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TEXTURAL CHARACTERISTICS AND HEAVY MINERAL ANALYSIS OF SURFICIAL SEDIMENTS FROM PARTS OF IGANGAN SHEET, SOUTHWEST NIGERIA: IMPLICATION FOR DEPOSITIONAL PROCESSES AND PROVENANCE INTERPRETATION

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ABSTRACT

Grain size and heavy mineral analyses were carried out on some surficial sediment (colluviums and stream sediments) collected within parts of NW Igangan sheet with the aim of characterizing the depositional processes and provenance. A total of twenty five (25) samples were subjected to sedimentological analyses including lithological description, textural analysis, heavy mineral separation and petrological identification of heavies recovered. Results show that the sediments were angular to sub-rounded and grain sizes ranged from granules to fine grain sediments. The sediments ranged from poorly sorted to moderately well sorted (0.66-2.08 ϕ); and have kurtosis and skewness values ranging from 0.81 to 8.65 ϕ and -7.27 to 3.83 ϕ suggesting platykurtic to leptokurtic, and strongly coarse skewed to strongly fine skewed sediments respectively. With a total of 2289 heavy mineral counts, 49.6% were non-opaque and were used in heavy mineral analysis. The dominant heavy minerals were zircon accounting for 22.3%, tourmaline (18.0%) and rutile (13.1%). Zircon-Tourmaline-Rutile index computed for the samples ranged from 52% – 70% suggesting moderate maturity of the sediments. Other varieties of heavy minerals observed apart from the opaques include hornblende, garnet, glaucophane, staurolite, apatite and Kyanite. Such assemblage reflects a mixed source of igneous and metamorphic provenance most probably of the surrounding south-western Nigerian basement complex. Most of the heavy mineral were near euhedral in form and retain their original habit while some others appeared sub-rounded indicating short travel distance from provenance. Deductions from bivariate analysis were consistent with the environmental regime responsible for transportation of the sediment since they all point to fluvial environment.

INTRODUCTION

The development of granulometric analysis of loose sands for characterization and interpretation of environment of deposition has gained relevance in the field of sedimentology for over eight decades. In many regards, understanding the textural characteristics of modern sediments has aided the interpretation of their ancient analogues (Friedman, 1961; Awasthi, 1970; Martin, 2003; Ganesh et al 2013; Okon, 2015; Okon and Essien, 2015; Adamu et al., 2020; Boboye et al 2021). Most provenance related studies derive their strength of application from the characteristics and nature of the parent materials from where these sediments were derived.

The degree of weathering as well as sediment recycling play significant role in the properties of the ensuing sediments during and after deposition (Okon et al., 2017; Agbenyezi et al., 2022; Okon et al., 2023). Of course, the impact of diagenetic changes cannot be ruled out and must be taken into consideration during interpretation. On this basis, surficial and stream sediments samples from part of Igangan Sheet (240) were collected and subjected to textural and heavy mineral analyses with the aim of characterizing their depositional processes and provenance indications. This approach was chosen due to the significance of textural analysis in determining the depositional processes and in paleoenvironmental reconstruction.

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It has been shown over the years that sediment textural analysis can be utilized in determining the energy of the depositing medium and classed as either turbulent or tranquil. According to Miola &Weiser (1968), values of kurtosis derived from statistical analysis of grain size analysis data may not be suitable for diagnosing paleoenvironments as do other textural parameters. Skewness on the other hand, may serve as a suitable environmental indicator (Duane, 1964; Rosen 1969; Inyang et al., 2014; Okon 2015; Okon & Essien 2019; Okon et al., 2021). More often when textural analysis is integrated with heavy mineral analysis, sedimentary structures and geochemical characteristics of the sediments, a closer approximation to the provenance and depositional setting and even the sedimentation processes is achieved (Otele et al., 2018; Ekwenye and Onyemesili, 2019; Agbenyezi et al., 2022., Okon et al., 2023). Noting the apparent limitations of the heavy mineral analysis (hydraulic sorting, effects on size, shape and density of the grains, recycling of sediments), its approach has gained some acceptance in the recent past in areas of provenance determination, age categorization and stratigraphic correlation, especially where fossils are not present (Rosen, 1969; Mange and Maurer, 1992; Ikhane et al., 2013; Boboye and Okon, 2014; Ekwenye and Onyemesili 2019).

Study area description

The area is located in parts of northwest Igangan Sheet (240), southwest Nigeria. It is bordered by the geographic coordinates, 3 00 00 to 3 15 00E and 7 45 00 to 8 00 00N (Fig 1). Isolated crystalline basement rocks are scattered around and dissected by rivers and rivulets. River-Oyan flows from north to south of the map area and constitutes the major river within the area. Notable settlements within the mapped area include Iwere-Ile, Idiko-Ile, Idiko-Age, Gbede, etc. The area falls within the southwest basement complex of Nigeria and is geologically composed of migmatites, gneisses, quartzites, phyllites, schists and amphibolites. These rocks have been intruded by granites and pegmatites. The relationship between these rocks create convenient atmosphere for the emplacement of economic minerals of industrial, construction and gem qualities. The geology of southwestern Nigeria comprises rocks of Precambrian Basement Complex and sedimentary basin (Dahomey basin and the Benin Flank). The Precambrian Basement rocks fall within the Late Proterozoic to Early Palaeozoic orogenic belt that occupies a position east of the West African Craton. These rocks have been folded and crumpled, raised into mountain ranges and word down by agents of denudations to gentle relief that characterizes most of the areas today.

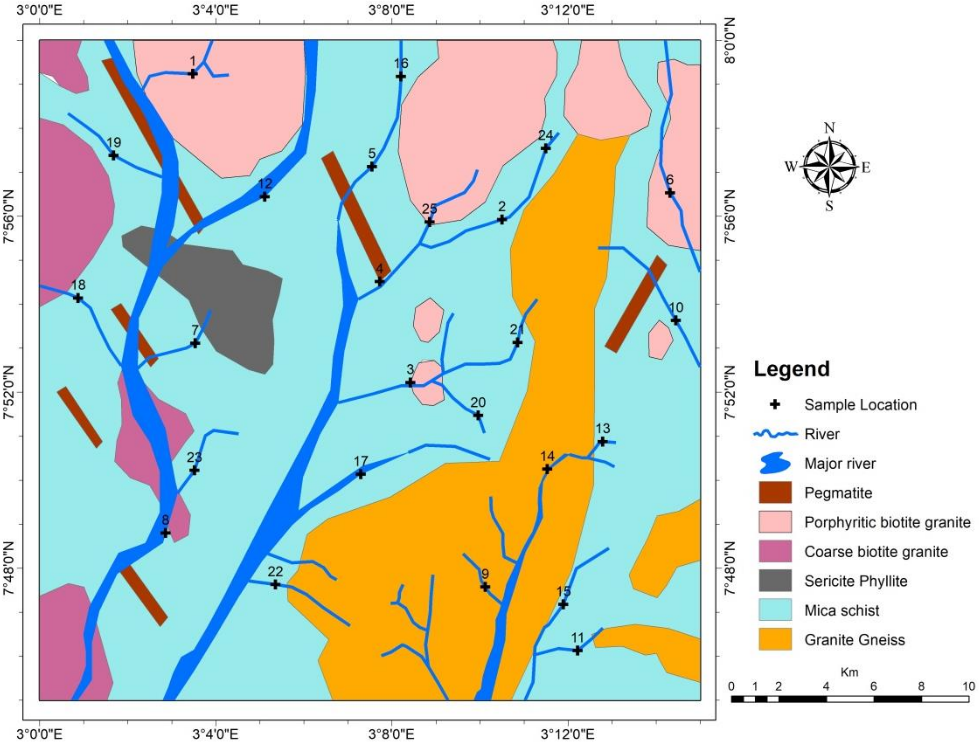

Figure 1. Map of parts of Igangan Sheet showing the sample location points

Lithologically, five major rocks units have been identified: the migmatite gneiss and quartzite rocks; slightly migmatized to unmigmatized metasediments (schists, phyllites and meta-igneous rocks), charnockites, gabbroic and dioritic rocks, granitoids of the Older Granite suite and unmetamorphosed dolerite dykes believed to be the youngest (Rahaman, 1989). Dominant structural elements of the metamorphosed basement rocks include foliations, mineral lineations, minor and major folds and faults. The dominant foliation trends are oriented N-S, occasionally NW-SE and NE-SW. Biotite, amphiboles and quartz are predominant as mineral lineation markers (Rahaman, 1989). Most tectonic joints in the southwestern Nigerian basement are directional manifestations of operative forces that suggest possible stress distribution of the deformed rocks. Mineral assemblages suggest metamorphism in the amphibolite facies grade of metamorphism. Rahaman (1976) suggested that regional metamorphism in the greenschist to amphibolite facies persists in the region with a grade decrease from amphibolite facies to greenschist facies from the SE to NW respectively. Barrovian type metamorphism is recognized in the metapelites around Aiyetoro, a central sillimanite and staurolite belt followed by an outward zone of staurolite-garnet and poorly defined biotite zone.

METHODOLOGY

Twenty-five (25) sediment samples were collected with good spread across the study area to determine their grain size distributions and heavy mineral assemblages. The significance of these analyses is to determine the textural properties and provenance (source) of the sediments with a view to appraise the mineralization potential of the area and evaluate the significance of provenance determination elements that can be applicable to the interpretation of ancient analogues. Granulometric analysis was performed by disaggregating the samples and removing all the organic components (roots and plant materials) that may have been included during sampling. 100g of each sediment sample was weighed out and emptied onto a standard sieve set arranged vertically from the coarsest at the top to the finest at the base. The sieve set was capped with a lid and mounted on an automatic Endocott sieve shaker. The procedure was allowed to shake for 15 minutes, after which measurements of each sieve and their containing sediments (weight retained) were determined. The data set generated from sieve analyses was subjected to the statistical procedures and interpretation as outlined by Folk and Ward, (1957), Folk (1974) and Friedman (1967).

Heavy mineral analysis was carried out using the 75um fraction from the sieved samples. The choice of using a similar size class for all the sediment was to minimize the effect of hydraulic sorting that is common in heavy mineral analysis and to forestall uniformity. The selected samples were boiled for an hour and treated with dilute HCl to detach the grains and remove any carbonates present in the samples. The samples were then washed with distilled water to neutralize the effect of the acid. After drying, 5g of each of the samples was measured out for heavy mineral separation. Bromofoam (SG 2.95 g/cc), held up in a separating funnel fitted on a retort stand was used for the separation which was carried out in a fume cupboard. The procedure used was gravity separation and the lighter minerals were held up by the heavy liquid, while the heavies were collected at the base of the funnel. The collected heavies were treated with acetone to remove any bromofoam left on the grains. The grains were mounted on glass slides using DPX mountant. The prepared slide was kept on a hot plate for 10 minutes and later on viewed under the microscope. Using the ribbon technique of Galehouse (1971), the grains were identified and counted, separating the opaques from the transparent heavy minerals. The result s was then use for provenance determination.

RESULTS AND DISCUSSION

The Textural characteristics of the sediments analysed viz: mean (M_z), sorting (SD), skewness (Sk_i) and kurtosis (K_G) were used to reconstruct the depositional environment of sediments following well established procedures (Folk and Ward 1957; Mason and Folk 1958; Friedman 1967; Angusamy and Rajamanickam 2006; Okon and Essien 2015). Attributes of textural parameters are presented in table 1. The sediments varied from granules to fine sand in texture, having a wide range of size classes. River borne sediments characterized by single direction of flow are typically characterized by poorly sorted grains, but depending on the distance of travel and the composition of the sediments at their provenance, the sorting may be affected. Sorting ranged from very poorly sorted grains (2.08 ϕ) to moderately well sorted grains (0.66 ϕ). Skewness, often regarded as a good environmental indicator for loose sediments ranged from -7.29 ϕ to 3.83 ϕ, averaging 0.09 ϕ suggesting sediments that are characteristically strongly coarse skewed to strongly fine skewed with a mean skewness values being near symmetrical (Table 1). The mean grain size if often used to connote the average textural composition of the sediments and directly signifies the energy gradient of the deposition. The current of deposition influences the size the depositing medium can carry. Strong currents tend to move coarser particles while tranquil currents transport fine particles. The average size class of medium size suggest a relatively high energy of deposition within the fluvial channel. This agrees with the overall poorly sorted nature of the sediments.

River borne sediments are capable of having a wide range of sediment grain size particularly during flood events where finer clasts are held in suspension but coarse clasts are able to be carried alongside hence its characteristic poor sorting coefficient as we have in the studied sediments. Kurtosis and skewness of the sediments are extremely leptokurtic and near symmetrical; suggesting almost even distribution of coarse skewed and fine skewed ranges. This attribute of the sediments, in the view of Awasthi (1970) that the sign of skewness indicates the state and energy of the depositing agents rather than the energy conditions directly. He stressed that within a fluvial setting, one expects to see bother negative and positive skewness depending on whether the sediments were taken from river confluences/upstream part of meander belts or downstream part of the meander belt respectively.

Bivariate plots are scatter graphs use by sedimentologists to distinguish depositional environments. These were adopted for discrimination between environments and for determination of the various depositional processes. The underlying concepts for these, using many modern and ancient sedimentary analogues are well established in the literature and this was adopted for this study (Friedman, 1961; Wang et al. 1998; Martin, 2003; Alsharhan and El-Sammak, 2004; Suresh Gandhi et al., 2008; Ramanathan et al., 2009). In sedimentary environments, statistical parameters of mean and sorting retain their covariance being both hydraulically controlled. This typically implies that the most sorted sediments would fall within the fine sand size ranges and vice versa (Tucker, 1990). The sediments plotted within the river dominated processes in the bivariate plots of mean size versus sorting and that of mean size versus skewness (Figs 2 & 3). Another significant tool for characterizing the depositional process is the Passega CM plot (Fig 4) which was designed to distinguish processes that characterizes the physics of sedimentary processes (modes of sediment transportation) among which include rolling, saltation and suspension (Passega, 1964; Essien and Okon, 2019). While the C represents the first percentile of the grain distribution (in microns), m signifies the median (50th percentile) of the size distribution, also in microns. The relationship between C and m represents the characteristic effects of sorting by bottom turbulence associated with tractive currents. Generally, the fields in the Cm plot is subdivided into N-O (rolling), O-P-Q (bottom suspension and rolling), Q-R (Graded suspension with no significant rolling), R-S (uniform suspension) and S (pelagic suspension). The analysed samples showed a Cm pattern of O-P-Q suggesting the dominance of bottom suspension and rolling with subordinate graded suspension mechanism of sediment transport (Passega, 1964). Tractive currents are characteristic of river current, marine current and wave action that touches the bottom; in these, the most applicable to the sediments under study is the river currents.

HEAVY MINERAL ANALYSIS

The distribution of non-micaceous heavy mineral constituents in the sediment is presented in table 2. A total of 2289 heavy minerals were counted, with 1131 being the population of non-opaques grains used for this analysis. The optical characteristic and diagnostic properties of the mineral grain aided the identification and counts for the grain (Mange and Maurer 1992). Typical examples of some selected mineral grain are as shown in figure 5. The percentages of ultra-stable grains are 22.4% Zircon, 18.0% tourmaline and 13.1% rutile grains. These were used to construct a ZTR plot for the analysed sediments (Fig 6). The distribution of heavies shows the dominance of tourmaline, zircon and rutile with some sub-ordinate staurolite, garnets and apatite grains. Hubbert (1962) used the percentage distribution of ultrastable heavy minerals to interpret the maturity of sandstones. With ZTR indices of X-Y, and having most of the samples plotting in a clustered fashion, it suggests that the sediments are at the verge of attaining maturity. Notably, Kyanite and glaucophane were the least represented in the heavy mineral distribution, their presence alongside zircon and apatite suggest a provenance of igneous and metamorphic terrain. The table of Feo-codecido (1955) was also used to further constrain the provenance of the sediments. The description of the mineral is as presented in table 3.

Table 1: Statistical parameters for the analysed samples

Sample	Mean		Sorting		Kurtosis		Skewness	
1	0.15	MS	1.11	PS	2.18	VLK	1.68	VF-S
2	-1.13	G	1.54	PS	4.43	ELK	0.40	VF-S
3	0.87	CS	1.07	PS	2.14	VLK	-0.11	C-S
4	1.15	MS	1.30	PS	3.36	ELK	1.46	VF-S
5	1.23	MS	1.12	PS	2.21	VLK	-1.30	VC-S
6	0.78	CS	1.21	PS	2.93	VLK	0.82	VF-S
7	1.78	MS	0.66	MWs	0.81	PK	-0.89	VC-S
8	1.57	MS	1.50	PS	4.38	ELK	-0.50	VC-S
9	2.22	FS	1.00	PS	1.45	LK	-2.55	VC-S
10	1.23	MS	1.29	PS	3.44	ELK	-1.49	VC-S
11	0.77	CS	1.21	PS	2.84	VLK	2.07	VF-S
12	1.85	MS	1.45	PS	3.77	ELK	-4.34	VC-S
13	0.35	CS	2.08	VPS	8.65	ELK	-7.29	VC-S
14	1.10	MS	1.38	PS	3.82	ELK	-0.73	VC-S
15	1.10	MS	1.10	PS	2.70	VLK	3.20	VF-S
16	0.25	CS	1.10	PS	2.07	VLK	1.23	VF-S
17	1.22	MS	1.32	PS	3.47	ELK	0.87	VF-S
18	0.85	CS	1.19	PS	2.79	VLK	0.84	VF-S
19	1.82	MS	1.35	PS	2.99	VLK	-0.45	VC-S
20	1.33	MS	1.41	PS	3.48	ELK	2.86	VF-S
21	0.90	CS	1.11	PS	2.40	VLK	0.95	VF-S
22	1.00	MS	1.40	PS	4.10	ELK	3.83	VF-S
23	1.52	MS	0.85	Ms	1.31	LK	-0.66	VC-S
24	1.00	MS	1.21	PS	3.03	ELK	1.00	VF-S
25	1.23	MS	1.38	PS	3.60	ELK	1.27	VF-S
min	-1.13	G	0.66	MWs	0.81	PK	-7.29	VC-S
max	2.22	FS	2.08	VPS	8.65	ELK	3.83	VF-S
Average	1.05	MS	1.25	PS	3.13	ELK	0.09	NS

Explanation: G-Granule; CS-Coarse sand; MS-Medium sand; FS-Fine sand; PS-Poorly sorted; VPS-Very Poorly sorted; MWs-Moderately well sorted; MS-Moderately sorted; ELK-Extremely Leptokurtic; VLK-Very Leptokurtic; LK-Lecptokurtic; VPK; PK-Platykurtic; NS-Near symmetrical; VF-S-Very fine skewed; VC-S- Very coarse skewed; C-S-Coarse skewed

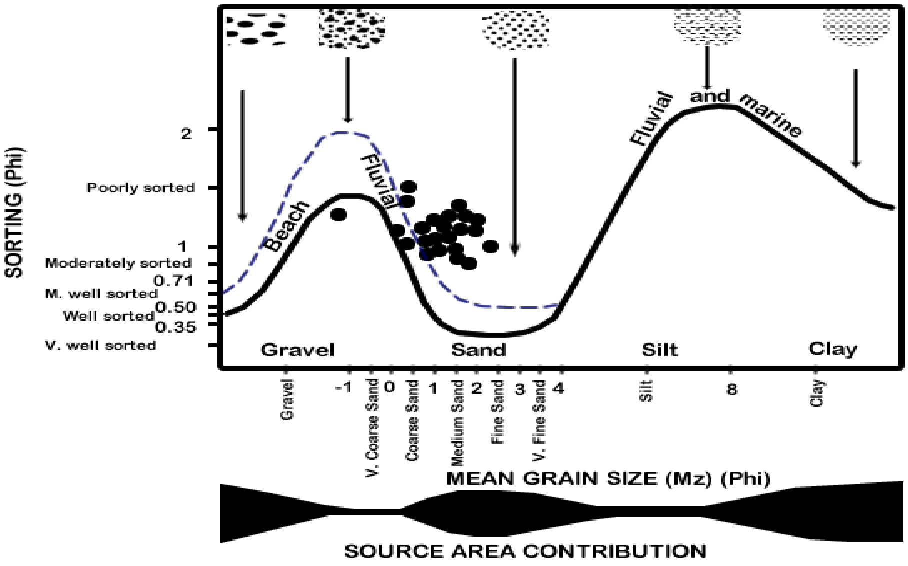

Figure 2. Plot of mean versus sorting (Modified after Folk & Ward, 1957)

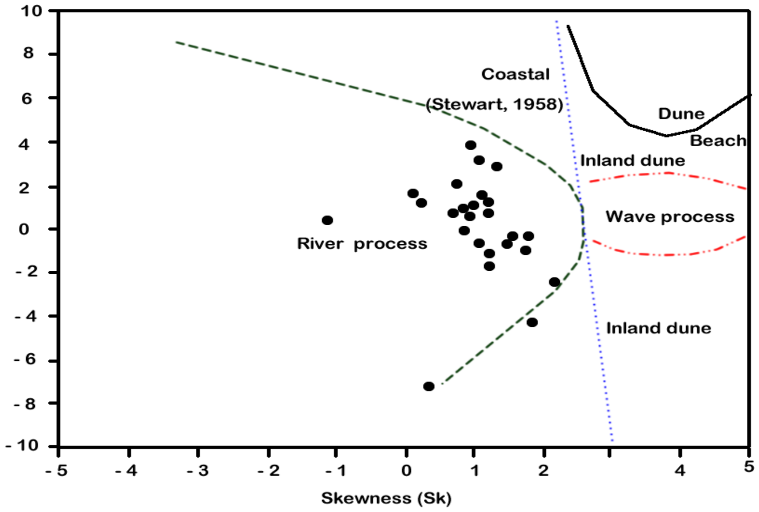

Figure 3. Bivariate plot of mean versus skewness (Modified after Martin, 2003)

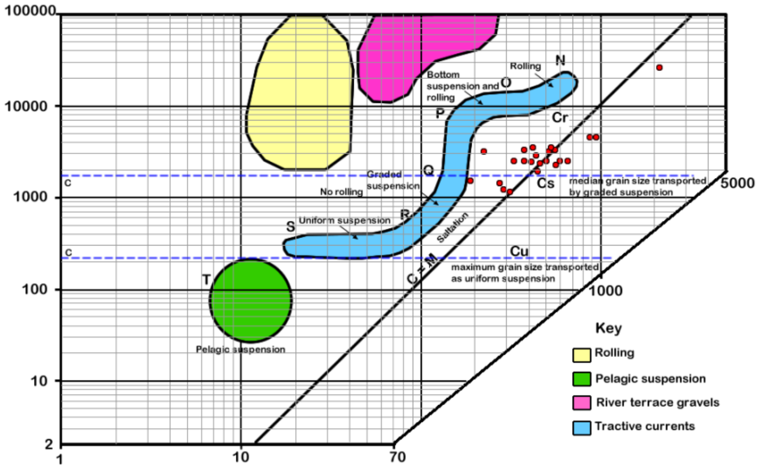

Figure 4. CM plot showing the significant depositional processes (Modified after Passega, 1964, Essien and Okon, 2019)

Table 2. Heavy mineral distribution in the study area

Sample No	L2	L3	L4	L5	L6	L10
Zircon	26	98	29	25	33	44
Tourmaline	38	85	35	35	25	57
Rutile	20	32	21	13	22	41
Hornblende	11	27	7	7	5	26
Biotite	-	28	8	4	1	17
Garnet	13	42	9	9	7	-
Glauconite	_	16	3	-	-	-
Staurolite	3	9	7	1	-	13
Apatite	6	44	9	4	10	10
Epidote	3	10	-	-	3	-
Others	5	34	34	12	10	8
Opaque	180	131	218	395	70	158
Non-Opaque	131	360	172	110	116	248
ZTR Index	64	65	52	69	70	62
Total	311	491	390	505	186	406

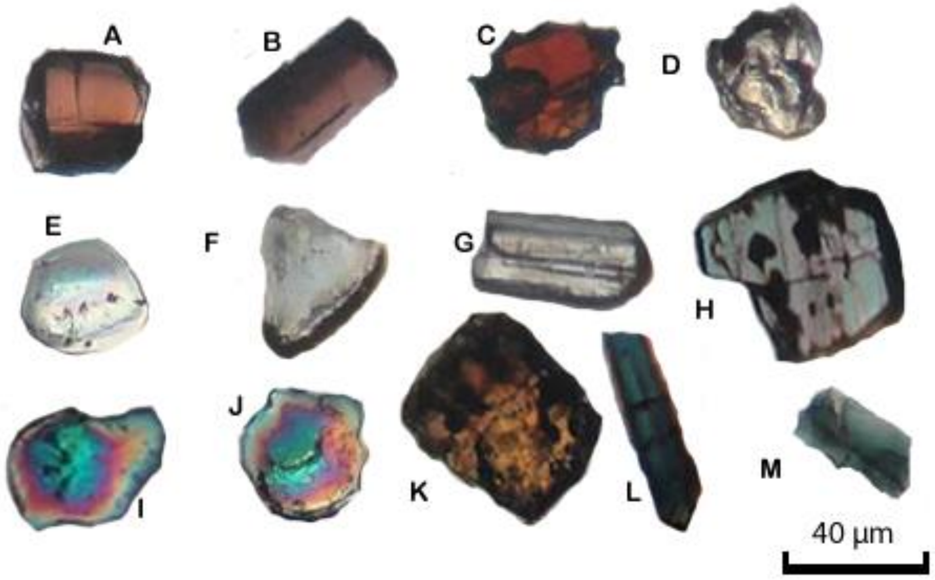

Figure 5. Some individual heavy mineral species selected under high magnification in plane polarized light (*NB: A-B = Tourmaline; D = Garnet; E-F = Apatite; G-H = Zircon; I-J = Epidote; C,K = Staurolite; L-M = Zircon*)

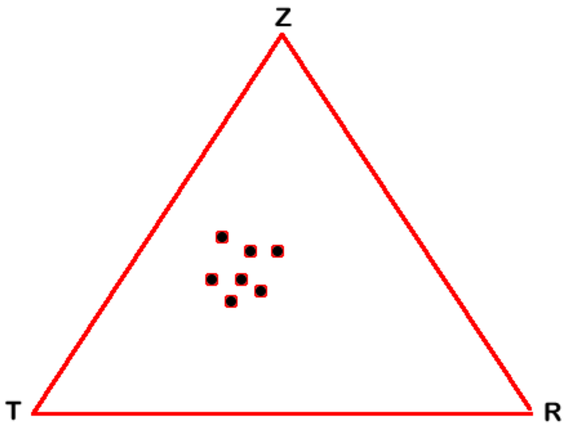

Figure 6: A ternary diagram of Zircon – Tourmaline – Rutile from the study area

Table 3. Characteristic heavy minerals associations and their corresponding provenance

Associations	***Source***
Apatite, biotite, brookite, hornblende, monzonites, muscovite, rutile, titanite, tourmaline (pink variety), zircon	*Acid Igneous Rocks*
Cassiterite, dumortierite, fluorite, garnet, monazite, muscovite, topaz, tourmaline (blue variety), wolframite, xenotime	*Granite pegmatites*
Augite, chromite, diopside, hypersthene, ilmenite, magnetite, olivine, picotite, pleonaste	*Basic igneous rocks*
Andalusite, chondrodite, corundum, garnet, phlogopite, staurolite, topaz, vesuvianite, wollastonite, zoisite	*Contact metamorphic rocks*
Andalusite, chloritoid, epidote, garnet, glaucophane, kyanite, sillimanite, staurolite, titanite, zoisite-clinozoisite	*Dynamothermal metamor-phic rocks*
Barite, iron ores, leucoxene, rutile, tourmaline (rounded fragments), zircon (rounded fragments)	*Reworked sediments*

(After Feo-codecido 1955)

IMPLICATIONS OF TEXTURAL AND HEAVY MINERAL ANALYSES ON THE IGANGAN SEDIMENTS

Identification of paleochannels are critical in locating sections (treasure sones) where economically significant fluvial places can be found (Dhinesh et al 2020; Kim 2001; Patyk-Kara et al 2001). Sedimentary processes and energy conditions of deposition are better analysed by the sediments' coefficient of sorting (Pradhan et al 2024). Since the best sorted sediments are commonly found near beach settings and poorly sorted sediment found in fluvial settings, this agrees with the depositional setting deduced for the studied sediments (Okon et al 2021; Pradhan et al 2024). The analysed sediment characteristics showed positive and negative skewness in different samples analysed, this may have resulted in the supply of fines during flooding events. Also, winnowing action produced during sediment deposition is responsible for negative sign of skewness and where the sediment show significant negative skewness (coarse skewed) can be evaluated further for the concentration of placer deposits that may be attributed to natural sieving of the sediments and their placer deposits during deposition. Kurtosis describes the deviation of the clasts overall distribution from normal frequency distribution curve and this is instructive in determining the nature of the sediments especially in areas where indications of placer concentration is outlined. Apart from the fluvial gold placers from Witwatersrand and the tin placer from Southeast Asia, not so mane paleofluvial placers are currently being mined and exploited due to paucity in locating and identifying the lodes (Smith and minter, 1980; Taylor, 1986; Dhinesh et al 2020).

CONCLUSIONS

Textural, statistical parameters and the analysis of transparent heavy minerals were used to constrain the depositional processes and provenance for the sediments from Igangan sheet, SW Nigeria. From the study, sediments composed of a wide size class range were present ranging from granules to fine sand, mostly poorly sorted with some moderately well sorted sediment and near symmetrical. Both tails and peak of the grain distribution were equally sorted, hence the leptokurtic nature of the sediments. These characteristics are common to river sands deposited by tractive currents in a continental (fluviatile) depositional setting. The integration of the heavy minerals analysis with grain size characteristic enabled the assignment of the sediments to a probable source and in this case, the basement complex of south-western Nigeria characterized by regional metamorphic and igneous rocks, is the most probable source. This was drawn from the fact that almost all the heavy mineral grains still retained their original form and shape due to short travel distances. The concentrations of the heavies in certain areas underlain by these rocks may constitute prospective areas for placer deposit occurrence especially where both the opaques and transparent heavies are considered.

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