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Grain Size Analysis of the Rappahannock and Potomac Rivers

Abstract

The environment of the Earth has changed drastically over the years, and many ancient landscapes have vanished, but we can gain an understanding of what the ancient Earth might have been like by understanding how the processes that shaped it work. However, before we can understand the past, we must understand the present. We must determine how grain characteristics differ between modern sources before we can use these methods on older sediment with confidence. This paper uses grain size analysis to examine the differences between grains on a beach and those in a river. This allows us to examine both how we can use grain characteristics to differentiate between these environments, and how environmental processes cause grain characteristics to develop. We analyze samples of grains taken from the Rappahannock and Potomac Rivers by sieving them in order to perform a grain size analysis and using software to measure their roundness and circularity. Then we will compare the data about the grain characteristics to that of a sample from Virginia Beach. The data points from the Rappahannock River and Potomac River most frequently fall on opposite sides of the Virginia Beach sample when entered in a plot that compares sorting against skewness, with the Potomac River being better sorted and more negatively skewed than the Rappahannock River, or even Virginia Beach. Therefore, we conclude that the grain size analysis did effectively show the differences between grain sizes, and how they vary between environments.

Introduction

Depositional environments directly influence the type and the characteristics of the sediment that is deposited within them. Because of this, sediment can vary greatly between two different areas. By studying the differences of the sediment deposited in different environments, we can learn more about both modern environments similar to those studied, and ancient environments that we can only understand through proxy data. Proxy data are a type of evidence that indirectly records the environment that they formed in. However, in order for proxy data to be useful we have to have a way to interpret it. The goal of this study is to use grain size analysis to examine grain characteristics as a type of proxy data, and see if they are an effective means of distinguishing between environments. We will be comparing proxy data from two modern environments, so that we can check if the data, and our interpretations of the data, accurately reflect the depositional environment. In order to keep the amount of variable factors between sites limited we will be taking samples from two major rivers in Virginia that are relatively close to each other, the Rappahannock and Potomac Rivers. Both are estuaries into Chesapeake Bay, but the Rappahannock has unilateral flow, where the Potomac has tidal input. This will allow us to observe the differences between grains from a strictly fluvial environment, and grains from an environment that has marine input.

Methods

We gathered sediment samples from the Rappahannock and Potomac Rivers, and then analyzed the samples.

Gathering Locations

For both the Rappahannock and Potomac rivers, sediments were gathered at multiple locations, each having a different distance to the river. The source locations on the Rappahannock river were selected along a transect that was placed across the river, 141 feet, 180 feet, and 225 to be precise. The area of the Rappahannock where the sediments were collected is located at the GPS coordinates: $38^{\circ}, 19', 18.81''$ North, and $77^{\circ}, 29', 24.76''$ West (Figure 1).

The four sediment samples from the Potomac river were gathered from four spots along the river bank, with the distance being measured from the water's edge. The locations that the samples were sourced from are 1.6 feet, 20 feet, 11.5 feet and 4 feet from the river. The GPS coordinates of the area from which the samples were taken are $38^{\circ}, 12', 04.24''$ North and $76^{\circ}, 55', 55.15''$ West. (Figure 2).

Sediment Weighing

First, we dried the samples using a drying oven, then the seven samples were individually weighed and sorted through a set of sieves with sizes ranging from 4 millimeters to 0.063 millimeters. The sorting process was driven by a Rotap machine. Once the sediments had been sorted in the Rotap for approximately 10 minutes, we emptied each of the sieves, and weighed the sediment on it. The weight deposited on each sieve was then used to calculate the grain characteristics of the sediment.

Calculation of grain characteristics.

We began by calculating the weight % of each sieve, and their cumulative weight %. We used weight % and cumulative weight % to create curves that plot cumulative weight % against grain size in Phi (e.g. figure 3) and histograms plotting weight % against the size of the grains (e.g. Figure 4). We used excel to determine the trend of the cumulative weight graphs, we then found certain Phi values along that trend line and used those points to determine the sorting, mean,

skewness, and kurtosis values of the sample. The formulas that were used to determine these values are as follows:

$$\text{Mean} = \frac{\varphi_{16} + \varphi_{50} + \varphi_{84}}{3}$$

$$\text{Sorting} = \frac{\varphi_{85} - \varphi_{16}}{4} + \frac{\varphi_{95} - \varphi_5}{6.6}$$

$$\text{Skewness} = \frac{\varphi_{84} + \varphi_{16} - 2\varphi_{50}}{2(\varphi_{84} - \varphi_{16})} + \frac{\varphi_{95} + \varphi_5 - 2\varphi_{50}}{2(\varphi_{95} - \varphi_5)}$$

$$\text{Kurtosis} = \frac{\varphi_{95} - \varphi_5}{2.44(\varphi_{75} - \varphi_{25})}$$

We determined the roundness and circularity of the grains. In order to do this we examined images of grain samples from the Rappahannock and Potomac rivers using the software ImageJ.

Results

The grain size analysis data show that there are trends in the range of characteristics of the Potomac and Rappahannock rivers, but also that there is overlap between the ranges.

The Potomac River samples had means of 1.44, 1.47, 0.25, and -0.81 respectively (Table 1). The Rappahannock samples' means were 1.18, 0.29, and 0.84 (Table 2). When comparing the two rivers, the Potomac grains have greater variance in grain size.

The sorting of the Potomac grains were 1.74, 0.46, 1.73, and 1.63. The Rappahannock grain sorting were 1.74, 1.74, and 1.31. On average, the grains from the Potomac are slightly better sorted.

The skewness values of Potomac samples were -0.62, -0.21, -0.70, and 0.20. The skewness of the Rappahannock grains were -0.08, 0.62, and -0.27. The average Potomac skewness was less coarse skewed.

The Potomac River grains had less kurtosis on average, as compared to grains from the Rappahannock River.

As distance from the river increased, grains from the Potomac tended to be larger and worse sorted, where grains from the Rappahannock tended to be better sorted and did not exhibit a distinct pattern of mean size.

When comparing sediments from the Potomac and Rappahannock rivers, sediments from the Potomac vary more in grain size, are slightly better sorted, less coarse skewed, and have less kurtosis. The Potomac sediments are also rounder, more spherical, and less angular than Rappahannock sediments. The means of the sediment show that the Phi values of the Potomac river average to a lower number, and have a greater range. Translating the Phi value to millimeters, we can determine that this means the grains are larger on average, and have greater variance in size. Both rivers' sediments were poorly sorted, but the Rappahannock sediment had a sorting value that was higher than that of the Potomac. The average skewness from the samples more openly differed, with the Potomac sediment being noticeably less coarse skewed than the sediment from the Rappahannock river. The ImageJ data indicate that Potomac river sediments have, on average, more circularity, and are more spherical; the difference is great enough that while Rappahannock grains had an average roundness of very angular, Potomac grains were angular on average.

Sorting vs skewness

For comparison to the results we had achieved, we pulled similar data from previous research in the area (Grothe, 2020). This data set included several years of sorting and skewness data from the Potomac and Rappahannock rivers, and had an entry for both sorting and skewness from Virginia Beach.

When looking at a chart of sorting against skewness (Figure 5) made from the Grothe dataset, we see that there is a wide variance in the range of both the Rappahannock and Potomac rivers, however, there are also distinct trends within the variance. The Potomac grains tend to be negatively skewed and well sorted or very well sorted. The Rappahannock grains are more positively skewed and less well sorted. Plotting the one data point from Virginia Beach shows us that it is nearly symmetrical, and moderately well sorted, and that while it is in between the main clumps of Potomac and Rappahannock data, it is closer to the Potomac grains.

Discussion/Interpretation

A study of Virginia Beach gives us a beach environment that we can compare to the rest of the data, which is especially useful as it gives us another data point to use in discussing the differences between beach and river environments; data courtesy of Dr. Grothe (Grothe, 2020). The Virginia Beach sediment has a notably larger mean Phi value than either the Potomac or Rappahannock river, which means that its grains are larger; in this aspect it is actually closer to the Rappahannock river. However, the sediment is on average both much better sorted, and much less skewed than either of the river samples, and these results are closer to the characteristics of the Potomac river. The end results are that the Virginia Beach sediment sample is moderately well sorted and nearly symmetrical, compared to the river samples which are poorly sorted and strongly coarse skewed in the case of the Rappahannock, and poorly sorted and coarse-skewed in the case of the Potomac. While this difference in sorting may seem to imply that sediment at beaches will be better sorted than at river banks, it is also important to acknowledge that beaches with poor sorting are not a rare natural feature. Holland and Elmore explain that poor sorting in a beach merely means that it is not heterogeneous. Examples of poorly sorted beaches include

‘Gravel-sand coasts’, which can be found in more than 25 countries (Holland and Elmore, 2008).

It is also important to consider the origin of the sediment at a beach. The same applies to the skewness of the samples, as Andrews and Van Der Lingen show that beach sediments are not all negatively (coarsely) skewed, and skewness is rather more indicative of the origin of the rocks (Andrews and Van Der Lingen, 1969).

However, in the samples we are studying, the origins of the sediment are not extremely different. While we should keep in mind the possible differences caused by sedimentary origin, sorting and skewness can still be a valuable tool in differentiating our environments. In fact, these papers, combined with the data from the rivers and the beach come together to give us a bit of a big picture view of the depositional environment. The Rappahannock river stands on one end of the scale, with the coarsest, most angular, and most poorly sorted sediment. The Potomac river is in the middle of the scale, with poor sorting like the Rappahannock, but less coarse and angular grains. Lastly, Virginia Beach has the best sorting and most rounded sediments. Two of the factors in the rounding of sediment are transport and being exposed to waves, and waves are more powerful in larger bodies of water. This combined with longer transport leads to sediment at beaches being more rounded than in rivers. The longer travel also aptly explains why the sediment from the Potomac and Virginia Beach is smaller, as large grains are quickly lost in transit, with as much as 94% lost in 16 miles of transit (Bradley, et al., 1972). Kurtosis, roundness, and circularity are not available from the Virginia Beach data, but as they are similar to angularity, it is not surprising that the Potomac samples are less tailed, more round, and more spherical. This further suggests that marine environments have more rounded sediment than fluvial ones. It is important to remember not to take any one characteristic out of context, as neither the mean, kurtosis, sorting, or skewness of a sample can be used to determine its origin as

fluvial or marine (Sevon, 1966). It stands to reason that this same limitation applies to the roundness, and circularity of the grains. Additionally, sorting has a large range of variance, even within beach environments, as shown in Edwards 2001, so it requires particular caution when being used.

Conclusion

When comparing the grains of sediment from river banks to those found in beaches it is important to consider the origin of the grains, as well as the data that we can directly extract from them. We see that the Rappahannock and Potomac sediments convey that, generally, the more marine sediment is present in an environment, the better sorted and more fine-skewed it is. This can be disturbed by differences in the origin of the sediment, and no one factor should be used to determine the origin of sediment. In short, while mean, sorting, skewness, and kurtosis can be used to differentiate sediment, it is important to monitor the factors that can influence these characteristics, such as location, and to use data about the sediment as a set rather than individually.

I believe an avenue for future research on the topic could involve using other samples comparing beaches and rivers not used in this study, and then possibly progressing to using grain size analysis techniques to study paleoenvironments.

Works Cited

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Edwards, A.C., 2001, Grain Size and Sorting in Modern Beach Sands: *Journal of Coastal Research*, v. 17 p. 38-52.

Figures and tables



Figure 1: an aerial view of the Rappahannock river. Image credits to Airbus and Google Earth.



Figure 2: An aerial view of the Potomac river. Image credits: Google Earth and Airbus.

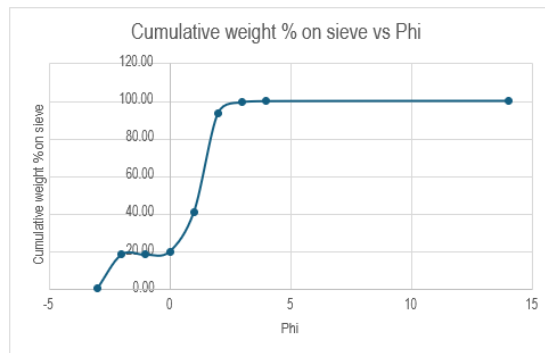


Figure 3: A graph that plots the cumulative weight of the total grains of a Phi value and the values lower than it. This graph depicts one of the Rappahannock samples.

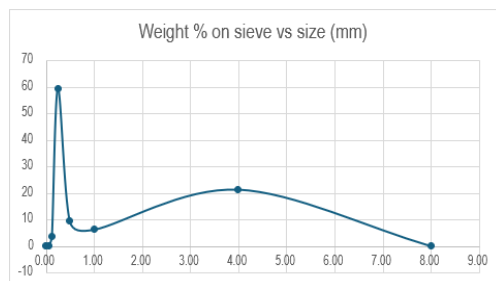


Figure 4: A graph that plots the grain size of each sieve by the percentage of that sample's weight that was on that sieve. This graph is of a sample from the Potomac river.

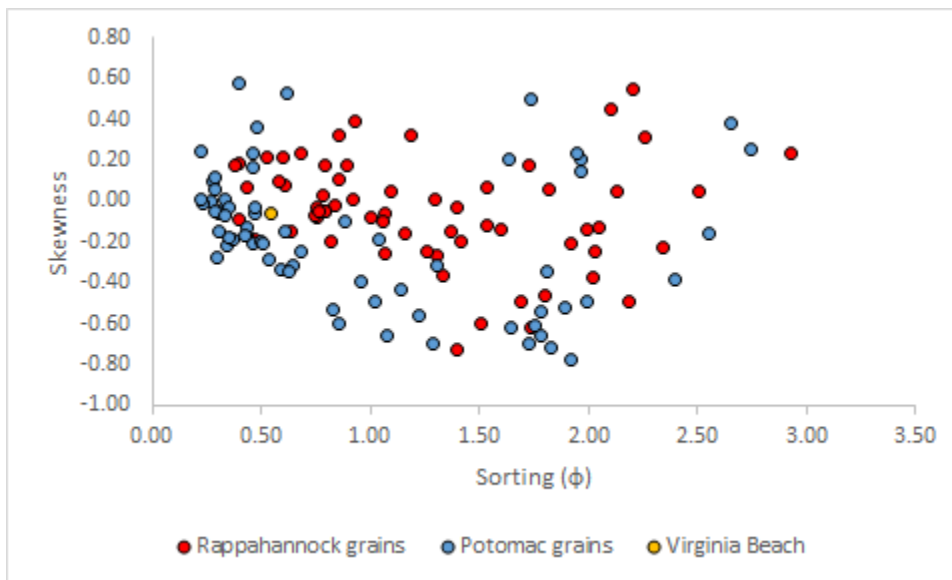


Figure 5: A graph that shows the skewness and sorting of grain size analysis data from Gothe, 2020. Rappahannock grains are shown in red. Potomac grains are shown in blue. The sample from Virginia Beach is yellow.

Table 1: A summary of the quantitative and qualitative values of the grain characteristics of the sediment from the Rappahannock river.

Rappahannock data	Mean	Sorting		Skewness		Kurtosis	Circularity	Roundness	Powers Roundness
Mean values	0.77	1.26666667	Poorly sorted	-0.32333333	Strongly coarse-skewed	1.31333333	0.7618	0.6874	Very angular

Table 2: A summary of the quantitative and qualitative values of the grain characteristics of the sediment from the Potomac river.

Potomac river data	Mean	Sorting		Skewness		Kurtosis	Circularity	Roundness	Powers roundness
Mean	0.5875	1.0625	Poorly sorted	-0.22	Coarse-skewed	0.9575	0.83335	0.74925	Angular

Table 3: A summary of the minimum, mean, and maximum values of grain characteristics from the Rappahannock river and Potomac river. The Rappahannock samples are presented first, the Potomac samples are presented second.

Rappahannock	Min	Mean	Max
Mean	0.29	0.77	1.18
Sorting	0.75	1.266667	1.74
	Moderately sorted	Poorly sorted	Poorly sorted
Skewness	-0.62	-0.323333	-0.08
	Strongly coarse-skewed	Strongly coarse-skewed	Nearly symmetrical
Kurtosis	0.97	1.31333333	1.52
Circularity		0.7618	
Roundness		0.6874	
Powers Roundness		Very angular	
Potomac	Min	Mean	Max
Mean	-0.81	0.5875	1.47
Sorting	0.43	1.0625	1.73
	Well sorted	Poorly sorted	Poorly sorted
Skewness	-0.7	-0.22	0.2
	Strongly coarse-skewed	Coarse-skewed	Fine-skewed
Kurtosis	0.64	0.9575	1.27
Circularity		0.83335	
Roundness		0.74925	
Powers Roundness		Angular	