Tidal Influence on Foraminifera Distribution in a Typical Mesotidal River; A Case Study of the Great Kwa River, Southeastern Nigeria.

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Abstract -A study of foraminifera species distribution in the Great Kwa River revealed a foraminiferal assemblage that is sparse, poorly preserved with exotic and displaced faunas. This study further revealed that the Great Kwa River is a partially mixed (semidiurnal mesotidal) river with exotic, usually small-sized and thin walled open sea forms transported into the river through the estuary from the open ocean by tidal flow. The recovery of a large amount of shell fragments indicates that the river is characterised by a shallow shelf setting with a strong tidal influence. The foraminiferal assemblage recovered from the Great Kwa River contained arenaceous forms (*Reophax spp* and *Karreriella spp*) and calcareous forms (*Globorotalia cerezoalensis* and *Praeglobobulimina ovata*). Paleoecological interpretation of the Great Kwa River was a bit difficult due to the presence of exotic forms. Factors such as taphonomy, post- mortem transport and preservation condition in the Great Kwa River and their effect on the foraminiferal distribution were considered. The distribution of foraminifera in the Great Kwa River is similar to those found in other mesotidal rivers with influences from the estuary and open ocean.

Index Term: Great Kwa River, Nigeria, Foraminifera, Exotic fauna, Mesotidal River, Bathymetry, Estuary

1 Introduction

Rivers are naturally occurring channelised bodies of water moving downstream under the influence of gravity. Tidal rivers are those rivers influenced by tides, and thus depict both downstream and upstream movement of water in the channel because they usually flow into tidal estuaries [1]. Hayes (1976), [2] classified tidal environment depending on tidal range, as microtidal (0-2m), mesotidal (2-4m) and macrotidal (4-6m). The Great Kwa is a typical mesotidal river [1].

Wang and Murray (1983) [3] identified three sources of foraminifera assemblages in river estuaries as follow:

1 Indigenous forms living in the estuary. These are euryhaline forms mainly dwelling on tidal flats and marshes

2 Reworked or relict forms derived from the erosion of pene contemporaneous or older deposits.

3 Exotic specimens transported from the open sea into the river by tidal currents either as bed load or in suspension within the water column. These are usually open sea forms including both benthic and planktonic species. Tests transported as bed load are well sorted abraided and larger in size. More frequently are test transported in suspension, which are normally very tiny, thin walled and in a good state of preservation [3].

Only the first of the three groups is represented by living specimens in river estuaries [3]. The second group consisting of reworked foraminifera may be derived from strata of various ages and relict fauna may also be of different origin depending on local geological setting and past environments. Wang (1983a) [4]

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opined that species are at least partly reworked from older deposits and subjected to hydraulic sorting, as the average test size of these species follow the grain size of the sediments. Reworked relict foraminifera seem not to be rare in river estuaries, but are recognised only when distinctly preserved.

Generally, the distribution patterns of living foraminifera assemblages are mainly determined by water salinity [5], whereas those of dead assemblages depend on the hydrodynamic regime of the tidal river [3], [6], [7]. In turn both the salinity and hydrodynamics of tidal rivers are the product of river discharge on the one hand and tidal flow on the other.

The river discharge is a function of the drainage area, precipitation over it and its forest cover as well as the flow gradient. In some climatic zones, the river discharge may display very significant seasonal fluctuations. As for tidal flow, strength can be measured by the total volume of water entering the river mouth from the sea, which depends on tidal range, tidal type (diurnal versus semi diurnal), volume of the river channel and river discharge [8]. In summary, the ratio between river discharge and tidal flow controls the water salinity and hydrodynamics of a river estuary and hence the foraminiferal distribution in the sediments.

For geological applications however, dead foraminfeiral assemblages are of great importance as the fossil faunas are closer to dead rather than living assemblages in sediment. Dead assemblages are not simply drawn from living ones through production and mortality, but also result from post-mortem modification through transport destruction [9].

There are many river estuaries with almost no foraminifera test in channel deposits due to specific hydrodynamic conditions. Typical examples as presented by [10], include channel deposits of the Luan river estuary, to the east of Beijing (Peking) north China, and those of the Nanliujiang river estuary, Guangri province, south west China which are distinguished by coarse granulometry of the bottom sediments and microtidal regime. The coarse or medium sands there yield almost no foraminiferas, since the high energy environment there are suitable neither for living individuals to inhabit nor for dead specimens to be deposited [10].

2 Location of study Area

The Great Kwa River is located in Cross River State, in the south east coast of Nigeria, (Fig 1). This river takes its source from the Oban Massif and empties into the Cross River estuary, the largest estuary in West Africa, which in turn flows into the Atlantic Ocean.

The Great Kwa River lies between Longitudes $8^0$22′E and $8^0$25′E Latitudes $4^0$46′N and $4^0$52′N. The study area extends from the mouth of the estuary towards the head of the river (Fig1.)

The study area (Great Kwa River) lies within the sub-equatorial tropical rainforest belt of Nigeria. Two seasons are predominant in the area, viz; the rainy season which extends from April to October; and the dry season, which extends from December to March. Maximum precipitation occurs within the month of July and minimum precipitation occurs within February [11]. The mean annual precipitation ranges from 3000mm to 4000mm, while run off is high [12].

The Great Kwa River drains through the crystalline basement rock of the Oban Massif and the sedimentary deposits of the Calabar Flank. The dominant sediments of the Niger Delta in the study area is the Benin Formation also called the coastal plain sands [12]. Lithologically, the Benin Formation is made up of sands which are mostly medium to coarse grained, pebbly, moderately sorted with local lenses of fine grained poorly cemented sands and silty clay.

Based on petrographic analysis, [13], pointed out that rocks of the Precambrain basement and the Benin Formation which outcrop in the study area are made up of about 95.99% quartz grains, 1.0-2% Na-K-mica, 0.5-1.0% feldspar and 2.3% dark coloured minerals. The Cretaceous rocks of the Calabar Flank include conglomerates, sandstones, shales, limestones, marls etc., while gneiss, shists, granodiorites, granites, pegmatite etc., constitute rocks of the Precambrain Oban Massif [14], [15], [16], [17] and[18].

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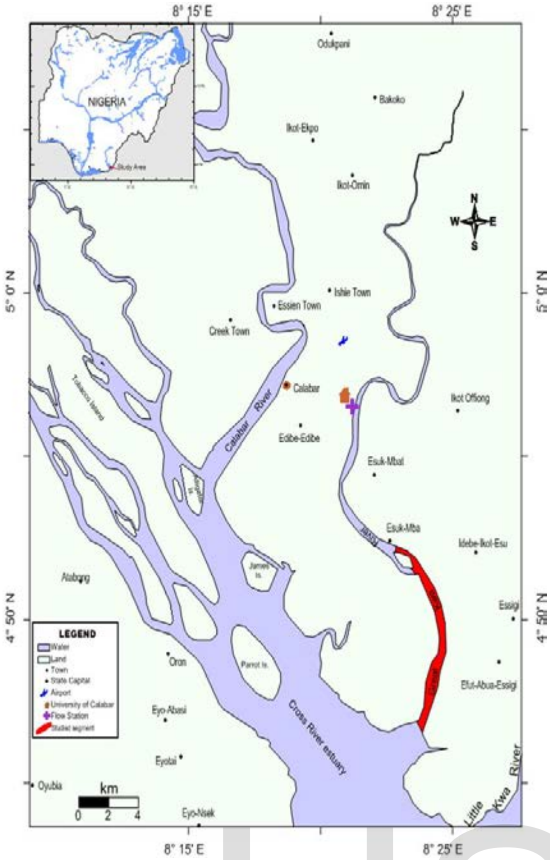

FIG. 1: Map of Cross River estuary showing Great Kwa River (study area), SE Nigeria (After Emeka, 2007) [1]

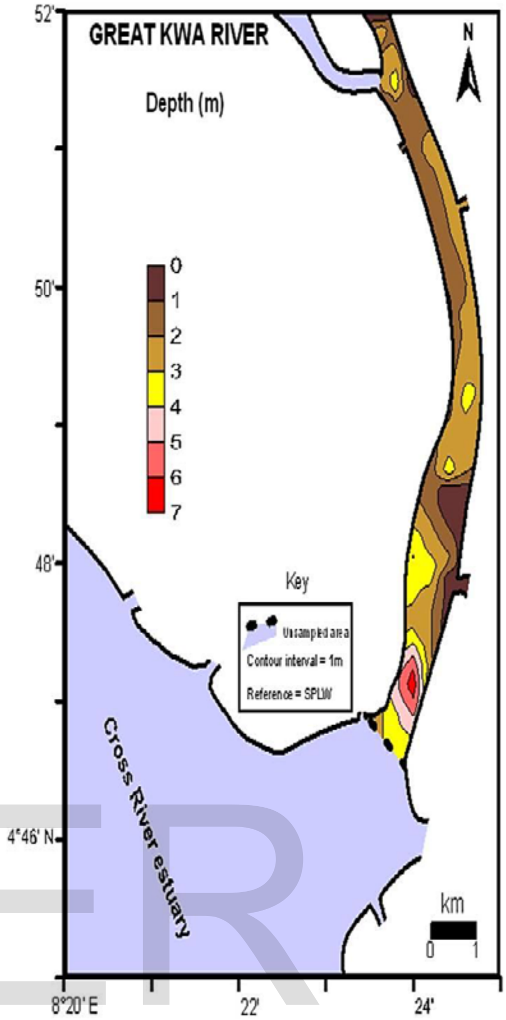

FIG. 2: Bathymeric map of Great Kwa River, SE Nigeria (After Emeka, *et al.*, 2010) [21]

3 Bathymetry

Depth is one of the obvious variables in rivers, seas and oceans. It has long been known that there is a depth zonation of foraminifera but useful and reliable data are scant, with some exceptions [19]. There is however, a certain amount of apparent confusion about these depth distributions. There seems to be rather widespread faunal boundreies at approximately 20m, 50m, 100m, 200-300m, 400-500m, 1000m and 2000m. The boundaries at 2000m are not so well known as the others because few faunas have been studied from such relatively great depths. Shchedrina (1958), [20] also suggest an ultra-abyssal boundary at 7,000m. The most marked faunal boundary seems to be at approximately 1,000m. The Great Kwa River channel is in its natural state because it has undergone negligible dredging throughout its history. Its bathymetry (Fig. 2) shows a shallow, low gradient channel.

Details on the bathymetry of the Great Kwa River by [21] shows that the river has a relatively uniform width apart from the bulge in the downstream section close to the mouth of the estuary where the minimum width of 35m was recorded. At the channel flanking Asuquo Island upstream, the maximum width of 655m was recorded. The channel has an average width of 398m with its greatest depth (6m) occurring at the mouth of the estuary. It narrows and deepens downstream. At the upstream sections, close to the island the maximium depth is 4.08m, the western bank is generally shallow and it has a gentle slope compared to the eastern bank. A good portion of both banks prograde into the river channel. Figs. 3 and 4 show channel bathymeric profiles and Bathymeric transect map of Great Kwa River

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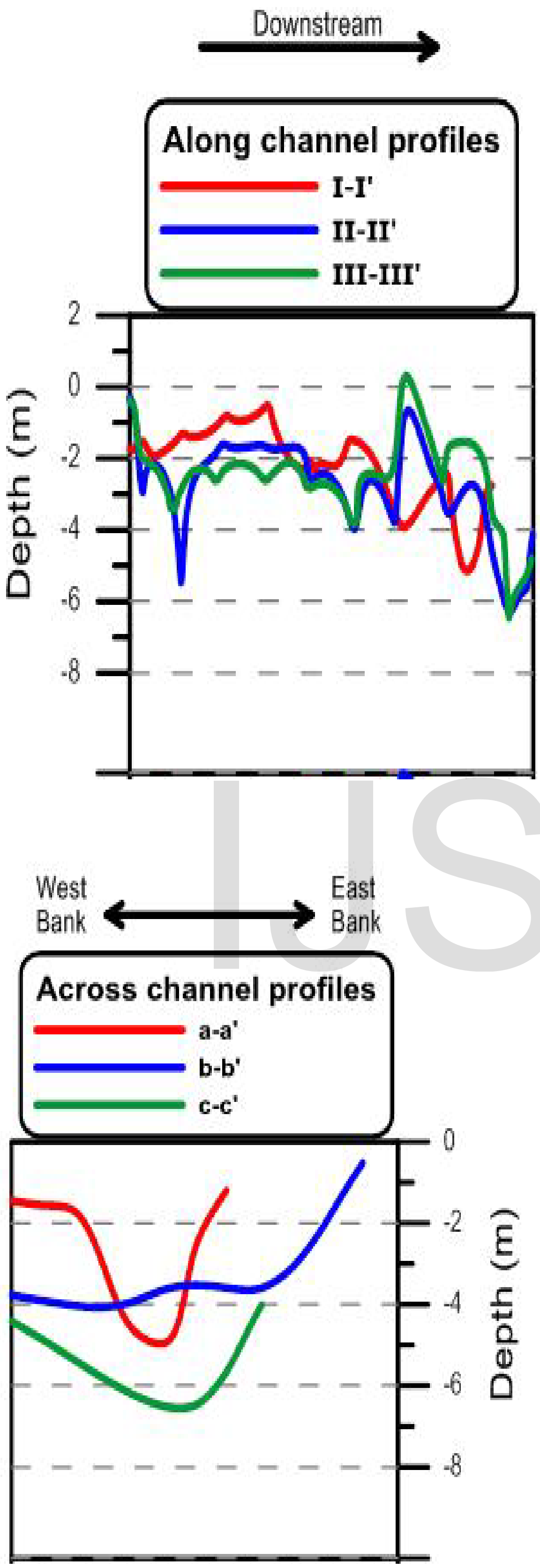

Fig. 3: Along channel and across channel bathymeric profiles of Great Kwa River, SE Nigeria (After Emeka, *et al.*, 2010) [21]

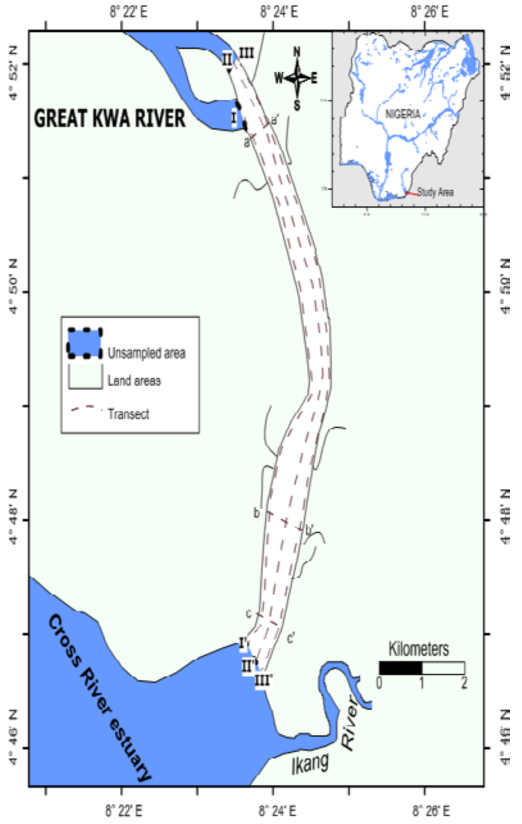

FIG. 4: Bathymeric transect map of Great Kwa River, SE Nigeria (After Emeka, 2010) [1]

4 Materials and methods

A total of 50 samples were collected from 10 locations (locations 1a, 1b, 1c, 1d, 1e, 2a, 2b, 2c, 2d, 2d, 2e, 3a, 3b, 3c, 3d, 3e, 4a, 4b, 4c, 4d, 4e, 5a, 5b, 5c, 5d, 6a, 6b, 6c, 6d, 6e, 7a, 7b, 7c, 7d, 7e, 8a, 8b, 8c, 8d, 8e, 9a, 9b, 9c, 9d, 9e, 10a, 10b, 10c, 10d and 10e) along the Great Kwa River channel. Fig. 5 presents a map of the Great Kwa River showing sample locations.

Samples collection was achieved with the use of a Van Veen grab suspended from a boat (sampling grid was 2.0km) and special care was taken to prevent contamination of the samples. The samples were collected in well labelled clear plastic bags, stored in boxes and transferred to the laboratory. The obtained samples were composited to 10km and used for foraminiferal analysis. The sample preparations were carried out in a standard micropaleontological laboratory and the processes were in line with the procedures of foraminiferal sample preparation outlined by [22], [23], [24]. Foraminifera taxa were identified by comparing them with forms that had previously been published.

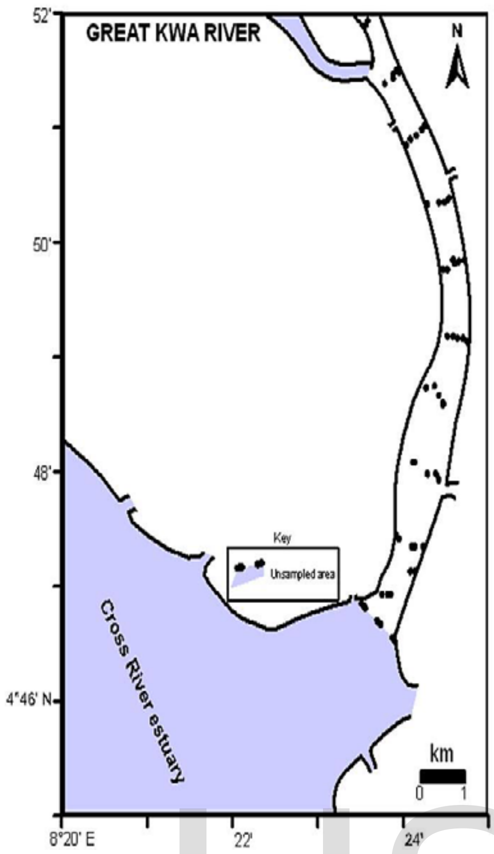

FIG. 5: Map of Great Kwa River, SE Nigeria showing sample locations (After Emeka, *et al.*, 2010) [21]

5 Results and Discussion

The foraminiferal assemblage recovered from the Great Kwa River channel is poorly preserved due to high tidal strength and poorly diverse in species and specimen abundance. The forms were mainly displaced and exotic species that were washed up the river channel from the Cross River Estuary and the Atlantic Ocean.

A high amount of shell fragments (26) recovered at the mouth of the estuary (location 1) confirms the Great Kwa River to be a mesotidal river in a shallow environment (Fig.6). These shell fragments must have been tests of foraminifera broken up by high tidal strength in a river channel.

Samples from locations 5, 6, 7, 8 and 10 were barren of foraminifera as no foraminifera specimen was recovered from these samples during the study. Low specimen abundance in the Great Kwa River is the result of high tidal strength. This is similar to findings by [6], which show that the tidal transport of foraminiferal tests affects their abundance in estuarine deposits.

Altogether, only four different foraminifera species were identified comprising of one planktonic and three benthic forms. The occurrence of only one planktonic species (*Globorotalia cerezoalensis)* is another indication of high tidal strength of the Great Kwa River as planktonic forms are more susceptible to destruction than their benthic counterparts. The benthic species consists of two arenaceous forms which include *Reophax spp* and *Karreriella spp* and a calcareous form (*Praeglobobulimina ovata).*

Along the channel profile, the only planktonic form in the assemblage was recovered at the middle of the channel profile (location 4). The presence of twenty six (26) shell fragments at the mouth of the estuary indicate that most of the planktonic forms were broken by tidal activity in the river channel. This indicates that the Great Kwa River has a high tidal strength. The presence of exotic and displaced forms in the Great Kwa River is another indication of strong tidal influence in the river. The arenaceous form *(Reophax spp*) recovered at the head of the river channel (location 9) is most likely a displaced fauna that was probably washed up the river channel from the Cross River estuary because *Reophax spp* is an arenaceous form characteristic of low salinity of brackish estuaries and lagoons. The aranaceous form (*Karreriella spp)* recovered from location (2) is an exotic specie washed in from the Atlantic ocean into the Cross River estuary and up the Great Kwa river channel by tidal activity (Fig 6). *Karreriella spp* is an extant outer shelf/ bathyal environment specie.

Due to the occurrence of mainly exotic and displaced fauna in the Great Kwa River, little inference can be drawn from the occurrence of arenaceous or calcareous forms in the Great Kwa River.

The salinity of the Great Kwa River probably increases down the river profiles due to ocean influence in the Cross River estuary. There is usually the mixing of fresh and marine water in mesotidal river estuary due to high tidal range which aids mixing of the waters; this makes the Great Kwa River estuary a mixed estuary.

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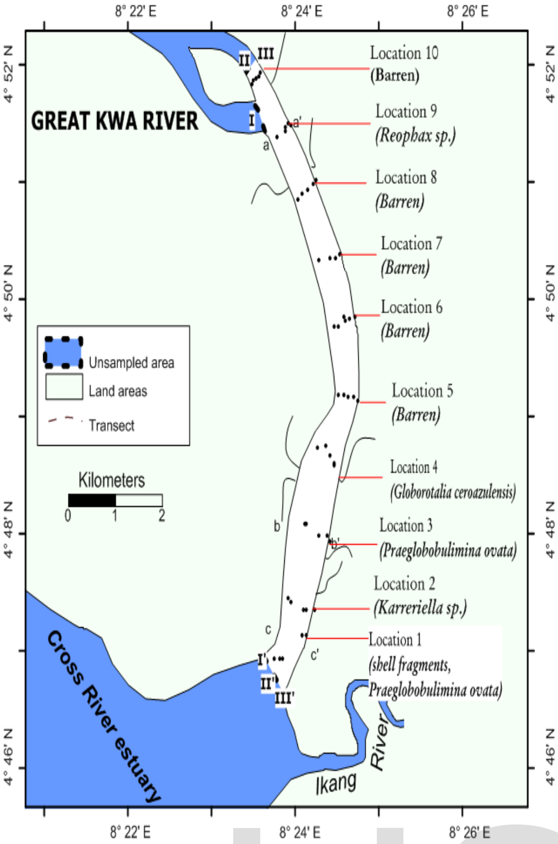

FIG.6: Map of Great Kwa River showing foraminifera data (After Ikediasor, 2010) [25]

The study area (the Great Kwa River) is basically a shallow shelf environment as the greatest depth obtained along the river-channel (6m) by [21], was at the estuary mouth. The high tidal influence in the river channel gave rise to a large amount of shell fragments, which were tests of foraminifera destroyed by tidal flow. The high amount of shell fragments in turn indicate a shallow shelf environment for the Great Kwa River.

5.1 Hydrodynamic control

Estuaries can be classified into four groups according to their circulation; salt-wedge (laminated) estuaries, partially mixed estuaries, well mixed estuaries and fjords. Since fjords can be considered as salt wedge estuaries with a deep lower layer [26], we have in principle three groups of estuaries. These generally relate to micro-tidal (< 2m tidal ranges), meso-tidal (2-4m) and macro-tidal (>4m) conditions [2]. The Cross River estuary into which the Great Kwa River flows is a meso-tidal estuary. Theoretically, foraminiferal test from the open sea can be transported by the tidal flow and other forces into all kinds of estuaries, but in practice these exotic forms may occur in a significant number and reach a noticeable distance upstream only in macro-tidal and meso-tidal conditions or in well and partially mixed estuaries, where all dead foraminiferal tests may be redeposited and size-sorted according to local hydrodynamic conditions [27]. In the Great Kwa River channel, an arenaceous form (*Karreriella spp)* which is an extant outer shelf /bathyal form was recovered from samples obtained from the river channel. This form which is an exotic form was brought into the Cross River estuary from the Atlantic Ocean and washed up the Great Kwa River channel.

Partially and well mixed (mesotidal and microtidal) estuaries have a significant proportion of exotic foraminifera introduced in suspension with a small thin-walled tests and high diversity characteristic [3]. Tidal strength is therefore the major reason for the formation of the two kinds of assemblages found in tidal rivers and estuaries. Tidal range is very important, but is only one of the factors determining tidal strength in tidal rivers [3].

The circulation type of tidal rivers may be subjected to seasonal variations. Chappel and Ward (1985), [28] used the South Alligator River in Australia as a case example where the low gradient coupled with the large tidal range (6m) enables the tidal influence to penetrate to practically the entire length of the river. In the dry season, the fresh water discharge is reported to be low and the coastal reach of the river become well mixed, while in the wet season a salt wedge estuary developes. This is similar to what happens in Great Kwa River. The variations have given rise to foraminiferal assemblage with a mixed exotic and indigenous composition in the river estuary.

The abundance of exotic foraminifera tests in estuarine sediments may vary seasonally as such changes in river run off mediate the effects of tidal transport of foraminifera tests. In the rainy season, tidal transport is handicapped by high fresh-water run-off and the number of foraminiferal tests transported from the sea is much less in the dry season [10].

5.2 Taphonomy

Paleoenvironmental interpretation of foraminiferal faunas not only requires knowledge of their ecology, but also their taphonomy, which is affected by post-mortem transport and preservation conditions [29]. A description of the observations of these factors and their effects in the Great Kwa River environment is presented below.

5.3 Transport

Where tidal currents are weak, (microtidal or diurnal mesotidal estuaries), foraminifera faunas in the bottom sediments are generally autochthonous [3]. Classical examples of foraminiferal test in microtidal or semidiurnal mesotidal estuaries with strong tidal flow from the UK, Elber Germany and China have been presented by various authors [30], [31], [32], [4] and [6]. Marine foraminifers in such system are carried and deposited up the estuary, particularly those that tend to float [29]. Transport in suspension is indicated by the occurrence of bethonic foraminiferal tests in the water column in the Elbe and Yangtse Rivers with species compositions comparable with that in the surface sediment beneath [32] and [33]. Together with resuspension from the sediment, foraminifers in macrotidal estuaries tend to become size sorted [27].

This is exactly the case in the Great Kwa River which is a semidiurnal mesotidal estuary. The benthic arenaceous form (*Reophax spp)* recovered at location 9, is characteristic or tolerant of low salinity of brackish estuaries and lagoons and was probably washed in from the Cross River estuary by tidal flow and washed up the Great Kwa River; it was probably transported in suspension to the river head, where it was recovered at location 9.

Another example from the forms recovered from the Great Kwa River is the benthic arenaceous form *(Karreriella spp)* recovered at location 2. The *Karreriella spp* is an exotic species washed in from the Atlantic Ocean into the Cross River estuary and the Great Kwa River channel. It is an extant outer shelf/ bathyal environment specie.

In most tidal rivers the proportion of marine forms in the channel sediment decreases upstream especially those with arenaceous and porcelaneous tests, whereas brackish water forms and small sized lighter forms prone to floating increase upstream [29]. This is also in line with the foraminiferal distribution in the Great Kwa River where the *Reophax spp* which is characteristic or tolerant of low salinity of brackish estuaries and lagoons was recovered furthest at the river head (location 9) and the marine form, *Karrerialla spp* which is an extant outer shelf/ bathyal environment specie that was probably washed in from the Atlantic Ocean was recovered closer to the river mouth at location 2 (Fig.6).

5.4 Preservation

The preservation potential of foraminiferal test varies with foraminiferal characteristics and with the characteristics of the depositional environment such as tidal strength, and its chemical properties like the P^H [29].

The recovery of a large amount of shell fragments at the mouth of the estuary (location 1) is indicative of a high tidal strength in the Great Kwa River and also confirms the Great Kwa River to be a mesotidal river estuary in a shallow environment. This results in the foraminiferal test being poorly preserved, dissolved and broken into fragments by tidal flow.

The distribution of calcareous versus arenaceous foraminfers in marginal marine environments is also controlled by P^H [34], [35] and [27]. In normal marine conditions the P^H value exceeds 8 and the water is normally saturated with calcium carbonate at shallow depths. However, P^H varies considerably in estuaries, and the foraminiferal fauna recovered from Great Kwa river contained both arenaceous and calcareous forms which ordinarily would indicate an average P^H, if they were indigenous forms but they are exotic forms brought in from the Atlantic Ocean and the Cross River estuary so little inference can be drawn from them regarding the P^H

5.5 Ecological control

Generally, the distribution pattern of living assemblages can be determine by water salinity [5], whereas those of dead assemblages depend on the hydrodynamic regime of the estuary [3], [6] and [7]. The ratio between river discharge and tidal flow controls the water salinity and hydrodynamics of a river estuary and hence the foraminifera distribution in its sediments.

Salinity and P^H seem to be the major ecological factors controlling the distribution of living faunas in tidal rivers estuaries [35]. In the Great Kwa River with mainly exotic and displaced faunas ecological interpretation is very difficult. This is so because only indigenous forms are useful in paleoecological interpretations, especially for reconstruction of paleosalinity and paleo-P^H; exotic forms transported from the open sea in to the river are indicative of tidal strength. Reworked or relict forms should be excluded from paleoecological studies, but their size sorting may be used for indicating hydraulic condition.

6 Conclusions

The Great Kwa River foraminiferal assemblage is characterized by sparse and poorly preserved forms with exotic and displaced faunas. This assemblage is a fall out of the tidal flow in the river and the Cross River estuary, leading to the introduction of exotic forms from the Cross River estuary and the Atlantic Ocean.

The recovery of a large amount of shell fragments further confirms the tidal strength of the Great Kwa River and also indicates that the environment is characterized by a shallow shelf setting.

In meso-tidal river and mixed estuaries like the Great Kwa river, the presence of exotic forms make paleo-ecological interpretation difficult. In a scenario like this, care must be taken to ensure that only the indigenous forms are used, if present.

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