IDENTIFYING PLANAR DEFORMATION FEATURES USING EBSD AND FIB. A. E. Pickersgill[1], M. R. Lee[1], [1]School of Geographical & Earth Sciences, University of Glasgow, Gregory Building, Lilybank Gardens, Glasgow G12 8QQ, U.K. (a.pickersgill.1@research.gla.ac.uk).

Introduction: Planar deformation features (PDFs) in shocked quartz grains are a key indicator of the impact origin of a geological structure [1]. It is essential to determine the crystallographic orientation of a planar microstructure within a quartz grain before it can be unequivocally identified as a PDF. This work can be undertaken using a petrographic microscope that is equipped with a universal stage or a spindle stage [2], but while they are informative, these techniques can be time consuming and require considerable expertise. Even after successfully making measurements, properly indexing the planar features can be problematic, although the development of a mathematical algorithm for automated indexing has significantly improved the speed and accuracy of this process [3]. The greatest difficulty in measuring PDFs on a universal stage is their increasing rarity, and the even greater scarcity of competent users who can train the next generation of impact scientists.

Electron backscatter diffraction (EBSD) can provide precise information on the orientation of a crystal, and its constituent microstructures, in a polished sample (thin section or block). With regards to shocked quartz grains, EBSD enables measurement of the crystallographic orientation of the 'trace' of a PDF (i.e., the line formed where the PDF meets the polished surface of the sample). This information therefore gives a preliminary indication of the orientation of the PDF, but may not provide a unique solution (i.e., more than one plane is likely to be parallel to the trace). In order to unambiguously index the PDF it is necessary to know its orientation in three dimensions (i.e., its trajectory beneath the sample surface).

In this study we have investigated whether the focused ion beam (FIB) technique can be used to help determine the true orientations of planar microstructures in quartz. If so, EBSD and FIB in combination will be a powerful new tool for indexing PDFs.

Methods: This study has used polished thin sections of impact melt rocks from the Gow Lake structure, Canada. Immediately prior to analysis the sections were polished in colloidal silica. Transmitted light microscopy was used to locate quartz grains containing potential PDFs, and two grains were selected for further study, here called GL1 and GL2. These grains were then characterised by secondary and backscattered electron imaging in a FEI Quanta 200F environmental SEM that is equipped with a TSL EBSD system. As the sample was uncoated (in order to produce the most intense backscatter Kikuchi patterns), the SEM was operated in low vacuum mode. EBSD work was undertaken at 20 kV. PDFs were imaged using the forescatter detector, which is situated beneath the phosphor screen. Kikuchi patterns were acquired at a rate of ~40 patterns/sec and grains were mapped at a step size of ~200 nm. Orientation data are plotted in upper hemisphere stereographic pole figures. After EBSD mapping, the thin section was coated with carbon, and trenches were cut into its surface using 30 kV Ga^+ ions in a FEI DuoMill dual-beam FIB. The trenches were oriented at 90º to the trace of the PDF, and their walls were imaged using ~5-20 kV electrons.

Results: Grain GL1 contains PDFs in two orientations, which are readily recognisable by transmitted light microscopy (Fig. 1), but can also be imaged using the forescatter detector (Fig. 2).

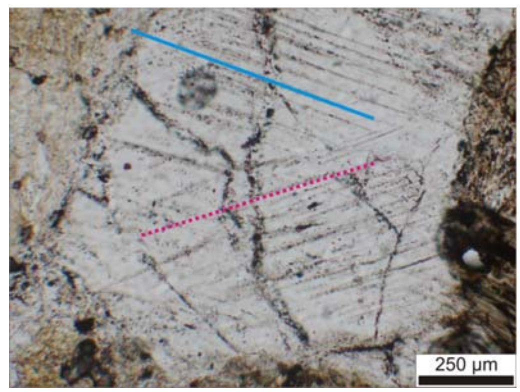

Figure 1: Plane polarized light image of quartz grain GL1 that contains two sets of decorated PDFs (highlighted by the solid/blue and dotted/pink lines).

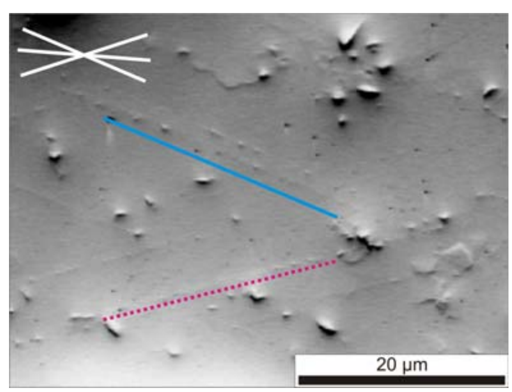

Figure 2: Forescatter image of GL1. Blue/solid and pink/dotted lines delineate the two sets of PDFs. Solid white lines show traces of the {10-13} planes (obtained from EBSD data), two of which are parallel to the traces of the PDFs.

An EBSD map was acquired from GL1, and by using the TSL software the traces of various planes were overlain on the forescatter image. Fig. 2 shows that both sets of PDFs lie parallel to the trace of {10-13}. This result was confirmed by plotting a {10-13} pole figure (Fig. 3), but the PDFs also lie close to the traces of {10-14} planes, in particular the set highlighted by the pink/dotted line (Fig. 3). GL1 is therefore a good example of where EBSD alone cannot be used to unambiguously index a PDF. For a unique solution the orientation of the PDF beneath the thin section surface must be determined. The three dimensional orientation of the set of PDFs that is highlighted by the pink/dotted line was determined by milling a trench into the thin section surface and at 90° to their trace. Results show that this set of PDFs is inclined at 80° to the surface of the thin section, which indicates that {10-13} is their true orientation.

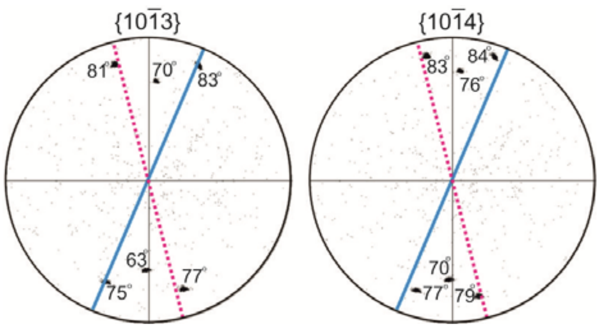

Figure 3: Pole figures of GL1 showing the orientations of poles to {10-13} and {10-14} planes. The angle of inclination of each plane relative to the thin section surface is also indicated. The blue/solid and pink/dotted lines are the poles to the traces of the two sets of PDFs, and show that they are oriented close to both {10-13} and {10-14}.

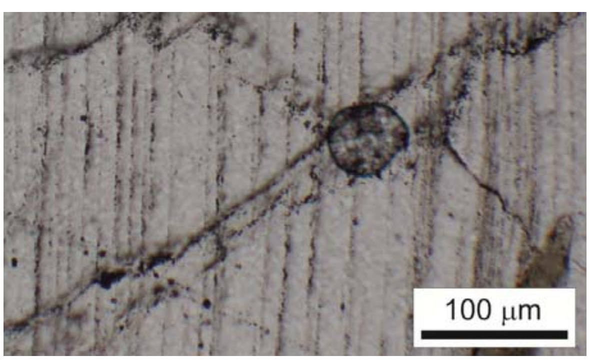

Figure 4: Plane polarised transmitted light image of the one set of PDFs in quartz grain GL2.

Quartz grain GL2 contains PDFs in one orientation (Fig. 4). Plotting of EBSD pole figures from this grain shows that five sets of planes are oriented parallel to the traces of these PDFs (Fig. 5a). A trench that was cut into the grain surface using the FIB technique shows that the PDFs are inclined at 72º the thin section surface (Fig. 5b). This information narrows the five potential planes down to one, {11-22}, and so provides a unique solution.

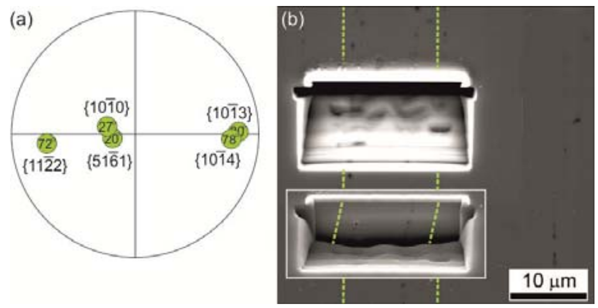

Figure 5: Orientation data for PDFs in GL2. (a) Pole figure showing the five planes that are parallel to the traces of the PDFs. The angle of inclination of each plane relative to the thin section surface is also indicated. (b) Backscattered electron image of the grain surface with the traces of the PDFs highlighted by the dashed green lines. The image was taken with the grain untilted and after FIB milling; the FIB-cut trench is in the upper part of the image. Into the lower part of the image has been inserted an image of the same FIB trench that was taken after tilting the thin section in the SEM in order to view the wall of the trench. The trajectory of the PDFs beneath the grain surface are highlighted by the dashed green lines, which show that they are inclined at 72º to the thin section surface. Only the {11-22} planes are parallel to the true orientation of the PDFs.

Conclusions: When used in conjunction with FIB milling, EBSD can successfully identify and index PDFs in shocked quartz grains. Whilst the EBSD-FIB method is unlikely to replace conventional universal stage work, we suggest that it is an important complimentary technique. An added advantage of our approach is that the EBSD maps that have been acquired can be used to characterise other microstructures in the quartz grains (e.g., subgrains, twins), and once the trenches have been milled in the FIB, little additional work is required to prepare and lift out a foil for transmission electron microscopy.

References: [1] French B. M. and Koeberl C. (2010) *Earth-Sci. Rev.* 98:123-170. [2] Ferrière L. *et al.* (2009) *Meteoritics & Planet. Sci.* 44:925-940. [3] Huber *et al.* (2011) *Meteoritics & Planet. Sci.* 46:1418-1424. [4] Stöffler D. and Langenhorst F. (1994) *Meteoritics & Planet. Sci.* 29:155-181.