ANALYSIS OF FRAGMENTATION DURING DYNAMIC LOADING: INVESTIGATIONS IN THE RIES IMPACT CRATER, GERMANY. D. Weimer[1], S. Hergarten[1], T. Kenkmann[1], [1]Institute of Earth and Environmental Sciences, University of Freiburg, Albertstr. 23B, 79104 Freiburg, Germany, Daniela.Weimer@hotmail.de.

Introduction: The research on fragmentation of rocks receives increasing interest in geosciences, especially in impact geology, as it represents an essential contribution to the understanding of impact cratering (e.g., [1-8]). The quantification of fragmentation provides information, e.g., about the particular energy input and partitioning as well as the influence of fragmentation on crater formation [9].

The aim of this study is two-fold: (i) We test different analytical methods to quantify fragmentation of rocks during dynamic loading. (ii) We apply the derived methodology at the well-preserved Ries impact crater in Germany to assess whether the degree of fragmentation relates to the distance from the center of the impact crater as proposed, e.g. by [1].

Approach: The investigation is based on two-dimensional patterns of fragmented rock structures, which were generated by mapping the fractures or fragment boundaries using Esri's ArcGIS based on associated images (Fig. 1). Investigations of rock fragmentation were carried out at various distances from the crater center. The pre-impact positions of these rocks were reconstructed with a precision of ~1 km.

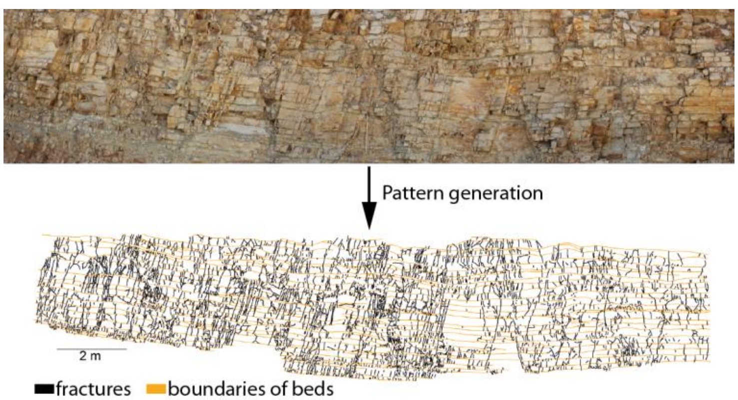


Figure 1: From basic image to pattern (exemplary for type A).

We included variable scales of observation ranging over 4-5 orders of magnitude. As fragmentation strongly depends on lithology [10], all investigations were carried out in upper Jurassic (malmian) limestone. We distinguish three fundamental types of patterns depending on whether there is a bedding or a fine matrix present in the limestone or not (Fig. 2). If possible, the mean bed thickness and the orientation of the analyzed section (radial or concentric with respect to the crater center) is considered to prove a relationship to fragmentation.

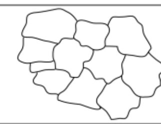
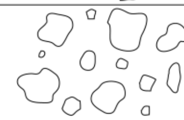
Type	Bedding	Matrix	Pattern
A	✓	✗	
B	✗	✗	
C	✗	✓	

Figure 2: Different types of patterns.

Analytical methods: The analysis occurred by means of cumulative fragment size distributions (FSD) which refer to the area (or the related mean diameter) of all fragments within a pattern. The diameter d is plotted against the cumulative number N. The fractal dimension D of the FSD being a characteristic property of the fragmentation process, can be extracted from a power-law fit of the FSD given as: $N(>d) \sim d^{-D}$.

In addition, the box-counting method was used and also applied to mapping [11-14]. A quantification by means of this method is based on the pattern's complexity described by the box-counting dimension D_b. A regular grid consisting of square boxes with box size r, is superimposed on a pattern. Then, the number of boxes N is counted that comprise parts of the analyzed phase in the pattern. To obtain a complete distribution N(r), r is gradually changed. Similar to FSD, this distribution can also be approximated by a power-law relationship: $N(r) \sim r^{-D_b}$ with $1 < D_b < 2$ for 2D box-counting. A mapping of D_b occurs by means of the sliding window procedure. A defined subimage slides stepwise over the pattern. For each position a separate box-counting analysis takes place.

Furthermore, a method that comprises the determination of the fracture index k, that describes the length of fractures per area, is implemented. In contrast to the other analytical methods, this procedure is independent of any scale-invariance of the patterns.

Results and discussion: The investigation shows that it is not always possible to prove a scale-invariance in fragmented rocks on the basis of 2D patterns. Partly this is related to an insufficient resolution of the image on which the pattern generation is based. In particular, this concerns the analysis by means of the box-counting method due to the lack of fractures at various scales of observation. The maps of D_b indeed show the inhomogeneity of fragmentation within a pattern qualitatively, but they do not provide any quantitative information. Concerning FSDs, more accurate results are obtained when determining the fractal dimension over several orders of magnitude by means of different distributions generated for the same location. However, in the framework of this study, the best results are achieved with the determination of fracture indices.

The related distribution of the degree of fragmentation vs. the distance from the crater center can be satisfactorily approximated by means of a power-law function (Fig. 3). However, alternative relations such as an exponential decay cannot be ruled out due to the limited range of distances.

The orientation of the faces of the fragmented structures as well as the mean bed thickness seem to have minor effects on fragmentation. An inverse relationship between fracture density and distance from crater center could be demonstrated and differences in fragmentation attenuation between near- and far-field [15-16] with respect to the crater center can be observed (Fig. 4). Extreme conditions proximal to the impact site possibly lead to deviations from the characteristic pressure decay regime at larger distances.

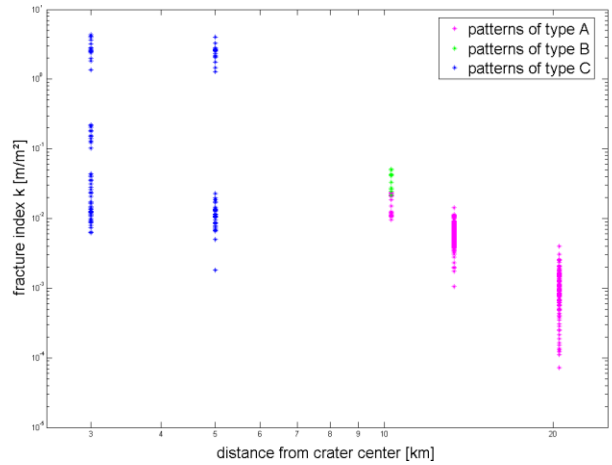


Figure 4: Distribution of k (for all types of patterns; k from type C may be underestimated due to low resolution of matrix) vs. distance from crater center. Differences in fragmentation attenuation between near- and far-field.

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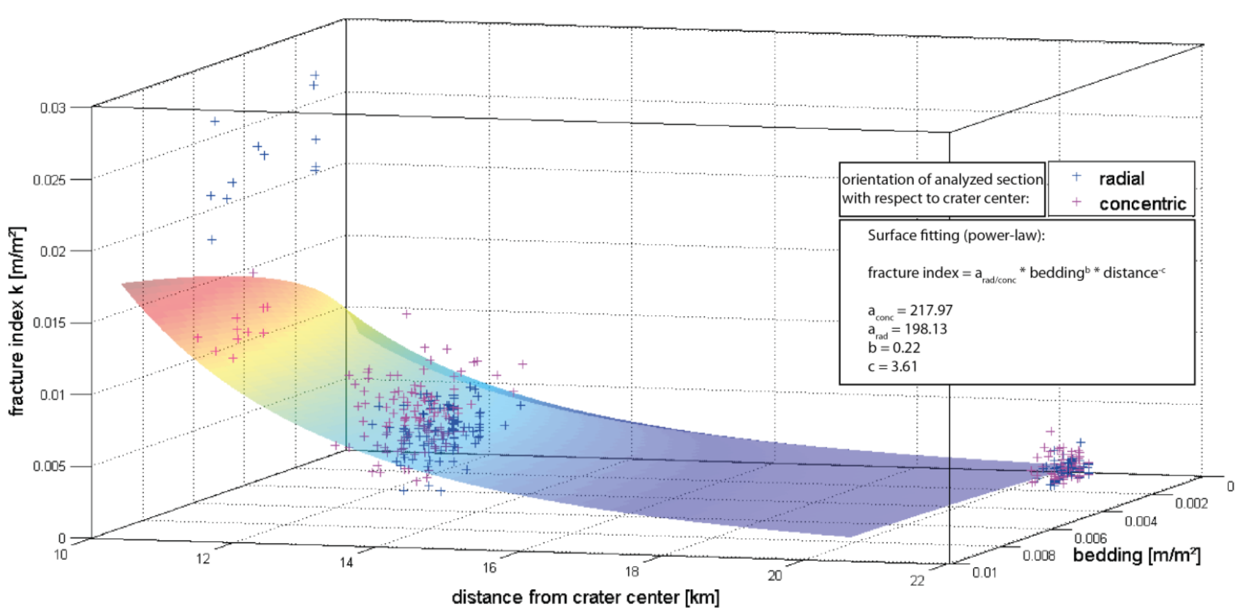

Figure 3: Distribution of k (for type A patterns; only far-field) vs. distance from crater center in consideration of bedding and orientation of analyzed sections. Surface fitting after power-law.