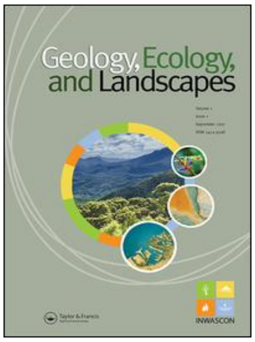

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RESEARCH ARTICLE

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Heavy mineral analysis of Eocene sands and sandstones of Nanka Formation, Cenozoic Niger Delta petroleum province

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ABSTRACT

The heavy minerals present in lithologic sand and sandstone units of Nanka Formation are mainly zircon, rutile, tourmaline, apatite, staurolite, and opaque minerals (Goethite, hematite, ilmenite), which are present dominant in weathered sandstones when analysed using petrographic varietal studies to infer provenance, diagenesis and source area weathering history. The low-diversity and relative abundance of heavy mineral assemblages are controlled by provenance and diagenetic processes, and these present limitations in accurate reconstruction of the paleo-history of these lithologic units using heavy minerals analysis alone. These lithologic Eocene units are derived from intensely weathered granitic and metamorphic source rocks and they are composed dominantly of matured polycyclic sediments.

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Heavy mineral; diagenesis; provenance; weathering; transportation; mineral assemblages

Introduction

Heavy minerals are vital in provenance determination and understanding of diagenetic processes. Heavy minerals specific gravity (sg) is greater than 2.89 (Bromoform) and they have been studied for various interest by many researchers such as Pettijohn, Potter, and Siever (1973), Morton (1985), Adekola, Akinlua, Ajayi, Adesiyan, and Ige (2018), Mange and Wright (2007), Morton (1984), Joevivek, Chandrasekar, and Shree (2018), Mange and Maurer (1992), Morton and Hallsworth (2007), Morton (1991), Weltje and von Eynatten (2004), and Nwajide (2013).

Heavy mineral composition is influenced by source area lithology, pre-depositional, and post-depositional effects on sediments. Generally, heavy minerals form accessory components or essential rock minerals and they are less than 3% in sands when highly impacted by weathering. Heavy mineral assemblages are influenced by physical properties (size, shape, and density) that affect selective sorting due to hydraulic effects, and each assemblage contains diverse heavy minerals with unique grains that convey its paleo-history. The reliability of heavy mineral analyses is affected by source area climate, physiographic settings, hydraulic factor, diagenesis, pH, and abrasion during transportation (Garzanti et al., 2013).

Garnet and tourmaline are mostly used for provenance studies due to their relative abundance in sediments, chemical and mineralogical diversity, different rock origin, physical and chemical resistance, and stability under severe geological condition (Mange-Rajetzky, 1995; Hawthorne & Henry, 1999; Morton, Knox, & Hallsworth, 2002; Morton & Hallsworth, 1999; Morton et al., 2004; Garzanti et al., 2013).

Zircon morphology has been used as a petrogenetic indicator (Pupin, 1976), and chrome spinel composition is reliable for provenance characterisation (Power, Pirrie, Andersen, & Wheeler, 2000). Hurst and Morton (2001) stated the relative abundance of heavy minerals and its abundance ratios. The hydraulic and diagenetic equivalent heavy mineral pairs were recommended for provenance studies (Hurst and Morton, 2001; Morton and Hallsworth, 1994). The geochemistry of heavy minerals reflects its provenance (Mange and Morton, 2007; Totten & Hanan, 2007; Yang, Jung, Choi, & Li, 2001; Zack, von Eynatten, & Kronz, 2004). Ilmenite is an important economic heavy mineral which has been utilised for provenance finger printing (Asiedal et al., 2000a; Grigsby, 1992; Pirkle, Pirkle, & Pirkle, 2007; Pownceby and Bourne, 2006)

The aim of this study is to evaluate the heavy minerals present in sand and sandstone units of Nanka Formation in other to infer its sediment provenance, diagenesis and weathering history with emphasis on the physical properties which encompasses mineral colour, inclusions, twinning, striations, overgrowth, zoning, grain sizes, roundness, etc. They need to evaluate these heavy minerals properties petrographically at higher magnifications (Greater than 40 µm used by previous studies in the study), and identify the dominant mineral

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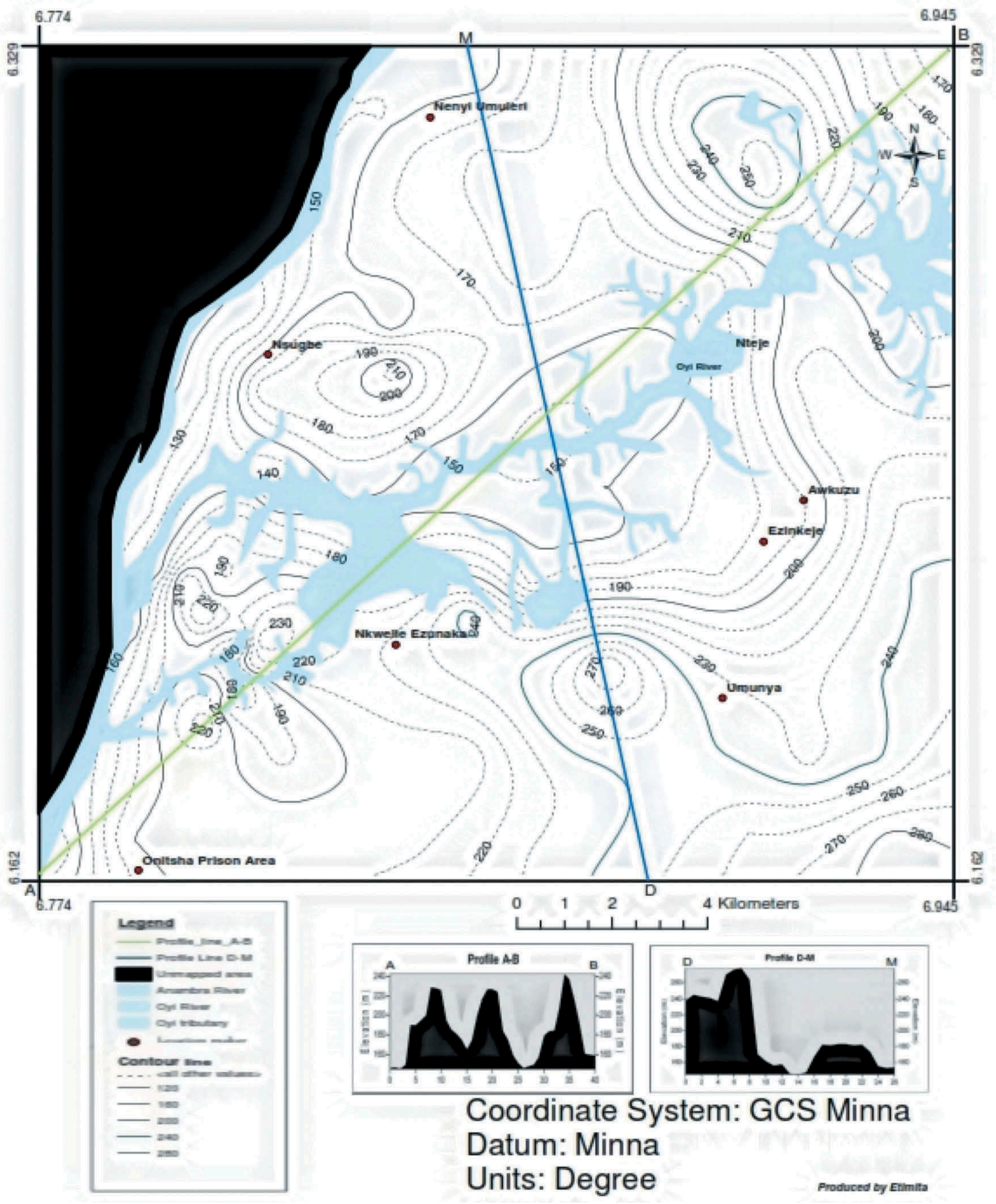


Figure 1. Map of the study area.

composition of lithologic samples using X-ray diffraction analyses in other consolidate present knowledge of heavy minerals in this study area (Figure 1).

Geological settings

The study area is located in Anambra state and lithologies evaluated are part of the outcropping units (Table 1) of the Cenozoic Niger Delta (Nwajide, 2013). They are mainly exposed in gullies and burrow pits. The general lithologies in the area are sands, sandstones, heteroliths, and claystones (Nwajide, 1980).

Methodology

Lithology samples were obtained from various outcrop locations within the study area and they were analysed mainly on micro-scale using polarising microscopes. Each sample was disaggregated, sieved (0.06–0.25 mm size fraction), and the minerals were separated in funnel using bromoform (sg = 2.89) to extract heavy minerals. The extracted minerals were then mounted on slides. Generally, a relatively large bulk of samples was chosen for disaggregation to obtain sufficient amount of heavy mineral grains for this analysis.

Table 1. Stratigraphy of outcropping units of the Cenozoic Niger Delta (Nwajide, 2013).

Age	Lithostratigraphy units	
Oligocene – Present	Benin Formation	
Oligocene – Miocene	Ogwashi to Asaba Formation	
Eocene – Early Oligocene	Ameki Group	Nanka Formation Ameki Formation
Paleocene – Early Eocene	Imo Formation	

Results and discussion

The heavy minerals (Figure 2) that are dominant in the sandstones are opaque minerals (O), zircon (Z), rutile (R), and tourmaline (T) while the sands have zircon, rutile, tourmaline, apatite (A) and staurolite (SQ). The heavy minerals present in these litho-units are continuously altered and gradually replaced by

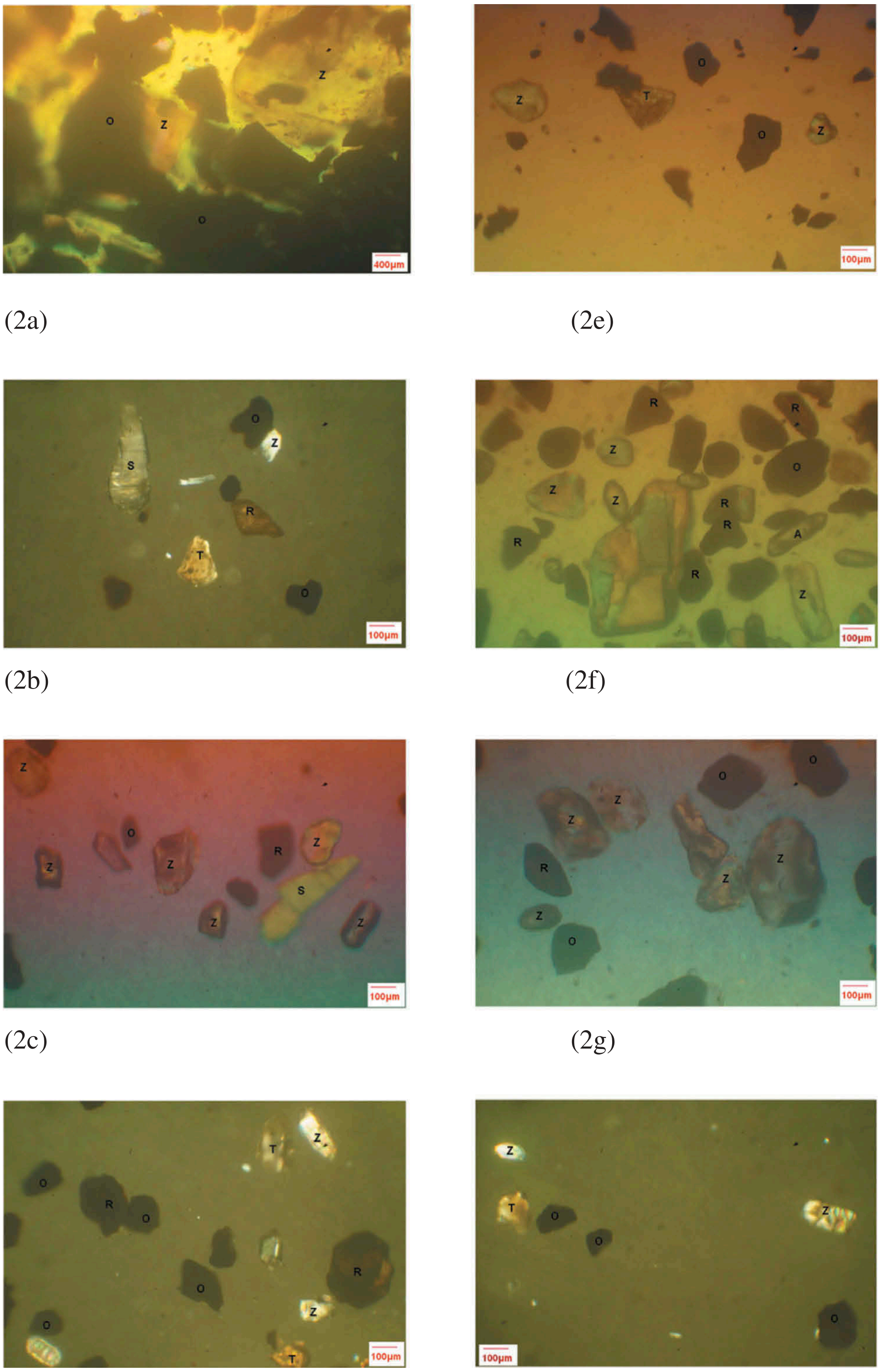

(2a) (2e)
(2b) (2f)
(2c) (2g)
(2d) (2h)

Figure 2. Photomicrograph of heavy minerals in sands and sandstone units of Nanka Formation.

opaque minerals, especially in weathered sandstones and near surface (Figure 2(a,e)).

The opaque minerals show diverse habit but they are commonly cubic or rhombohedra. The heavy minerals are rarely striated with some having octahedral faces, uncommonly well-developed prisms with penetrative twin that are typically lamellar.

The relative abundance of heavy mineral is greatly influenced by post-depositional conditions such as dissolution and iron replacement in sandstones. Consequently, less stable minerals are removed while ultra-stable minerals like zircon, rutile, and tourmaline are mainly preserved. The absence of unstable minerals probably infers that the sediments source area lithology is a low-grade metamorphic terrain, or it may imply that the sediments are matured, polycyclic, and highly impacted by diagenetic dissolution or changes.

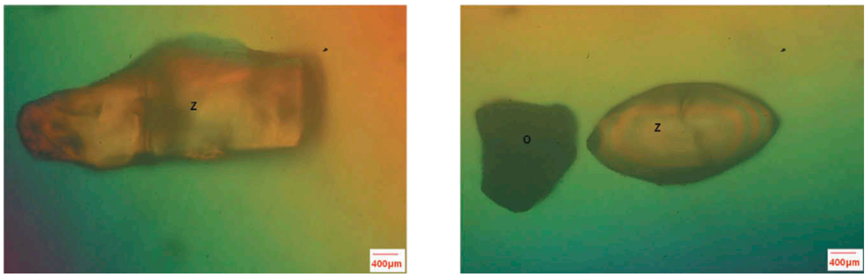
The presence of dominantly red wine coloured, non-rounded, and euhedral rutile grains with mainly pyramidal terminations infers high-grade metamorphic source area (Figure 2(d–g)). These pyramidal terminations commonly have simple to repeated contact twins showing geniculate or cyclic forms (Figure 2(d)). The rutile present shows irregular or conchoidal breakage patterns (Figure 2(f,g)).

The tourmaline has variable habit with dominantly rounded triangular cross section and they show the presence of inclusions (Figure 2(d,e,h)). They are vitreous, transparent to translucent, pleochroic with yellow brown to pale yellow colour dominance. This shows that the tourmaline may be irons or magnesium bearing (Mange & Maurer, 1992).

The sillimanite (S) grains are rare, colourless, white, greenish, and transparent to translucent prismatic grains (Figure 2(b,c)). The apatite identified shows hexagonal prism or pyramidal habit and is commonly transparent to subtranslucent, colourless, and white to grey (Figure 2(f)).

Generally, Zircon grains are the most stable non-opaque heavy mineral observed in this lithologic unit (Figure 3). These grains have subangular to subrounded edges and they are transparent to translucent, microfractured, inhomogeneous, and dominantly pitted with obvious discontinuous zones.

The microfractures observed may have resulted from grain to grain collision during sediment transportation or they are products of diagenesis. The grains are dominantly sharp euhedral crystals with prismatic and anhedral fragment imprints. This zircon grain abundance suggests granitic and metamorphic source rock derivations. Goethite was significantly identified in disaggregated sandstones grains sizes that are less than 2 µm using X-ray diffraction analysed (Figure 4).



(3a) (3b)

Figure 3. Photomicrograph of zircon (Z) grains showing inhomogeneity.

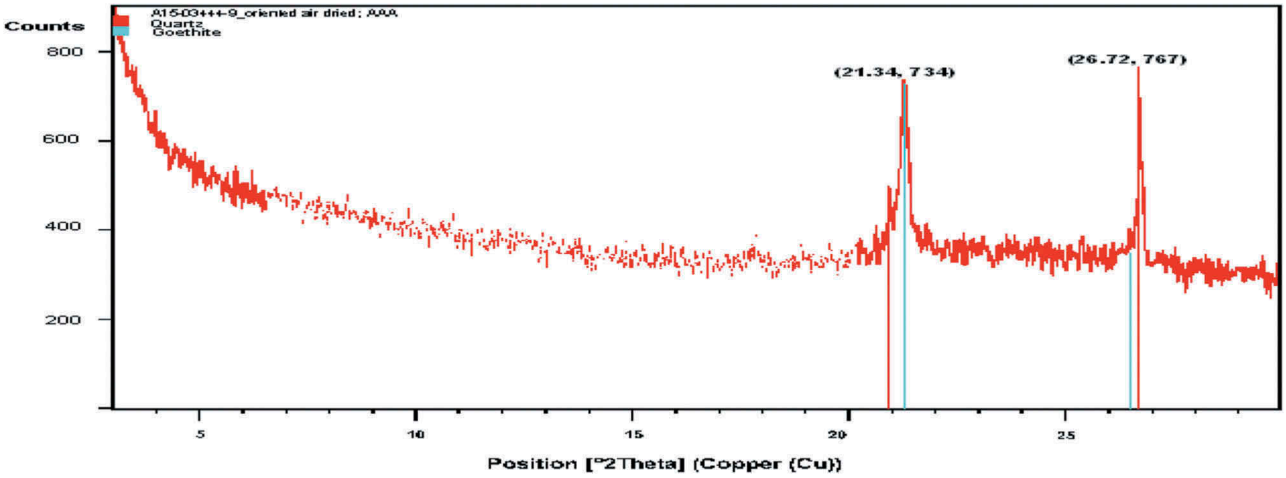


Figure 4. Typical X-ray diffraction patterns of sandstones <2 µm size fraction.

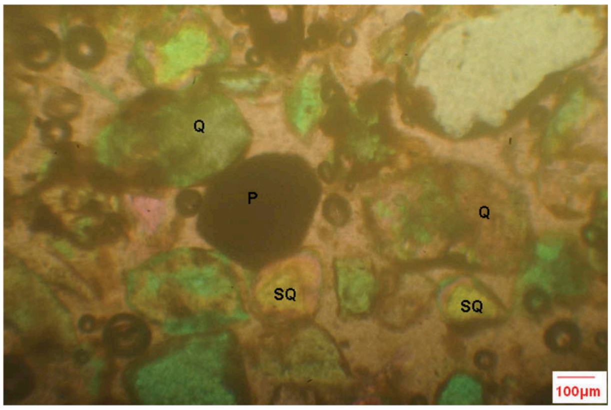


Figure 5. Microphotograph of staurolite (SQ) inclusions in quartz (Q) grains.

The staurolite present is bright yellow and occurs as quartz inclusions (Figure 5). They are evidences of diagenetic changes in minerals which included the presence of microcracks, plastic deformation of pelitic grains, and mashing of mica grains as documented by Morton and Hallsworth (1999). The relative abundance of opaque minerals with low-diversity of heavy mineral assemblage, poor preservation, high zircon-tourmaline-rutile index, and grain roundness indicates intense in-situ and deep weathering in source area and diagenetic dissolution of unstable heavy mineral components.

Generally, they are no sudden variations in a heavy mineral assemblage that indicates any changes in source lithologies which may suggest tectonic evolution or basin configuration changes in these litho-units. In addition, they are an increasing or decreasing trend in heavy mineral relative abundance with depth due to disparities in environmental and climatic paleo-conditions.

Conclusion

The heavy minerals present in these Eocene sand units are accurately identified and they show low-diversity and abundance which has been influenced mainly by provenance, diagenetic dissolution, and dominant mineral replacement by iron oxyhydroxides minerals with decreasing burial depth. They is an insignificant amount or absence of unstable heavy minerals, and the ultra-stable heavy minerals attribute observed infers granitic and metamorphic source rock derivations which are probably from intensely weathered areas. These lithologic sediments are matured and they are of polycyclic regimes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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