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Delineating Sediment Maturity and Provenance from Field Geology and Heavy Mineral: A case study of Lokoja-Basange Formation South-South Nigeria

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Abstract— **Heavy minerals analysis is a veritable tool for determining the compositional maturity of sediments. Their proper understanding is a means of determining the travel history of the deposit. Fourteen sandstone samples from Lokoja-Basange Formations (the Edo arm of Bida Basin) exposed at the road cut along Auchi Igarra road at the latitudes$7^{o}32^{1}39^{11}$N and $7^{o}32^{1}40^{11}$N were analysed for heavy mineral content with the sole purpose of determining the provenance and compositional maturity of the sediment. The analysis indicates opaque minerals are in abundance and non-opaque minerals with an average Zircon value of 23.5 %, Sillimanite 10.8%, Apatite 10.2%, Tourmaline 22.3% and Garnet 11.0% are present in the sediment samples. Furthermore, the ultra-stable minerals (Zircon, Tourmaline, and Rutile) have a percentage within the sample, with zircon having the most, being 23.5% which suggests they have undergone long travel history and are more resistant to chemical weathering. Stable Apatite and Garnet have a low percentage in composition, and moderately stable Sillimanite has the most miniature composition.**

The Zircon, Tourmaline and Rutile (ZTR) index values vary from 61.8% to 71.4%, indicating high maturity. Furthermore, the presence of Zircon, Tourmaline and Rutile suggest that the sediments originated from an acidic igneous rock, while Garnet, Apatite and Sillimanite suggest a metamorphic provenance.

Keywords—Provenance, Paleoclimatic, Paleoenvironment, Lokoja-Basange, ZTR index

Introduction

Sediment deposited in an area has a history. History is valuable in understanding various geological processes that have affected them, from their disintegration from their parent rock to the time they are deposited in their present location ((Nichols Gary 2009). In understanding this, the use of the heavy mineral is very germane. Chemical weathering has a high impact on sediments, making unstable minerals such as feldspar to be dissolved in solution during transportation. More stable minerals that can withstand prolonged chemical weathering processes and abrasion during transportation possess various signatures of identifying the geological events that have occurred before deposition (Mout & Sarmah 2022, Mout & Sarmah 2021, Venkatesan 2015).

Heavy minerals are any mineral that can be separated by a liquid whose specific density is more than 2.85g/cm^{3} (Nichols Gary 2009). The heavy mineral analysis involved the separation of sand grains into different sizes and densities. Using a transmitted light microscope, separating heavy minerals using heavy liquid and counting each mineral's rich number of grains.

Location of the Study Area.

The study area is Lokoja Basange formation, in the middle Niger basin (Lokoja-sub-basin), situated by the side of Auchi-Igarra road (07^{o}07.201'N, 0.06^{0} 13.011'E) Estako-east Edo state Nigeria. The study area is underlain by several beds of sedimentary rocks, such as sandstone, which ranges from medium to coarse-grained, poorly sorted, and suggestive of rapid deposition in a low energy setting, probably on a shelf or flood plain based on field observation. The observed variations in the sandstone colouration are attributed to the nature of the cementing materials and several alterations in colour and texture. Most of the inhabitants of the area are engaged in farming and trading.

Geology of the Mid-Bida Basin

The Middle Niger (Bida) Basin is a linear intracratonic sedimentary basin in central Nigeria. It trend and is roughly perpendicular to the Benue Trough (Osokpor & Okiti 2013). It is separated from the basal continental bed of the Sokoto Basin by a narrow outcrop of the crystalline basement rocks in the west, and it is adjacent to the Anambra Basin in the east (Fig.1). The basin occupies a gently down warped trough (Osokpor & Okiti 2013). The epeirogenesis responsible for the basin genesis appears closely connected with the Santonian tectonic crustal movements, mainly affecting the Benue Basin and SE Nigeria. The underlain basement complex perhaps has a high relief (Adepoju et al. 2020), and the thick sedimentary successor is approximately 2000 meters, as shown by a gravity survey (Madikwe et aMaeeeee) comprised of unfolded post-tectonic molasse facies and thin marine strata. Borehole logs, Landsat images interpretation, and Geophysical data across the basin suggest that it is bounded by a NW-SE trending system of linear faults (Osokanor & Okiti 2013). Gravity survey studies also corroborate central positive anomalies flanked by negative anomalies (Madukwe et al. 2014). This trend is greed with rift structures as observed in the adjacent Benue Trough/Basin. A detailed study of the facies indicates rapid basin-wide changes from various alluvial fan facies through flood-basin and deltaic facies to lacustrine facies (Braide 1992). Consequently, a simple sag and rift origin earlier suggested may not account for the basin's evolution (Overare et al. 2020). Paleogeographic reconstruction suggests that lacustrine environments were widespread and elongated. Lacustrine environments occurred at the basin's axis and close to the margins. This indicates that the depo-centre must have migrated during the basin's depositional history and subsided rapidly to accommodate the 3.5 km thick sedimentary fill (Osokpor & Okiti, 2013)

Geology of the Study Area

The detrital sedimentary sequence comprises subequal proportions of alternating sandstones and clay at the lower part of profile A. The northern and southern Middle Niger (Bida) basins contain about 3km thick Campanian to Maastrichtian continental to shallow marine sediments. The south of the Middle Niger (Bida) Basin includes the basal Campanian Lokoja Formation (mainly conglomerate and sandstone), Maastrichtian Patti Formation (shale, claystone and sandstone) and the youngest Agbaja Formation (Ironstone). Their lateral stratigraphic equivalents in the northern Bida Basin consist of the basal Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone and sandstone) and Batati Formation (Ironstone).

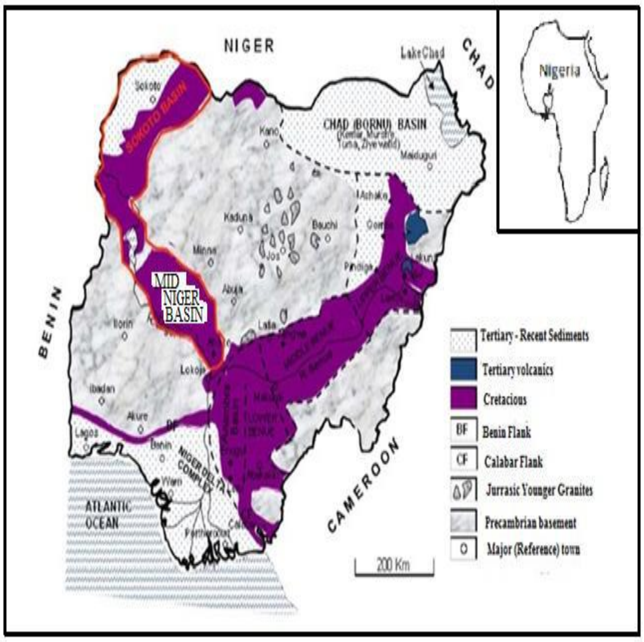

Figure 1: ***Geological map of Nigeria showing locations of the Middle Niger Basin (After*** Obaje 2019)***.***

Material and Method

The fieldwork involved description, logging, measurement and sample collection of various lithological units. It covers outcrops around Lokoja and Agbaja, where Lokoja Formations were encountered. Most outcrops were road cuts representing the different lithofacies of the Formations. About fourteen (14) samples (Figure 2.0) were collected for laboratory analyses. The laboratory work involved textural, geochemical, petrographic and heavy minerals analyses of sandstone samples at the geology Department University of Ibadan.

Result and Interpretation

The result of the heavy mineral analysis carried out on fourteen (14) representatives rock samples collected during the field mapping indicates the presence of Zircon (Z), Rutile (R), Tourmaline (T), Sillimanite (S), Garnet (G), Apatite (A) and opaque minerals (OP) in the selected samples. The details of the result are presented in table 1.0 below.

Opaque minerals are generally in abundance within the sediment. They are usually metallic minerals or iron-stained materials which are very difficult to be penetrated by the plane-polarised light of the petrographic microscope (Mackenzie & Adams 2003). The percentage of the non-opaque minerals in the samples ranges from 11.0% to 23.5% (fig. 3.0), with ultra-stable Zircon being the most abundant in the samples, with an average of 23.5 % and sillimanite having the lowest percentage, with an average of 10.8. This is an indication of a hurriedly mixed sedimentary deposit. Further chemical analytical approaches can only

Table 1: Shows the result of Heavy Minerals in the Samples.

SAMPLE NO	Z	R	T	S	G	A	OP
LKB 1	**8**	**6**	**7**	**5**	**3**	**4**	**25**
LKB 2	**6**	**5**	**9**	**4**	**2**	**4**	**23**
LKB 3	**7**	**8**	**7**	**4**	**5**	**3**	**22**
LKB 4	**8**	**9**	**7**	**5**	**4**	**4**	**24**
LKB5	**10**	**7**	**8**	**3**	**4**	**3**	**23**
LKB 6	**8**	**9**	**7**	**2**	**5**	**3**	**25**
LKB 7	**9**	**6**	**8**	**3**	**3**	**4**	**23**
LKB 8	**7**	**4**	**9**	**4**	**4**	**2**	**25**
LKB 9	**9**	**7**	**7**	**5**	**3**	**3**	**24**
LKB10	**6**	**8**	**9**	**4**	**5**	**3**	**21**
LKB 11	**8**	**7**	**6**	**3**	**4**	**4**	**23**
LKB 12	**9**	**8**	**9**	**5**	**3**	**4**	**25**
LKB 13	**7**	**5**	**6**	**4**	**4**	**3**	**22**
LKB 14	**8**	**6**	**7**	**5**	**4**	**4**	**24**

study them. Zircon appears commonly colourless. They are primarily euhedral, though some may be sub-euhedral to rounded shapes, which exhibit concentric zoning. However, Zircon is commonly widespread in granitic rock and is an accessory in igneous rocks and detrital deposits derived from such rocks. Its presence within the sediment body is a crucial indication of minerals in interpreting igneous and metamorphic rocks' origin (Nichols Gary 2009). The sedimentary rocks maintain a relatively high (22.4%) value in Pegmatite. It is usually brown in colour or brownish yellow. Its shape is commonly euhedral. It is a common detrital heavy mineral in sedimentary rocks(Nichols Gary 2009, Mackenzie & Adams 2003, Nton & Bankole 2012). Some varieties of tourmaline are used as gemstones. Tourmaline has a relatively high (22.4%) value occurring in Pegmatite. It is usually brown in colour or brownish yellow. Its shape is commonly euhedral (Mackenzie & Adams 2003). It is a common detrital heavy mineral in sedimentary rocks. Some varieties of tourmaline are used as gemstones. Tourmaline occurs in low quantities in most samples, while they are absent in some. They exhibit doubly terminated euhedral structures and are mostly yellow. The mineralogical composition of most of the samples indicated that they are either from acid igneous rock or dynamo thermal metamorphic rock. Rutile also has an average abundance which accounts for 19.9%. The varieties of rutile recognised range from deep golden yellow to brown, while some are almost opaque. Rutile is a common accessory mineral in high-temperature and high-pressure metamorphic and igneous rock. According to (Nichols Gary 2009), Rutile is a non-silicate mineral occurring as an accessory constituent of igneous rock and many Granite, Diorites, and their metamorphic derivatives such as Gneisses and Amphibolites. Rutile is used as a source of titanium. Titanium dioxide is the most important intermediate product of the world's titanium industry. The whites of titanium oxide and light scattering effect make it the only suitable pigment for the paint, paper and rubber industries (Gujar et al. 2007). Sillimanite is 11.97% of the total sediment and is characterised by transparent to brownish colour of angular to sub-angular grains of minerals. They are index minerals for high-grade metamorphic rock. Garnet, which comes next with 11.32% abundance, is variable in shape and size. It occurs as angular to sub-rounded grains and is free from any inclusion. The surface texture of the garnets is characterised by pitting, grooving and etching. The colour ranges from green to blue and is colourless. Apatite, next after Garnet, is the least distributed mineral in the sample. As a composition of 10.26%, it is brownish in colour throughout the entire sample, and it ranges from angular to sub-angular; the surface texture is characterised by grooving.

Furthermore, (Nichols Gary 2009), the non-opaque or transparent non-micaceous heavy mineral assemblage of the quartz is predominantly zircon, tourmaline and rutile and these grains are ultimately concentrated in sandstones by prolonged abrasion. The Zircon, Tourmaline, and Rutile (ZTR) percentage index (Table 2 & Fig. 4.0) for the fourteen samples indicates variations from 61.8%-71.4%. ZTR index from all the samples shows they have similar long travel histories. (Ejeh, O. I., Akpoborie & Etobro 2015; Ilevbare & Imasuen 2020), For sediment to be considered mature, it must have a ZTR index greater than 75%. The high ZTR indices suggest that almost all the pieces are within the threshold of full mineralogical maturity.

Conclusion

The presence of zircon, Apatite and Tourmaline indicates that most sediment is of acidic igneous rock. They constitute the more significant percentage of the heavy minerals present within the deposit. Sillimanite and Garnet are good indicators of high-grade dynamo-thermal and contact metamorphic rocks. The ZTR percentage shows that they are within the maturity threshold. The lowest is 63.6%, while the highest is 71.4%.

Table 2: The ZTR index for the sediments

SAMPLE	ZTR INDEX %
1	**63.6%**
2	**66.7**
3	**64.7**
4	**64.8**
5	**71.4**
6	**70.6**
7	**69.6**
8	**66.7**
9	**67.6**
10	**65.7**
11	**65**
12	**68.4**
13	**62.1**
14	**61.8**

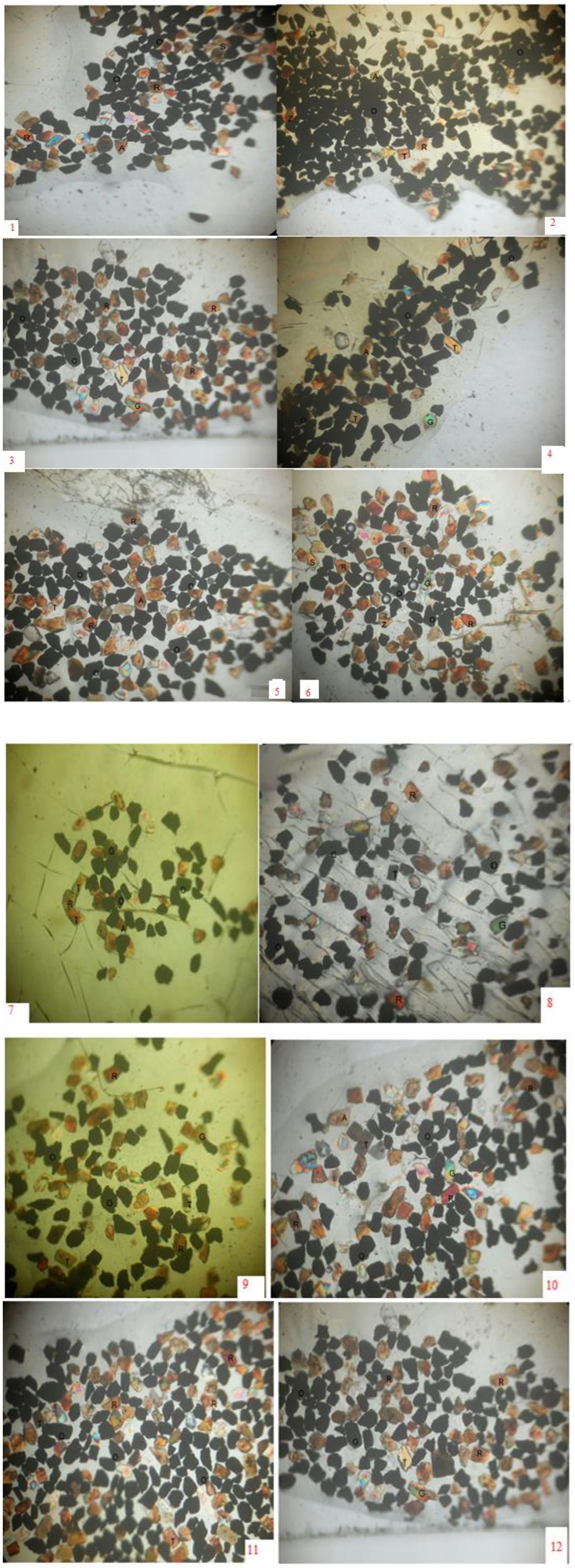

Figure 2.0: Photomicrograph of Heavy minerals in the selected samples of the study area.

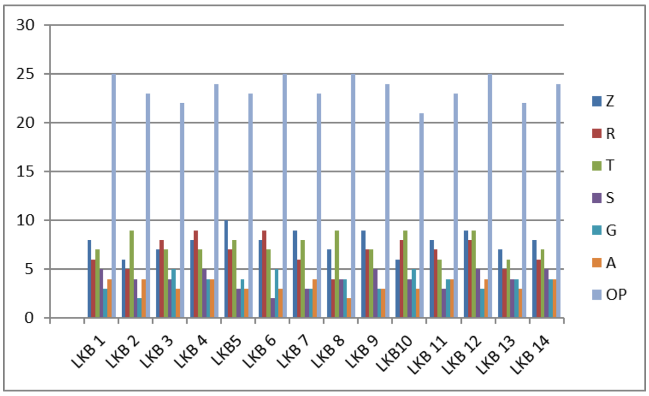

Figure 3.0: Bar Chart showing the opaque and non-opaque mineral distribution.

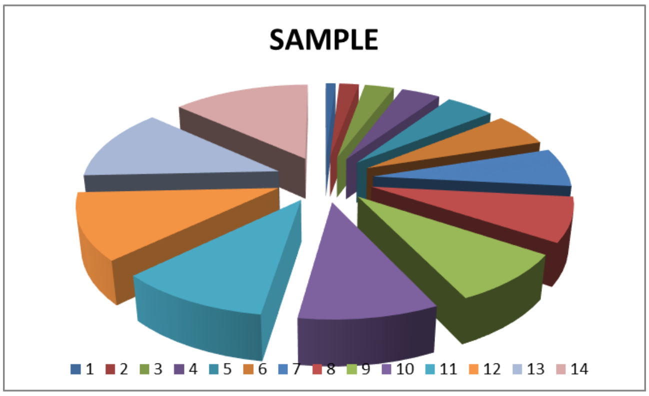

Figure 4.0: Pie chart of the ZTR.

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