

## Zircon Typology as Indicator of Provenance in Neoproterozoic Sandstones of the Voltaian Basin, Ghana

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**Abstract:** An investigation to identify the suitability of zircon crystals as provenance indicators of the relatively mature sandstones of the Neoproterozoic strata in the Voltaian Basin was conducted. A total of 154 zircon grains were critically studied, all extracted from 14 sandstones samples; 7 from Lower Voltaian Kwahu-Morago Group and 7 from the Middle Voltaian Oti-Pendjari Group. Zircon typology analysis indicates anatectic origin with some contribution of a volcanic material for the Kwahu-Morago Group. Zircons from the Oti-Pendjari Group, however, showed an evolution in the source-area with three probable main sources identified for the sediments. These are; (1) zircon sub-population of crustal origin as one of the sources, (2) zircon sub-population with a strong mantle affinity and towards a more aluminous type. These zircon sub-populations have been interpreted as coming either from the same calc-alkaline source rock; or that it has its origin in two distinct sources, one with calc-alkaline and the other one with a subalkaline origin. The zircon typology study here shows that the Kwahu-Morago Group experienced sediment supply mainly from the Birimian sedimentary basins with some contribution from the volcanic belts. On the other hand sediments from the Oti-Pendjari Group were mostly derived from the calc-alkaline rocks of the Pan-African orogen with minor contribution from the Birimian granitoids. This study clearly showed that zircon typology does not only help establish provenance study but also adds a considerable degree of sophistication.

**Key words:** Provenance, sandstone, typology, voltaian basin, zircon

### INTRODUCTION

Heavy mineral assemblages in sandstones retain fundamental provenance information despite the complex overprinting processes that affect their distribution (Morton and Hallsworth, 1999). The analysis of such high density accessory detrital minerals of sandstones offers a high-resolution approach to determination of sandstone provenance (Morton and Hallsworth, 1999; Pettijohn *et al.*, 1972).

The typology study of zircon populations is an extremely valuable tool, especially since this mineral is highly resistant and exhibits a morphology controlled by the physical and chemical conditions under which it crystallized. Zircons that have been reworked in a sedimentary deposit display typologies that make it possible to identify the different igneous rock-types present in the source region (Dabard *et al.*, 1996). A petrogenetic classification by means of zircon typology is at least partially beyond the influence or control by deuteric processes which could appreciably alter their chemical as well as mineralogical compositions (Pupin, 1980).

The African continent is composed mostly of highly deformed metamorphic rocks and granitic intrusions forming over half of the total area (Wright *et al.*, 1985). The other half is underlain by a rather thin layer of nearly broad shallow basins, which unconformably overlie these basement rocks (Fig. 1). Large cratonic basins have existed on the African continent since the late Proterozoic (Hartley and Allen, 1994). One of these basins is the Voltaian Basin situated in the West African craton. Sediments of the Voltaian Basin overlie the eastern part of the West African craton, separated by the intensely thrust-faulted rocks of the Togo Formation from the mainly Pan African rocks of the Benin-Nigeria Province (Fig. 2).

The Neoproterozoic Sandstones of the West African Craton particularly in the Voltaian Basin of Ghana have not been well investigated to any appreciable extent except for that of Anani (1999), Osaie *et al.* (2006), Carney *et al.* (2010), Kalsbeek *et al.* (2008) and Anani (2000). A lot of relatively good pioneering fieldwork has, however, been undertaken by some workers (Junner and Hirst, 1946; Sulutiu, 1968; Affaton *et al.*, 1980; Bozhko, 1969).

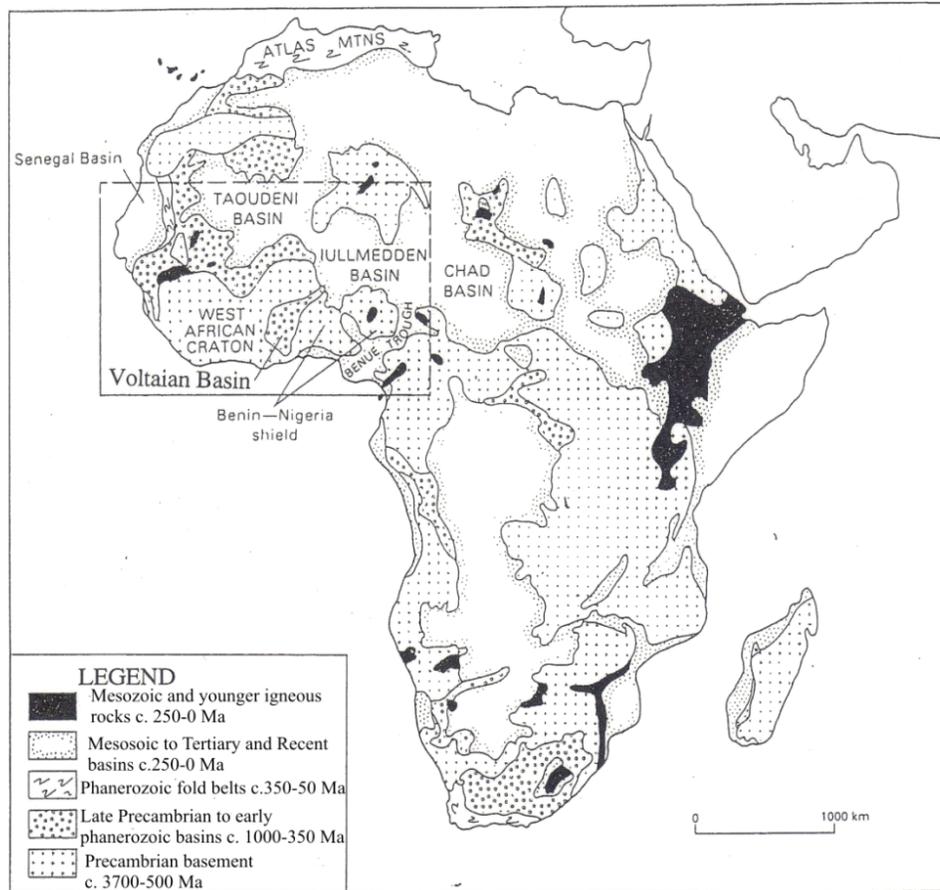


Fig.1: The 'basin-and-swell' structure of the African continent. The swells are underlain by older metamorphic and igneous rocks. The basins contain mostly undeformed younger sediments. The rectangle outlines approximately, the West African region. After Wright *et al.*, (1985).

Provenance study of the relatively mature sandstones in the Voltaian Basin is well enhanced by the study of zircons, which are ubiquitous in terrigenous sediments. This paper looks further into the sandstones of the southeastern Voltaian Basin to deduce the source of the sandstones as well as their source rock characteristics by varietal study of zircon.

**Geological setting:** The Voltaian Basin is considered to reflect more than one tectonic setting (Affaton *et al.*, 1980; Wright *et al.*, 1985). Its central and western parts represent typical platform cover, but the eastern part is deeply buried and resembles a continental passive margin. The sediments of the Voltaian Supergroup cover an area of 103,600 km<sup>2</sup>, almost one-third of the area of Ghana (Kesse, 1985). They are generally flat-lying and unmetamorphosed. Magnetic basement has its greatest depth of 4-5 km along a N-S trough at 0° longitude between 7° and 9° N latitude. The western and northern thirds of the basin are less than 3 km thick and the

southeastern third generally over 3 km thick, (Ako and Wellman, 1985). The Voltaian Supergroup consists mainly of sandstone, shale, mudstone and conglomerate. There are few detailed geologic descriptions of sediments of the Voltaian Supergroup sequences in Anani (1999).

The study area, bounded by 6°30' N and 6°45' N latitude and 0°30' W and 0°45' W longitude, lies in the southeastern part of the Voltaian Basin (Fig. 2). Two sandstone members crop out over most of the study area (Fig. 3). There is no completely exposed section through the Voltaian Supergroup due to deep weathering and low topographic relief. Correlations within the Supergroup and the groups of the area are therefore difficult.

Two divisions were identified in the present work; the Sandstones of the Lower Voltaian Kwahu-Morago Group (synonymous to Kwahu Sandstone Member of Anani, 1999) and the Sandstones of the Middle Voltaian Oti-Pendjari Group (Fig. 3). The former corresponds to the Lower Voltaian Formation of Kete (1980) and Saunders (1970). The latter also corresponds to the Anyaboni

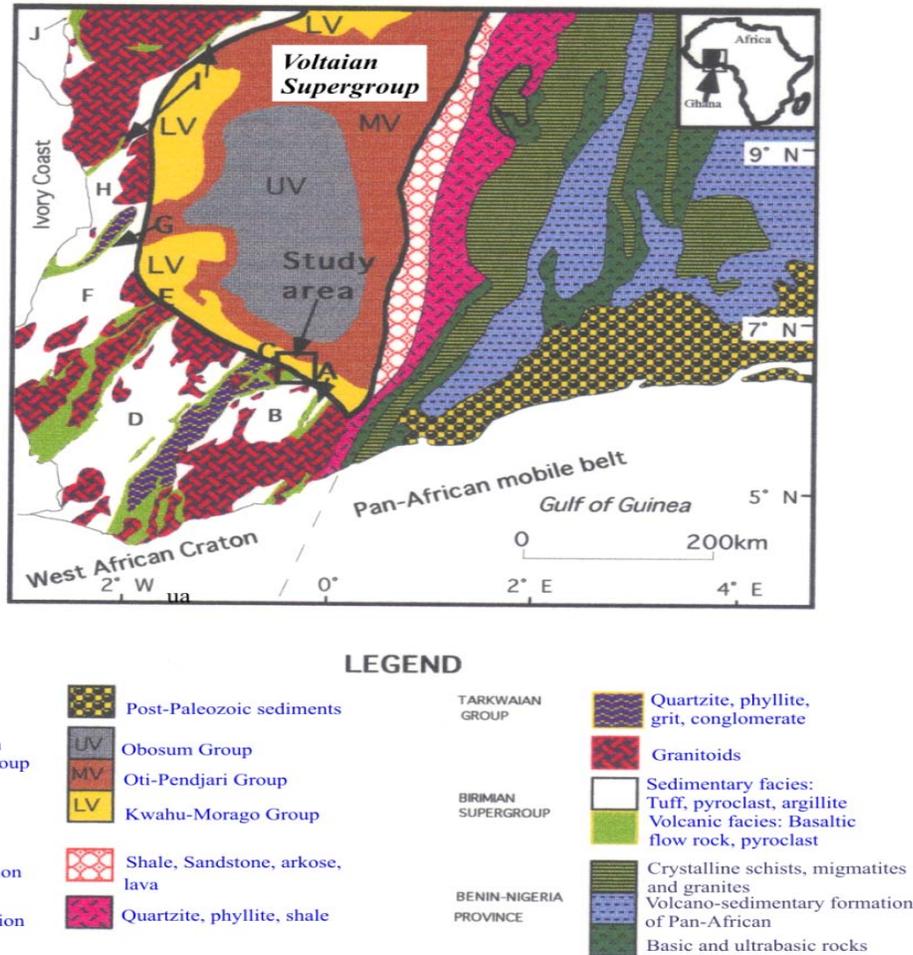


Fig. 2: Generalized geological map of the West African Craton (Ako and Wellman, 1985 and partly modified). Belts and basins in the Birimian are defined after Leube *et al.*, (1990) as follows:  
 A-Kibi-Winneba belt, B-Cape Coast basin, C-Ashanti belt, D-Kumasi basin, E-Sefwi belt, F-Sunyani basin, G- Bui belt, H- Maluwe basin, I-Bole Navrongo belt, J-Lawra belt

Formation of Saunders (1970) and correlative of the Upper Voltaian Formation of Kete (1980). The division of these rocks is based on the horizontal and the sub-horizontal nature of the rock and the topography.

Basement rocks of the Neoproterozoic to early Cambrian Voltaian Basin constitute the easternmost portion of Paleoproterozoic rocks of the West African craton. Other surrounding rocks of the Voltaian Basin are the Buem Formation, the Togo Formation, and the Benin-Nigeria Province on the east.

#### APPROACH AND METHODOLOGY

Assessment of the occurrence of heavy minerals in both Sandstones of the Kwahu-Morago Group and the Oti-Pendjari Group revealed that zircon, tourmaline, rutile

and opaque minerals occur to a large extent. The characterization of sandstone provenance adopted here was based on zircon typology in both groups.

Zircon crystals (populations) were separated from sandstone samples collected from both the Kwahu-Morago and Oti-Pendjari groups. The samples were moderately crushed and sieved using a 44 and 250  $\mu\text{m}$  sieves, respectively. The heavy minerals were concentrated using bromoform (tribromoethane), and a zircon concentrate was prepared using a magnetic separator. The zircon crystals were then hand-picked and mounted on glass slides using petropoxy 154. Sections were made from 14 samples (7 from the Oti-Pendjari Group and 7 from the Kwahu-Morago Group). In all, a

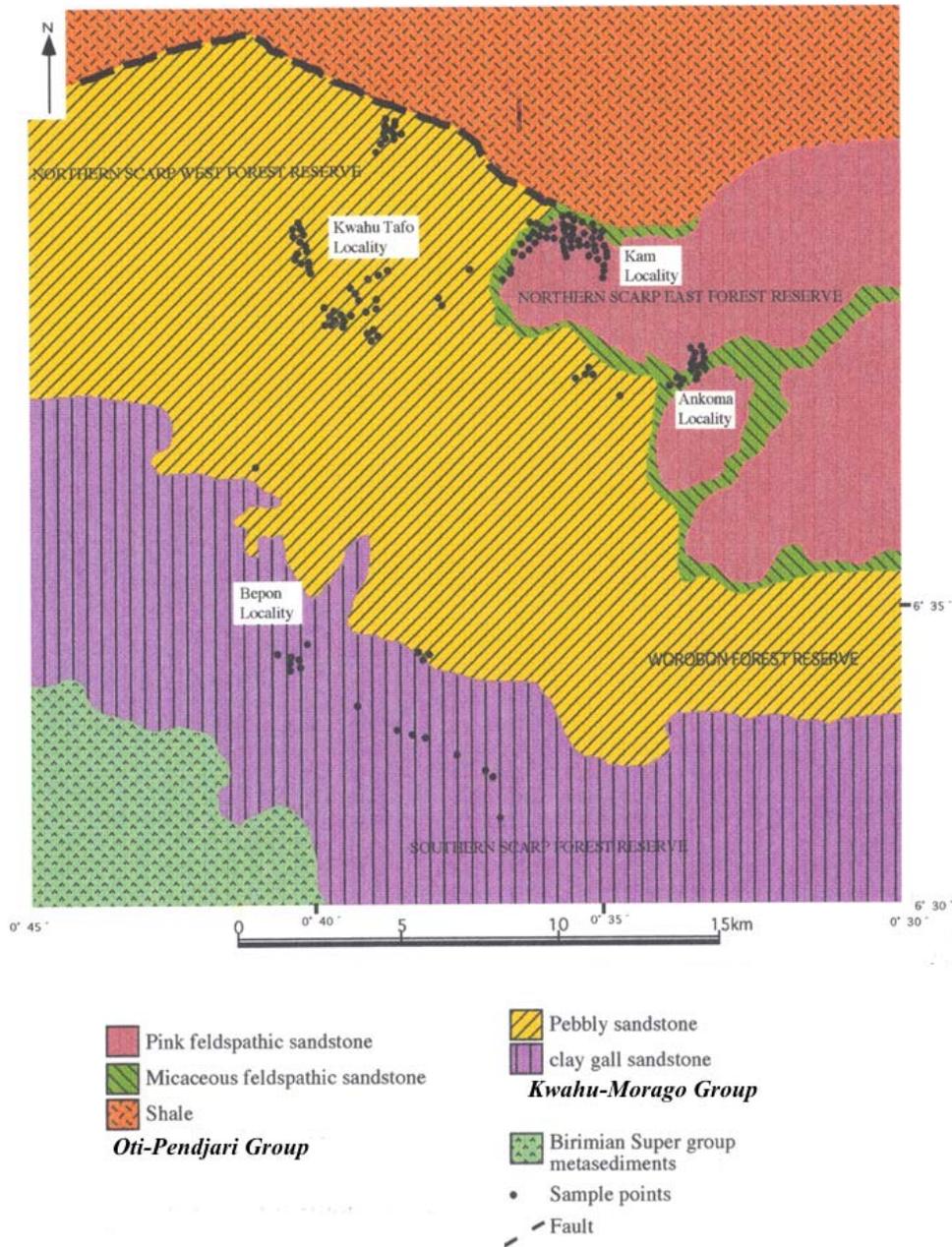


Fig. 3 : Geological map of the Voltaian supergroup in the Southeastern part of the Voltaian Basin.

total of 63 and 91 zircon crystals from both the Kwahu-Morago Group and Oti-Pendjari Group were studied respectively. Rounded and broken crystals were avoided. Analysis was undertaken based on the analytical technique developed by Pupin (1980) for igneous and metamorphic rocks.

The physical and chemical conditions under which zircon crystallizes control the relative development of prism faces (100) and (110), as well as pyramid faces (101) and (211) (Pupin, 1976, 1980). On the typology

diagram (Fig. 4) two indices are used to characterize each type or sub-type. Index A corresponds to the degree of development of pyramidal forms and is controlled by an anti-correlation (Loi and Dabard, 1997) between aluminum and alkalis. Index T corresponds to the development of prismatic forms and is controlled by crystallization temperature.

In igneous rocks, the chronology or sequence of appearance of zircon crystal forms during definite stages of magmatic crystallization leads to the establishment of

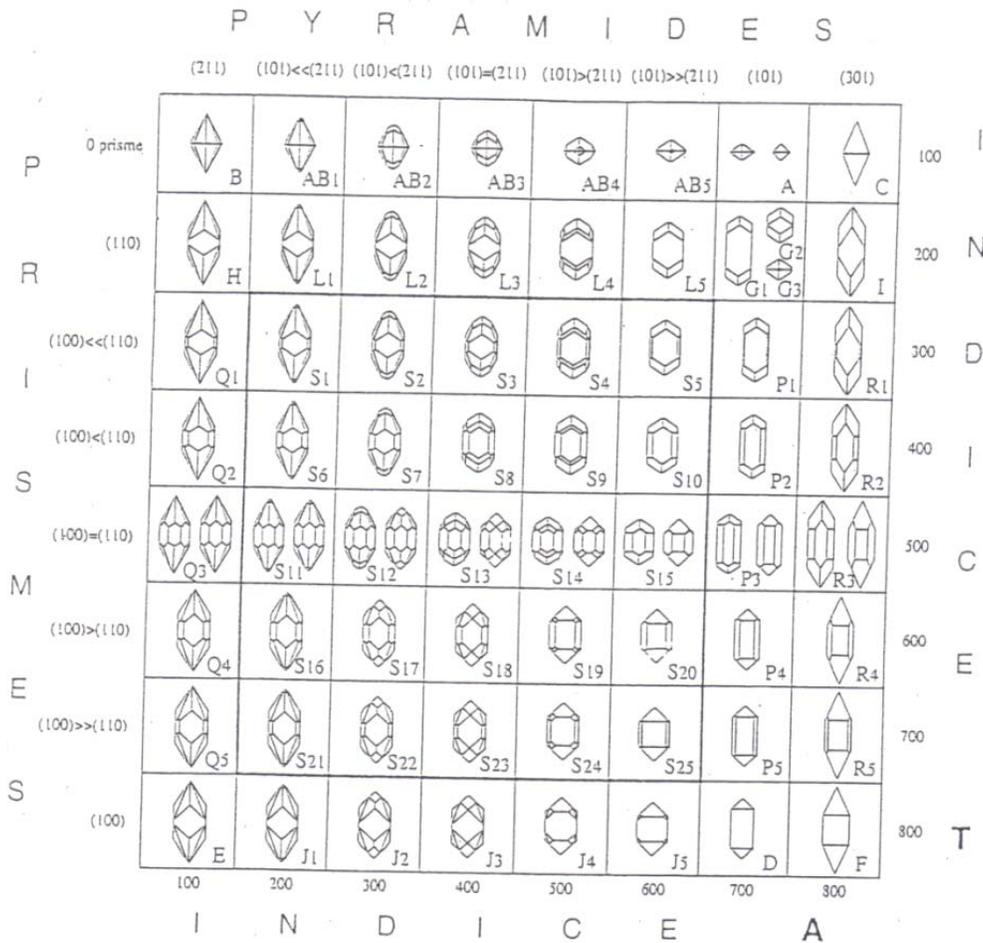


Fig. 4: Main types and sub-types of the typologic classification. After Pupin (1980). The two variables (A,T) correspond to the relative development of the crystalline faces (respectively, pyramids and prisms of the zircon)

individual 'Typological Evolutionary Trend' (T.E.T) (Pupin and Turco, 1972). Sediments experience the mixing of sub-populations from different lithologies thus making it impossible to establish a T.E.T. However, the types and subtypes of zircon found in the sediments are indicative of the different natures of their source-rocks.

Pupin (1980) has proposed a petrogenetic classification based on field observations, petrographical and geochemical data of granites examined with the distribution of their zircon typological populations and their T.E.T. A summary of the classification is as follows;

- Granites of crustal or mainly crustal origin (orogenic granites)
- Granites of crustal + mantle origin, hybrid granites (orogenic granites)
- Granites of mantle or mainly mantle origin (anorogenic granites)

For details (which is beyond the scope of this study) including the logical distribution of some non granitic groups of endogenous rocks (Pupin, 1980). Figure 4 from Pupin (1980) has been adopted for the purpose of this study.

## RESULTS

The distribution pattern demonstrates a variety of proportional disparities and characteristics in zircon populations as well as variable trends on the typology diagram (Fig. 7 and 8). Zircon crystals in the sandstones of the Kwahu-Morago Group are relatively bigger and most are rounded or angular fragments (Fig. 5). Generally, only about 27.4% of a total of 229 grains from the Kwahu-Morago Group have the morphology susceptible to typological study. By contrast, zircons in the sandstones of the Oti-Pendjari Group are relatively

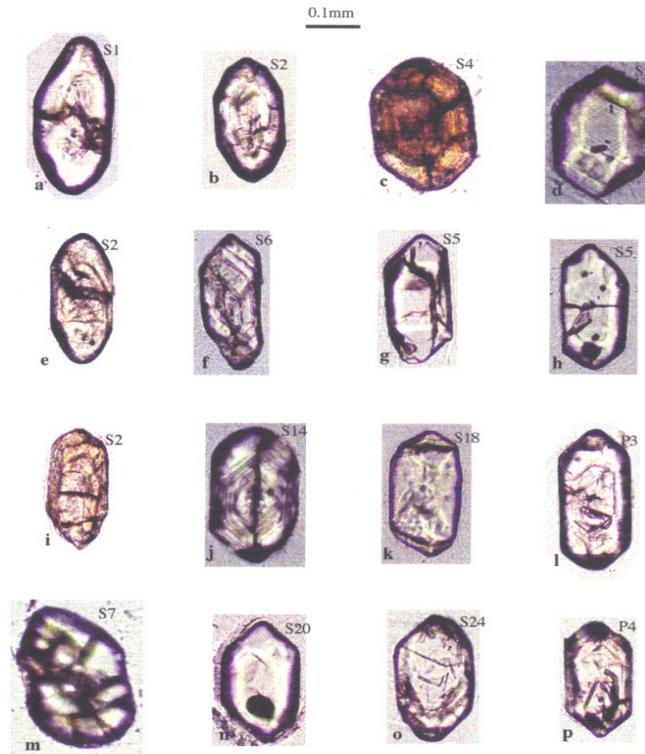


Fig. 5 : A few examples of detrital zircon crystals from the Kwahu-Morago Group susceptible for typology analysis

smaller and are quite sharp euhedral crystals (Fig. 6). A few rounded and angular fragments are present. A total of 54.6% out of 166 grains have the morphology susceptible to typologic study.

**The Kwahu-Morago group:** Distinctly, two dominant zircon sub-populations are identified here with traces of a third sub-population emerging (Figs. 7b and c). The first sub-population exhibits a low A and T indices (Figs. 7b and c), with zircons plotting in fields characteristic of sub-types S1, S2, S6 and S7. Some of the zircons are transparent with no internal features; they are quite inclusion-poor. Generally, the characteristics of the zircons mentioned above indicate that they probably crystallized in a plutonic body under conditions of crustal anatexis (Figs. 7c and 8) and (Pupin, 1980).

However, some of the zircons show growth discontinuities (Fig. 5a and e) and somewhat smooth edges. A volcanic origin is quite likely for zircons with growth discontinuities. The second sub-population, which is least abundant in the Kwahu-Morago Group, displays high A and T indices (Fig. 7b and c). The zircons plot into the fields for sub-type S18, S20, S24 and P4 (Fig. 7a and c). Few crystals show sharp edges (Fig. 5n and p). Others show inclusions of fluid and/or solid phases (Fig. 5l, o and p); these types of zircons, most likely, are of a

volcanic origin. The zircon sub-population here is derived from source-rocks with a dominant mantle type component and could have a calc-alkaline origin (Fig. 7c and 8).

The third sub-population and one of the two dominant contributors in the Kwahu-Morago Group displays high A and low T indices (Fig. 7b and c). It constitutes sub-types S4, S5, S10, S14, S15, P1, and P3. Some show overgrowths indicating some degree of metasomatization and a very few are dark colored. These characteristics indicate that most of these zircons probably crystallized in a plutonic body. This sub-population could be interpreted as originating from source material of calc-alkaline affinity (Figs. 7c and 8). However, a few of the zircons show sharp edges like (Fig. 5d, g and h) with very few inclusions; they probably originated from a volcanic material.

The distribution of the Kwahu-Morago Group sub-populations on the typology diagram (Fig. 7c) coupled with the characteristics of zircon grains seem to indicate a clastic supply from two main sources. One is predominantly crustal, mostly granitoids with very little contribution from volcanic material. The other being calc-alkaline (crustal with very little mantle affinity?) also mainly granitoid with very little volcanic material contribution.



Fig. 6: A few examples of detrital zircon crystals from the Oti-pendjari Group susceptible for typology analysis

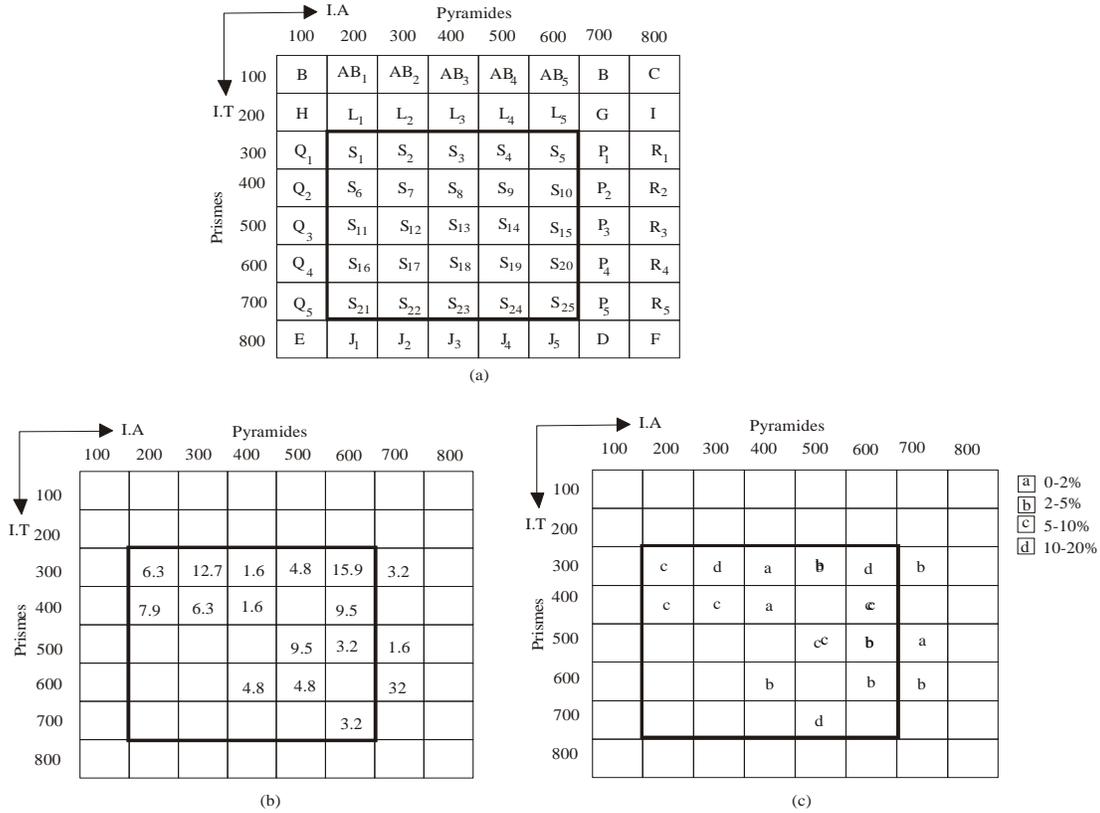


Fig. 7: Typologic and not typologic distribution of zircon populations from the Kwahu-Morago Group (*I.A* is index A and *I.T* is index T) (a) Simplified main types and subtypes of the typologic classified from Pupin, 1980. (b, c) typologic frequency distribution of the population

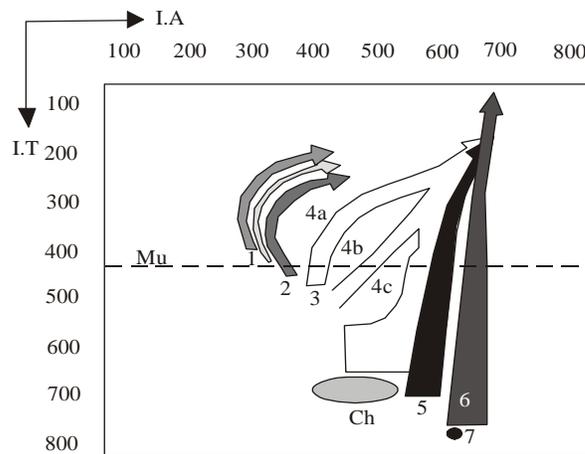


Fig. 8: Distribution of mean points and mean T.E.T (typology evolution trend) of zircon populations (Pupin 1980) from: Granites of crustal or mainly crustal origin (1, 2, 3). Granites of crustal + mantle origin, hybrid granites (4a, b, c) calc-alkaline series granites (dark dotted area = granodiorites + monzogranites); clear dotted area = monzogranites + alkaline granites; (5) sub-alkaline series granites. Granites of mantle or mainly mantle origin: (6) alkaline series granites; (7) tholeiitic series granites. Mu, limit of muscovite granites (*I.T* < 450); Ch, magmatic charnokites area

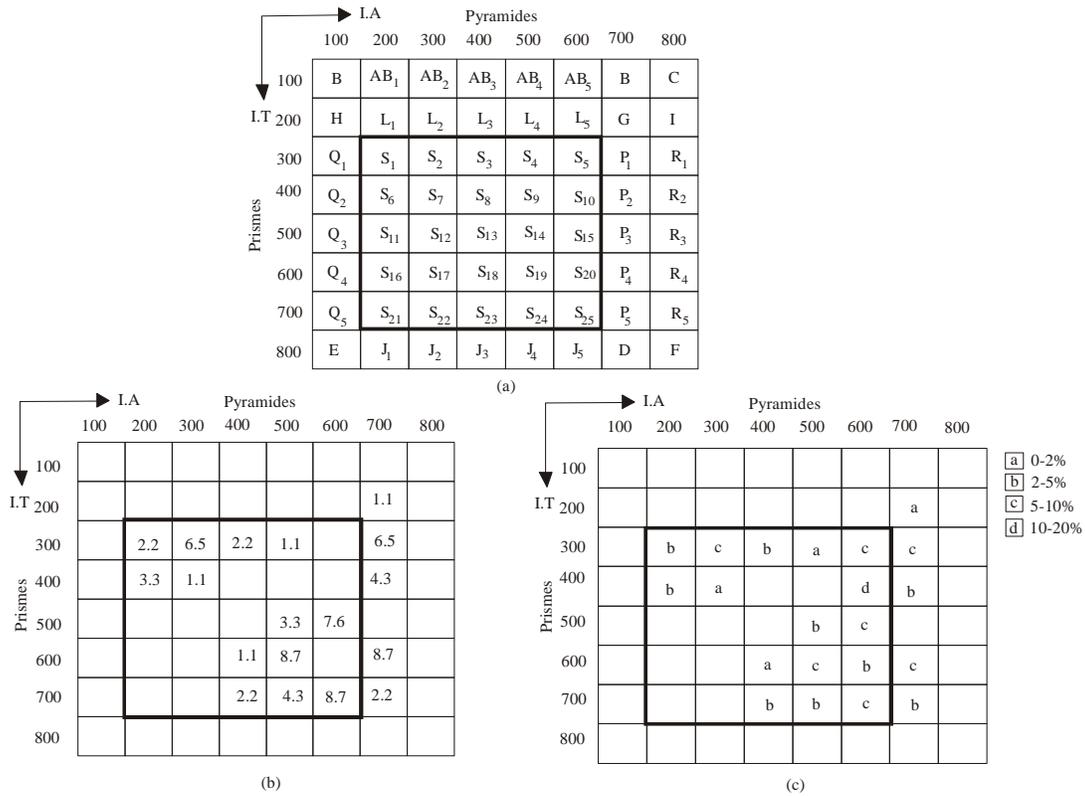


Fig. 9: Typologic and not typologic distribution of zircon populations from the Oti-Pendjari Group (*I.A* is index A and *I.T* is index T) (a) Simplified main types and subtypes of the typologic classified from Pupin, 1980. (b,c) typologic frequency distribution of the population

**The Oti-Pendjari group:** Three dominant sub-populations are identified here.

- In the first sub-population, with low A and T indices (Fig. 9b and c), the zircons plot in fields characteristic of subtypes S1, S2, S3 and S6 (Fig 9a and c). Most of these zircons are dark colored, smooth edges and some negative crystal inclusions (Fig. 6g). These characteristics indicate that they probably have a plutonic origin. These zircons crystallized under crustal conditions (Fig. 8 and 9c).
- The second sub-population displays high A and T indices (Fig. 9b and c). The zircons plot in fields characteristic of subtypes S19, S20, S23, S24, S25, P4 and P5 (Fig. 9a and c). These zircons are mostly dark colored, some show overgrowths; characteristics which indicate that they probably crystallized predominantly in a plutonic body. The distribution trend here seems to be favorably toward S25, P4 and P5 domain (Fig. 9a and c) suggesting that this sub-population is derived from source rocks with a strong mantle component. The spread of sub-types from S24 to P4 suggests crystallization of igneous rocks of a

mixed pattern; one source material of calc-alkaline and the other being of a subalkaline affinity (Fig. 8 and 9c).

- The third sub-population displays high A and low T indices. These are clustered within the fields characteristic for sub-types S5, S10, P1 and P2 (Fig. 9a and c). Some of these zircons have inclusions of rutile crystals (Fig. 6r and y), others have probable negative crystal inclusions (Fig. 6h); they could have a plutonic or volcanic origin with a strong mantle-like component. The relatively high frequency for sub-types P1 and S10 in this sub-population suggests a possible mixing from two igneous source materials. Contribution from a calc-alkaline source. The other source being probably subalkaline (Fig. 9c and 8).

The distribution of the Oti-Pendjari Group sub-populations on the typology diagram coupled with the characteristics of zircon grains seem to indicate a clastic supply probably from three main sources. One is crustal mostly granitoids; the other being calc-alkaline (i.e., a hybrid material constituting crustal plus mantle) and the third source could probably be of a subalkaline origin.

## DISCUSSION

The results obtained from the typological analysis of zircon grains did not only confirm the provenance of the sandstone composition as indicated above but added a considerable degree of sophistication to that determination.

Zircon typology for the Kwahu-Morago Group identified two possible provenance sources; one being, granitoids predominantly of anatectic origin with some contribution of a volcanic material and the other being calc-alkaline with very little volcanic material contribution. Zircon dating by (Kalsbeek *et al.*, 2008) on Kwahu-Morago Group indicate predominantly paleoproterozoic ages. These zircons were mostly derived from the granitoids within the Birimian basins. These granitoids are S-type and per-aluminium in character and have been interpreted as being derived from the melting of meta-sedimentary rocks (Leube *et al.*, 1990). Anani (1999) indicated that the quartz analyses and tourmaline composition of sandstones to the east of this present study showed that the sandstones were probably derived largely from granites with some input from metasediments. A similar but detailed assertion is being made as a result of the zircon typology study in this research.

The second possible source being calc-alkaline (crustal with very little mantle affinity?) with very little volcanic material contribution. These zircons were most likely derived from the granitoids in the Birimian volcanic belts. These granitoids are meta-aluminous and of I-type character. They have been interpreted as being derived from partial melting of basaltic source (Dampare *et al.*, 2005).

However, (Kalsbeek *et al.*, 2008) obtained zircon subpopulation of ages between 1000 and 1500 Ma. These suggest contribution of sediments from the calc-alkaline rocks of the Amazonian craton (Santos *et al.*, 2000; Kalsbeek *et al.*, 2008).

The study of zircons from the Oti-Pendjari Group shows an evolution in the source-areas (Fig. 9). Three probable main sources are identified for the sediments. Granitoids of crustal origin are identified as one of the sources. There seems to be a clear decrease however, in the supply of sediments of crustal origin to the Oti-Pendjari Group as compared to the Kwahu-Morago Group (Fig. 7 and 9). The shift in relative abundance from zircons of a crustal origin to zircons crystallized from magmas with a strong mantle components may probably be indicative of an interruption of a period of quiescence; probably a tectonic movement. The extension of the zircon sub-population to those with a strong mantle affinity and towards a more aluminous type gives a relevant prove of a "basin type" granitoid (Fig. 2 and Hirdes *et al.*, 1992) being a major provenance source to

the Oti-Pendjari Group. These zircon sub-populations have been interpreted as coming either from the same calc-alkaline source rock; or that it has its origin in two distinct sources, one with calc-alkaline and the other one with a subalkaline (tholeiitic?) origin. The zircons with crustal origin seem to be derived from granitoids within the Birimian basins. These granitoids are S-type and per-aluminium in character and have been interpreted as being derived from the melting of meta-sedimentary rocks (Leube *et al.*, 1990). In the Birimian volcanic belts, tholeiitic characteristics associated with the belt granitoids similar to tholeiitic basalts in the belts have been recorded (Hirdes *et al.*, 1992). Kalsbeek *et al.* (2008) have logically suggested that some zircons from the Oti-Pendjari Group were derived from the Pan-African orogen which underlies vast areas east of the Trans-Saharan suture zone and that, apart from reworked older basement, the Pan-African orogeny contains juvenile calc-alkaline magmatic arcs. Thus, the rocks of Pan African age to the east of the Voltaian Supergroup seem to be the most likely source rocks for the Oti-Pendjari Group.

## CONCLUSION

The characteristics of zircon grains in the Kwahu-Morago Sandstone Group suggests a major supply of sediments from the sedimentary basins in the Birimian Supergroup with minor contribution from the Amazonian craton as well.

In the Oti-Pendjari Sandstone Group however, the characteristics of zircon grains suggests the Juvenile calc-alkaline magmatic arcs of the Pan-African orogeny to the east of the study area as its major source of sediment supply. However, both the Birimian belt type and basin type granitoids also contributed sediments.

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