Textural Maturity Analysis and Sedimentary Environment Discrimination Based on Grain Shape Data

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INTRODUCTION

Sediment grain shape provides important information regarding its origin, transport and depositional history. However, there is a deficit of standardised methodology for quantitative grain shape measurement and data synthesis. In this study, large population of loose sediment samples were analysed from a variety of depositional environments. This research aims to determine a suite of parameters correlated with textural maturity and their potential in ordering samples in relative order of maturity. The possibility of using population level measurements to discriminate between sedimentary environments is explored.

SAMPLING SITES

Environment	Locality	Sample no.	Latitude and Longitude	Age of deposit	Source of sediments
Glacial	Myrtleville, Ireland	G1, G2	51°46'59.0"N 8°17'43.2"W	Late Pleistocene	Sedimentary rocks (Upper Palaeozoic)
	Ballycotton, Ireland	G3	51°49'34.7"N 8°00'05.7"W		
	Churchbay, Ireland	G4	51°47'39.9"N 8°16'50.5"W		
Aeolian	Bikaner, India	A1	27°58'50.6"N 73°16'44.9"E	Late Pleistocene	Alluvial deposits
	Salasar, India	A2	27°43'25.6"N 74°42'18.7"E		
	Jaisalmer, India	A3	26°54'00.7"N 70°54'42.9"E		
	Jodhpur, India	A4	26°20'43.8"N 73°01'27.2"E		
Beach	Kilkee, Ireland	B1	52°40'47.5"N 9°39'02.7"W	Holocene	Sedimentary rocks (Upper Palaeozoic)
	Ballycotton, Ireland	B2	51°49'35.5"N 8°00'03.5"W		
	Hookhead, Ireland	B3,B4,B5,B6	52°09'22.3"N-52°09'39.8"N 6°52'56.6"W-6°54'01.0"W		
Fluvial	River Lee, Ireland	F1, F2, F3, F4, F5, F6	51°50'02.8"N-51°54'12.9"N 8°37'54.2"W-9°19'52.8"W	Holocene	Sedimentary rocks (Upper Palaeozoic)

Table 1 Details of samples collected for this study.

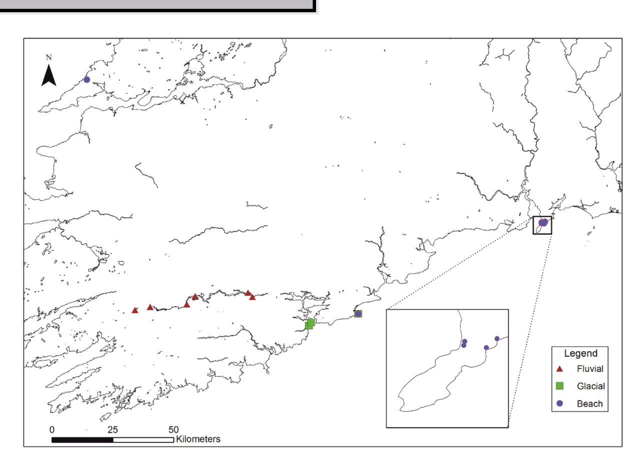

Fig. 1 (a) Sampling locations for fluvial, glacial and beach samples in Ireland.

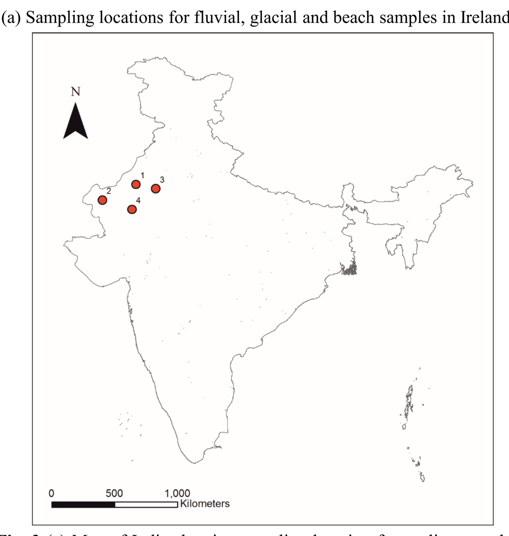

Fig. 2 (a) Map of India showing sampling location for aeolian samples. Geographical location of Bikaner, Jaisalmer, Churu and Jodhpur are represented by the numbers 1, 2, 3 and 4 respectively.

METHODOLOGY

- **Image Processing**

Fig. 3 (a) Microphotograph of sand grains.

Edge Detect

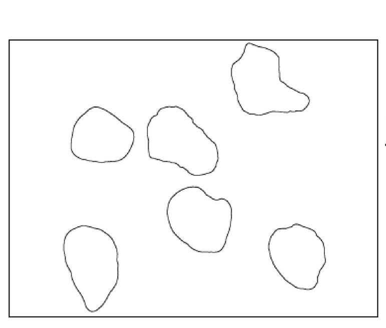

Fig. 3 (b) Edges of grain boundary determined using Edge detection algorithm,.

Watershed Transform

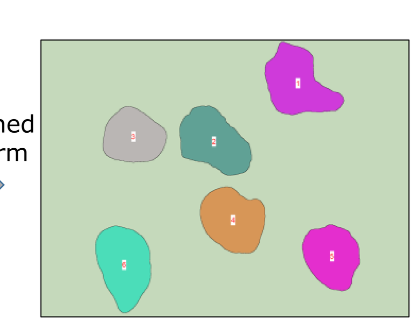

Fig. 3 (c) Individual grain regions identified using Watershed Transform algorithm.

Shape Measurement

Fully automated methodology

- **Shape Parameters**

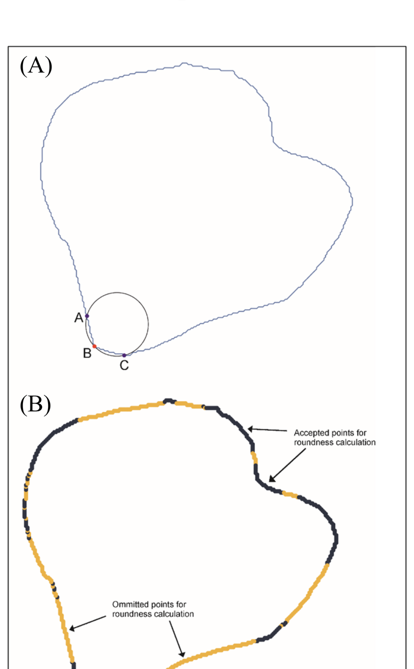

Fig. 4 (a) Radius of curvature at each individual boundary point of the grain is calculated. Here, radius of curvature is calculated at point B using the circle formed by the three points A, B and C. (b) Average radius of curvature of the boundary points having radius of curvature greater than the radius of largest inscribing circle is calculated as **roundness**.

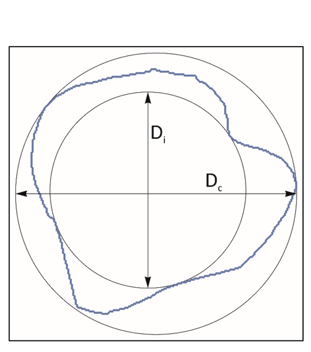

Fig. 5 Square root over the ratio of diameter of the largest inscribing circle (Di) by the diameter of the smallest circumscribing circle (Dc) is **circularity**.

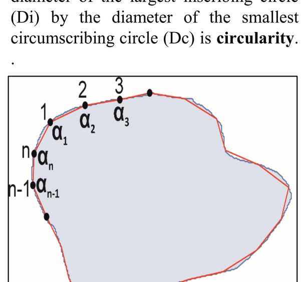

Fig. 6 Grain boundary is represented by n sided polygon. Internal angles α1, α2, α3 to αn for the polygon is measured. Differences within the successive internal angles are measured and the five largest differences of internal angles are averaged to calculate **angularity**.

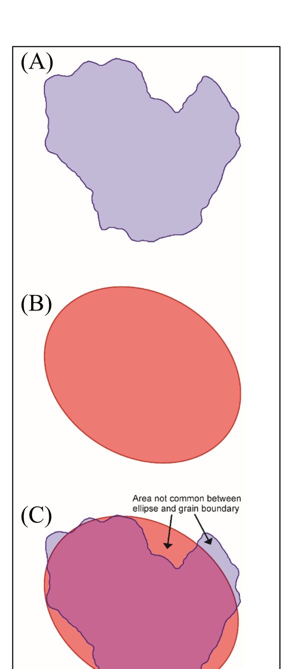

Fig. 7 The ratio of Area not common between best fit ellipse and the grain over the area of the best fit ellipse is **irregularity**. (a) showing the boundary of grain to be measured, (b) oriented best fit ellipse for the grain boundary and (c) showing the overlap between the best fit ellipse and the grain boundary.

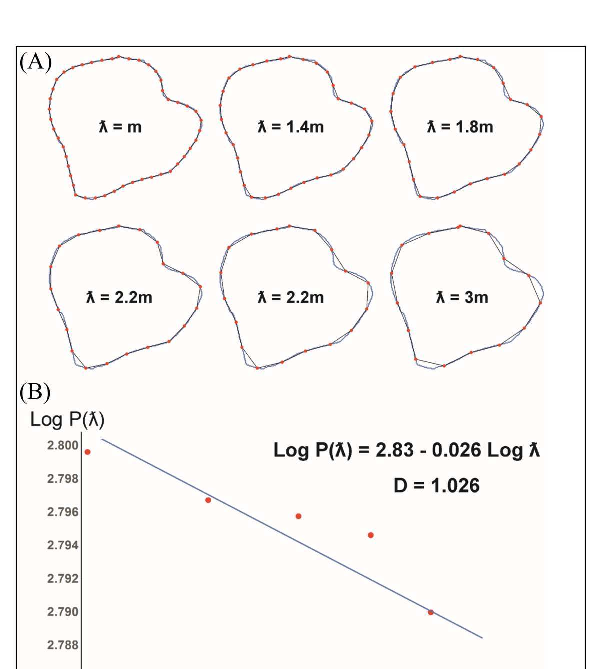

Fig. 8 Fractal dimension calculation for a grain using the divider method. (a) shows the boundary length P(λ) of a grain measured using increasing length scale λ. The value of m, taken as 13.28 in this case, is based on the grain size. (b) Plot of Log P(λ) versus Log λ. Slope of the best fit line over the points gives the fractal dimension of the grain D as 1.026.

RESULTS

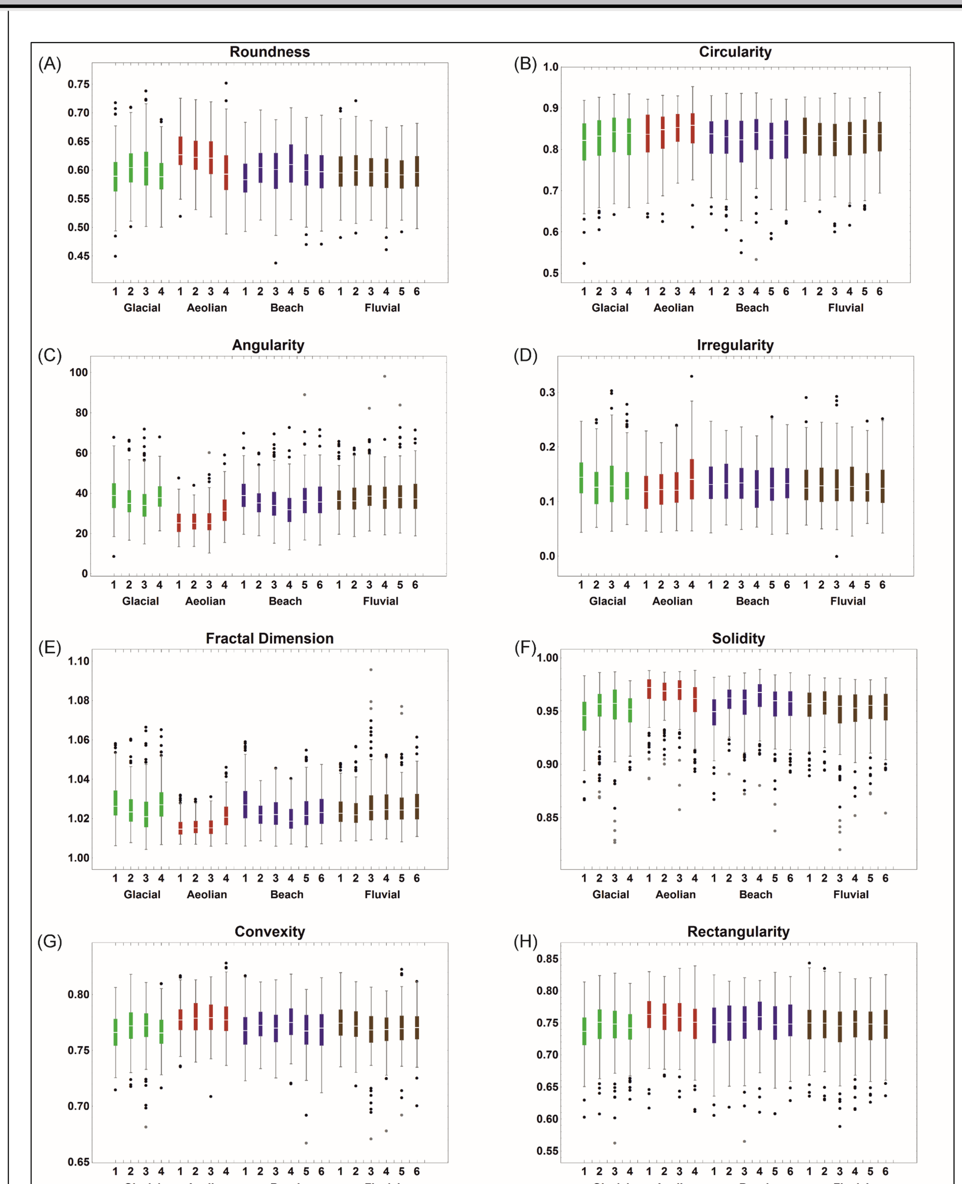

Fig 9 BoxWhiskers Plot for all the 20 samples showing the shape parameter distributions of (a) roundness, (b) circularity, (c) angularity, (d) irregularity, (e) fractal dimension, (f) solidity, (g) convexity and (h) rectangularity.

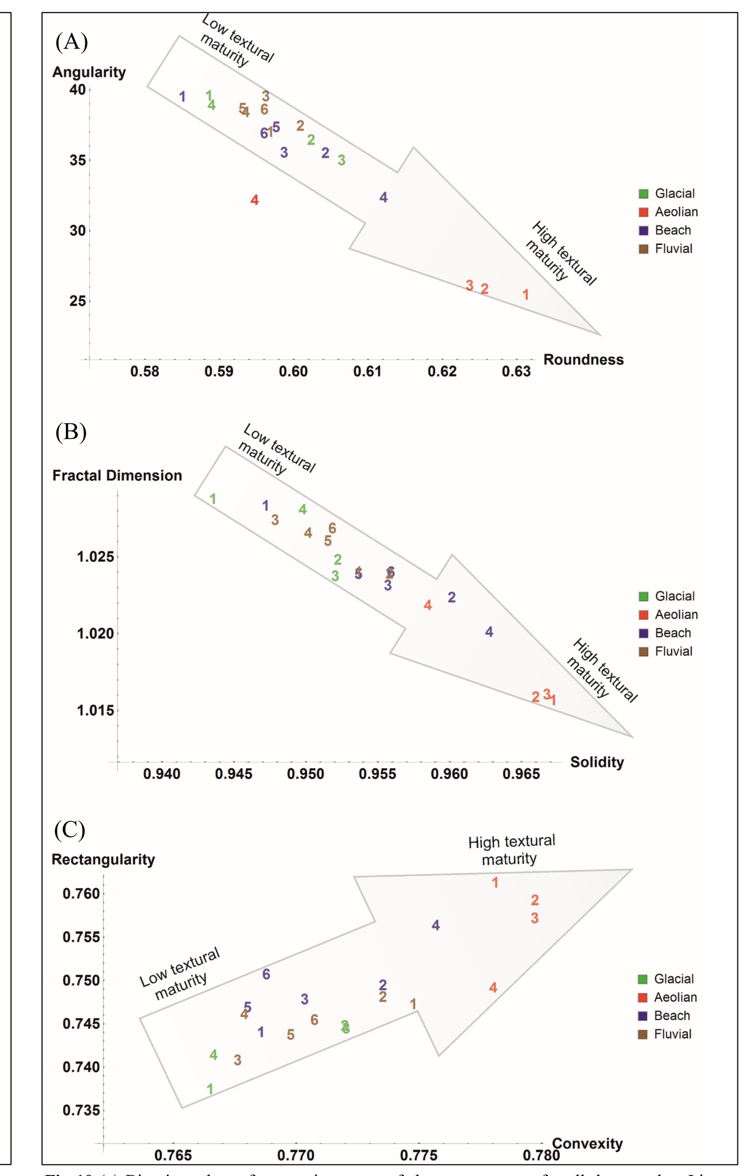

Fig 10 (a) Bivariate plots of comparing mean of shape parameters for all the samples. Linear trend in the plots represent the progression of textural maturity for the samples (a) Compares mean roundness of the samples with mean angularity, (b) bivariate plot of mean solidity versus fractal dimension; and (c) comparison between mean convexity and mean rectangularity.

	Glacial	Aeolian	Beach	Fluvial
Roundness	G1,G4 < G2,G3	A4<A1,A2,A3	B1<B3,B5,B6<B2<B4	
Angularity	G1,G4 > G2,G3	A4>A1,A2,A3	B1>B3,B5,B6,B2>B4	
Circularity	G1<G2,G4<G3	A1<A2<A3<A4	B3,B5<B1,B2,B6<B4	
Irregularity	G1>G2,G3,G4	A4>A1,A2,A3		
Fractal	G1,G4 > G2,G3	A4>A1,A2,A3	B1>B3,B5,B6,B2>B4	F4,F6>F3,F5>F1>F2
Aspect Ratio		A1>A2>A3>A4		
Modratio		A1>A2>A3>A4		
Compactness		A1<A2<A3<A4		
Rectangularity	G1<G4 < G2,G3	A4<A3<A1,A2	B1<B5,B6,B3,B2<B4	
Convexity	G1,G4 < G2,G3		B1,B5,B6<B3<B2<B4	F3,F4<F5<F6<F2<F1
Solidity	G1<G4 < G2,G3	A4<A1,A2,A3	B1<B5,B6<B3<B2<B4	F3,F4<F5,F6,F1<F2

Box Colour	(red)	(green)
Remarks	Kruskal-Wallis test with p-value > 0.05	Kruskal-Wallis test with p-value < 0.05

Table 2 (a) Comparative results for the Kruskal-Wallis and ad hoc Dunn tests performed on the median (the mean produced the same results) of 11 grain shape parameters used to describe grains from four differing depositional environments. The samples are compared within each environment type. Significance of the Kruskal-Wallis test is indicated by the fill colours. Where a significant difference is present, the Dunn test shows how different each sample is to every other sample.

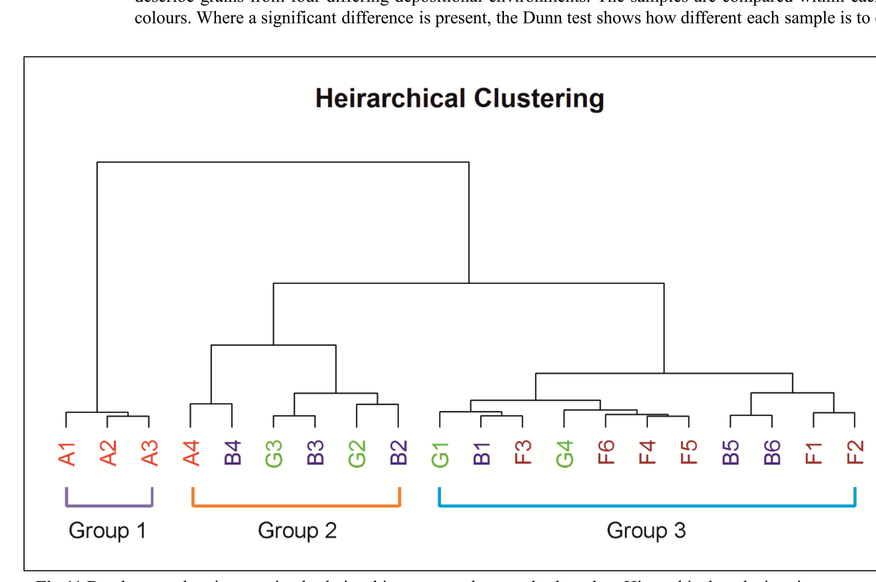

Fig 11 Dendogram showing proximal relationship amongst the samples based on Hierarchical analysis using summary statistics value of roundness, angularity, irregularity, fractal dimension, convexity, rectangularity and solidity.

Cluster no.	Glacial (n= 800)	Aeolian (n= 800)	Beach (n= 1200)	Fluvial (n=1200)
Cluster 1	27.25	73.25	31.42	20.75
Cluster 2	51	24.25	49.67	56.25
Cluster 3	21.75	2.5	18.92	23

Table 3 Percentage of grains from each environment in the three clusters formed by k-means clustering.

	Number of Groups	Random Forest	CART
Individual Samples	20	92.12	92.61
Sedimentary Environments	4	62.41	62.07
Textural Maturity	3	42.66	41.58

Table 4 (a) Percentage error of decision tree classifiers: RandomForests and CART methods. The predictive model was trained using 70% of the dataset and remaining 30% was used for testing.

Shape Parameter	Importance
Angularity	470.56
Fractal Dimension	321.06
Solidity	291.89
Irregularity	268.68
Roundness	254.46
Convexity	251.26
Rectangularity	237.94

Table 5 Importance of each shape parameter in categorising a grain to a given sample, independent of its environment, given by Random Forests method. Higher values indicate greater importance.

CONCLUSIONS

Roundness, angularity, irregularity, Fractal dimension, solidity, convexity and rectangularity were found to be the relevant shape parameters for textural analysis of sediment grains. Angularity and Fractal dimension were found to be the two most important parameters for texturally classifying samples using decision tree classifiers. It is demonstrated that samples within a given sedimentary environment can be ranked based on the population level shape data. However, absolute discrimination between different depositional environments on the basis of shape parameters alone is less certain.

Acknowledgement: *"This project is funded by the Irish Shelf Petroleum Studies Group (ISPSG) of the Irish Petroleum Infrastructure Programme (PIP) Group 4. The ISPSG comprises: Atlantic Petroleum (Ireland) Ltd, Cairn Energy Plc, Chrysaor E&P Ireland Ltd, Chevron North Sea Limited, ENI Ireland BV, Europa Oil & Gas (Holdings) plc, ExxonMobil E&P Ireland (Offshore) Ltd., Kosmos Energy LLC, Maersk Oil North Sea UK Ltd, Petroleum Affairs Division of the Department of Communications, Energy and Natural Resources, Providence Resources plc, Repsol Exploración SA, San Leon Energy Plc, Serica Energy Plc, Shell E&P Ireland Ltd, Sosina Exploration Ltd, Statoil (UK) Ltd, Tullow Oil Plc and Woodside Energy (Ireland) Pty Ltd."*