# Digital Characterization of Localized Deformation Bands in Homogeneous Rock Under True Triaxial Stress (Postprint)

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## Abstract

In deep complex stress fields, the heterogeneous behavior of microcrack evolution and localized deformation concentration within rock masses represents a key mechanism for inducing catastrophic events such as rockbursts and slip failures. In image analysis, the ease of structure identification largely depends on its scale, boundary sharpness, and grayscale contrast. In contrast, compaction bands, due to their small scale, blurred edges, and weak grayscale contrast, present a significant challenge for image recognition and extraction. Particularly under true triaxial stress states, where stress path disturbances are enhanced, conventional segmentation methods become even more inadequate for extracting such structures. To address this challenge, this study employs Bleurswiller homogeneous sandstone as the research subject, and conducts high-resolution industrial CT scanning under four typical true triaxial stress conditions ($\sigma_1$=$\sigma_2$=60MPa, $\sigma_2$=60MPa/$\sigma_3$=40MPa, $\sigma_2$=80MPa/$\sigma_3$=40MPa, $\sigma_2$=80MPa/$\sigma_3$=60MPa), establishing a standard image preprocessing pipeline (median filtering, edge cropping, grayscale normalization, etc.) to ensure stable and comparable image quality. For image analysis, local porosity analysis method and K-means clustering are first employed for preliminary segmentation to determine the locations and approximate outlines of potential deformation bands. On this basis, the coefficient of variation (COV) metric is introduced to construct a "local porosity-COV" joint feature model, which, combined with spatial heterogeneity features extracted via sliding windows, further enhances the recognition accuracy of fine compaction structures. Finally, morphological operations (erosion-dilation-connected component analysis) are applied for spatial optimization of the clustering results, significantly enhancing the boundary sharpness and overall continuity of the extracted structures, thereby constructing a well-visualized deformation band map. Experimental results demonstrate that this method can stably extract narrow, low-contrast compaction band regions under multiple stress states, achieving an average Silhouette coefficient (a metric measuring the compactness of clusters and inter-cluster separation) of 0.79, with three-dimensional reconstruction results consistent with macroscopic experimental observations. This study provides a generalizable new approach for the digital characterization of localized rock structures under high stress, offering a valuable reference for intelligent image analysis and engineering rock mass evaluation.

## Full Text

## Digital Representation of Localized Deformation Bands in Homogeneous Rock under True Triaxial Stress

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## Abstract

In deep and complex stress fields, the heterogeneous evolution of microcracks and concentration of localized deformation within rock masses constitute a key mechanism triggering catastrophic events such as rockbursts and slip failures. In image analysis, the identifiability of structures largely depends on their scale, boundary clarity, and grayscale contrast. Compaction bands, however, pose a significant challenge for recognition and extraction due to their small scale, blurred edges, and weak grayscale contrast. This difficulty is further compounded under true triaxial stress conditions, where stress path disturbances are amplified and conventional segmentation methods prove inadequate for extracting such subtle features.

To address this challenge, this study employs Bleurswiller homogeneous sandstone as the research subject and conducts high-resolution industrial CT scanning under four representative true triaxial stress conditions ($\sigma_1$=$\sigma_2$=60MPa, $\sigma_2$=60MPa/$\sigma_3$=40MPa, $\sigma_2$=80MPa/$\sigma_3$=40MPa, $\sigma_2$=80MPa/$\sigma_3$=60MPa). A standardized image preprocessing workflow—including median filtering, edge cropping, and grayscale normalization—is established to ensure stable and comparable image quality. For image analysis, local porosity analysis and K-means clustering are first utilized to perform preliminary segmentation, delineating the locations and approximate contours of potential deformation bands. Building upon this foundation, the coefficient of variation (COV) metric is introduced to construct a "local porosity-COV" joint feature model. Combined with spatial heterogeneity features extracted via sliding windows, this approach further enhances the identification accuracy of fine-scale compaction structures. Finally, morphological operations (erosion-dilation-connected component analysis) are applied to spatially optimize the clustering results, significantly improving the boundary clarity and overall coherence of extracted structures to construct well-visualized deformation band maps.

Experimental results demonstrate that the proposed method can stably extract narrow, low-contrast compaction band regions across multiple stress states, achieving an average silhouette coefficient—a metric evaluating clustering compactness and inter-class separation—of 0.79. The three-dimensional reconstruction results are consistent with macroscopic experimental observations. This research provides a generalizable new pathway for the digital characterization of localized rock structures under high stress conditions, offering valuable insights for intelligent image analysis and engineering rock mass evaluation.

**Keywords:** Deformation band identification; CT image analysis; COV (Coefficient of Variation); K-means clustering; Local porosity

*Note: Figure translations are in progress. See original paper for figures.*