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Depositional environment and morphometric analysis of pebbles from a river bed at Odufor, Etche in Rivers State, Nigeria

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Abstract

In this study, the depositional environment of parts of Etche in Rivers State was determined using pebble morphometric analysis. This involved the collection and classification of approximately 100 pebble samples from stream deposits at Odufor, Etche. Morphometric measurements taken, included the Long (L), Intermediate (I), and Short (S) axes, using a Vernier caliper. These raw data were then used to calculate indices such as Flatness Ratio (FR), Elongation Ratio (ER), Maximum Sphericity Projection Index (MPSI), and Oblate–Prolate (OP) Index. Results from the analysis showed that the flatness ratio had an average value of 0.52 ± 0.12, elongation ratio (ER) has values within the range of 0.98– 0.65 with mean value of 0.84 ± 0.08, The roundness has values ranging from 10% to 90% with mean value of 45.5% all suggesting a fluvial environment. While the mean maximum projection sphericity index (M.P.S.I) for pebbles is 0. 36± 0.04 with range of 0.48 to 0.94 indicates a marine influence, But the Bivariate plot for flatness index vs sphericity (MPSI) showed that the pebbles beds from Odufor clustered in the fluvial area. The morphometric analysis of the pebbles suggests the presence of a mixed nature of transport and an environment of deposition that is presumably of fluvial with marine influence. This quantitative evaluation helps to verify the transport processes and interpret the depositional environments within the Niger Delta Basin.

Keywords: Morphometric Analysis; Flatness Ratio; Elongation Ratio; Bivariate Plot; Depositional Environment

1. Introduction

The Benin Formation is the youngest lithostratigraphic unit of the Niger Delta basin followed by the Agbada Formation and the Akata Formation at the base. It's a continental deposit that consists predominantly of coarsed-medium grained poorly sorted sands interbedded with minor clay, silty clay and occasional pebble lags indicative of high energy depositional processes (Nwozor, 2025)

Pebble morphormetrics is an invaluable technique in determining paleoenvironments. Several works have been done on pebble morphometrics in sedimentary basin in Nigeria as discussed by Odumodu and Ephraim (2007), Odumodu and Odumodu (2012), Ephraim et al (2015), Ogbe et al (2019), Onwuegbuchulam et al (2019). They used morphometric parameters such as the Flatness Ratio (FR), Elongation Ratio (ER), Maximum Sphericity Projection Index (MPSI), and Oblate–Prolate (OP) Index to analyze the transport mechanisms and depositional settings in several basins.

However, this paper aims to improve on the existing knowledge of the Benin Formation that is well exposed at the Odufor area in Eche Local Government Area of the Niger Delta Basin by using pebble morphometric analysis to determine the depositional Environment.

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2. Location of study area

Odufor which is the study location is located in Etche L.G.A., Rivers State, which lies on longitude 7°04′E and latitude 5°11′N, with an elevation of about 39m, accessible by a network of roads connecting it to Port Harcourt and neighbouring towns such as Oyigbo, Eleme, and Ikwerre. Etche is located within the Niger Delta Basin (Figure 1).

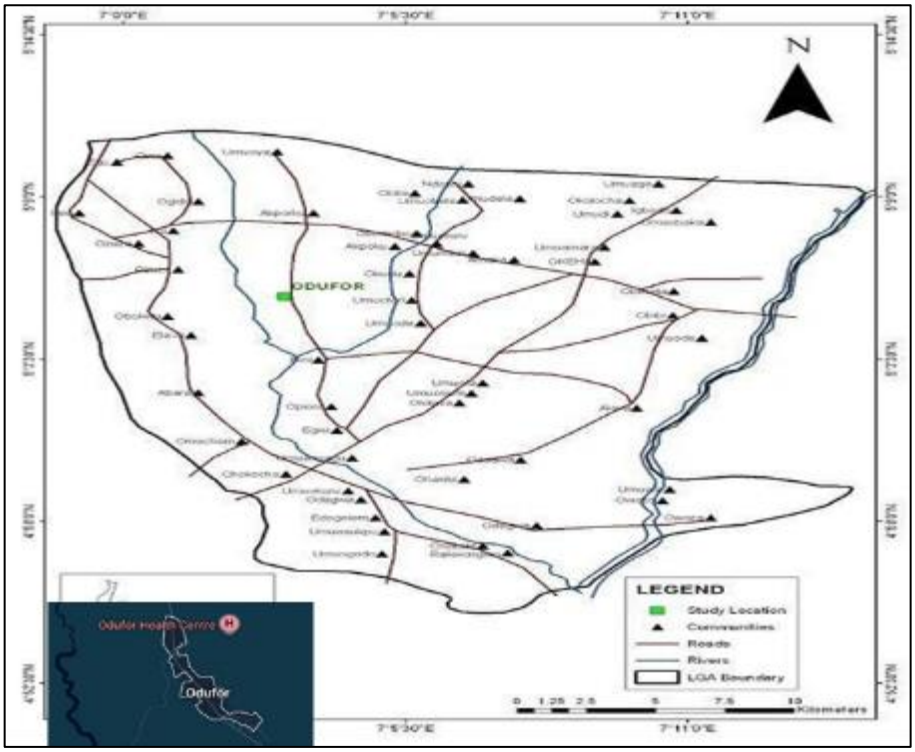

Figure 1 Regional map of Rivers State showing the study area Odufor

3. Regional geologic setting

The Niger Delta lies along the West African continental margin within the Gulf of Guinea It extends across the Niger Delta Province, approximately between longitudes 5°E and 8°E and latitudes 4°N and 6°N (Tuttle et al. 1999). The Niger Delta Basin is bordered to the east by the Calabar Flank, which represents the subsurface continuation of the Oban Massif, and to the west by the Benin Flank, the subsurface extension of the West African Shield. It is limited to the north by the post-Abakaliki Anambra Basin, while its southern margin opens into the Atlantic Ocean (Murat, 1972).

The Niger Delta stratigraphic succession is characterized by a regressive, upward-coarsening sequence of Tertiary sediments that exhibit pronounced diachroneity (Weber and Daukoru, 1975; Evamy et al., 1978). The Cenozoic stratigraphy of the Niger Delta reflects the interplay of multiple depositional environments that governed sediment accumulation through time.

The stratigraphic framework of the Niger Delta basin has been discussed extensively by Frankyl and Cordry (1967), Short and Stauble (1967), Avbovbo (1978), Evamy et al. (1978), Ejedawe et al. (1984), Nwachukwu and Chukwura (1986), Haack et al. (2000), and Reijers (2011).

4. Materials and methods

More than 100 pebbles were randomly sampled from a river bed in the study area. The study location was geo referenced using a Global Positioning System device. The pebbles were washed, air dried, labelled and transported to the laboratory. The sampled pebbles were later screened to remove unbroken ones and pebbles of high resistance to abrasion was chosen for morphometric analysis. The analysis involves measuring the long(L), intermediate(I), and short(S) axes of the pebbles (Fig 2) using a Venier Caliper (Zingg, 1935, and Krumbein, 1941). The morphometric indices such as Flatness Ratio (FR), Elongation Ratio (ER), Maximum Sphericity Projection Index (MPSI), and Oblate–Prolate

(OP) Index were calculated using established equations in table 1, as given by the different authors. Zingg (1935) classification system was used to classify the shape of the pebbles into spherical, disc, rod, and blade shapes based on the ratios of their axes).The various derived morphometric indices were used to construct bivariate plots such as flatness ratio (FR) vs maximum projection and sphericity index (MPSI) for environment of deposition, flatness ratio (FR) vs elongation ratio (ER) for the pebble form to verify paleoenvironmental interpretations of the 100 pebbles sample collected with the provenance, transport, and depositional processes.

Figure 2 Laboratory analysis of pebbles from morphometric analysis

Table 1 Morphometric indices and formula

S/No	Formula	Reference
1	Maximum Projection Sphericity Index (MPSI) = $\{S^2/LI\}^{1/3}$	Sneed and Folk, 1958
2	Elongation Ratio, (ER) = I/L	Lutig, 1962; Sames, 1966
3	Flatness Ratio **FR = S/L**	Lutig, 1962
4	Flatness Index = (L – I + S) / L	Illenberger 1992
5	Oblate – Prolate (OP) Index =1 0(L-I-0.5)/(L-S)/(S/L)	Dobkins and Folk 1970

5. Results and Discussions

The results obtained from the morphometric analysis of pebbles from Odufor is presented in the tables 2 and 3.

Table 2 Morphometric Data for the Benin Formation exposed at a River bed at Odufor, Etche Rivers State.

Pebbl e ID	L (cm)	I (cm)	S (cm)	Flatness ratio (S/L)	Elongation Ratio (I/L)	$\overline{LL--SI}$	MPSI S2 /LI)1/3	OPI
O1	12.62	11.81	7.6	0.60222	0.93582	0.16135	0.37082	-2.0394
O2	17.47	12.25	5.79	0.33143	0.7012	0.44692	0.3002	-0.1759
O3	10.62	9.29	8.02	0.75518	0.87476	0.51154	0.43319	0.08714
O4	12.15	9.27	5.96	0.49053	0.76296	0.46527	0.37543	-0.1704
O5	11.08	8.82	6.49	0.58574	0.79603	0.49237	0.40496	-0.0447
O6	10.62	9.68	7.78	0.73258	0.91149	0.33099	0.42299	-1.2382
O7	14.61	12.46	7.53	0.5154	0.85284	0.30367	0.34584	-1.0119

O8	11.15	9.98	7.78	0.69776	0.89507	0.34718	0.41196	-1.0663
O9	12.31	9.14	5.49	0.44598	0.74249	0.46481	0.36542	-0.1569
O10	14.61	12.46	7.53	0.5154	0.85284	0.30367	0.34584	-1.0119
O11	17.41	14.61	7.71	0.44285	0.83917	0.28866	0.31179	-0.9359
O12	17.31	15.11	8.16	0.4714	0.87291	0.24044	0.31481	-1.2236
O13	10.83	7.9	4.92	0.45429	0.72946	0.49577	0.38598	-0.0192
O14	10.25	9.75	6.36	0.62049	0.95122	0.12853	0.39925	-2.3049
O15	12.82	8.87	5.46	0.4259	0.69189	0.53668	0.36346	0.15624
O16	23.26	17.8	10.99	0.47248	0.76526	0.44499	0.2983	-0.2599
O17	9.78	8.56	5.84	0.59714	0.87526	0.30964	0.41166	-1.1367
O18	15.56	14.06	8.53	0.5482	0.9036	0.21337	0.33909	-1.5713
O19	11.14	10.78	6.29	0.56463	0.96768	0.07423	0.37415	-2.4041
O20	12.68	11.96	8.19	0.6459	0.94322	0.16036	0.37799	-2.1938
O21	15.69	12.91	3.67	0.23391	0.82282	0.23128	0.26265	-0.6286
O22	12.13	9.78	5.26	0.43364	0.80627	0.34207	0.35394	-0.6849
O23	15.38	14.49	5.4	0.35111	0.94213	0.08918	0.28937	-1.4424
O24	10.56	9.69	6.31	0.59754	0.91761	0.20471	0.39508	-1.7645
O25	15.83	14.93	7.2	0.45483	0.94315	0.10429	0.31232	-1.7998
O26	14.25	13.01	8.53	0.5986	0.91298	0.21678	0.35833	-1.6953
O27	12.38	10.26	6.28	0.50727	0.82876	0.34754	0.36703	-0.7734
O28	13.86	12.58	6.33	0.45671	0.90765	0.16999	0.33112	-1.5072
O29	13.78	12.24	5.54	0.40203	0.88824	0.18689	0.32025	-1.2588
O30	20.24	18.43	12.68	0.62648	0.91057	0.23942	0.32394	-1.6325
O31	20.96	19.27	6	0.28626	0.91937	0.11296	0.44669	-1.1079
O32	13.94	13.06	10.59	0.75968	0.93687	0.26269	0.38746	-1.8028
O33	12.52	12.1	7.31	0.58387	0.96645	0.08061	0.36406	-2.4487
O34	12.19	11.81	6.13	0.50287	0.96883	0.06271	0.3492	-2.199
O35	12.72	11.08	8.24	0.6478	0.87107	0.36607	0.38812	-0.8676
O36	12.28	11.14	5.48	0.44625	0.90717	0.16765	0.34216	-1.4831
O37	11.72	10.35	6.65	0.56741	0.88311	0.27022	0.37988	-1.3038
O38	15.3	13.81	10.09	0.65948	0.90261	0.28599	0.3628	-1.4114
O39	14.24	11.64	5.8	0.4073	0.81742	0.30806	0.32708	-0.7818
O40	14.19	12.76	7.27	0.51233	0.89922	0.20665	0.34243	-1.5029
O41	14.68	12.47	5.87	0.39986	0.84946	0.25085	0.3177	-0.9963
O42	11.06	9.71	7.69	0.6953	0.87794	0.40059	0.41526	-0.6912
O43	17.4	11.65	6.64	0.38161	0.66954	0.53439	0.31996	0.13122
O44	15.68	12.18	6.98	0.44515	0.77679	0.4023	0.33186	-0.4349
O45	12.35	10.67	5.83	0.47206	0.86397	0.25767	0.35368	-1.144

O46	9.52	8.98	6.24	0.65546	0.94328	0.16463	0.41792	-2.1982
O47	12.86	12.54	4.48	0.34837	0.97512	0.03819	0.30286	-1.6088
O48	13.58	11.95	7	0.51546	0.87997	0.24772	0.35071	-1.3004
O49	16.78	14.33	7.58	0.45173	0.85399	0.2663	0.3159	-1.0557
O50	13.56	11.34	6.73	0.49631	0.83628	0.32504	0.35241	-0.8684
O51	14.24	10.92	9.73	0.68329	0.76685	0.73614	0.397	1.61353
O52	12.45	10.51	5.15	0.41365	0.84418	0.26575	0.34016	-0.969
O53	15.59	11.64	9.17	0.5882	0.74663	0.61526	0.36971	0.67798
O54	17.39	12.11	10.34	0.59459	0.69638	0.74894	0.36618	1.48016
O55	13.99	10.9	4.4	0.31451	0.77913	0.32221	0.30672	-0.5592
O56	15.72	13.96	6.27	0.39885	0.88804	0.18624	0.30571	-1.2514
O57	15.38	12.37	8.34	0.54226	0.80429	0.42756	0.3526	-0.3928
O58	10.74	7.82	6.35	0.59125	0.72812	0.66515	0.42285	0.97643
O59	11.45	10.58	6.35	0.55459	0.92402	0.17059	0.37425	-1.8269
O60	10.83	9.77	6.44	0.59464	0.90212	0.24146	0.39336	-1.5374
O61	14.44	8.37	6.11	0.42313	0.57964	0.72869	0.36976	0.96766
O62	18.94	10.35	6.12	0.32313	0.54646	0.67005	0.31488	0.54946
O63	11.99	10.32	5.29	0.4412	0.86072	0.24925	0.34967	-1.1063
O64	11.84	10.35	6.12	0.51689	0.87416	0.26049	0.36826	-1.238
O65	9.69	8.43	4.27	0.44066	0.86997	0.23247	0.3739	-1.1789
O66	16.9	14.58	11.56	0.68402	0.86272	0.43446	0.36067	-0.4483
O67	13.54	9.91	6.24	0.46086	0.73191	0.49726	0.35961	-0.0126
O68	14.36	10.45	4.44	0.30919	0.72772	0.39415	0.30929	-0.3273
O69	13.13	10.31	6.76	0.51485	0.78522	0.4427	0.36825	-0.295
O70	16.52	12.83	9.4	0.56901	0.77663	0.51826	0.35397	0.10389
O71	10.26	8.6	5.35	0.52144	0.83821	0.33809	0.39286	-0.8443
O72	12.54	11.78	5.09	0.4059	0.93939	0.10201	0.32541	-1.6154
O73	10.4	8.98	6.98	0.67115	0.86346	0.4152	0.42123	-0.5691
O74	13.42	11.4	8.27	0.61624	0.84948	0.39223	0.37811	-0.6641
O75	10.08	8.53	5.27	0.52282	0.84623	0.32225	0.39428	-0.9293
O76	11.56	9.39	6.76	0.58478	0.81228	0.45208	0.39638	-0.2802
O77	11.3	10.25	6.6	0.58407	0.90708	0.2234	0.38481	-1.6155
O78	9.51	8.54	6.48	0.68139	0.898	0.32013	0.43051	-1.2256
O79	13.3	11.42	10.31	0.77519	0.85865	0.62876	0.40792	0.99815
O80	14.09	11.5	6.26	0.44429	0.81618	0.33078	0.33806	-0.7518
O81	11.85	8.55	7.82	0.65992	0.72152	0.81886	0.42577	2.1042
O82	11.27	8.45	4.59	0.40728	0.74978	0.42216	0.36392	-0.317
O83	10.82	8.03	6.44	0.59519	0.74214	0.63699	0.42006	0.81533

O84	13.23	10.87	4.75	0.35903	0.82162	0.2783	0.32085	-0.796
O85	13.24	12	6.44	0.4864	0.90634	0.18235	0.34351	-1.5451
O86	16.03	13.71	7.28	0.45415	0.85527	0.26514	0.32116	-1.0666
O87	12.77	10.77	7.3	0.57165	0.84338	0.36563	0.37581	-0.7681
O88	10.6	9.49	5.72	0.53962	0.89528	0.22746	0.38454	-1.4707
O89	13.06	11.12	5.2	0.39816	0.85145	0.24682	0.3296	-1.0081
O90	10.13	7.9	6.18	0.61007	0.77986	0.56456	0.42584	0.39384
O91	8.84	7.32	6.2	0.70136	0.82805	0.57576	0.45759	0.53133
O92	9.39	8.35	5.94	0.63259	0.88924	0.30145	0.42313	-1.256
O93	15.39	12.61	6.31	0.41001	0.81936	0.30617	0.31917	-0.7947
O94	11.09	8.16	6.96	0.62759	0.7358	0.70944	0.42527	1.31445
O95	10.02	9.12	4.11	0.41018	0.91018	0.15228	0.35563	-1.4263
O96	10.9	9.68	6.5	0.59633	0.88807	0.27727	0.39495	-1.3282
O97	8.7	7.2	5.07	0.58276	0.82759	0.41322	0.43257	-0.5057
O98	9.16	8.46	6.58	0.71834	0.92358	0.27132	0.43953	-1.6427
O99	11.5	9.74	4.62	0.40174	0.84696	0.25581	0.34551	-0.981
O100	15.97	12.64	7.09	0.44396	0.79148	0.375	0.32749	-0.5549
Mean	**13.1946**	**11.0676**	**6.7554**	**0.52185**	**0.84295**	**0.33842**	**0.36494**	**-0.7956**
STdev	**2.73885563**	**2.30725**	**1.65982**	**0.11704**	**0.08186**	**0.17017**	**0.04087**	**0.91442**

Table 3 Summary of Environmental Diagnosis for pebble morphometric analysis of the Odufor Pebbles

Morphometric indices	**Characteristics**	**Environmental indicators**
Flatness Ratio	Average value = 0.52	Fluvial
Elongation Ratio	Average value =0.84	Fluvial
Maximum Projection Sphericity	Average value =0.36	lithoral
Oblate Prolate	Average value =-0.8	Fluvial
Dominant pebble forms	Elongated (E) and Bladed (B)	Fluvial
Plot of flatness ratio (FR) versus maximum projection Sphericity	90% fluvial and 20% beach	Fluvial

As shown in Tables 2 and 3, the mean flatness ratio (FR) for the pebbles from Benin Formation in the study area is 0.52 ± 0.12 suggesting a fluvial environment. (Dobkins and Folk 1970). Similarly, elongation ratio (ER) has values within the range of 0.98– 0.65 with mean value of 0.84 ± 0.08

With the pebble suites more equant or rod-shaped, suggesting a fluvial environment (Fig 3)

The roundness has values ranging from 10% to 90% with mean value of 45.5%. The degree of roundness for each pebble set from the Benin Formation and its mean are shown in Table 4. Indications from the results showed that pebbles from the Benin Formation range from subangular to well rounded.

The mean maximum projection sphericity index (M.P.S.I) for pebbles from the Benin Formation in the study area is 0. 36± 0.04 with range of 0.48 to 0.94 indicates a marine influence, However in Figure 4, The Bivariate plot for flatness

index vs sphericity (MPSI) showed that the pebbles from Odufor clustered in the fluvial area. The Oblate – Prolate index values for the Benin Formation for the suites of pebbles in Odufor ranged from -0.01to 1.60 with mean value of -0.8± 0.9 also suggesting a fluvial environment (Dobkins and Folk 1970).

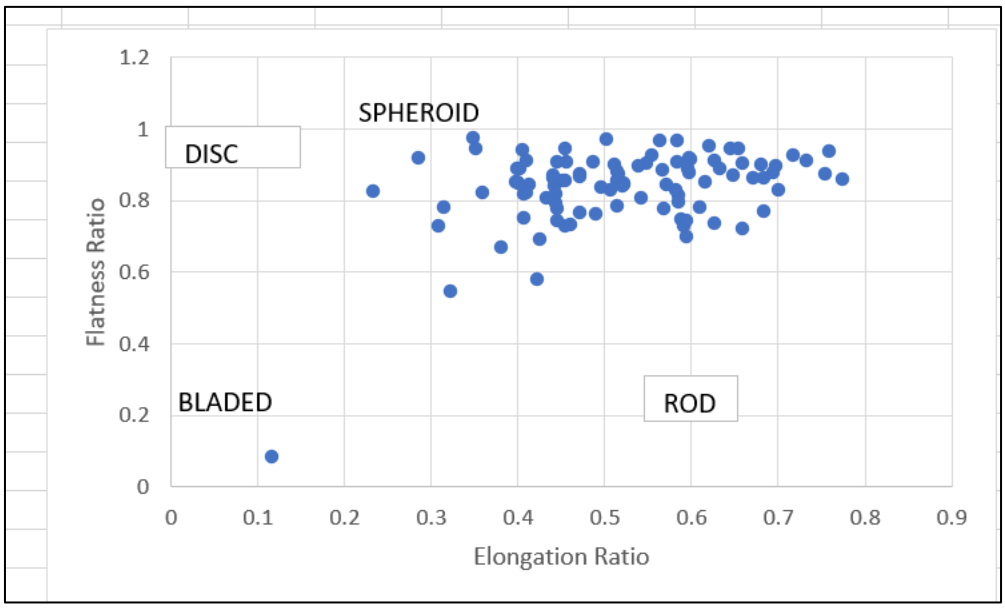

Figure 3 Bivariate plot for pebble shape from the river bed at Odufor, Etche

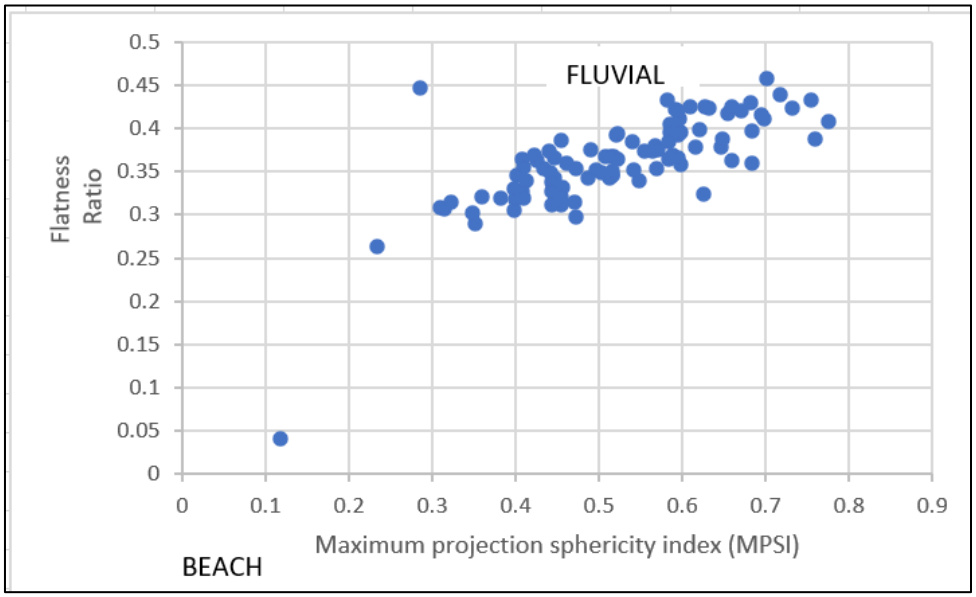

Figure 4 Bivariate plot for flatness index vs sphericity (MPSI) showed that the pebbles from river bed at Odufor clustered in the fluvial area

The morphometric characteristics of the Pebbles reaffirm that the upper parts of the Niger Delta sequence are primarily continental and river-dominated, forming the proximal portion of a prograding delta system.

6. Conclusion

The pebble morphometric indices from the Benin Formation exposed at the river beds at Odufor, Etche in the Niger Delta basin suggests the presence of a mixed nature of transport and an environment of deposition that is presumably a medium- high energy fluvial environment with influence from marine

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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