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Quantitative Morphological Analysis of Detrital Grains: A Multi-Descriptor Approach for Sedimentary Process Interpretation

ARNAUD L. BACK[1] AND L.PAUL BÉDARD[2]

[1]UQAC
[2]Université du Québec à Chicoutimi

Detrital grain morphology preserves critical information about sedimentary processes, transport history, and source-area characteristics. However, traditional grain descriptions often based on qualitative or semi-quantitative methods that lack accuracy and reproducibility. Traditional roundness charts have long provided insights into sedimentary dynamics, but a comprehensive analysis of computable grain shape descriptors promises a deeper understanding of clastic transport, depositional energy, and provenance.

Recent advances in imaging systems and automated segmentation now allow high-throughput acquisition and analysis of grain images across scales (micrometers to centimeters). This study proposes a quantitative framework based on more than 100 shape descriptors, including elongation, roundness, roughness, and Fourier amplitudes, extracted using Python-based image analysis. Despite extensive literature on shape quantification in sedimentology and related fields, standardized approaches remain elusive due to ambiguous use of descriptors and methodological inconsistencies.

By applying principal component analysis (PCA) to a comprehensive dataset of shape descriptors, we have identified the most significant morphological parameters for characterizing detrital grains. Method validation using synthetic shapes, varying in form, roundness, and roughness, demonstrated high precision and led to a new definition of shape. Applying the technique to heavy mineral samples (gold, galena and zircon) from fluvio-glacial deposits, the method confirmed its accuracy and validated the proposed shape definition. This approach successfully quantifies shape variations within natural grain populations, revealing the dominant morphological trends in accordance with geological expectations of rounding and smoothing induced by sedimentary processes.

Our results highlight the interdependence of morphological descriptors and the challenges in selecting optimal parameters for sedimentary interpretations. By integrating PCA with image-based quantification, this method provides a robust tool for quantitative grain shape analysis, offering new insights into sedimentary processes.