FEATHER FEATURES: MICROSTRUCTURAL DEFORMATION IN THE LOW-SHOCK PRESSURE REGIME M. H. Poelchau[1], T. Kenkmann[1]. [1]Museum für Naturkunde, Leibniz Institute at Humboldt University Berlin, Invalidenstr. 43, 10115 Berlin, Germany. michael.poelchau@mfn-berlin.de.

Introduction: The recognition of planar deformation features, or PDFs, in quartz and other minerals is generally accepted as one of the strongest unequivocal indicators for shock metamorphism, and thus is commonly used to determine if a geological structure is an impact feature. Experimental research has shown that the onset of PDF formation is at >10 GPa. To date, very little systematic research has been done in the shock pressure regime from ~3 to 10 GPa. The recognition of the lowest possible pressures at which unequivocal shock features are induced requires further experimental work and the comparison to natural samples. Feather features (FFs), a recently discovered planar microstructure found in shocked quartz, have the potential to become a standard low-shock pressure indicator. First described by [1], hardly any data has been produced on these features so far [1-3].

Results: In the current study, feather features in samples from the Nördlinger Ries and the Matt Wilson impact structure were microscopically analyzed and crystallographically indexed. FFs occur as short, parallel to subparallel lamellae with a similar spacing as, or sometimes even narrower than, planar deformation features, and are always found in combination with a planar fracture (PF; Fig. 1a-b). FFs are crystallographically controlled to a certain degree, with the majority of lamellae oriented parallel to rational low index crystallographic planes, with $\{10\bar{1}3\}$ and $\{10\bar{1}2\}$ orientations lacking (Fig. 1c, see also [1-3]). FFs are typically straight and parallel close to their base at the PF and become increasingly curved with progressing length, sometimes even intersecting each other. Thus the crystallographic control of FFs is strong near the PF. With increasing distance from the PF they can transform and propagate as standard, uncontrolled fractures. Angles measured between PFs and sets of FFs average at 50-60°.

Microscopic analysis of quartz grains with feather features show that their formation is linked to shearing along the associated PFs during shock deformation. When the direction of shearing can be determined, FFs are oriented according to the sense of shear. The acute angle formed between the PF and FFs is always opened against the direction of shear displacement (Fig. 1a). The formation of FFs along sheared PFs implies that high deviatoric stresses in the order of ~5 GPa are necessary [4], along with elevated confining pressures found in low-pressure shock waves that have progressed further away from the point of impact.

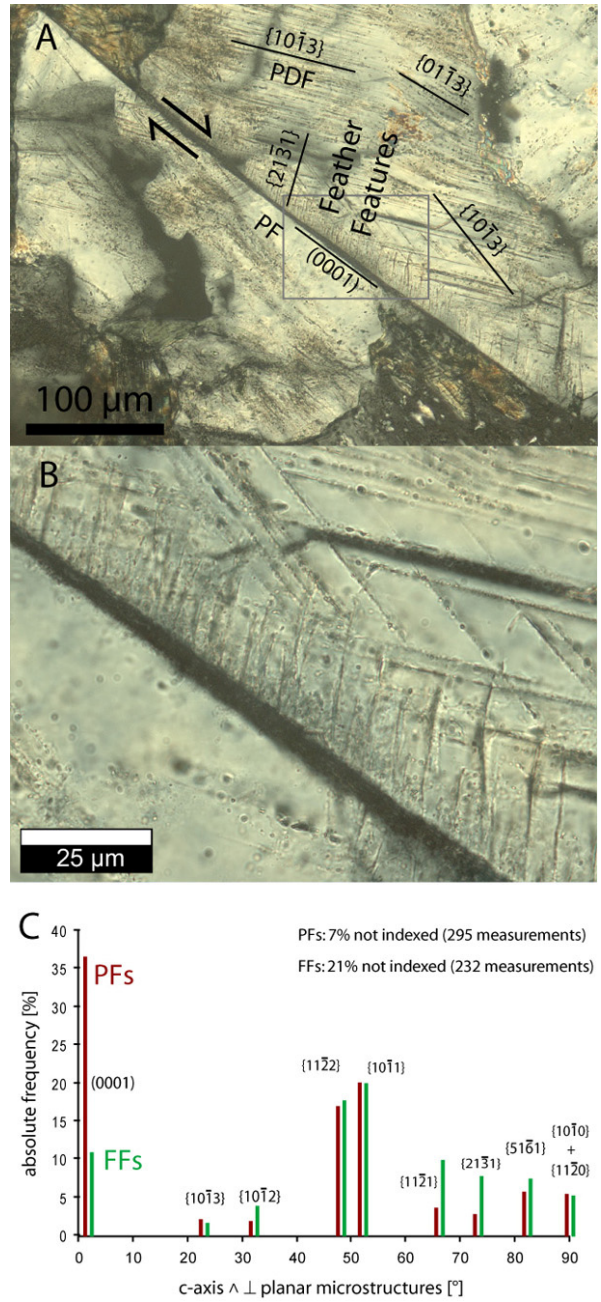

Fig. 1: A) Shocked quartz grain from the Nördlinger Ries suevite, showing indexed PDFs and PFs together with FFs related to shear displacement. B) Close-up of A). C) Compilation of indexed FFs and PFs based on own data and [2-3].

In order to observe the orientations of FFs and their associated PFs relative to each other, 20 quartz grains

in one thin section of an unoriented sample, MW7, a coarse-grained sandstone, were measured with a U-stage and plotted in stereoplots (Fig. 2b-d). PFs in the thin section can be divided into two groups with arbitrarily defined NE-SW and NW-SE trending strike (Fig. 2c), and represent a conjugate set of shear fractures. The FFs on the other hand show a different trend, with the strike of the great circles running ± N-S, and the surface normals plotting in the E and W of the stereoplot (Fig. 2b). PFs and their associated FFs can also be divided into two groups with sinistral shear and dextral shear. An additional microscope stage survey of the same sample was performed. Of 90 observed FFs, 78% emanated in the same direction, to the N (Fig. 2a). No FFs were observed that ran E-W, and most FFs only deviated <±20° from a N-S trend. The orientation of PFs and FFs in rock samples is suggested to be controlled by loading along the principle axis of stress in the shock wave, with sheared PFs at ~45° angles to the axis and feather features aligned ±parallel to the axis.

Shock Experiments: Controlled plane wave shock recovery experiments were performed at the Ernst Mach Institute in Weil am Rhein, Germany. The high explosive experimental setup was employed as described by [5]. A cylindrical sample (15 mm diameter, 10 mm thick) was composed of a quartz-K-feldspar-quartz sandwich in which the contact surfaces of the three crystals and the c-axes of the quartz crystals were oriented parallel to the propagation direction of the shock wave. The vertical configuration of the quartz and K-feldspar slices in combination with the interaction of the shock wave with the iron container surrounding the sample led to the generation of a shear fracture in each of the quartz crystals. Both shear fractures exhibit feather features with straight, parallel lamellae emanating from one side of the fractures with a spacing of 15 µm. Crystallographic orientations are $\{10\bar{1}1\}$ for the fractures, and $\{11\bar{2}1\}$ and $\{21\bar{3}1\}$ for the FFs. Based on estimates of the pressure decrease from the top to the bottom of the sample, FFs were generated in the pressure range of ~7-10 GPa, thus confirming that FFs are microstructures that can be induced by low-pressure shock waves. It should be noted that the FFs point in the direction from which the shock wave came, and thus could be used as an indicator for the local direction of shock propagation in natural samples.

Conclusions: Experiments and FFs found in natural samples that lack PDFs show that FFs can be defined as microstructures that have a lower formation limit at shock levels <10 GPa. The current lower limit for their formation is estimated to be at or above the Hugoniot elasitic limit, which typically varies between 5-8 GPa, but can be as low as 3.5 GPa, depending on the crystallographic orientation of quartz [6]. The FFs' connection to shearing indicates that high differential stresses typical for weak shock waves in the deformational shock regime, which may lie at 4-5 GPa, are additionally important for their formation. Based on their appearance in shocked quartz grains in an increasing number of impact craters (25 so far) and the current lack of reports of these features in endogenically deformed crustal rocks, their uniqueness as a new type of impact-induced planar microstructure alongside PDFs and PFs is proposed.

References: [1] French B.M. and Cordua W.S. (1999) *LPS XXX*, Abstract#1123. [2] French B.M. et al. (2004). *GSA Bulletin*, 116, 200-218. [3] Morrow J.R. and King D.T. (2007) *GSA Field Forum*. [4] Christie J.M. et al. (1964) *Am Jour Sci,* 262, 26-55. [5] Müller W.F. & Hornemann U. (1969) *EPSL,* 7, 251-264. [6] Wackerle J. (1962) *Jour Appl Phys,* 33, 922-937.

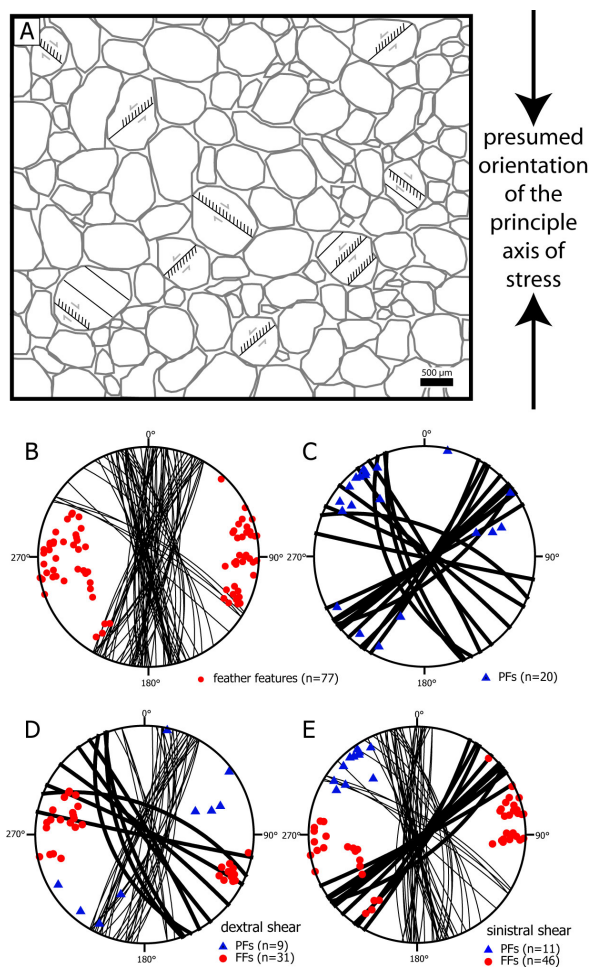

Fig. 2: A) Simplified sketch of a thin section with PF and FF distribution and orientation. B-E) Stereoplot of FFs and PFs from sample MW7 showing strong preferred orientations.