Heliyon 6 (2020) e03539

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Lithological effects on rocky coastline stability

Cynthia Borkai Boye *, Etornam Bani Fiadonu

University of Mines and Technology, Tarkwa, Ghana

ARTICLE INFO

Keywords:
Environmental science
Earth sciences
Shoreline change
Stacks of rocks
Petrography
Mineralogy
Microscopy
Recession
Accretion
Quartz-feldspar ratio
Sandstones

ABSTRACT

Rock coasts are perceived to be stable, however, recent occurrence of stacks of rocks and subsequent loss of some rocky coasts poses a challenge for research. This study sought to assess the impact of waves on the compressive/tensile strength of the rocks and further investigated the lithological properties of coastal material that influence shoreline change along the heterogeneous rock coast of the western region of Ghana. The study determined how the petrology and mineralogy of the various rocks types influence the stability of rocky shoreline. Data used included available historic topographic maps and images, Geological map, directional wave data, field measurements of rock hardness and rock samples collected for laboratory investigations. Schmidt's hammer was used to measure *in-situ* rock hardness. Shoreline features for the study period (1974–2005) were extracted from multi-temporal dataset into a geodatabase, and change statistics computed by end point rate method using DSAS, an extension of Arc GIS software. Thin sections were produced from rock samples collected from the field, and petrographic and microscopic analyses were carried out on them. It was found that wave impact was minimal compared with the tensile strength of the rocks in the study area; thus wave is not the key geomorphic agent in the study area. The results showed shoreline accretion at few sites, whereas other parts of the rocky shoreline are eroding at varying degrees. It was observed that the site lithology of the rock coast as well as the quartz feldspar ratio content of the rocks influence the shoreline change rates, as quartz bearing rocks are often more resistant to weathering. It was also noted that the strength of the intact rock had moderate correlation with the shoreline change rates; instead the mineralogy, state of weathering and textural properties of the rocks explains the shoreline change rates along the coast.

1. Introduction

Coastline stability is an issue of concern to coastal planners, management, and engineers as the coast serves as home to between 23% and 60% of the world's population (Al-Tahir and Ali, 2004; Church et al., 2006; Dadson et al., 2016; Hinrichsen, 1998). The preference of human habitation along the coast is probably due to food security, ocean transportation, recreation and modified atmospheric weather and climate (Stewart, 2008). It is however reported that most coastlines in the West African states are eroding at variable rates (Ibe and Awosika, 1991) and that sandy beaches are vulnerable to coastal erosion (Schlacher et al., 2007). Although coastal erosion is a natural process in coastal landform, its occurrence often poses risk to livelihoods and coastal assets. Oftentimes, coastal lands are permanently lost when coastal cliffs or rock shores collapse and retreat landward. Erosion of coastlines in Ghana are usually associated with loss of valuable lands and properties of coastal dwellers (Appeaning Addo et al., 2008). Shoreline change, which is the displacement of the land-sea interface (Boak and Turner, 2005), serves as a good indicator of coastal erosion (Srivastava et al., 2005) and thus shoreline change analyses could inform researches of the stability of coastlines.

Coastal landforms usually originate through geological processes and are modified by marine processes. The dynamics of coastal landforms often spans several geological time scale particularly for rock coasts, however, the recent occurrence of stacks of rocks and the subsequent loss of portions of some rocky coasts is an issue which call for research. Rock coast morphology is often attributed to lithology, structural configuration, waves, climate, and minor relative changes in sea level, which are very different worldwide (Woodroffe, 2002; Granja, 2004). Even though rocky shores account for more than 33% of the world's coastlines, geomorphology of these shores have received little attention in scientific literature (Johnson, 1988; Sunamura, 1992).

Coastline stability has been investigated from different perspectives. For instance, Rosser et al. (2013) studied the stability of the coast as a result of rocky cliff failures in the North Sea of the United Kingdom. It was observed from his study that failure propagation could operate

* Corresponding author.
E-mail address: cboye@umat.edu.gh (C.B. Boye).

https://doi.org/10.1016/j.heliyon.2020.e03539
Received 14 September 2018; Received in revised form 2 December 2019; Accepted 2 March 2020

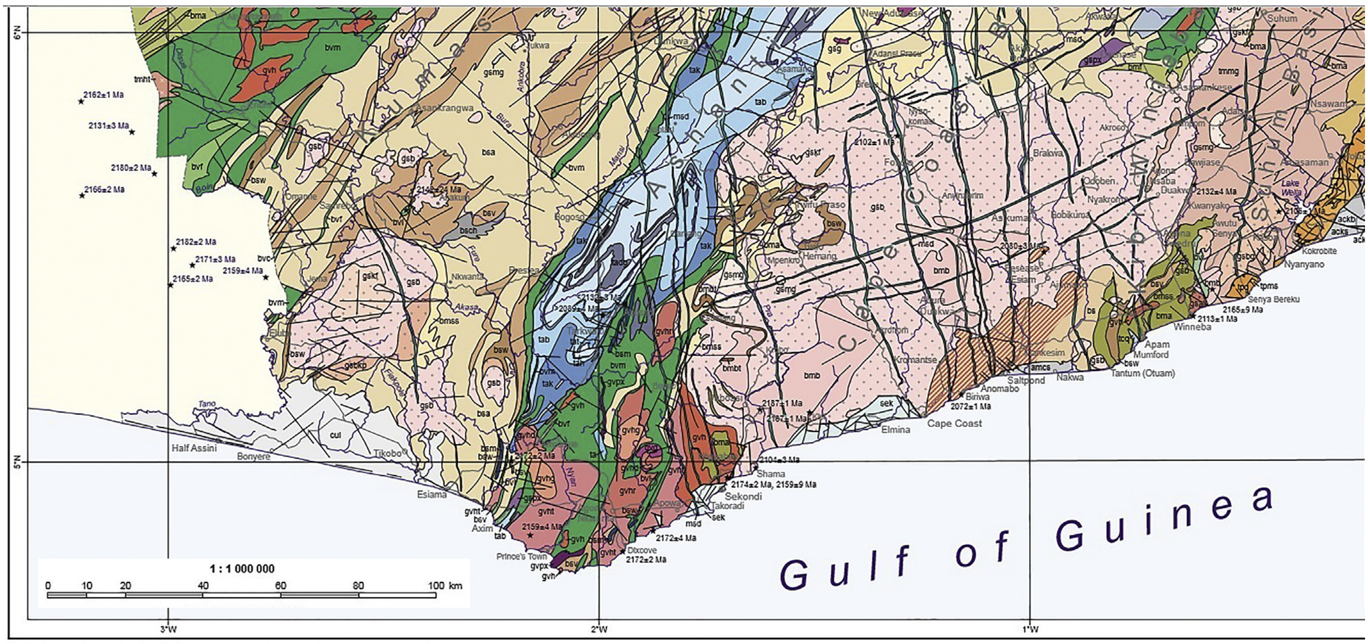

Figure 1. Geological map of the study area (source: Geological survey of Ghana).

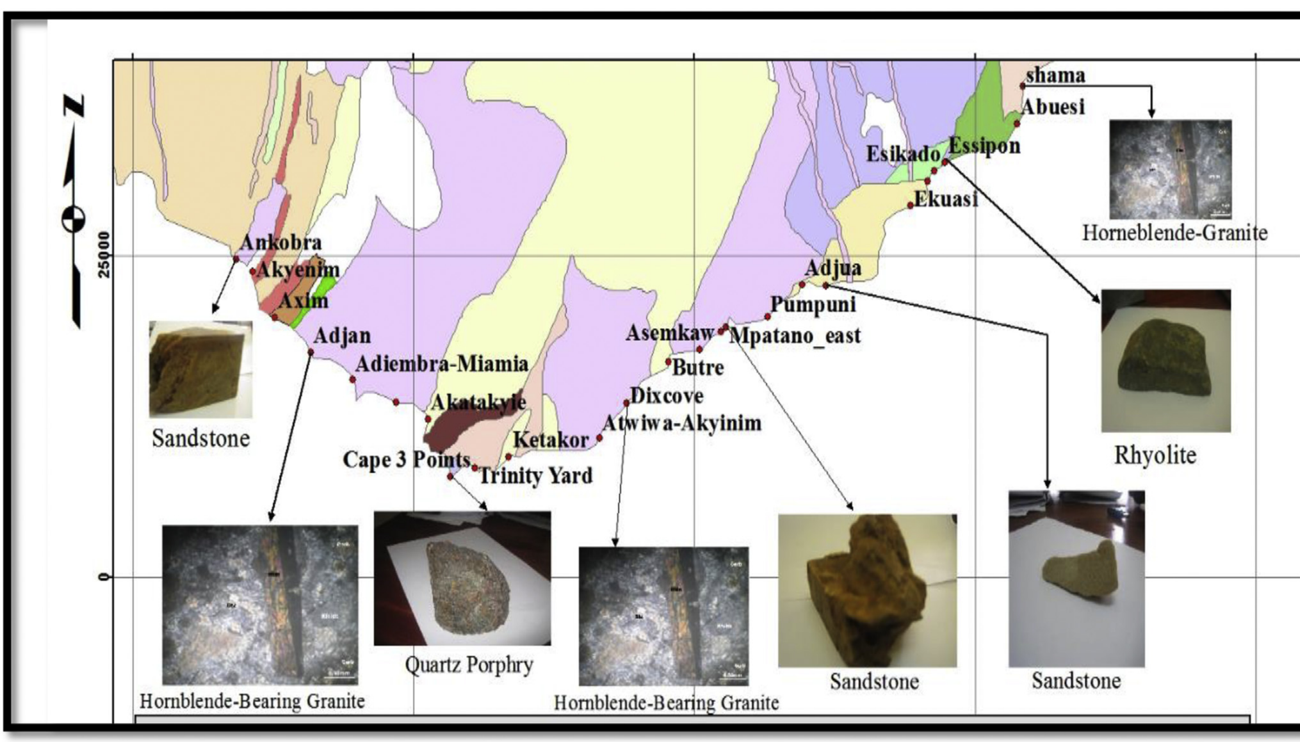

Figure 2. Selected hand samples collected/photomicrographs obtained from selected sites of the study area.

independent of external environmental forces, and that they are closely tied to prevailing subaerial and oceanographic conditions. Violante (2009), determined geological processes that regulate rapid sediment transfers along rocky coasts. It was noted that proper comprehension of coastal mass wasting hazard requires the inclusion of marine and historical investigations from reliable past geological events occurring on land. The study of Brandolini et al. (2009) on the phenomenon of geomorphological instability along the rocky coast of the Tigullio Gulf revealed that useful information on evolution of landslides was obtained from in-depth analysis of the subsoil geology and monitoring activity. Other studies have debated whether waves or subaerial processes are the active morphologic agents for coastal evolution. While findings of some researches (e.g. Kennedy et al., 2011; Sunamura, 1977, 1992; Moura et al., 2011 among others) point to wave impact as associated to coastal evolution, findings of other studies show no direct correlation between coastal rock evolution and waves, rather subaerial processes (e.g. Kennedy et al., 2011; Stephenson and Kirk, 1998, 2000; Dickson et al., 2004). All these studies have linked the stability of rock coast to either waves or the geology of the area.

Figure 3. Photographs of some parts of the rock coast of the study area.

Sunamura (1992), also expressed the stability of the coast as a function of the erosive forces and the resistance of the coastal material. Under similar conditions of erosive forces, the resilience of the coastal material and therefore the geology determines/explains the stability of the shores particularly at rocky sites. Though the Sunamura's relation is widely used, various physical properties of coastal material served as proxies for the erosive forces as well as the material resistance by different authors (Mano and Suzuki, 1999; Trenhaile, 1983; Wilcock, 1998). Limber et al. (2014), in their study assumed coastline retreat increases with wave energy and decreases with rock strength. Boye (2015), in her study along the western coast of Ghana associated the variability of the shoreline change in the area to the variability of the geological properties of the rocks. It is however, unclear how the inherent geological properties of rocks influence their stability or vulnerability to oceanic conditions. The present study seeks to probe the impact of waves on the coastal rocks, and further investigate how the petrology and mineralogy of the various rocks types influence the stability of rocky coastlines.

2. Study area

Ghana is a West African country bordered by Togo to the east, Cote D'Voire to the west, Burkina Fasso to the north and the Gulf of Guinea (Atlantic Ocean) to the south. The Western Region of Ghana lies within latitudes 4°40′ and 5°10′ north and longitudes 3°07′ and 1°40′ west (Figure 1) and the coastline stretches to about 192 km constituting about 35% of the Ghana coastline. The coast is generally low lying with topographic elevation not exceeding the 30 m above mean sea level (Boye, 2015). Waves approaching the shores of Ghana consist of swells originating from the oceanic area around the Antarctica continent and seas generated by local occurring winds (NA, 2019). The swell wave direction

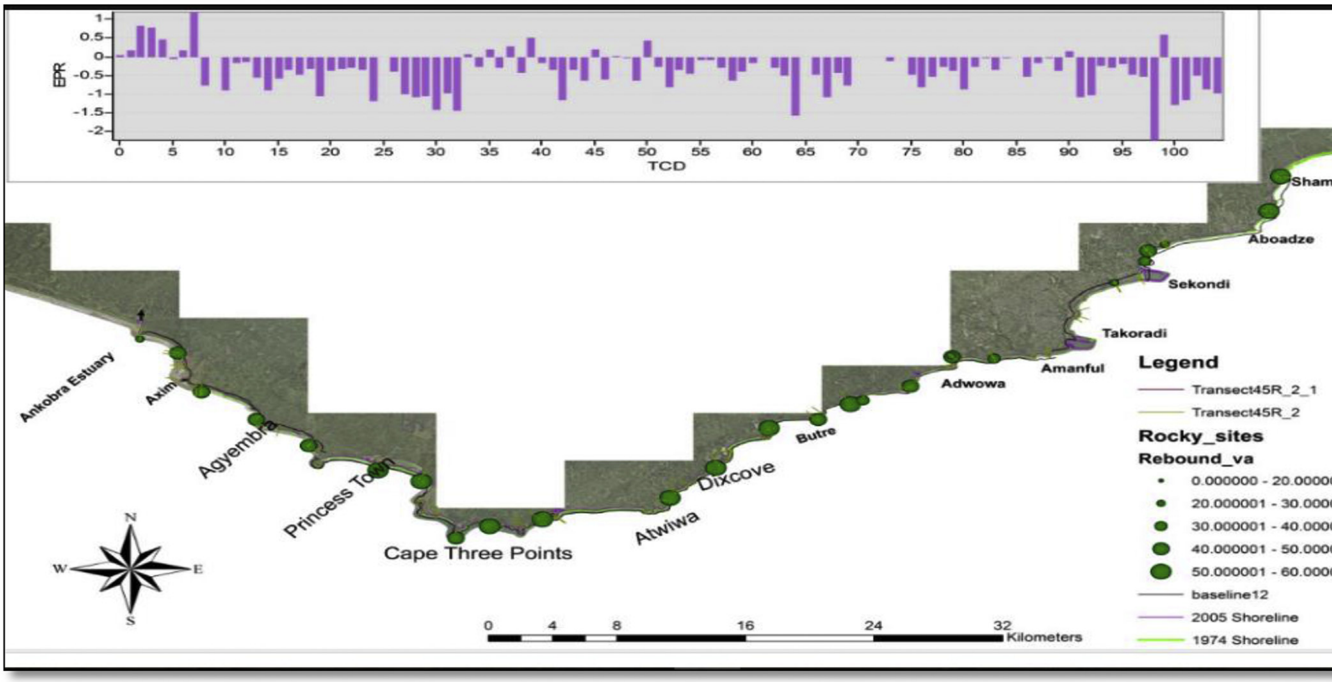

Figure 4. Shoreline change rates and coastal rock strength along the rocky sections of the study area.

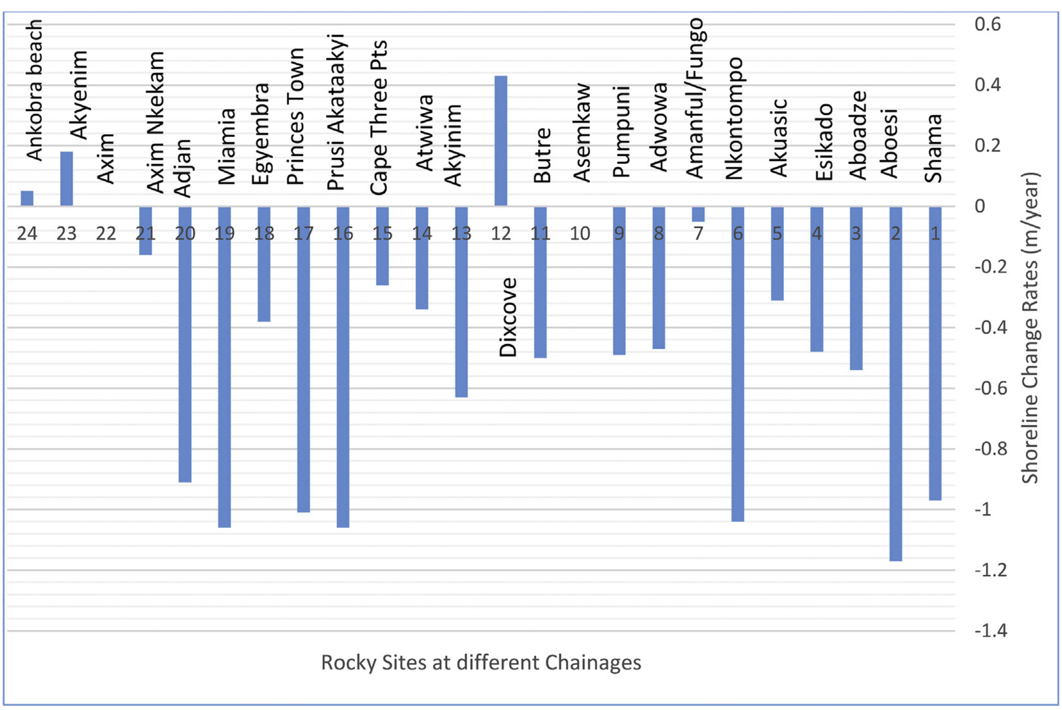

Figure 5. Shoreline change at rock coast sites.

Table 1. Wave energy flux generated per section.

Name of Section	Angle of breaking wave crest with shore (α)	Wave Energy Flux factor (Pls) (N/s)	Potential Sediment Transport (N/s)	Sediment Transport per hour (N/hr)
Dixcove-Shama	143.08	-2698.980	-1052.602	-0.120
Cape Three Points - Atwiwa	102.08	2724.064	1062.385	0.121
Axim-Princess Town	71.08	2515.772	981.151	0.112

Table 2. Mean compressive/tensile strength of coastal rocks per section.

Name of Section	Selected Samples	Rebound Values	Median	Compressive Strength/Mpa	Tensile Strength/Mpa
Shama-Dixcove	SC1	44.46	44.48	32.304	1.989
	AB1	45.85			
	ADC1	33.5			
	PUC1	44.5			
	MPC1	46.27			
	ASC1	44.08			
Atwiwa -CapeThree Points	ATC1	50.94	50.94	36.121	2.104
	KTC1	58.56			
	C3PC1	47			
Princess Town - Axim		52.25	46.73	33.633	2.030
		44.08			
		42.67			
		49.38			

is almost always from the south or south-west with a primary period of 12 s and generally travels to the north-west. The significant wave height of the study area is generally between 0.9 m and 1.4 m, while the most common value in the region is 1.0 m. Tide along the coast of Ghana is regular and semi-diurnal; the tidal range is 0.90 m at Takoradi with the average Neap and Spring tide values increasing from west to east of the country (Hermas, 2016). The continental shelf (200 m water depth contour) has a generally regular near shore bathymetry with isobaths running parallel to the coast. The study area has large and small basins rivers that discharge their fluvial sediment load to adequately nourish (1×10^5 tonnes of sediment per day) the shores daily thereby making the shores stable at the mouths of the rivers and lagoons (Boye et al., 2018). The general orientation of the coastline is categorized into three sections namely, Dixcove - Shama, Cape Three points – Atwiwa and Axim - Princess Town oriented at 46°, 87° and 118° respectively. The coastal material is composed of about 60% sandy beaches and 40% composite rock/sandy beaches (rocky headlands alternating with sandy bays).

The coastal rocks are heterogeneous with rock types ranging from granites, granitoids, through shales, sandstones to low strength soils (Kesse, 1985). The rocks in the region comprise extension of Paleo-proterozoic Birimian greenstone belt of the metavolcanic and meta-sedimentary, and intrusive granitoids to the coast, which are overlain by Neo-proterozoic and recent deposits of sediments. Some identifiable areas include, Shama, Axim, Cape Three Points and Ankobra areas. The Axim area is located at the southwestern end of the Ashanti belt and extends from the Ankobra River to the village of Anyaame. The area is dominated by Birimian units of interbedded metasediments and metavolcaniclastics, which are intruded by a NNE-SSW trending intermediate intrusive body, portions of which are porphyritic in texture. Birimian metavolcanic and Tarkwaian clastic units underlie the central portion of the area.

The Ankobra area is located at the southern end of the Ashanti Belt, near the Kumasi Basin. The area is highly sheared as it is found within the contact between the belt and the basin. Massive andesitic and basaltic flows, tuff and Tarkwaian clastic units (phyllite and quartzite) are the main rock types intruded by large felsic belt-type granitoid. Occasional interbedded schist and cherty horizons are present in the metasedimentary unit. The Cape Three Points area is the southernmost point in the country, and features a range of flat-topped, steep sided hills that crest at about 30 m above mean sea level. The Cape Three Points band of Birimian greenstone units is located in the central portion of the southernmost end of the Ashanti Belt. The band is wedged between two large intermediate granitoid complexes; on the eastern side is the Dixcove complex whereas on the western side, there is the Prince's Town complex. Both of these granitoids are dominated by hornblende-bearing phases that are tonalite to granodiorite in composition (Loh et al., 1995). The coastal area is dominated by ultramafic intrusion varying in composition from peridotite to pyroxene and dunite (Loh et al., 1995).

Mafic intrusive rocks are encountered in this study at Akitekyi, Mpohor and around Axim town. At Akitekyi, the mafic intrusives are ultramafic metaperidotites, altered fine grained dunitic rocks and gabbro/norite intrusive rocks. Similarly, gabbroic rocks are found in north of Mpohor and Axim town. Sedimentary and metasedimentary rocks such as sandstones, silt and shales are found in Ajua, Butre, Punpuni, Sekondi and Asemkew. Contact between the Ajua shale and granitoid is seen at Asemkew and the shale is underlain by conglomerate. Between Axim and Nkubem are Tarkwaian sediments made up of greyish – green quartzite and arkoses inter-bedded with silt sediments.

3. Materials and methods

Data used for the study included available historic topographic maps and images, Geological map, directional wave data measured from a buoy offshore the study site, field measurements and sample collected for laboratory investigations. Schmidt's hammer was used for field measurement of in-situ rock hardness (Goudie, 2006; Strzelecki, 2011). The topographic map acquired in 1974 and ortho photographs (1:5000) taken in 2005 and was obtained from the Survey and Mapping Division (SMD) of the Lands Commission, Ghana were used for the shoreline change analysis. Field data of selected Ground Control Points (GCP) were measured with dual frequency Global Positioning System (GPS) receivers to ascertain the positional accuracy of the 2005 ortho photograph used for the study; detail description is presented in Boye et al. (2016). The shoreline feature was extracted by digitising the High Water Line (HWL) from the ortho photographs and appended with the available 1974 shorelines dataset in a GIS environment. The HWL was used a proxy for the shoreline because it is visible in ortho photograph and commonly used as a proxy for shoreline mapping by the SMD. A Geodatabase was created for storage of the shoreline dataset, into which a baseline feature was created and perpendicular transects cast at interval of 100 m to cross the merged shoreline positions and the shoreline change rates were computed using DSAS, an ArcGIS extension (Thieler et al., 2009). The uncertainties associated with extraction of the shoreline emanates from digitising errors of the shoreline from the ortho photograph (0.50 m), topographic map error (0.20 m) giving a total uncertainty of ± 0.70 m (Boye et al., 2018). The shoreline change statistics were computed using the End Point Rates (EPR). Detailed discussion on this method could be found in Dean and Dalrymple (2002); Frazer et al. (2009); Galgano and Douglas (2000) and Dolan et al. (1991). From the directional wave data measured offshore the study site, the significant wave height (H_S) and the wave height at breaking H_b were computed and the net wave direction relative to the mean shoreline orientation (α) for three different sections

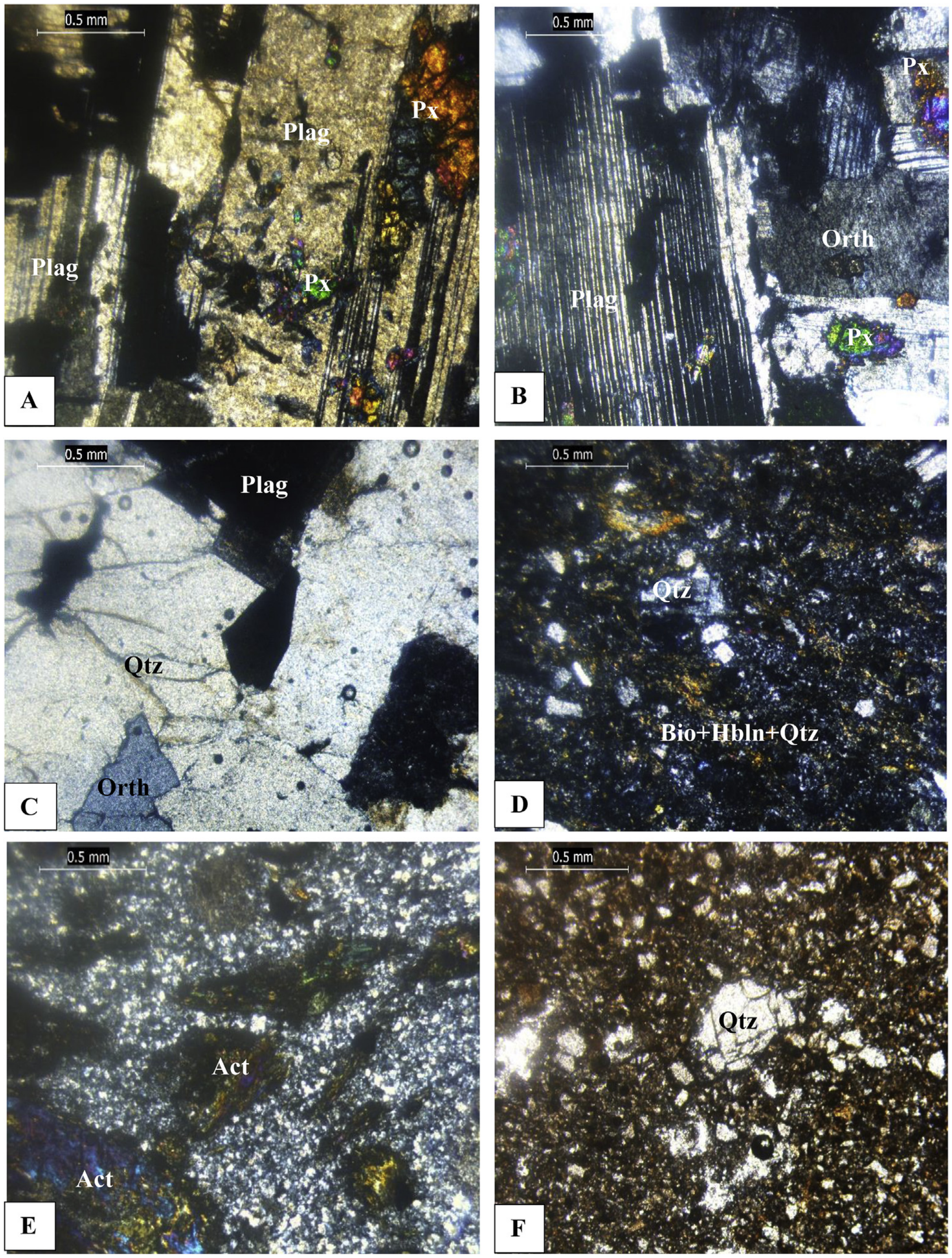

Figure 6. Photomicrographs of thin sections of some rock samples along the coast (a&b): granodiorite shows phenaritic lath of plagioclase with pyroxene inclusions (c): granite with subhedral grains of feldspars (orthoclase and plagioclase) interlock in anhedral quartz, d) fine to medium grain dioritic rock with plagioclase and quartz in fine groundmass of biotite, hornblende and quartz, e) porphyritic hornblende granodiorite at cape three, f) sandstone.

of the study area were also determined. The potential sediment transported alongshore (Q) due to breaking waves was computed using the CERC Eq. (1) which is based on the wave energy flux (Pls) (Bayram et al., 2001; Kumar et al., 2003; Van Wellen et al., 2000).

$$Q = KPls = K\left(\frac{\gamma}{16} * H_b^2\, C_{gb} Sin\ (2\alpha)\right) \tag{1}$$

where, Q = longshore sediment transport
H_b = wave height at breaking
C_{gb} = wave celerity at breaking
α= angle of the breaking wave crest with the shoreline
γ= specific weight of water
K = empirical coefficient

From a systematic sampling of the study area at 2 km intervals rock exposures within the study sites were identified (total of 29 sites were identified), and their surface hardness measured as an indicator of their resistance to coastal erosion. The internal resistance of the rocks to externally exerted stress (which is a measure of their strengths) were measured by means of a Schmidt's or Rebound hammer. The Schmidt's technique was adopted following the American Society for Testing Material (ASTM D5873) procedure since it provides a simple, quick, accurate and non-destructive test results (Hack and Huisman, 2002). The correlation between the measured rebound values of rocks and their corresponding shoreline change rates was determined. The petrographic aspect of the study comprises field work and subsequent microscopy analysis of the rock. Thin sections were prepared from the rock samples collected from the field (see Figure 2) and analysed. Figure 3 shows some

Table 3. Field descriptions of categorised erosive areas.

Shoreline change rate Category	Sample Point	Sample ID	Field Petrographic Description
Relatively High Erosive Sites (r ≥ -1 m/yr)	Abuesi		Foliated gneiss with quartz veins
	Nkontompo	MPC1	Highly weathered shales
	Prusi Akatakyie		Fine grained, dark metamorphic rock with network of quartzofeldspatic veinlets likely to be shear zone
	Prince's Town		Highly jointed granitic rock with quartz vein
	Miamea		
Intermediate Erosive Sites (-0.5 ≤ r < -1 m/yr)	Shama	SC1	Highly jointed, moderately weathered granitic rock
	Aboadze	AB1	Weathered massive sandstone
	Akyinim	ATC1	Granitoids with coarse grained quartzo feldspathic dykes
	Adjan		Highly fractured granitic rock with quartz vein
Low Erosive Sites (r < -0.5 m/yr)	Ekuasi/Sekondi		Massive sandstone
	Ketakor	KTC1	Belt-type granitoids with abundant mafic minerals
	Butre		Highly jointed greenish fine grained igneous rocks
	Adjua	ADC1	Adjua Shales inter bedded with sandstone
	Esikado		Gneiss with pegmatite intrusions
	Essipon		Sandstone, sea stack and isolated pegmatic veins.
	Pumpuni	PUC1	Very fine grained shales with interbedded sandstone.
	Agyembra		
	Ankobra		Red brown fine grained foliated metamorphic rock
	Ekuasi/Sekondi		Massive sandstone
	Ketakor	KTC1	Belt-type granitoids with more mafic minerals
	Cape Three Point	C3PC1	Highly jointed porphyritic granitoids

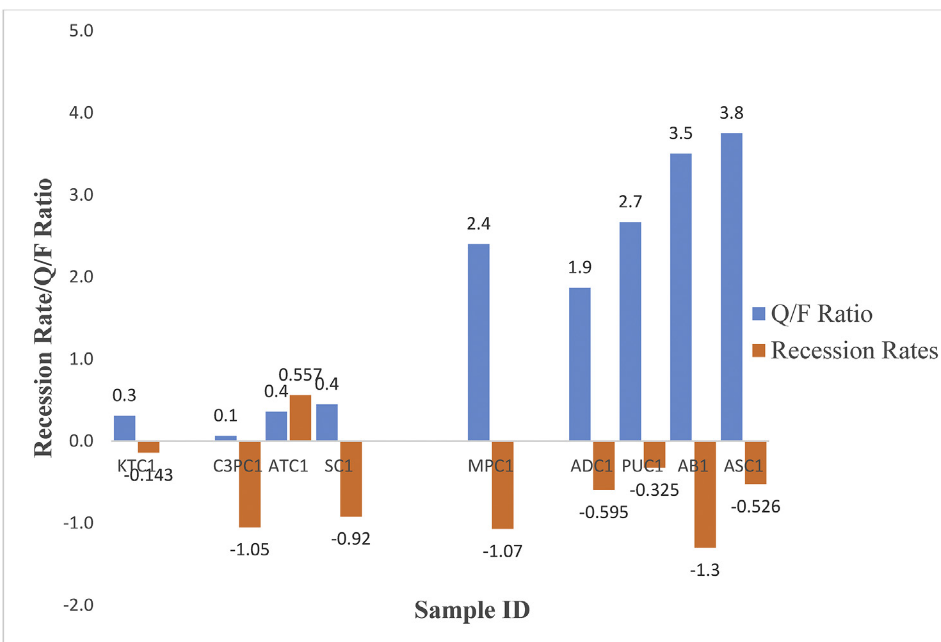

Figure 7. Histogram of quartz/feldspar ratio and shoreline recession rate.

photographs taken at selected sites of the rock coasts. Point-counting was adopted to determine the approximate modal composition of the rock samples.

4. Results

The shoreline change computed showed both accretion and recession taking place along the rock coast of the study area. The spatio-temporal changes in the shoreline at the rocky sites over the 31 years period of the shoreline analysis (*i.e.* 1974 – 2005) is shown in Figure 4. The results revealed minimal accretion or no erosion at few sites (12.5%) such as Akyenin (+0.56 m/yr) and Ankobra Beach (+0.05 m/yr). Minimal shoreline recession rates of < -0.5 m/yr was recorded at 50% of the sample sites over the study period (these sites include Axim, Agyembra, Cape Three Points, Adwowa, Dixcove, Ekuasi, Pumpuni, Esikado and Butre). Moderate shoreline change rates of < -1.0 m/yr was recorded at 28% of the sample sites (Shama, Aboadze, Akyinim, Miamea and Ajan) whereas relatively high shoreline recession rates of > -1.0 m/yr were observed at 10% of the sites (Aboesi, Nkontompo, Prusi Akatakyie, Princes Town and Miamea). The relatively high recession sites include

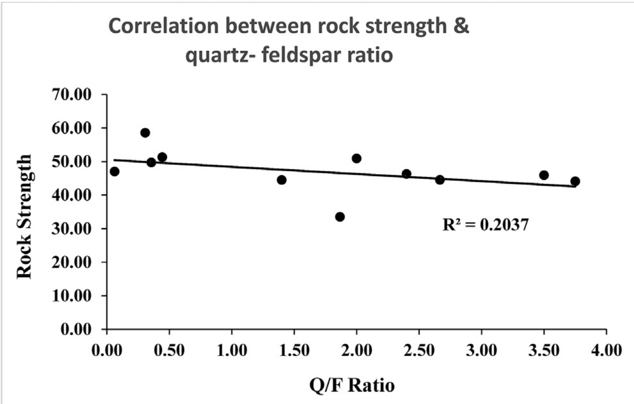

Figure 8. Correlation between rock strength and quartz-feldspar ratio.

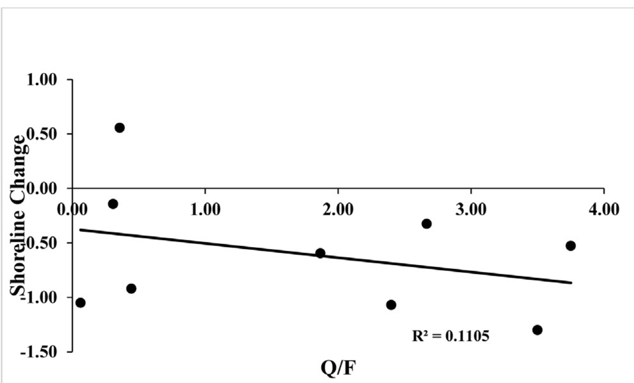

Figure 9. Correlation between Q/F ratio and shoreline change.

Aboadze, Nkontompo and west of Cape Three Points. Figure 5 shows the spatial location of the rocky sites as well the magnitude of the rebound values of the rocks indicating the strength of the rocks.

The outcome of the wave energy consideration for the three sections as against the compressive/tensile strength of the rocks along the coast are presented in Tables 1 and 2 respectively.

The analysis of prepared thin sections were carried out by categorising them into three classes, according to the classification of shoreline change rates at the rocky areas. These are sites which are recording accreting, no change or eroding minimally (-0.5 m/year < r), sites eroding between the rates of -0.5 and -1.0 m/year as intermediate erosive areas, and sites eroding more than 1.0 m/year as erosive area. Thin sections from these three categorized areas were analysed under the petrographic microscope for mineral composition, alterations and texture. The coastal area comprises mainly of granitoid bodies, mostly granodiorite in composition with porphyritic textures (Hirdes et al., 1992; Opare-Addo, 1992). Granodiorite have abundant phaneritic holocrystalline plagioclase lath and minor biotite and pyroxene as the mafic minerals. The main minerals found in these rocks are plagioclase (andesine – oligoclase composition), orthoclase, quartz, hornblende and minor biotite, Figure 6 (A, B and C). At some places the hornblende in the granodiorite is altered to actinolite Figure 6E. Areas predominant of granodiorite are Prince's Town, Butre, Dixcove and Cape Three Point.

In addition to the granitoids, plagioclase-hornblende porphyry was observed at Cape Three Point, epidotized hornblende and pink porphyry feldspar granite found at Dixcove (Loh and Hirdes, 1999). Finely quartz grains are the main minerals in the matrix of the sandstones (Figure 6 F). Table 3 shows the petrographic descriptions of the collected samples. Figures 6 (A - B) shows the microphotographs of some main rocks in the study area. Subhedral grains of feldspars (Orthoclase and Plagioclase) interlock in Anhedral Quartz, D) Fine to medium grain dioritic rock with plagioclase and quartz in fine groundmass of Biotite, Hornblende and Quartz, E) Porphyritic Hornblende Granodiorite at Cape Three, F) Sandstone.

5. Discussion

From Tables 1 and 2 a comparison of the values of the sediment transport rate per hour due to wave energy flux with the mean tensile strength of the rocks show that the former is far less than the latter, thus wave impact is not the key agent causing the evolution of the rock coast at the study area. From Figures 1 and 2, low or no erosion rates were found in areas of sandstones, granites and granitoids. The sites with sandstones include Ekuasi, Asemkaw, Adwowa, Pumpuni and Ankobra beach; those with the granites and granotoids are found at Dixcove, Axim, Akyenim, Cape Three Points, Egyembra and Esikado. Sites where moderate shoreline recession rates were recorded have granites and granotoids that have undergone varying degree of weathering at the surfaces. The sites experiencing relatively high shoreline recession are made up of basaltic flow sub volcanic rocks and hornblende - biotite granitoids (Figure 5). This observation suggests that generally, the area lithology of rock coast influences the shoreline change rates at that site. This finding confirms Sunamura (1992) assertion that the rate of cliff retreat on receding coastlines varies greatly with rock type.

Analysis of the mineralogy of the coastal rocks revealed that the susceptibility of minerals to chemical weathering, when exposed to surface conditions influences their erodibility. The kind of changes that take place in minerals are specific to the mineral and the environmental condition; for instance, quartz is unaffected by chemical weathering whereas feldspars are easily altered to form clay minerals. From Table 2,

Table 4. Mineral compositions, Q/F ratio and the recession rate of the various rocks.

Sample ID	Rock Type	Modal Mineral Composition				Grain Size (mm)		Rock Strength (N/m^2)	Recession Rate (m/yr)	Q/F Ratio
		Qtz	Feld	K-feld.	Acc	Qtz (mm)	Fel (mm)			
KTC1	Granitoid	20	40	25	15	0.2–3	0.7–5	58.56	-0.14	0.3
C3PC1	Granodiorite	5	45	35	15	0.1–0.3	0.2–0.4	47	-1.05	0.1
ATC1	Granitoids	25	40	30	5	0.3–5	0.5–6	50.94	0.557	0.4
SC1	Granite	20	30	15	35	0.2–2	0.4–3	44.46	-0.97	0.4
MPC1	Sandstone	60	20	5	15	0.05–1	0.01–0.2	46.27	-1.07	2.4
ADC1	Shale	28	11	4	57			33.5	-0.595	1.9
PUC1	Shale	24	9	-	67			44.5	-0.82	2.7
AB1	Sandstone	70	15	5	10	0.04–0.3	0.02–0.1	45.85	-1.30	3.5
ASC1	Sandstone	75	10	10	5			44.08	-0.526	3.8

Note: Qtz = Quatz, Feld = Plagioclase Feldspar, K-feld = k-feldspar, Acc = Accessory minerals, Ss = Sandstone.

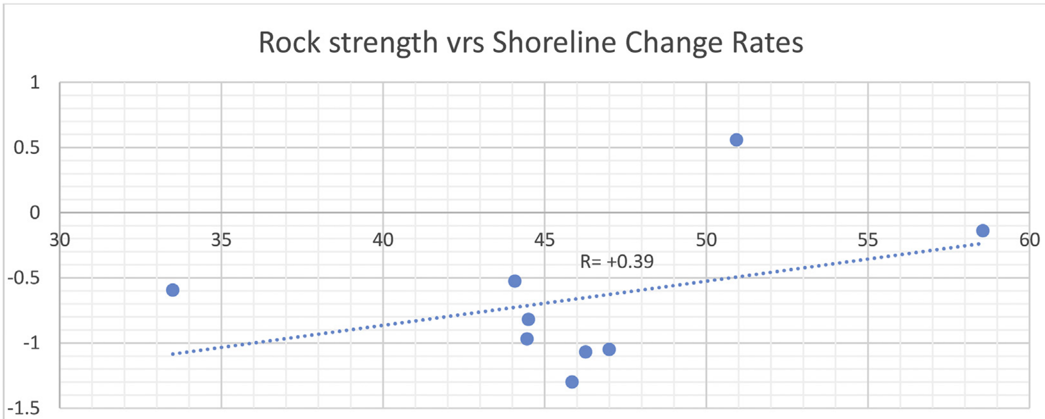

Figure 10. Correlation between rock hardness and shoreline change.

sites experiencing high erosion are dominated by granites and granodiorite which have low quartz to feldspar ratio (*i.e.* 0.1–0.6) and have phaneritic grains of plagioclase and hornblende. Sites with Q/F ratio of between 0.1 - 0.6 gives an indication that the feldspars in the rocks have undergone chemical weathering due to constant interaction with water and carbon dioxide to produce clay mineral through the process of hydrolysis. Whereas feldspar may be altered to form clay minerals, quartz remains unchanged and resistant to erosion. Sections of the coast covered with sedimentary rocks have high Q/F ratio and tend to experience low shoreline change rates, as quart bearing rocks are often more resistant to weathering.

In the case of the granodiorite as pertains in Cape Three Points (Table 2) the rocks composed mainly of k-feldspar and plagioclase feldspar with little amount of quartz (<5%). When such rocks undergo weathering process the most common products would be clay minerals, quartz and dissolved ions most of which tends to be washes into the ocean leaving only the quartz as the primary constituent of sand. As weathering continues and most of the products of weathering are washed offshore, the shore as well as the beach at that section of the coast would be depleted of coastal material thus the shoreline would continue to recede. The effect of weathering is seen from the regression graphs in Figures 8 and 9. There is a negative correlation between the strength of the rock and its Q/F ratio. This is contrary to the well-established fact by Meriam et al. (1970) and Mendes et al. (1966) that as quartz and feldspar ratio increases the mechanical property (tensile strength) of the rock increases. In this study, instead of the strength of the rocks increase as Q/F ratio increases it rather decreases. The only reason for this trend is the effect of weathered feldspar in the rocks. The clay minerals that are formed as weathering product of feldspar are washed away by waves/currents and this creates or increases the intergranular pores in the rocks causing weakness in the strength of the rocks, and for that matter erosion of the shoreline also increases as seen in Figure 8. Rocky shore in the study area experiencing intermediate rate of erosion have quartz to feldspar ratio ranging from 0.7 to 3 with medium grain sizes of minerals. Less erosive areas have rocks with quartz to feldspar ratio ranging from 4.7 to 7.5 and are more stable due to the modal composition of quartz mineral.

Figure 7, shows clearly the effect of lithology (mineralogical composition) on the recession rate of the shoreline in the study area. Most of the areas with high quartz/feldspar ratio such as Adjua, Punpuni and Asemkaw exhibited minimal recession rates with the exception of Aboadze where the rate of recession was relatively high. Field investigation shows that the Aboadzi shore is partly covered with weathered sandstone and sandy beach. Despite the high quartz content of the sandstone however, the sandy beach is eroding at a faster rate resulting in the formation of stacks (see Figure 9). In addition, the presence of groins at the shore gives an indication of previous knowledge of high rate of erosion in that area. Other factors such as production and distribution of beach sediment either from fluvial process or waves may also account for this anomaly. Figure 8 shows moderate correlation (Taylor, 1990) between the rock strength and the shoreline change rate, thus the strength of the intact rock have some effect on the shoreline change rates in the study area. However, the rock resistance to erosion is more dependent on the state of weathering and the nature of weaknesses in the rock. From Table 4, it is evident that the factors that control the variation in the shoreline change rate at the study area are mineralogy and textural properties of the rocks along the coast (see Figure 10).

6. Conclusions

The study has shown that wave impact is not the key agent driving the evolution of the rock coast at the study area. The study also revealed that some portions of the rocky sites of the shore are accreting while erosion is taking place at most sections. Generally, the area lithology of the rocky coast influences the shoreline change rates that pertains at that site. It was observed that the quartz/feldspar ratio content of the coastal rocks in the study area explain to some extent the shoreline recession rates recorded at those sites. Again the degree of weathering taking place in the rocks is linked to the recession rate at those sites. Sections of the rock coast with sandstones have high Q/F ratio and tend to experience low shoreline change rates, as quart bearing rocks are often more resistant to weathering. It was also noted that the strength of the intact rock had moderate correlation with the shoreline change rates; instead the mineralogy, state of weathering and textural properties of the rocks explains the shoreline change rates along the coast. This study has demonstrated that the rocky coast in the case study area are eroding gradually as against the general perception that rocky shores are stable. The study also informs coastal management to formulate policies regarding the type of material to use for sea defence projects. This method applied in this study could replicated along rock coast that have granitoids such as White Cliffs of dover in England, Normandy beach of France, Queensland of Australia and cook Island of New Zealand.

Declarations

Author contribution statement

C. B. Boye: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

E. B. Fiadonu: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors are grateful to the Materials Section of the Ghana Highway Authority, Accra-Ghana and the Geological Engineering Department of the University of Mines and Technology, Tarkwa- Ghana for providing Laboratory facilities used for the study. We are also thankful to the staff and students of the Marine Science and Fisheries Department of the University of Ghana, Legon-Ghana for their contributions.

References

Al-Tahir, R., Ali, A., 2004. Assessing land cover changes in the coastal zone using AerialPhotography. Survey. Land Inf. Sci. 64 (2), 107–112.
Appeaning Addo, K., Walkden, M.J., Mills, J.P., 2008. Detection, measurement and prediction of shoreline recession in Accra, Ghana'. J. Photogrammetry Remote Sens. 63 (5), 543–558.
Bayram, A., Larson, M., Miller, H.C., Kraus, N.C., 2001. Cross-shore distribution of longshore sediment transport: comparison between predictive formulas and field measurements. Coast. Eng. 44 (2), 79–99.
Boak, E.H., Turner, I.J., 2005. Shoreline definition and detection. J. Coast Res. 21 (4), 688–703.
Boye, C.B., 2015. Causes and Trends in Shoreline Change in the Western Region of Ghana. http://197.255.68.203/.ugspace.ug.edu.gh/handle/123456789/8444.
Boye, C.B., Appeaning Addo, K., Williams, E., 2016. Positional accuracy assessment for effective shoreline change analysis. Ghana Mining J. 15 (2), 1–7.
Boye, C.B., Appeaning Addo, K., Wiafe, G., Dzigbodi-Adjimah, K., 2018. Spatio-temporal analyses of shoreline change in the western region of Ghana. J. Coast Conserv. 22 (4), 769–776.
Brandolini, P., Faccini, F., Robbiano, A., Terranova, R., 2009. Slope instability on rocky coast: a case study of Le Grazie landslides (eastern Liguria, northern Italy). Geol. Soc. London Spec. Publ. 322 (1), 143–154.
Church, J., Wilson, S., Woodworth, P., Aarup, T., 2006. Understanding Sea-Level Rise and Variability, 15. UNESCO Workshop, Paris, pp. 12–18.
Dadson, I.Y., Owusu, A.B., Adams, O., 2016. Analysis of shoreline change along Cape coast-sekondi coast, Ghana. Geography J. 2016.
Dean, R., Dalrymple, R.A., 2002. Coastal Processes with Engineering Applications. University Press, Cambridge, UK.
Dickson, M.E., Kennedy, D.M., Woodroffe, C.D., 2004. The influence of rock resistance on coastal morphology around Lord Howe Island, southwest Pacific. Earth Surf. Process. Landforms: J Br Geomorphol Res Group 29 (5), 629–643.
Dolan, R., Fenster, M.S., Holme, S.J., 1991. Temporal analysis of shoreline recession and accretion. J. Coast Res. 723–744.
Frazer, L.N., Genz, A.S., Fletcher, C.H., 2009. Toward parsimony in shoreline change prediction (I): basis function methods. J. Coast Res. 25 (2), 366–379.
Galgano, F.A., Douglas, B.C., 2000. Shoreline position prediction: methods and errors. Environ. Geosci. 7 (1), 1–10.
Granja, H.M., 2004. Rocky coasts. http://www.eolss.net/Eolss-Samples.
Goudie, A.S., 2006. The Schmidt Hammer in geomorphological research. Prog. Phys. Geogr. 30 (6), 703–718.
Hack, R., Huisman, M., 2002, September. Estimating the intact rock strength of a rock mass by simple means. In: Proceedings 9th Congress of the International Association for Engineering Geology and the Environment, 1620. Durban, South Africa.
Hermas, A., 2016. An Assessment of Socio-Economic and Environmentalimpacts of Oil and Gas Operations: a Case Study of the Host Communities under Western and Central Coastlines of Ghana (Doctoral Dissertation).
Hinrichsen, D., 1998. Coastal Waters of the World: Trends, Threats, and Strategies. Island Press, Washington D.C.
Hirdes, W., Davis, D.W., Eisenlohr, B.N., 1992. Reassesement of Proterozoic granitoid ages in Ghana on the basis of U/Pb zircon and monazite dating. Precambrian Res. 56, 89–96.
Ibe, A.C., Awosika, L.F., 1991. Sea level rise impact on African coastal zones. In: Omide, S.H., Juma, C. (Eds.), A Change in the Weather: African Perspectives on Climate Change. African Centre for Technology Studies, Nairobi, pp. 105–112.
Johnson, M.E., 1988. Why are ancient rocky shores so uncommon? J. Geol. 96 (4), 469–480.
Kennedy, D.M., Paulik, R., Dickson, M.E., 2011. Subaerial weathering versus wave processes in shore platform development: reappraising the Old Hat Island evidence. Earth Surf. Process. Landforms 36 (5), 686–694.
Kesse, G.O., 1985. The Mineral and Rock Resources of Ghana. Balkema, Rotterdam. Ghana Geological Survey.
Kumar, V.S., Anand, N.M., Chandramohan, P., Naik, G.N., 2003. Longshore sediment transport rate—measurement and estimation, central west coast of India. Coast. Eng. 48 (2), 95–109.
Limber, P.W., Brad Murray, A., Adams, P.N., Goldstein, E.B., 2014. Unraveling the dynamics that scale cross-shore headland relief on rocky coastlines: 1. Model development. J. Geophys. Res.: Earth Surface 119 (4), 854–873.
Loh, G., Hirdes, W., 1999. Explanatory Notes for the Geological Map of Southwest Ghana. Bulletin 49, 149. Ghana Geological Survey.
Loh, G.W., Hirdes, W., Anani, C., 1995. Geological Map of Ghana; Axim and Sekondi Sheets. Geological Survey of Ghana/BGR, Pub., Hanover.
Mano, A., Suzuki, S., 1999. Erosion characteristics of sea cliff on the Fukushima coast. Coast Eng. J. 41 (1), 43–63.
Mendes, F.M., Aires-Barros, L., Rodriques, F.P., 1966. The use of modal analysis in the mechanical characterisation of rock masses. In: Proc, 1. 1st Inc. Cong. Rock Mech., Lisbon, pp. 217–223.
Meriam, R., Herman, H.R., Kim, Y.C., 1970. Relation between texture and mechanical properties of crystalline rocks. Bull. Int. Assoc. Eng. Geol. 22, 173–177.
Moura, D., Gabriel, S., Jacob, J., 2011. Coastal morphology along the Central Algarve rocky coast: driver mechanisms. J. Coast Res. 790–794.
NA, N., 2019. Deepwater Tano Cape Three Points (DWT CTP). Update 3, 15-05.
Opare-Addo, E., 1992. Aspects of Early Proterozoic Granitoids and Migmatites in Southern Ghana: Implications for Crustal Evolution. Unpublished PhD. Thesis. Univ. Cambridge, p. 290.
Rosser, N.J., Brain, M.J., Petley, D.N., Lim, M., Norman, E.C., 2013. Coastline retreat via progressive failure of rocky coastal cliffs. Geology 41 (8), 939–942.
Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, Anton, Defeo, O., 2007. Sandy beaches at the brink. Divers. Distrib. 13 (5), 556–560.
Stephenson, W.J., Kirk, R.M., 1998. Rates and patterns of erosion on inter-tidal shore platforms, Kaikoura Peninsula, South Island, New Zealand. Earth Surf. Process. Landforms: J Br Geomorphol Group. 23 (12), 1071–1085.
Stephenson, W.J., Kirk, R.M., 2000. Development of shore platforms on kaikoura peninsula, south Island, New Zealand: Part one: the role of waves. Geomorphology 32 (1-2), 21–41.
Stewart, H.R., 2008. Introduction to Physical Oceanography. Texas A & M University, Texas.
Strzelecki, M., 2011. Schmidt hammer tests across a recently deglacierized rocky coastal zone in Spitsbergen-is there a "coastal amplification" of rock weathering in polar climates? Pol. Polar Res. 32 (3), 239–252.
Srivastava, A., Niu, X., Di, K., Li, R., 2005. Shoreline Modelling and Erosion Prediction. In: Paper presented at the ASPRS 2005 Annual Conference on Geospatial Goes Global: from Your Neighborhood to the Whole Planet, Baltimore, Maryland.
Sunamura, T., 1977. A relationship between wave-induced cliff erosion and erosive force of waves. J. Geol. 85 (5), 613–618.
Sunamura, T., 1992. Geomorphology of Rocky Coasts. Wiley, Chochester.
Taylor, R., 1990. Interpretation of the correlation coefficient: a basic review. J. Diagn. Med. Sonogr. 6 (1), 35–39.
Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., Ergul, A., 2009. The Digital Shoreline Analysis System (DSAS) version 4.0-an ArcGIS extension for calculating shoreline change (No. 2008-1278). US Geol Sur.
Trenhaile, A.S., 1983. The width of shore platforms; a theoretical approach. Geogr. Ann. Ser. A Phys. Geogr. 65 (1–2), 147–158.
Van Wellen, E., Chadwick, A.J., Mason, T., 2000. A review and assessment of longshore sediment transport equations for coarse-grained beaches. Coast. Eng. 40 (3), 243–275.
Violante, C., 2009. Rocky coast: geological constraints for hazard assessment. Geol Soc, London, Special Publ 322 (1), 1–31.
Wilcock, P.R., 1998. Two-fraction model of initial sediment motion in gravel-bed rivers. Science 280 (5362), 410–412.
Woodroffe, C.D., 2002. Coasts: Form, Process and Evolution. Cambridge University Press.