Lithological responses to sea erosion along selected coastlines between Komenda and Saltpond, Ghana

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Abstract

Understanding the processes of coastal erosion calls for several methods to assess its extent and impact. Geomorphological investigation into coastal erosion is based on the shape and size of particles. Its importance is manifested in its ability to interpret past and recent geological forms and processes and to envision paleogeographical environments. This study examined how the lithological makeup of the coastline responds to erosion. It focused on the coastline between Gold Hill (Komenda) and Amisano (Saltpond) in the Central Region of Ghana. Cailleaux's Indices of Roundness and Flatness were used to ascertain the responses of lithology to erosion along the coastline.

Abrasion and attrition were the major erosional processes that left evidence for observation. Through these processes, the characteristic behaviour of rock types was established. It was observed that the roundness of schist is short-lived although it is attained quickly, while quartzite sustains its roundness for a longer time. Though the same erosional processes prevail, the shoreline retreats at different rates due to differences in lithology.

Keywords: lithology, abrasion, particle shape, Ghana, erosion, pebble indices

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Introduction

Coastal environments are continuously changing due to pressure exerted on them by many opposing natural forces (Williams 2001). For instance, the demands on the coastal environment for housing, tourism activities, port facilities and fisheries processing are typical components that exert pressure on the coastal area. This makes it vulnerable to all forms of natural hazards such as landslides, flooding and erosion, which are influenced by a rise in sea levels. Consequently, erosion along the coast continues to become catastrophic, thereby raising concerns among coastal researchers, planners and policy makers. To understand the extent and processes of coastal erosion, researchers have used several spatial, numerical and analytical methods such as the Generalized Model for Simulating Shoreline Change (GENESIS), the Digital Shoreline Analysis Software (DSAS) and the Soft Cliff and Platform Erosion (SCAPE) (Young et al., 1995; Koukoulas et al., 2005; Appeaning-Addo et al., 2008). For instance, DSAS is used to estimate historical rates of landward displacement of coastlines (AppeaningAddo et al., 2008). However, it does not account for the actual processes that cause erosion. The SCAPE model of cliff retreat and cliff-top recession which has been linked to a new flexible GIS tool (i.e. the SCAPEGIS) provides visualisation and analytical capability for model results (Koukoulas et al., 2005).

Numerical models such as Bruun's model for sandy coastlines and the GENESIS, were developed to simulate the long-term shoreline change on an open coast that is produced by spatial and temporal differences in longshore sediment transport. Numerical indices such as Trask's and Cailleaux's have also been used as indicators to model and analyse coastal erosion scenarios (Trask, 1932; Bruun, 1962; Krumbein & Sloss, 1963; Koukoulas et al., 2005).

In geomorphological investigations, attempts are made to use particle geometrical parameters such as shape and size to infer coastal erosion. The transport of rock particles along the shore causes them to collide and rub against one another; the result of this abrasive process produces different shapes. The likely consequences of the abrasive process are the loss of mass and alteration of the forms of the rock particles. The importance of particle geometric parameters is manifested in their ability to interpret past and recent geological forms and processes and giving a fair knowledge of paleogeomorphological environments. Though findings are inadequate in terms of research on particle geometric parameters, researchers such as Wentworth (1922), Cailleaux (1945) cited in Dei (1972) and Dei (1972) have confirmed the usefulness of shape parameters in envisaging paleogeomorphological environments. Parametric investigations on marine sediments suggest that irregular particles have a high degree of erodibility and rounded particles are manifestations of intense erosion in most cases, although erodibility is partly dependent on the type of lithology (Krumbein & Sloss, 1963; Poudel et al., 2012).

An important consequence of the abrasion and attrition processes is a reduction in size which alters pebble movement and hence can influence the form and evolution of a beach profile (Domokos et al., 2014). Abrasion and attrition produce sand and silt that is deposited on the downdrift side of beaches, and the degree of rounding observed in pebbles is used to infer ancient flow conditions. Sternberg (1875), cited in Domokos et al. (2014), first reported the result that pebble size decreases exponentially with distance downstream in rivers, a phenomenon he attributed to abrasion. Its manifestation is seen downdrift in ocean transport as marine sediment goes through attrition and abrasion (Powell, 1990).

Lithological responses to sea erosion are established in particle size, roundness, sphericity, flatness and asymmetry (Cailleaux & Tricart, cited in Dei, 1972). Particle movement is a result of the drag force of the fluid overcoming the gravitational and cohesive force of the particle (Hearn, 2008; DavidsonArnott, 2010). Hence, particle movement exists in littoral drift and it is intensified when the sea level rises (Krumbein & Sloss, 1963; Dean, 1973). As in fluid dynamics, a rise in sea level facilitates the movement of particles in that the increased volume of water overcomes the cohesive and gravitational force of the particles (Krumbein & Sloss, 1963; Adrian, 1991; Hearn, 2008). This implies that smaller particles are set in motion more than larger ones as they offer less resistance to the force of the waves (Hearn, 2008). The constant battering of waves against rock outcrops through hydraulic action disintegrates the rocks and generates sediments on the beach. Erosion through abrasion and attrition processes causes further breakdown which reduces the mass and shape of brecciated particles to polished sub-rounded and rounded particles (Dei, 1975; Davidson-Arnott, 2010). Pebble roundness, flatness and rate of reduction in mass depend partly on the strength of the waves and the type of rock, and partly on the nature of the coast, whether sheltered with vegetation cover or exposed (Dei, 1972; Hearn, 2008; Davidson-Arnott, 2010). The intensity of erosion is established by the morphology of particles such as their roundness and flatness. Thus, the higher the roundness and flatness indices, the greater the intensity of erosion (Cailleaux & Tricart, cited in Dei, 1972).

The classification of shape may be developed in different ways, such as visual, graphical, comparative and digital image processing. Image processing is one of the new techniques for classifying shape parameters (Bowman et al., 2001). For instance, sand particle morphology is characterized by developing sand shape descriptors using a complex Fourier analysis which is based on standard shape measures such as squareness, triangularity, irregularity and elongation. Poudel et al. (2012) identified twenty-one different shape particles using Charge Coupled Devices (CCD) and camera and image processing Matrox Imaging Library (MIL) software, and analysed them using the MatLab platform.

These platforms render particle shape characterization easier, as they show side by side what the human eye can not perceive (Blott and Pye, 2008).

Various attempts have been made to characterize particle shape. Some methods measure the overall shape or form or concentrate more on features such as angularity versus roundness, while others concentrate on the still finer textural differences between shapes (Barrett, 1980). Studies on particle shape revealed shape parameters including angularity, sub-angularity, roundedness, sub-roundedness, sphericity and asymmetry. However, other studies on particle shape have shown that the concepts of 'angularity', 'roundness' and 'roughness' are vague, and it is evident that there are some differences in the daily use of these terms (Poudel et al., 2012). This has generated the search for a quantifiable method of measurement of particle shape. Using an index, this study provides a more quantitative measure of particle flatness and roundness.

A survey conducted along the study area between Saltpond and Komenda showed ongoing erosion processes with variation in the lithological makeup of the coastal rock outcrop (Hughes & Farrant, 1963; Dei, 1975). The study was undertaken to examine how the various lithological makeups of the coastline respond to erosion.

The study site

The study area is a coastline of approximately 68 kilometres. It stretches from Gold Hill in Komenda, 5º 02' N and 1º 30' W, to Amisano in Saltpond, 5º 12' N and 1º 00' W (Figure 1). The locations were selected based on evidence of erosional activity and the availability of rounded pebbles, and they were Elmina, Cape Coast and Abandze.

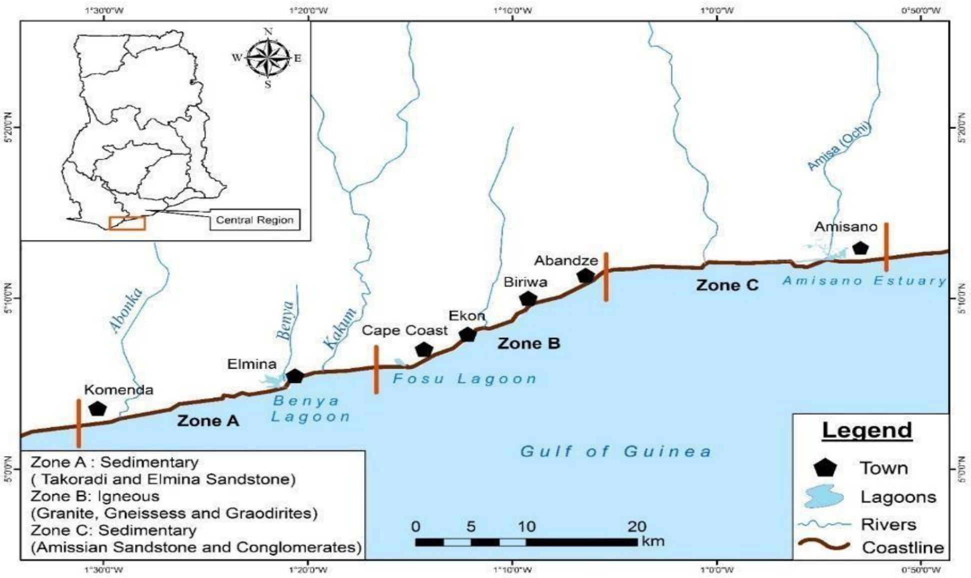

Figure 1: Map of study area showing the various sections (Zones A, B and C) of the coastline

The general wave climate is assumed to be the same as what pertains on the coast of Accra since the two areas have the same climatic conditions, with significant wave height for 50% of the time reported to be 1.2 m. Relatively long wave periods of between 10 and 15 seconds prevail from the southsouthwest direction (Architectural and Engineering Services Corporation (AESC), 1980; AppeaningAddo et al., 2008). The prevailing climatic condition is the equatorial type, characterized by wet and dry seasons with a southwest monsoon wind. Evidence of climate change was manifested in the local sea level which was rising in conformity with the global trend at a historic rate of approximately two millimetres a year. This is expected to increase, potentially up to about six millimetres a year (Intergovernmental Panel on Climate Change (IPCC), 2007; Appeaning-Addo et al., 2008). There was little evidence upon which to base estimates of the influence of climatic change on future wave conditions.

The major rock types are igneous and sedimentary formations. They belong to the Precambrian, Palaeozoic and Devonian eras (Hughes & Farrant, 1963; Dei, 1975; Bird & Schwartz, 1985). The sedimentary formation runs from the beach at Komenda (the Gold Hill) to the west of Fosu Lagoon in Cape Coast (Zone A). It is made up of feldspathic Elmina and Takoradi/Sekondi sandstones (Dei, 1975). According to Dei (1975), the rocks are friable, massive and bedded with shaly sandstone at the base, and with exposed surfaces limonitised. The limonitisation of the rock surfaces, especially at Komenda (Gold Hill), has rendered the rocks quite resistant to erosion and they have been relatively stable. The igneous formation **(**Zone B) runs from the east of the Fosu Lagoon in Cape Coast to Abandze. The zone consists of granites, pegmatite and granodiorite of the Lower and Upper Birimian types (Hughes & Farrant, 1963; Dei, 1975). Lastly, Amissian sandstone and conglomerates belonging to the Lower Birimian rocks are the major underlying rocks found in Zone C, which runs from Kormantse to Amisano (Hughes & Farrant, 1963; Dei, 1975). There are no rock outcrops in this zone.

The general topography of the area was of moderate relief. There were remains of erosion surfaces known as *Coastal Surface* (Dei, 1972, 1975) made of lateritic capping which was generally low in height (about 40-60 metres a.s.l.). Some of these occurred close to the sea in many places, such as Saltpond, Kormantse, Abandze and Moree (GCGS Annual Report, 1938-39, cited in Dei, 1975). Some of these are considered to be erosional surfaces of Mio-Pliocene origin. Below the lateritic surfaces were *buttes temoins* about 15-30 metres high, representing the degraded laterite surface (Dei, 1975).

The area was drained by a major river (Amisa/Ochi) and small streams which formed an estuary and a number of lagoons respectively. The mouths of these lagoons were often closed and sometimes destroyed during the rainy seasons, either by tidal currents or storm surges, or by artificial means (excavation by natives) when it resulted in flooding (Environmental Protection Agency (EPA), 2004; Digital Topographic Sheet (DTS), 1996).

Materials and methods

The area was divided into three lithological zones, A, B and C (Figure 1), based on the lithological characteristics of the beach. Each zone is made up of a distinct rock type. Zone A is mainly sedimentary, from which were collected sandstones. Zone B is entirely igneous and it has undergone some form of metamorphism, which has yielded the schist. The coastline at Zone C is sandy but underlain with Amissian conglomerates.

The entire shoreline of the study area was traversed on foot over the period October 2008 to May 2011. Specific areas that showed active erosive processes were revisited 17 times during high and low tides to collect pebbles and to observe erosion processes and short term changes to the coastline. Much of the fieldwork was devoted to observation, note taking, photograph taking and collection of pebble samples. The equipment used included sampling sacks, note pad and pencil, gloves and a micrometric cible. The study employed purposive sampling to collect pebbles from rocky beaches, since rounded pebbles were not present at all rocky beaches. The pebbles were collected at Elmina (Zone A), Cape Coast (Zone B) and Abandze (Zone C). Pebbles of different rock types were collected. The predominant rocks (pebbles) collected were the Lower Birimian schist from Cape Coast, quartzite from Abandze and sandstone from Elmina**.** Thirty (30) pebbles of the same rock type and almost the same size, were collected from each location during low tides. In all, ninety (90) pebbles were used for the analysis.

Laboratory analysis

The variables (radius, length, thickness and breadth of the pebbles) in the roundness and flatness indices were extracted by means of measurement using the micrometric cible. The micrometric cible is a calibrated sheet of paper with concentric rings. The interval between each concentric ring was a millimetre. The micrometric cible was preferred because it made it easier to measure the breadth (b), which is the change in curvature of the most rounded portion of the pebble. Shape parameters of individual pebbles were recorded accordingly (Dei, 1972, 1975; Pyökäri, 1982).

Data analysis

The following mathematical models were used to analyse particle shape distribution in the field:

Cailleaux's pebble indices

$$\text{Roundness index: } R = (2r/d)\ (1000) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where *R* is the roundness of the pebble, *r* is the radius of the smallest curvature of the pebble, and *d* is the diameter of the pebble, which is also equivalent to the length, all in millimetres. The average method was used to ensure accuracy in getting the true radius of the pebbles. This was achieved by measuring all four radii and finding the average; i.e.:

$$r = r^1 + r^2 + r^3 + r^4 /4 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The whole fraction was multiplied by 1000 because of the almost insignificant value of the index, so that the value could be read easily. Values above 1000 imply a perfectly normal roundness. Due to differences in mineralogy, physical and chemical properties, the pebbles collected from the different locations were grouped according to the types of rocks (sandstone, schist and quartzite) to analyse the effect and responses to erosion.

$$\text{Flatness index: } F = L + b/2E \ldots\ldots\ldots\ldots\ldots (3)$$

where *F* is the flatness of the pebble, *L* is the length (may be equal to 2r or the diameter), *b* is the breadth, the point at which there is a change in the curvature of the pebble, and *E* is the thickness of pebble, all in millimetres (Krumbein & Sloss, 1963).

Pebble flatness also implies intensity of erosion. Just as roundness is influenced by factors such as mineral constituent, physical and chemical properties, so is pebble flatness. Therefore, the grouping of pebbles during measurement and analysis was done to ensure accuracy. Statistical parameters of flatness and roundness values were graphically presented using SPSS version 13.0.

Results

Cailleaux's indices have been widely accepted and used by many researchers on particle shape analysis and they are also easily interpreted. The interpretation was based on field observations and on

Cailleaux's two indices of wear and tear (roundness and flatness). According to Dei (1972), roundness and flatness are basically related to wear during transport or constant wet sand blasting of stationary materials. Therefore, roundness and flatness were considered as measures of the susceptibility of such materials to erosion.

Morphology of pebbles

Table 1: Roundness and flatness values of schist

Pebble	F = (L+b /2E)	R = [2r/L (1000)]
1	1.8	785.7
2	1.8	900.0
3	2.8	400.0
4	4.0	625.0
5	1.3	900.0
6	1.5	700.0
7	1.9	857.1
8	4.0	625.0
9	1.8	900.0
10	1.5	833.3
11	1.1	642.9
12	2.0	593.8
13	7.5	444.4
14	2.3	600.0
15	1.2	1250.0
16	3.8	714.3
17	1.3	875.0
18	2.0	750.0
19	2.3	600.0
20	1.9	466.7
21	5.5	700.0
22	7.0	250.0
23	3.0	500.0
24	3.8	272.7
25	3.8	444.4
26	2.8	800.0
27	2.8	583.3
28	1.3	650.0
29	4.8	250.0
30	2.3	875.0

Source: Laboratory analysis, 2010

Table 2: Percentage representation of roundness and flatness values of schist

Description	Range of values for roundness	Percentage	Range of values for flatness	Percentage
Less	250-500	26.6	1.0-2.0	46.6
Moderately	501-1000	73.3	2.1-5.0	43.3
Highly	Above 1000	0.1	5.1-10.0	10.1
Total		100.0		100.0

Source: Laboratory analysis, 2010.

Table 1 shows roundness and flatness values of schist collected from Amoakofua in Cape Coast. Flatness values ranged from 1.1 to 7.5. The Cape Coast schist was platy-like, had basal cleavages and easily broke at the joints, revealing a high attrition rate, hence its high flatness values. Roundness of schist was moderate, with most values below 1000. Roundness was short-lived due to the susceptibility of schist to fragmentation after attaining roundness. Most of the pebbles were moderately rounded, as they were undergoing the process of rounding again after fragmentation (73.3% of pebbles as shown in Table 2), with only 0.1% having values exceeding 1000. Perhaps the pebble with the lone value that exceeded 1000 (Table 1) had gone through serious abrasion processes in potholes and achieved a high roundness value. The frequent fragmentation of the highly-metamorphosed Cape Coast schist is a result of its fissility.

Table 3: Roundness and flatness values of Elmina sandstone

Pebble	F= (L+b/2E)	R= [2r/L (1000)]
1	3.5	300.0
2	3.5	300.0
3	4.8	250.0
4	1.2	714.3
5	0.9	800.0
6	1.9	545.5
7	1.9	466.7
8	0.8	900.0
9	1.0	850.0
10	2.0	500.0
11	4.8	250.0
12	3.0	571.4
13	1.5	700.0
14	6.8	180.0
15	2.2	400.0
16	2.6	333.3
17	2.5	357.1
18	2.3	916.7
19	1.4	785.7

20	1.6	550.0
21	2.2	850.0
22	1.6	600.0
23	2.3	875.0
24	1.8	400.0
25	1.1	1125.0
26	1.0	1000.0
27	2.5	700.0
28	1.5	642.8
29	4.1	285.7
30	1.8	400.0

Source: Laboratory analysis, 2010

Table 4: Percentage representation of roundness and flatness values of sandstone

Description	Range of values for roundness	Percentage	Range of Values for flatness	Percentage
Less	180-500	43.3	0.8-2.0	53.3
Moderately	501-1000	53.3	2.1-5.0	43.3
Highly	Above 1000	3.4	5.1-10.0	3.4
Total		100.0		100.0

Source: Laboratory analysis, 2010

Roundness of sandstone ranged from 180 to 1125 (Table 3). Pebbles were moderately rounded, with few values exceeding 1000. From observation, pebbles showed polished brecciated surfaces that indicated intensity of erosion. The lone figure above 1000 may have been picked from an area of increased wave energy such as potholes where pebbles were turned constantly. Flatness of sandstone ranged from 0.8 to 6.8. It is seen from Table 4 that the majority of pebbles were moderately rounded, forming 53.3% of the entire sample. Only 3.4% had values exceeding 1000. The rest (43.3%) had values ranging from 180 to 500 and were less rounded. Sandstone was described as moderately rounded because of the presence of unstable minerals such as feldspar. Sandstone weathers more easily, and more than half of the sample (53.3%) fell within the moderate range of 501-1000. It was observed on the field that groundwater intrusions along joints and cracks aid marine erosion in disintegrating sandstone outcrops. Hence, pebbles collected were semi-weathered and succumb easily to fragmentation, even when just touched with the hand.

Table 5: Roundness and flatness values of quartzite

Pebble	F= (L+b/2E)	R= [2r/L (1000)]
1	1.1	550.0
2	2.1	400.0
3	0.8	1285.7
4	2.5	500.0
5	1.2	692.3
6	0.8	1250.0
7	1.7	500.0
8	1.3	500.0
9	0.8	666.7
10	1.6	600.0
11	0.8	1700.0
12	1.6	514.3
13	1.3	1125.0
14	1.7	600.0
15	0.8	1400.0
16	0.7	3000.0
17	1.3	1062.5
18	1.8	650.0
19	0.8	1166.7
20	1.8	650.0
21	1.3	666.7
22	1.8	500.0
23	1.1	1333.3
24	1.1	1214.3
25	1.1	1071.4
26	2.3	600.0
27	1.1	1071.4
28	1.2	1050.0
29	3.0	454.6
30	2.2	642.9

Source: Laboratory analysis, 2010

Table 6: Percentage representation of roundness and flatness values of quartzite

Description	Range of values for flatness	Percentage	Range of values for	Percentage roundness
Less	100-500	20.0	0.1-2.0	83.3
Moderately	501-1000	40.0	2.1-5.0	16.7
Highly	Above 1000	40.0	5.1-10.0	00.0
Total		100.0		100.0

Source: Laboratory analysis, 2010

Flatness of quartzite ranged from 0.8 to 3.0 (Table 5). About 16.7% of the pebbles were moderately flat, with nothing recorded under the description 'Highly Flat' (Table 6). It was seen that quartzite was the least flat (compared to schist and sandstone), with 83.3% of the flatness values falling within 0.12.0 (Table 6). On the other hand, pebble roundness was high, with the majority of values exceeding 1000. The values of roundness ranged from 400 to 3000. Forty percent (40%) had achieved roundness values above 1000, with only 20% being less rounded (from 400 to 500). There were no roundness values below 400 and no flatness value above 5.0 because the pebbles were highly rounded. There was an inverse relationship between flatness and roundness and this was manifested in the Abandze quartzite, as shown in Table 6. The quartzite was the most rounded among the three types of rocks, with values as high as 3000. It was also inferred from the pebble morphology (Tables 1, 2 and 3) that roundness increased eastwards from Komenda to Saltpond (from Zones A to C), which was also indicative of increased abrasion in the same direction.

Graphical presentation of pebble morphology

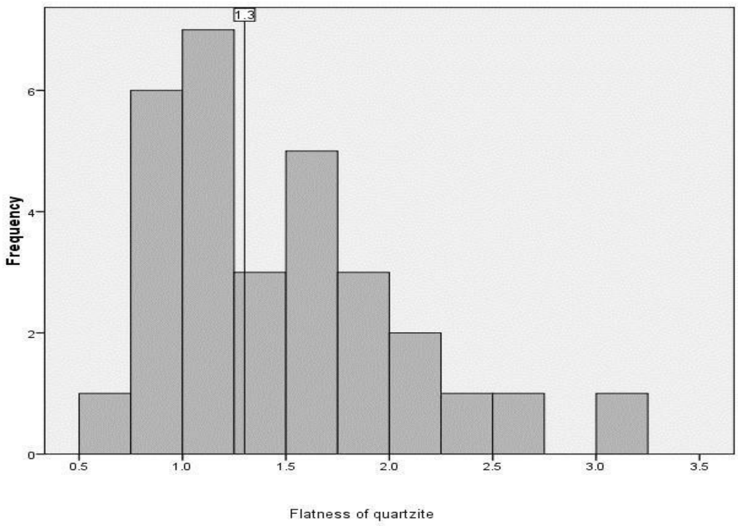

Figure 2: A histogram showing the flatness of Abandze quartzite

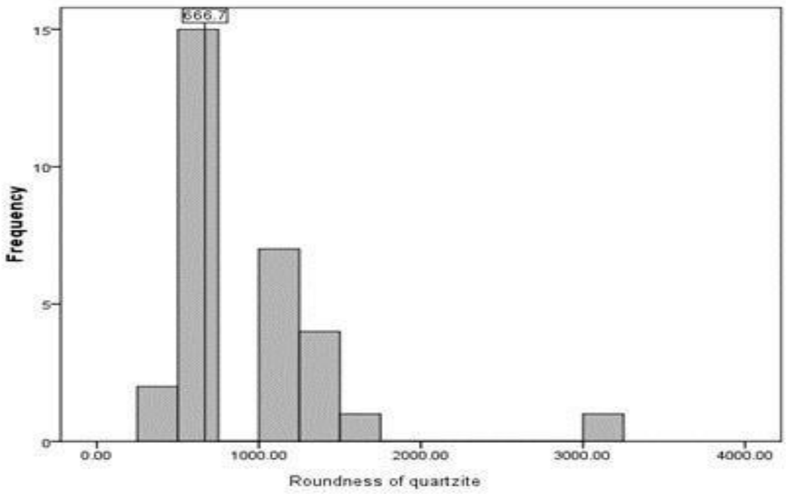

Figure 3: A histogram showing the roundness of Abandze quartzite

The histograms (Figures 2 and 3) showed bimodality and trimodality respectively of quartzite, and this characteristic nature of the graphs indicated that pebbles originated from different beach environments with different environmental conditions. Flatness of quartzite had a median value of 1.3 (Figure 3), which was very low, implying an increase in roundness with a very high median of 666.7 (Figure 4). Both graphs were trimodal and indicative of samples collected from three different environments, with the majority coming from high abrasion and attrition zones.

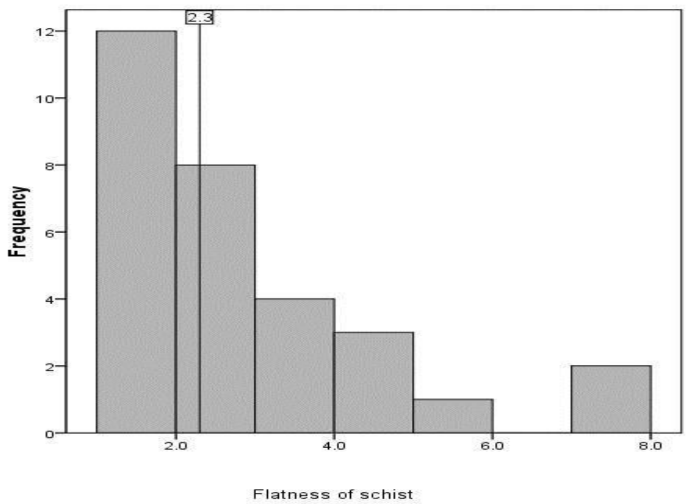

Figure 4: A histogram showing the flatness of Cape Coast schist.

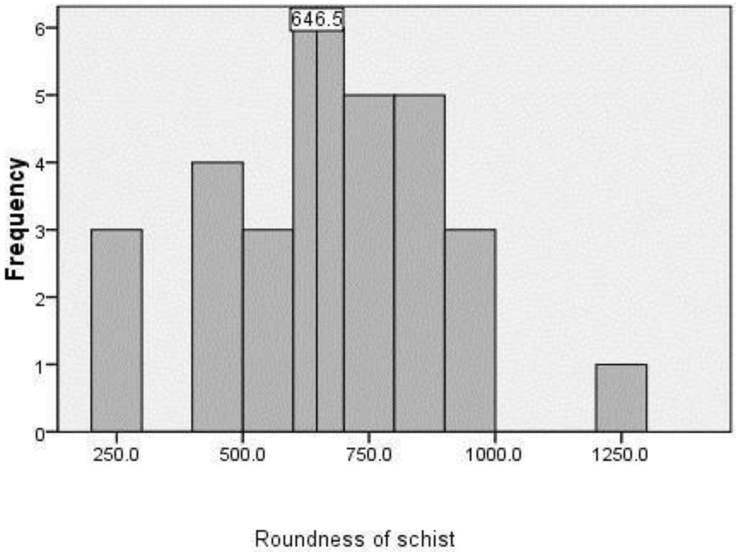

Figure 5: A histogram showing the roundness of Cape Coast schist.

The schist had bimodal and trimodal graphs of flatness and roundness respectively. The contrast in its modality was a result of its fissility. Increase in flatness was a result of fragmented pebbles originating from high energy zones. A relatively high median of 2.3 for flatness showed an increase in flatness, implying high wave energy.

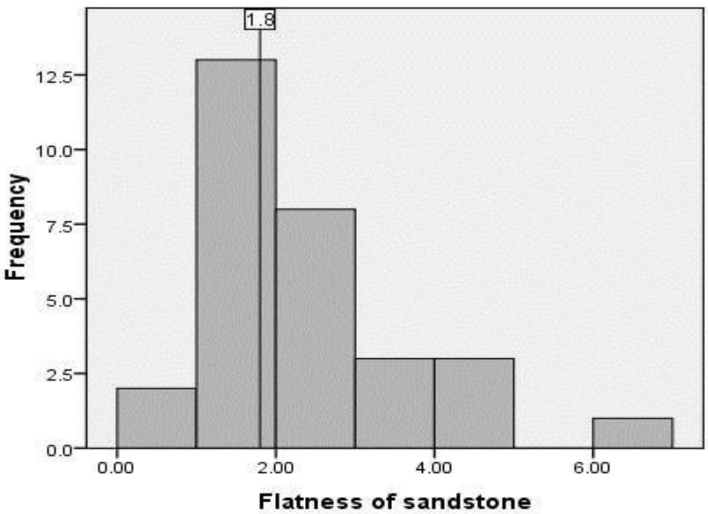

Figure 6: A histogram showing the flatness of Elmina sandstone

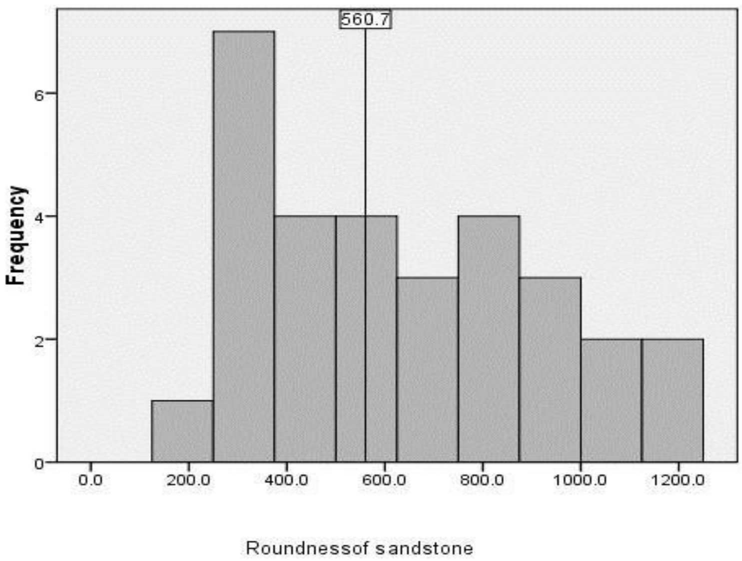

Figure 7: A histogram showing the roundness of Elmina sandstone

The roundness and flatness of sandstone were bimodal. Due to the sub-rounded nature of the sandstone, both roundness and flatness values were moderate and influenced by outliers. The tables and graphs confirmed the inverse relationship between roundness and flatness.

Discussion

Field observations showed that rocks found in sheltered beaches, such as estuarine beaches with vegetation cover, were brittle, fragile and appeared 'decayed' due to the presence of humic acid released from the microbial activities resulting from the decomposition of dead plants and animals. Such was the case with the sandstone found at the Kakum River estuary at Iture near Elmina, where most of the rocks appeared decayed and weak, and hence were susceptible to groundwater intrusions. Sandstone contains large amount of feldspar which cannot withstand hot humid conditions (Dei, 1972, 1975; Hearn, 2008; Davidson-Arnott, 2010). The sandstone was uniform made up of hard grains, contained feldspars, and was brownish-pink in colour because of the presence of pink feldspars and dark brown limonitic cement (Crow, 1952, cited in Dei, 1972). However, in areas where these rocks appeared limonitised and lithified, such as at the Gold Hill in Komenda, they were quite resistant.

On the other hand, rocks on rocky coastline devoid of vegetation appeared less fragile and quite resistant to erosion due to the absence of humic acid. Therefore, in hot humid conditions, particles of higher mechanical and chemical resistance such as quartzite and schist achieved roundness faster than those with less mechanical and chemical resistance. The Cape Coast schist and Abandze quartzite were rarely found in sheltered areas (devoid of 'decay') and were exposed to direct sea action. This partly explains why the quartzite of Abandze and the schist of Cape Coast had higher roundness values, but due to the schistosity of the Cape Coast schist its roundness was short-lived. Quartzite is both chemically and physically more resistant. This confirms the proposition put forward by Dei (1972) that the rounding of quartzite takes longer and may be accelerated through corrosion by calcite, which in turn may lead to the pitting of the surface of the rocks. The quartzite might have undergone such a process of corrosion; hence it was more rounded and less flat.

Inferring from the data in Tables 1, 3 and 5, it is clear that increases in roundness led to low flatness values, implying an inverse relationship between roundness and flatness. The quartzite has high roundness values and low flatness values due to increased fetch distance, increased erosion activity eastwards and accelerated corrosion of quartzite by calcite (Dei, 1972). Close examination of the pebble samples indicated that the sediments were derived from pre-existing geological forms such as underlying rocks of the substratum and rock outcrops or promontories, with few originating from subaerial processes. Typical evidence was found on the polished surfaces of rounded quartzite pebbles. They showed matt surfaces and ferruginised coatings, which implied that the pebbles had undergone renewed abrasion with increased wave energy due to increasing sea levels.

Conclusion

Abrasion and attrition reduce pebble size, which influences pebble mobility and hence can influence the form and evolution of a beach profile. Reduction in size also leads to finning of sediment downdrift which is partly proportional to the distance travelled, hence the accumulation of both fine sediment and the most rounded pebbles in Zone C, the downdrift side of the study area. The findings suggest that schist, although highly metamorphosed, is the most vulnerable to erosion (attrition process) due to its fissile nature, making transportation easier.

The observed increase in pebble roundness eastwards is partly associated with general wave energy increases in the same direction. This conclusion suggests that such a pile up of wave energy eastwards, coupled with the sandy nature of the shoreline (in Zone C), is one of the causes of the increased erosion activity on the eastern shores of the study area.

The effect of erosion on lithology depends on a number of factors such as weathering, type of rock, vegetation cover and the nature of coastline (whether sheltered or not). Differences in lithology of the coastline resulted in differences in erosion activities. Hence, with increasing sea levels and erosion, the coastline will retreat at different rates at different locations, assuming more inlets and promontories, and changing its shape in the study area and in Ghana as a whole in the years to come.

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