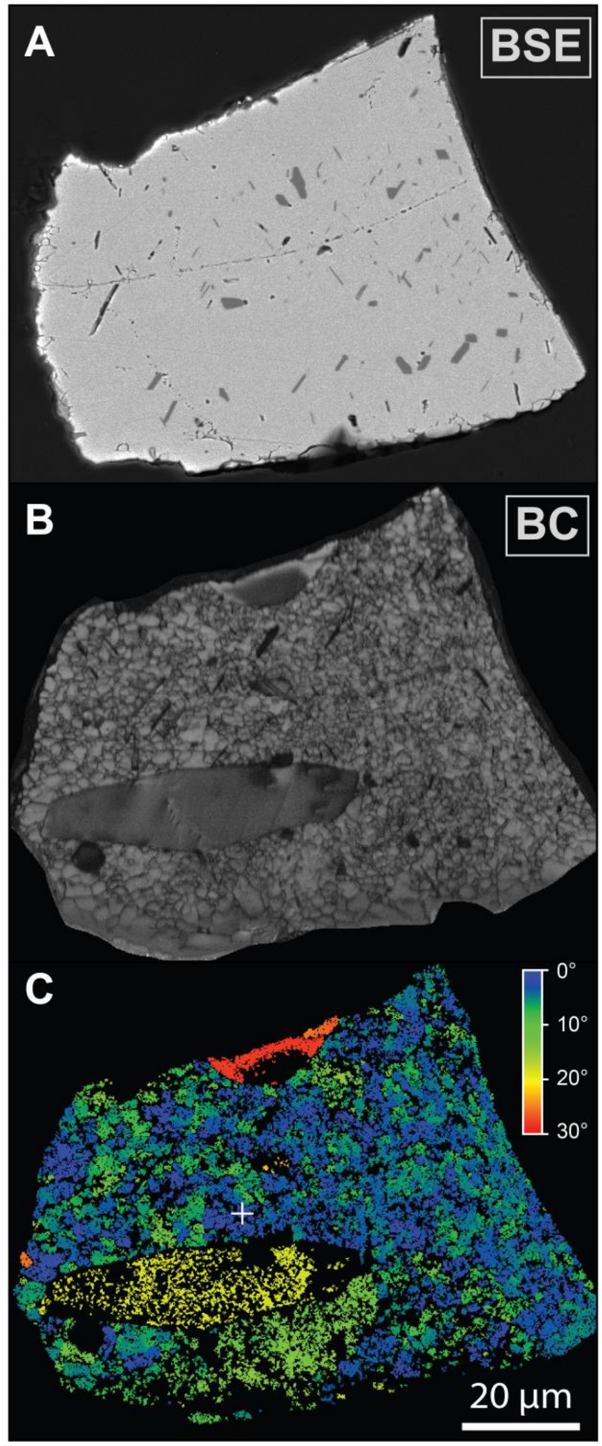

Fig. 2. Imaging and electron backscatter diffraction (EBSD) analysis of an interior surface of a shock-recrystallised apatite grain from Paasselkä.
A: Backscattered electron (BSE) imaging. **B:** EBSD band contrast (BC) image. **C:** EBSD map showing misorientation relative to the white cross.