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Quantifying grain shape with MorpheoLV: A case study using Holocene glacial marine sediments

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Abstract. As demonstrated in earlier works, quantitative grain shape analysis has revealed to be a strong proxy for determining sediment transport history and depositional environments. MorpheoLV, devoted to the calculation of roughness coefficients from pictures of unique clastic sediment grains using Fourier analysis, drives computations for a collection of samples of grain images. This process may be applied to sedimentary deposits assuming core/interval/image archives for the storage of samples collected along depth. This study uses a 25.8 m jumbo piston core, NBP1203 JPC36, taken from a ~100 m thick sedimentary drift deposit from Perseverance Drift on the northern Antarctic Peninsula continental shelf. Changes in ocean and ice conditions throughout the Holocene recorded in this sedimentary archive can be assessed by studying grain shape, grain texture, and other proxies. Ninety six intervals were sampled and a total of 2319 individual particle images were used. Microtextures of individual grains observed by SEM show a very high abundance of authigenically precipitated silica that obscures the original grain shape. Grain roughness, computed along depth with MorpheoLV, only shows small variation confirming the qualitative observation deduced from the SEM. Despite this, trends can be seen confirming the reliability of MorpheoLV as a tool for quantitative grain shape analysis.

1 Introduction

Quantitative grain shape analysis is a strong proxy for determining sediment transport history and depositional environments. As demonstrated in earlier works, grain angularity can be quantified by determining the roughness coefficient (Rc) from Fourier harmonics range [2, 3, 5, 8, 11]. We present MorpheoLV, a well-documented and publicly available code written in Matlab devoted to the computation of roughness coefficients from unique grain images. The new key feature is the opportunity to analyse a collection of samples of grain images all at once to compute roughness variations along a distance or a duration, for instance. Benchmark images proposed in [1] are processed for both validation and interpretation purposes.

A 25.8 m jumbo piston core, NBP1203 JPC36, was taken from a ~100 m thick sedimentary drift deposit from the Perseverance Drift on the northern Antarctic Peninsula continental shelf. Changing ocean and ice conditions throughout the late Holocene are recorded in this sedimentary record. The sediment from this core is composed of laminated, black- to olive-colored diatomaceous mud and ooze. The core's mineralogy is mainly quartz and it contains several horizons of ikaite crystals. Various proxies such as grain shape, grain texture, and grain size can be studied to determine the sediment transport history and assess various proportions of current-transported, iceberg-rafted, and aeolian-transported sediment, thus giving clues on past climate conditions. Microtextures of individual grains, observed in SEM images, exhibit a very high abundance of authigenically precipitated silica that covers the surface of most grains, blurring the broader grain shape. Despite this, MorpheoLV enables the measurement of any small changes in grain shape variation recorded along depth.

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2 Roughness calculation with MorpheoLV

MorpheoLV (LV for Light Version) is a small (about 500 lines), well-documented Matlab code derived from MORPHEO [1]. The new features are roughness calculations following [5] and the opportunity to analyse a collection of samples of grain images, all at once. Comparing to MORPHEO, MorpheoLV analyses unique grain images with more speed by a reduction in complexity of the image processing part of the code. Steps of a grain image analysis (outline and centroid determination, polar decomposition and Fourier analysis using `NbHarms` harmonics) are described with detail in [1] and documented in the downloadable archive[1]. Note that images input to MorpheoLV are assumed to come with a jpeg or a tiff extension, while MorpheoLV's output images are png or Matlab figures.

[1] http://icube-web.unistra.fr/cs/index.php/Software_download

This convention prevents output images to be considered in any further analysis.

Subsection 2.1 discusses the computation of roughness coefficients from the result of Fourier analysis applied to the pictures of a single clastic sediment grain. The analysis of a sample of grain images, typically grains collected at the same place, the same depth, or observed at the same time, and the analysis of a collection of such samples are then presented in subsections 2.2 and 2.2, respectively. Benchmark images proposed in [1] are discussed in subsection 2.4 to validate the new development and to interpret the case study results.

2.1 Roughness of a single grain

Grain morphology may be quantified from a Fourier expansion, the harmonics coefficients of which contain information [1–3, 5, 8] on the overall shape of the grain and the grain provenance from lower order harmonics (1-10), and on processes such as weathering and sediment transport history from higher order harmonics (11-20).

The roughness coefficient Rc_{a-b} computed from prescribed range (a, b) of harmonics coefficients R_n

$$Rc_{a-b} = \sqrt{0.5}\sum_{n=a}^{b} R_n^2, \qquad (1)$$

provides an accurate, dimensionless measure of the grain shape. The harmonics range $a - b$ is chosen in accordance with the grain information sought. As the roughness coefficient increases, the angularity of the grain increases. The harmonics range a, b can be edited in the function `MorpheoLV_Grain('GrainName',NbHarms)`. The parameter `NbHarms` represents the number of computed harmonics.

2.2 Sample analysis

The roughness analysis can be applied to a sample of grains with “common history”, collected at the same place, the same depth or observed at the same time for instance, and stored in the same folder. The function, `MorpheoLV_Sample('SampleName',NbHarms)` considers any files in the folder named `'SampleName'` with a jpeg or a tiff extension as part of the grain image sample. MorpheoLV analyses them, individually, as described in subsection 2.1.

The mean roughness coefficient $\overline{Rc_{a-b}}$ and the standard deviation for the sample of grains are output in the Matlab command window. MorpheoLV produces its own histograms to plot the distribution of the roughness coefficient values by using predetermined classes for a fair comparison between the different samples of the same collection. User-defined classes can be edited in the function `MorpheoLV_Histo`.

2.3 Collection analysis

The collection of samples of grain images are assumed to be stored in a “collection/samples/grain images” file system, the main folder being hereafter named `'CollectionName'`. The function `MorpheoLV_Collection('CollectionName',NbHarms)` lists the sample subfolders. For each sample, MorpheoLV evaluates the roughness coefficient of each grain individually using a total of `NbHarms` harmonics in the Fourier analysis.

The provided routine may be adapted to read information, a depth for example, about the location or the time of collection from the folder name or from a complementary file. Means and standard deviations computed for the different samples may be then associated to this key information in a graph to observe their variations, down-core for instance. The naming convention discussed in the case study may serve as an example for such an analysis.

Table 1. Mean roughness coefficients for benchmark images

Samples	$\overline{Rc_{1-10}}$	$\overline{Rc_{11-20}}$	$\overline{Rc_{17-21}}$	$\overline{Rc_{21-40}}$
Angular	7.6e-02	1.0e-02	5.7e-03	6.4e-03
Sub-angular	9.8e-02	1.1e-02	5.2e-03	5.3e-03
Sub-rounded	7.8e-02	6.4e-03	2.7e-03	2.3e-03
Rounded	6.8e-02	1.9e-03	8.4e-04	1.6e-03
Well-rounded	6.0e-02	1.1e-03	5.4e-04	8.9e-04
Round coins	8.9e-04	5.7e-04	1.7e-04	8.4e-04
Dodecagonal	1.4e-03	2.8e-03	9.2e-05	4.2e-04

2.4 Validation tests using MorpheoLV

The Taylor, Russell and Pettijohn chart [7] is split into files of unique grains, taking into account their roundness (well-rounded, rounded, sub-rounded, sub-angular, angular) to sort them into five folders. Similarly, the coin image presented in [1] is split into single images and stored in a folder. The dodecagon coin is taken out from the coin folder to be analyzed alone. These folders and images are part of MorpheoLV’s download.

Roughness computations carried out for the seven samples and the dodecagonal coin are reported in Table 1 for different ranges of harmonics. As expected, even if grain samples have very few elements, the mean roughness coefficient allows for a sorting into well-rounded, rounded, sub-rounded, sub-angular classes. As noticed in [1], the distinction between the sub-angular and angular classes of the chart [7] becomes clear only when the higher harmonics ranges are considered. Roughness coefficients for a perfect disc are zero. The uncertainty in the image processing may be thus evaluated through the analysis of the round coin samples. This yields expected small roughness coefficients, less than 1.0e-3 whatever the range of harmonics. The dodecagonal coin results indicate this can be considered as a well-rounded grain for the overall shape and the higher harmonics ranges. Therefore, the main harmonic is the twelfth and this impacts only the roughness coefficient Rc_{11-20}.

3 Case study

The core NBP1203 JPC36 described in Section 1 is chosen as a case study from [11]. Ninety six intervals were

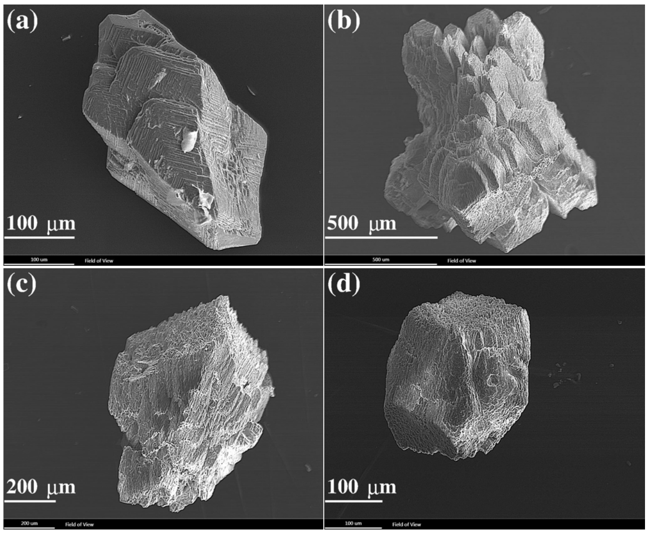

Figure 1. Euhedral ikaite crystal (a), degraded ikaite crystals (b,c,d),

sampled along depth for grain shape analysis. This included only quartz grains that were 63 μm or greater. Interval samples were introduced into the CILAS Laser Particle Size Analyser (LPSA) to capture images of individual quartz grains and to measure the dominant mode of transport from quartz grain roughness. To study grain microtextures, a subset of these 96 intervals were sampled to observe ikaite and quartz grains under the Scanning Electron Microscope (SEM).

3.1 Grain microtexture with SEM

The ikaite crystals found in the core, were studied only under the SEM to determine their elemental composition and to capture an image, see Fig. 1. Grain shape analysis, to provide clues on past climate records, on ikaite crystals was not performed due to the mineral's tendency to degrade to glendonite overtime and its in-situ formation, which does not provide evidence on transport history [12]. SEM images are segmented by adapting the Matlab's tutorial for cell detection, then analysed as described at §2.1. Roughness coefficients reported in Tab. 2. As expected, the overall angularity/roundness property is well captured by the first ten harmonics, while roughness and texture are better described by the higher harmonics. The coefficient Rc_{21-40}, with a very small value for the euhedral crystal, is the most appropriate to reveal the very smooth texture of such a grain. On the other hand, quartz grains, Fig. 2, can reflect whether the dominant mode of transport [4, 5, 14] was glacial, which will result in rougher, angular grains, or nonglacial, which will result in smoother rounder grains, as shown in Tab. 2. Note that the majority of microtextures of individual quartz grains observed in SEM show a very high abundance of authigenically precipitated silica that obscures the original grain shape.

Table 2. Roughness coefficients for the ikaite (I) and quartz (Q) crystals

Grains		Rc_{1-10}	Rc_{11-20}	Rc_{17-21}	Rc_{21-40}
I Euhedral	(a)	1.1e-01	7.9e-03	4.4e-03	2.9e-03
I Degraded	(b)	8.9e-02	9.7e-03	5.5e-03	8.9e-03
I Degraded	(c)	6.7e-02	9.9e-03	4.9e-03	5.5e-03
I Degraded	(d)	3.9e-02	5.2e-03	1.5e-03	3.1e-03
Q Aeolian	(e)	9.6e-02	5.9e-03	2.5e-03	2.5e-03
Q Glacial	(g)	8.0e-02	1.2e-02	4.3e-03	3.6e-03

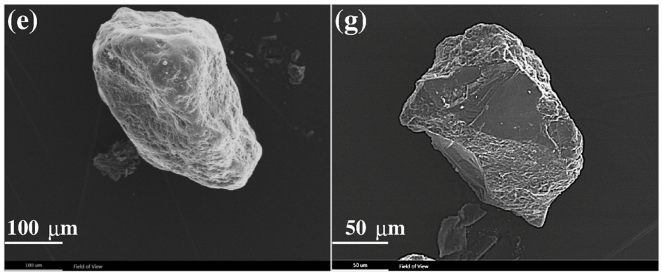

Figure 2. Quartz grains with aeolian (e) or glacial (g) microtextures

Table 3. Mean roughness coefficients for some intervals in NBP1203 JPC36

Depth	$\overline{Rc_{1-10}}$	$\overline{Rc_{11-20}}$	$\overline{Rc_{17-21}}$	$\overline{Rc_{21-40}}$
6.47 m	7.4e-02	8.1e-03	3.6e-03	3.3e-03
18.72 m	6.6e-02	6.1e-03	2.6e-03	4.2e-03
22.96 m	7.1e-02	5.1e-03	2.2e-03	2.9e-03

3.2 Core analysis

By convention in Antarctic geology, samples are named by the ship's name, year, and number of the cruise. In this work, the core folder "NBP1203 JPC36" stores the 96 interval folders for a total of 2319 grains. These secondary repositories are named from the core name and depth information and contain individual images of particles. The depth information may be thus read in the name of the folder under study and is associated to the roughness calculations for the related interval. MorpheoLV, run as described at subsection 2.3, anlyses this core in 15 seconds of an Intel ® Core^{TM} i5-3380M CPU at 2.90GHz.

The mean roughness coefficient values and standard deviations computed for different ranges of harmonics are plotted down-core of NBP1203 JPC36, Fig. 3. In this study, see Tab. 3, the highest mean $\overline{Rc_{17-21}}$ value is 0.0036 and is at 6.46 m, while the lowest mean Rc value is 0.0022 and is at 22.96 m. The median Rc value of 0.0026 at 18.72 m is also shown. Following Tab. 1, the interval at depth 6.46m lies in between the sub-rounded and sub-angular samples, while the grains of interval at depth 22.96m are more rounded and are less rough. Clear trends throughout the core are observed. Using harmonics 17-21, provided reliable quantitative grain shape results.

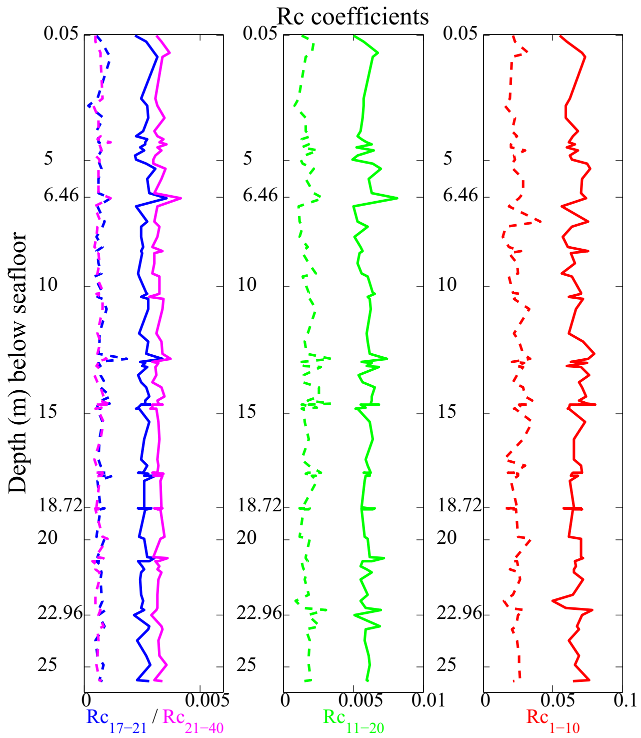

Figure 3. *Rc* coefficients (solid lines) and standard deviations (dashed lines) along depth for different harmonics ranges

3.3 Discussion on transport history

The sediment transport history for the Perseverance Drift was interpreted from entire sediment core's quantitative grain shape results and other proxies, such as grain size and grain texture. Results from the SEM study showed amorphous silica precipitation as the dominant microtexture in the sediment core [6, 9, 10, 13]. The silica precipitation results in smoother grains and covers most of the original microtextures that would give clues about the sediment transport history to the site. However, small changes in grain shape variation are still recorded. These trends are only made clear by being able to observe many grains, as made possible by MorpheoLV. By using other proxies, such as grain size and quantitative pebble analysis, lithostratigraphic facies were assigned and a shift in late Holocene climate from cooler to warmer is observed [11].

4 Conclusion

Using Fast Fourier Transform, MorpheoLV is a reliable method to quantify grain shape by calculating the roughness coefficient of a single grain, a sample of grains with a "common history", or a collection of samples. The validity of MorpheoLV was tested on benchmark images, ikaite crystals, quartz grains, and a sediment core from the Perseverance Drift, which prove the higher harmonic values provide an accurate roughness measurement. In the case study, despite the silica covering the original microtextures, small variations can be seen because of the ability to run many grains as made possible by MorpheoLV. As MorpheoLV is an open source code, the interested user may implement other shape indicators. The full study [11] used multiple proxies, including grain shape and grain microtextures, to help reconstruct late Holocene paleoclimate by studying the sediment transport history to the site.

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