**Kinked Biotite as a Stress Orientation Indicator in Chicxulub’s Peak Ring**

M. Ebert¹, M. H. Poelchau¹, T. Kenkmann¹, ¹Institute of Earth and Environmental Sciences – Geology, Universität Freiburg, Germany, Albertstraße 23B, 79104 Freiburg, Germany (matthias.ebert@geologie.uni-freiburg.de)

**Introduction:** Although kinking in micas has been observed in a variety of terrestrial craters, the structural information of this feature has rarely been used to understand the heterogeneous deformation that have occurred during large meteorite impacts, probably due to the coeval occurrence in tectonic settings. It has been known since the 1960s that shocked micas (in particular biotite) kink by pressure-induced gliding with external rotation, and the spatial orientation of the kink bands allows conclusions to be drawn about the maximum principle axis of stress $\sigma_1$ in the shockwave [1,2,3]. Detailed ground truth data of shock wave orientation and propagation in target lithologies can potentially yield important new insights into the cratering process, but, to date, are lacking in the literature.

The recent drilling into Chicxulub’s peak ring revealed a ~580 m thick unit of shocked granites [4], and provided an excellent dataset of well-documented samples whose orientation relative to geographic north (as well as the crater center) was known. Here, we use kink bands in biotite to derive a first set of local $\sigma_1$ orientations and thus document the three-dimensional state of stress in these peak-ring granites. We then benchmarked this against $\sigma_1$ data from recently obtained feather feature (FF) orientations [5].

**Methods:** Polished thin sections from various depths within the granitic section of the drill core were systematically searched for kinked biotites (Fig. 1).

Fig. 1. Photomicrograph of a granite including intense kinking of biotite and FFs in shocked quartz. The FF lamellae (trending to the NNE) are oriented perpendicular to the kink bands and parallel to $\sigma_1$.

The three-dimensional orientation (azimuth and dip) of the kink plane and the biotite’s basal {001} plane relative to the thin section reference frame were determined with a u-stage microscope. We defined the orientation of $\sigma_1$ as (i) the normal to the kink plane for single kink plane orientations and (ii) as the acute bisecting angle between the poles of conjugated kink plane sets (Fig. 2). (iii) If kinked as well as uninked biotites occur in the same sample, the poles of the basal planes of uninked biotites are additionally used as a reference for $\sigma_1$. Azimuth and dip of $\sigma_1$ were calculated from the u-stage data using stereonet software (Stereo32®). $\sigma_1$ data were then reoriented to geographic north using rotational corrections from [6].

**Results:** Out of 60 surveyed thin sections of granite, 8 were found to contain measurable kinked biotites. Post-impact hydrothermal alterations of biotite to chlorite often resulted in a substantial loss of kink bands throughout the granite.

The biotites vary in size between ~50 µm and ~1 mm, show no preferred orientation in the granitic samples, and generally feature lens- to spindle-shaped kink bands. Kinking appears straight when the bands are present in low densities, but evolve to be curved where the density is higher (e.g., Fig. 1). Individual kink bands occur, but conjugated sets are more common, with one set being more dominant than the other. Kinking is oriented at moderate to high angles to the {001} cleavage (e.g., approx. 90° in Fig. 1). In a few cases it is even possible to observe a 2nd generation of kink bands within a kink band. In addition to the kinking, the biotites typically show a gentle bending. We also compared the orientation of the feather feature lamellae in shocked quartz with the kink bands (Fig. 1). Both microstructural features show a high angle relative to each other (~75° to 90°).

In total, the orientations of ~200 kink band planes were measured (see density map of Fig 3). In individual thin sections, the kink bands show nearly uniform orientations. The angles between conjugated kink sets
are within the range of ~20° and ~40°. The azimuth values of the kink planes are particularly striking, as they show a radially-oriented trend relative to the crater center; recognizable by the clear girdle with WNW-ESE strike (Fig. 3).

σ₁ values could be determined for each of the 8 thin sections (Fig. 3). Except for two sample, the values are obtained on the measurement of conjugated kink band sets. Although the data volumes are still statistically rather low, an increase in the inclination angle of σ₁ is recognizable, from relatively shallow >20° to steep ~65° between ~750 and ~1200 mbsf.

Fig 3. Density map of 192 measurements of biotite kink plane poles for eight samples between ~750 and 1200 mbsf. Data form a girdle oriented radially to the crater center. The values for the sample at 1249 mbsf are not included in the density map due to inaccurate reorientation of the drill core. Filled dots are averages of σ₁ orientations from biotite kink planes. Open dots are averages from FF measurements from [5]. Sample numbers are core depth in [mbsf] with the number of measured kink planes given in parentheses.

Discussion: In a recent study [5], we analyzed the same samples to determine σ₁ values using FF orientations. Both methods (kink planes vs. FFs) show strikingly similar σ₁ orientations (cf. Fig 3). Their corresponding azimuth and inclination angles only differ by <20° (except for the sample at 1249 mbsf with ~30°) and <10°, respectively. The strong correlation between these two stress orientation markers shows that FFs and biotite kinks were formed under the same stress field within the shock wave, and that the two can be used interchangeably to determine σ₁ orientations. With these useful tools, structural deformation can be derived from shocked target materials that would otherwise prove difficult to analyze.

For the case of the Chicxulub peak ring granites, our obtained data supports the assumption that at the drill core location a sub-horizontally expanding shockwave [7,8] produced kink bands and FFs oriented relative to an initial sub-horizontal σ₁ orientation. During the crater modification and peak ring formation, the granitic basement rock must have been rotated from their original position [7,8]. The final rotation of these granites is estimated at ~90° from numerical simulations [7], suggesting that σ₁ orientations should be sub-vertical within the core. While the kink band data and the FF data from [5] confirm this for the lower parts of the granite, the data also indicate that the granite between 750 and 1200 mbsf behaved as a semi-coherent block that underwent internal folding, due to the increase of the σ₁ inclination angle with depth (Fig. 3). The internal fold axis strikes NNO-SSW, i.e., concentric to the crater center (Fig. 3). The sample at 1249 mbsf (Fig 3) is from the lowest part of the peak ring core (below 1200 mbsf), which is interpreted as the main outward thrust zone active during imbrication of the peak ring [8]. Here, high-strain deformation processes in the thrust zone may induce small-scale rotational movements in this peak ring unit, which results in a deviating σ₁ orientation compared to higher units between 750 and 1200 mbsf.

Outlook: Additional samples without post-impact hydrothermal alterations are to be prepared and analyzed. [9] used kinked biotites as a strain marker in shocked gneisses of hypervelocity impact experiments. We intend to check to what extent this method can be applied to the biotites from the peak ring.

Conclusions: This study shows a clear directional dependence between the biotite kink band orientation of Chicxulub’s peak ring and the presumed shock front, and indicates a strong deviatoric stress component of the stress tensor. In combination with other deformational markers like FFs, the stress situation within the shock wave and the subsequent movements of the rock units can be traced. It should be noted that although kinked biotites are common in impacts, they can also be produced tectonically and are thus not a unique criterion for shock metamorphism.


Acknowledgements: We are grateful to the DFG for funding this project (PO 1815/2-1, KE 732/26-1). Expedition 364 was funded by IODP with co-funding from ICDP.