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RESEARCH ARTICLE

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Petrography of detrital zircons from sandstones of the Lower Devonian Accraian Formation, SE Ghana: Implications on provenance

Chris Y. Anani[1] | **Richard O. Anim**[1] | **Benjamin N. Armah**[1] | **Joseph F. Atichogbe**[1] | **Patrick Asamoah Sakyi**[1] | **Edem Mahu**[2] | **Daniel K. Asiedu**[1]

[1] Department of Earth Science, University of Ghana, Accra, Ghana
[2] Department of Marine Fisheries Sciences, University of Ghana, Accra, Ghana

Correspondence
Chris Y. Anani, Department of Earth Science, University of Ghana, PO Box LG 58, Legon, Accra, Ghana.
Email: cyanani@ug.edu.gh; agbekoen@yahoo.com

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Integrated petrographic studies entailing quartz-type analysis and zircon typologic studies were carried out on sandstones of the Lower Devonian Accraian Formation of southern Ghana to constrain their provenance and tectonic setting. The stratigraphic succession of the Devonian Accraian Group consists mainly of sandstones in the Lower Accraian Formation, shales in the Middle Accraian Formation, and sandstone–shale intercalations in the Upper Accraian Formation. Systematic sampling of sandstones was conducted in the Lower Devonian Accraian Formation. Modal petrographic analysis indicates that the sandstones are quartz arenites with their framework grains consisting on average of, 99.8% quartz, 0.14% lithics with little or no feldspars. They are subangular to subrounded in shape. Modal mineralogy of the sandstones suggests that they are of craton interior origin with an affinity to recycled orogenic provenance. Quartz-type analysis was used to unravel distinct characteristic features of the quartz grain, namely its polycrystallinity, nonundulose, and undulose nature to constrain the source rock. This pointed to multiple sediment supply from both a plutonic origin and a medium- to high-grade metamorphic terrain. Furthermore, a comprehensive zircon typology study on 298 zircon grains indicate multiple provenances of calc-alkaline affinity. This study revealed that the Lower Accraian Formation sandstones probably received sediment input from the Paleoproterozoic Birimian Basin granitoids and their associated metasedimentary rocks and some additional supply from the Neoproterozoic sedimentary rocks from the Volta Basin which are inclusive of sediments derived from the Dahomeyide Belt of the Pan-African Orogeny.

KEYWORDS
Accraian, calc-alkaline, modal mineralogy, orogenic provenance, Palaeozoic

1 | INTRODUCTION

Provenance studies are especially important to our understanding of palaeogeography. When coupled with studies of depositional environments, they help us interpret the relative positions of ancient oceans and highlands at given times in the geologic past (Boggs, 2009).

The overall composition of siliciclastic sediments is influenced by several factors that include the source area composition, climate, sediment transport processes, burial, and diagenesis (e.g., Armstrong-Altrin et al., 2012; Armstrong-Altrin, Lee, Verma, & Ramasamy, 2004; Johnsson, 1993). In petrographic studies, the modal compositions of sandstones and the nature of quartz grains as well as lithic fragments can be utilized to infer the type of source rocks (Asiedu, Suzui, & Shibata, 2000; Blatt, Middleton, & Murray, 1980; Folk, 1974, 1980; Pettijohn, Potter, & Siever, 1987) and their tectonic setting (Basu, 2003; Dickinson et al., 1983; Dickinson & Suczek, 1979; Weltje, 2002). Although rock fragments (lithics) or individual mineral grains are excellent indicators of source area, several problems may arise during interpretation. These issues are particularly related to the lithological and/or compositional similarities between different source areas and the biased distribution of detrital materials in the sedimentary rock because of different responses of each fragment or mineral to weathering, erosion, transport, and/or diagenesis (Boggs, 2009).

Zircon has, however, played a prominent and complex role in interpreting the composition and history of modern and ancient sediments. Because zircon is highly refractory at the Earth's surface, it occurs in virtually all sedimentary deposits and so provides a critical link in understanding the source history of a deposit (Fedo, Sircombe, & Rainbird, 2003).

Proterozoic to early Cambrian rocks underlie over 80% of Ghana. These rocks also host most of the mineral deposits mined in Ghana. Consequently, the tectonic history of Ghana during the Proterozoic to Cambrian times has received much attention (e.g., Affaton, Aguirre, & Me'not, 1997; Anani, 1999; Anani, Mahamuda, Kwayisi, & Asiedu, 2017; Anani, Bonsu, Kwayisi, & Asiedu, 2019; Davis, Hirdes, Schaltegger, & Nunoo, 1994; Leube, Hirdes, Mauer, & Kesse, 1990; Petersson, Scherstén, & Gerdes, 2018; Taylor, Moorbath, Leube, & Hirdes, 1992;). Compared to the Precambrian, the Phanerozoic

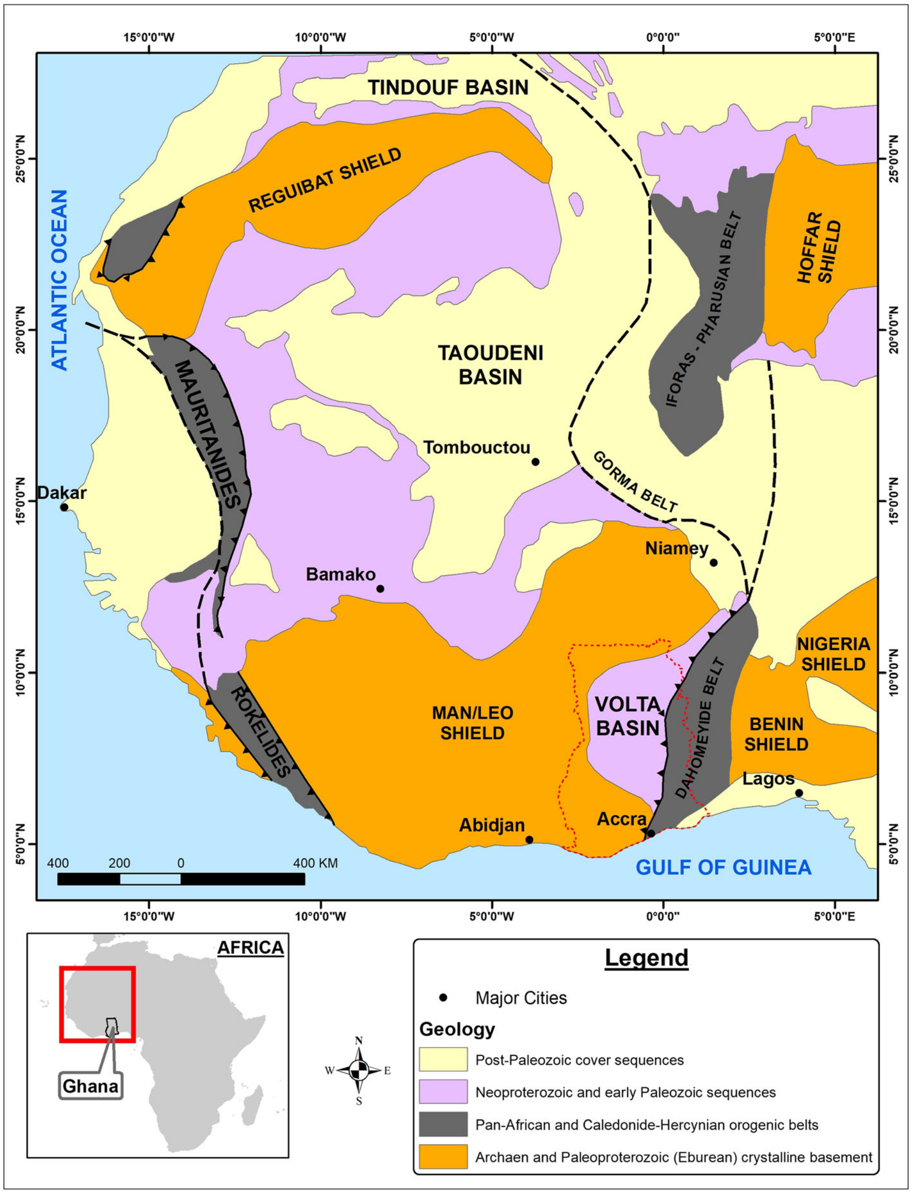


FIGURE 1 Simplified geological map of the Leo-Man Shield of the West African Craton (WAC) indicating the position of Ghana modified after Carney et al. (2010). Inset showing a simplified map of Africa showing the position of Ghana [Colour figure can be viewed at wileyonlinelibrary.com]

tectonic history of sedimentary rocks which are mostly found on the coastal stretch of Ghana, have received very little attention.

The coastal region of Ghana is interspersed by a number of sedimentary rocks which have been suggested to be Devonian in age (McCallien, 1962). To understand the tectonic history of Ghana during the Ordovician to early Cretaceous periods, Asiedu, Hegner, Rocholl, and Atta-Peters (2005) and Asiedu, Atta-Peters, Hegner, Rocholl, and Shibata (2010) reported on Nd isotope and trace elements of the Sekondian Group of rocks to the west of the Accraian rocks. Anani, Kwayisi, Agra, and Asiedu (2018) also reported on the petrographic and whole-rock geochemistry of the Accraian Group of rocks.

Previous studies have mainly dealt with the biostratigraphy and the depositional environment of these coastal rocks (e.g., Anan-Yorke, 1974; Asiedu, Atta-Peters, & Peprah, 2000; Atta-Peters, 1999; Mensah, 1973). It is therefore, the objective of this paper, to investigate the sandstones of the Lower Devonian Accraian rocks, with particular emphasis on zircon analysis, to unravel their provenance.

2 | GEOLOGIC SETTING

The West African Craton (WAC; Figure 1) in NW Africa is made up of the Archaean Reguibat Shield in the North, and the Leo-Man Shield in the south, which are separated by the Neoproterozoic–Palaeozoic Taoudeni Basin (Petersson et al., 2018). The geology of Ghana falls within the southeastern portion of the West African Craton (WAC; Figure 1). It is divided into four tectono-stratigraphic units (Figure 2). These are: (a) Late Palaeozoic to Mesozoic sedimentary basins; (b) mobile belt situated to the east of the West African Craton, and evolved during the Pan-African Orogeny (around 600 Ma) also known as the Dahomeyide Belt; (c) early Proterozoic crystalline rocks collectively known as the Birimian and Tarkwaian rocks with ages ranging between ~2.31 and 2.06 Ga (de Kock, Armstrong, Siegfried, & Thomas, 2011), and (d) Neo-Proterozoic sedimentary cover called the Voltaian Basin.

On the west to northwest of the study area are the Birimian volcanic belts, granitoid gneisses, and sedimentary basins trending NE–SW which dominate the Palaeoproterozoic basement of Ghana (Hirdes, Davis, Lüdtke, & Konan, 1996; Leube et al., 1990; Figure 2). The volcanic belts gradually evolve from tholeiitic basalts at the base to more calc-alkaline andesites, dacites, and rhyolites in the upper sections (e.g., Boher, Abouchami, Michard, Albarède, & Arndt, 1992; Sylvester & Attoh, 1992). The metasedimentary basins are composed of volcanoclastics, greywackes, argillitic rocks, and chemical sediments that have been isoclinally folded, and different suites of felsic rocks intrude both the volcanic belts and the metasedimentary basins: Winneba, Cape Coast, Dixcove, and Bongo (Leube et al., 1990). Rocks of the Winneba suite are granitic to granodioritic, the Cape coast suite which predominantly intrude the metasedimentary basins are peraluminous biotite-granodiorites, the Dixcove suite which mainly

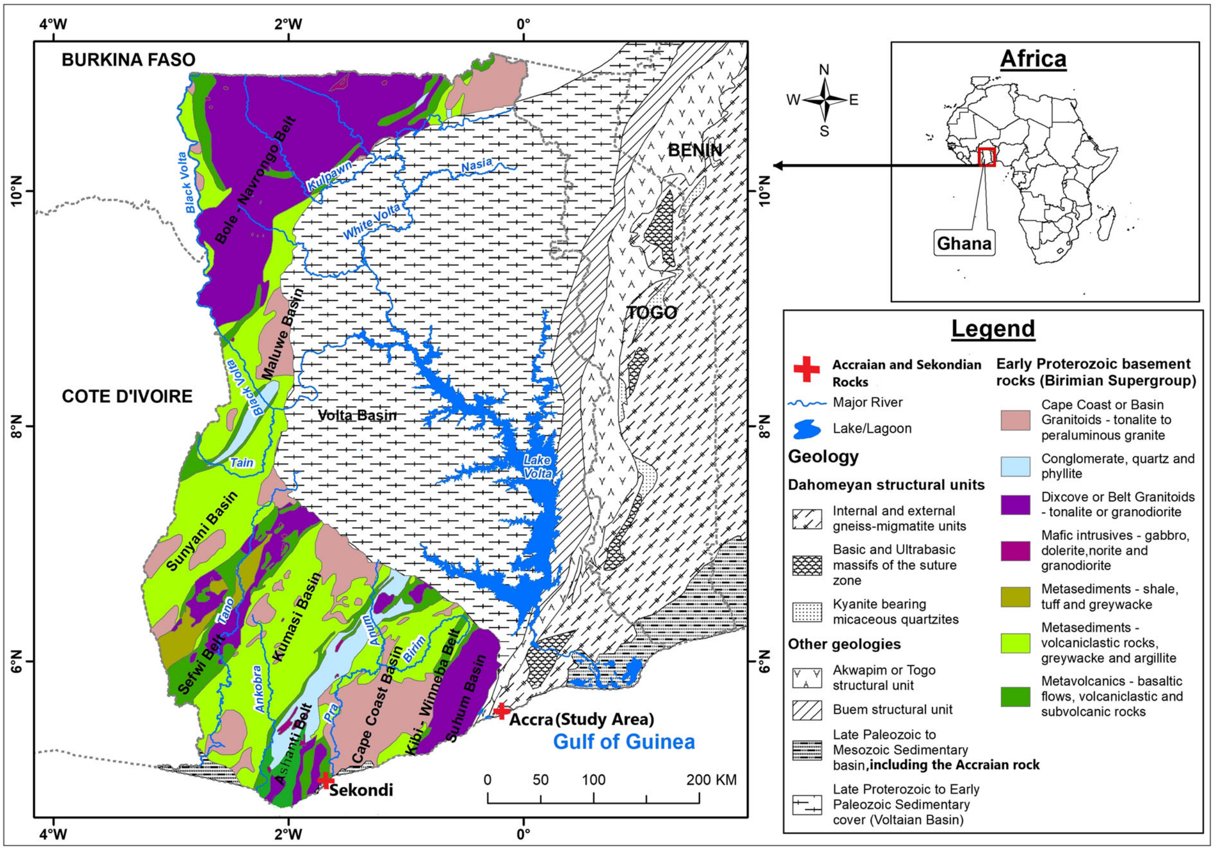


FIGURE 2 Geological map of Ghana showing, basins, belts, and main rock units surrounding the study area modified after Petersson et al. (2018) and Tairou, Affaton, Anum, and Fleury (2012) [Colour figure can be viewed at wileyonlinelibrary.com]

intrude volcanic basins are normally metaluminous hornblende bearing granitoids, and rocks of the younger Bongo suite are potassium-rich granites found in northern Ghana intruding the Tarkawaian sediments (Leube et al., 1990, Figure 2). To the north and west, north-west of the study area are the Volta Basin and Dahomeyide orogenic belt, respectively. The Pan-African Dahomeyide orogenic belt occupies an approximately 1,000 km long stretch from southeastern Ghana, through Togo, Benin, to Nigeria (Attoh, 1998; Attoh & Nude, 2008; Figure 2). It forms part of the very long (>2,500 km) Trans-Saharan mobile belt which formed during the Pan-African orogenic event. The Pan-African Dahomeyide orogenic belt comprises three structural units. From west to east, these are the Buem, the Togo, and the Dahomeyan structural units (Figure 2). The Dahomeyan structural unit rocks, which form an unconformity with the Accraian rocks, are around 600 Ma with pockets of 2.1 Ga (Attoh, Samson, Agbossoumondé, Nude, & Morgan, 2013; Ganade et al., 2016; Tairou et al., 2012).

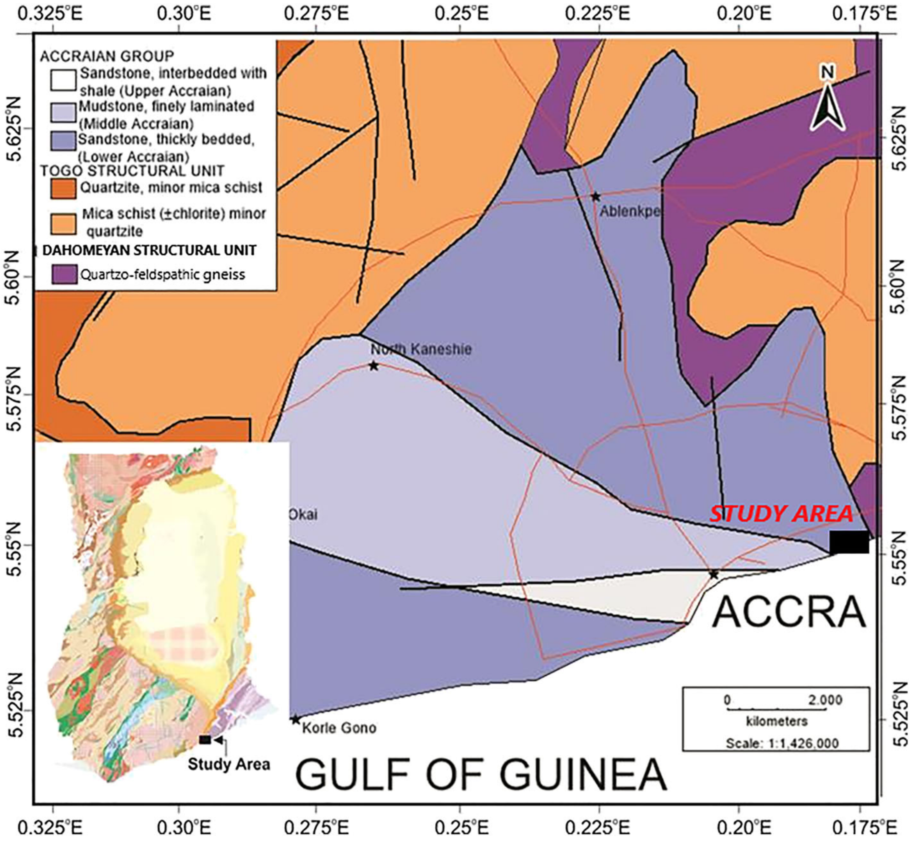


FIGURE 3 Geological map of the study area after Anani et al. (2018). Inset showing a simplified map of Ghana [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 4 Sandstone beds of the Lower Accraian showing an up close nature of the sparsely distributed pebbles [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 5 Lower Accraian sandstone beds showing the relative thinning of beds upwards [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Detrital modes of quartz arenites from the Lower Accraian sandstone samples

									QtFL%			QmFLt%		
Sample	**Qm**	**Qp**	**P**	**K**	**Ls**	**Lv**	**Lm**	**L**	**Qt**	**F**	**L**	**Qm**	**F**	**Lt**
AC 2	481	8	0	0	1	0	0	1	99.8	0	0.2	98.2	0	1.8
AC 4	479	13	0	2	1	0	0	1	99.4	0.4	0.2	96.8	0.4	2.8
AC 11	482	8	0	0	3	0	0	3	99.4	0	0.6	97.8	0	2.2
AC 12	466	33	0	1	0	0	0	0	99.8	0.2	0	93.2	0.2	6.6
AC 17	479	15	0	0	1	0	0	1	99.8	0	0.2	96.8	0	3.2
AC 21	478	15	0	0	0	0	0	0	100	0	0	97.0	0	3.0
AC 22	455	44	0	0	0	0	0	0	100	0	0	91.2	0	8..8
AC 23	473	27	0	0	0	0	0	0	100	0	0	94.6	0	5.4
AC 24	486	11	0	0	0	0	0	0	100	0	0	97.8	0	2.2
AC 25	484	6	0	0	1	0	0	1	99.8	0	0.2	98.6	0	1.4

Abbreviations: F, K + P; K, K-feldspar; L, Ls + Lv + Lm; Lm, metamorphic lithic fragments; Ls, sedimentary lithic fragments; Lt, Qp + L; Lv, volcanic lithic fragments; P, plagioclase; Qm, monocrystalline quartz; Qp, polycrystalline quartz; Qt, Qm + Qp.

TABLE 2 Quartz-type modal composition of Lower Accraian sandstone samples (Diamond Diagram)

					Qu Qn Qp(2–3) Qp(>3)%			
Sample	**Qu**	**Qn**	**Qp (2–3)**	**Qp (>3)**	**Qu**	**Qn**	**Qp (2–3)**	**Qp (>3)**
AC 2	85	369	7	1	17.4	81	1.4	0.2
AC 4	126	353	12	1	25.6	71.8	2.4	0.2
AC 11	136	346	4	4	27.8	70.6	0.8	0.8
AC 12	120	346	29	4	24.1	69.3	5.8	0.8
AC 17	132	347	12	3	26.7	70.3	2.4	0.6
AC 21	73	405	11	4	14.8	82.2	2.2	0.8
AC 22	92	363	39	5	18.4	72.8	7.8	1.0
AC 23	102	371	23	4	20.4	74.2	4.6	0.8
AC 24	101	385	7	4	20.3	77.5	1.4	0.8
AC 25	92	392	6	0	18.8	80.0	1.2	0

Abbreviations: Qn, nonundulose monocrystalline quartz; Qp(>3), polycrystalline quartz with more than three crystals making up less than (<25%); Qp(2–3), polycrystalline quartz with two–three crystals greater than 75%; Qu, undulose monocrystalline quartz.

The Voltaian Supergroup that fills the Volta Basin (Figure 2) is made up of Neoproterozoic to early Palaeozoic strata up to ~5 km thick. The strata consist of a succession of sandstones, mudstones, and few proportions of limestone (Affaton, Sougy, & Trompette, 1980; Anani et al., 2017; Kalsbeek, Frei, & Affaton, 2008). It covers a surface area of ~115,000 km^2.

The study area (Figures 2 and 3) is along the coastline in the southeastern portion of Ghana. They overlie unconformably on the Dahomeyan basement complex and with an area extension of approximately 11.7 km^2 (Kesse, 1985). The Accraian rocks consist of quartz grits, sandstones, shales, and mudstones generally dipping gently to the southwest. According to McCallien (1962), these sedimentary rocks can be divided into three formations; (a) the lower sandstone formation being the oldest, (b) the middle shale formation, and (c) the upper sandstone-shale formation being the youngest.

The Accraian Group in Ghana is Devonian in age (McCallien, 1962). The shales of the Middle Accraian Formation have yielded fossils such as trilobites, bivalves, and gastropods. It is interesting to note that the Accraian fossils are like those of the Middle Devonian of North America (McCallien, 1962). The thickness of the shale Formation has been estimated by the Geological Survey Authority of Ghana as ~116 m.

The Lower Accraian Sandstone rocks, which are the subject under investigation, are essentially sandstones with subordinate amounts of coarse materials such as grits, breccia, and pebbles; these subordinate amounts of pebbles are sparsely distributed within the lower portions of the beds and therefore described loosely here as pebbly sandstone beds (Figure 4). They are quite massively bedded from below. These beds fine upwards as medium to thin beds with some sparse shale intercalations (Figure 5). These pebbly sandstones which form the older portion of the Lower Accraian Formation overlie the Dahomeyan basement rocks of the Dahomeyide belt (Figures 2, 3) and appear to be steeply dipping but rather dip gently westwards further away from the basement rocks.

3 | MATERIALS AND METHODS

Fresh and unweathered sandstone samples (from the Lower Accraian Formation) were obtained from the beach (Figure 3) east of Accra, the capital of Ghana. Ten sandstone thin sections were prepared for petrographic analysis/point counting (Table 1). Point-counts were mostly in the range of 400–500.

The quartzose nature of the Lower Devonian Accraian sedimentary rocks prompted the use of quartz-type analysis adopted by Basu, Young, Suttner, James, and Mack (1975). Comparison of undulosity of the monocrystalline quartz with the amount of polycrystalline quartz can be used to differentiate recent and ancient sands of plutonic and low- and high-rank metamorphic origins. This analysis was adopted on the Accraian sedimentary rocks (Table 2).

3.1 | Zircon mineral separation

Characterization of sandstone provenance adopted here was also based on zircon typology. Zircon crystals (populations) were separated from sandstone samples collected from the Lower Accraian

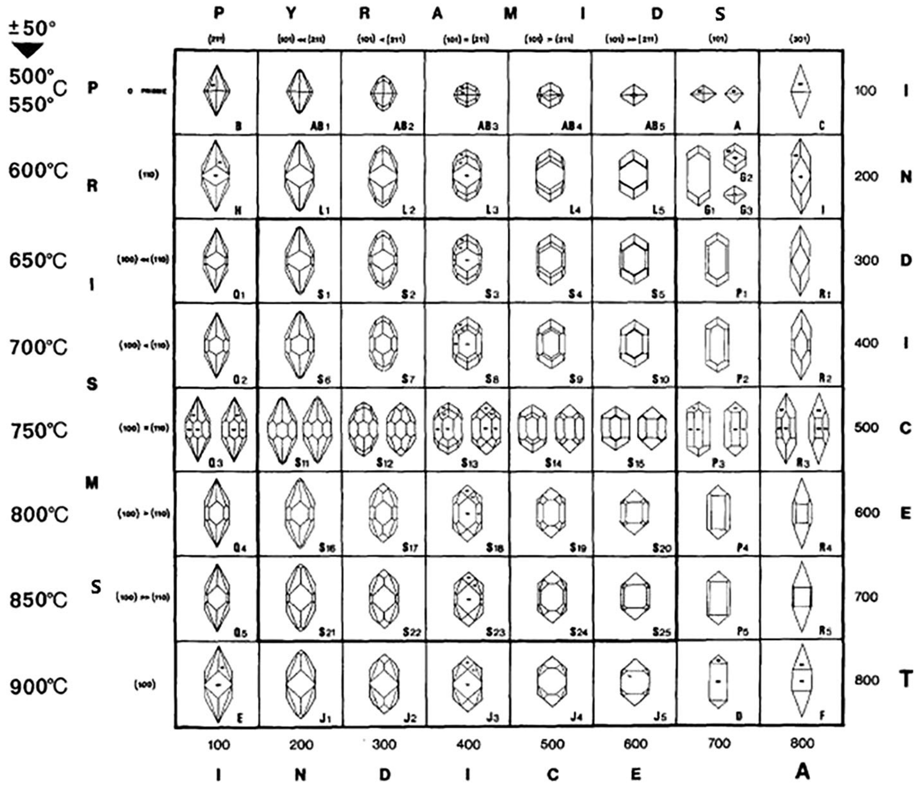


FIGURE 6 Zircon typological classifications proposed by Pupin (1980). Index A reflects the Al/alkali ratio, controlling the development of pyramids in the crystals. Index T reflects the effects of temperature on the development of prisms

Formation. The samples were moderately crushed and sieved using 150–300 μm size fractions.

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 10 samples. In all, a total of 298 zircon crystals from the Lower Accraian Formation were studied. Rounded and broken crystals were avoided. Analysis to assess zircon typology was undertaken based on the analytical technique developed by Pupin (1980) for igneous and metamorphic rocks (Figure 6). To characterize zircon crystals based on morphology, the following steps were undertaken according to Pupin (1980) and Gärtner et al. (2013) (Figure 6): (a) scanning of grain mounts under the optical microscope carefully identifying zircon grains in each visual field to complete up to ~298 grains of detrital zircons, (b) zircon grain characterization by specific morphometric parameters such as elongation and roundness (Gärtner et al., 2013) and degree of face development, (c) zircon classification (Figures 9,10), and (d) generate the specific typological classification.

This work was performed in the laboratory of the Earth Science Department, University of Ghana.

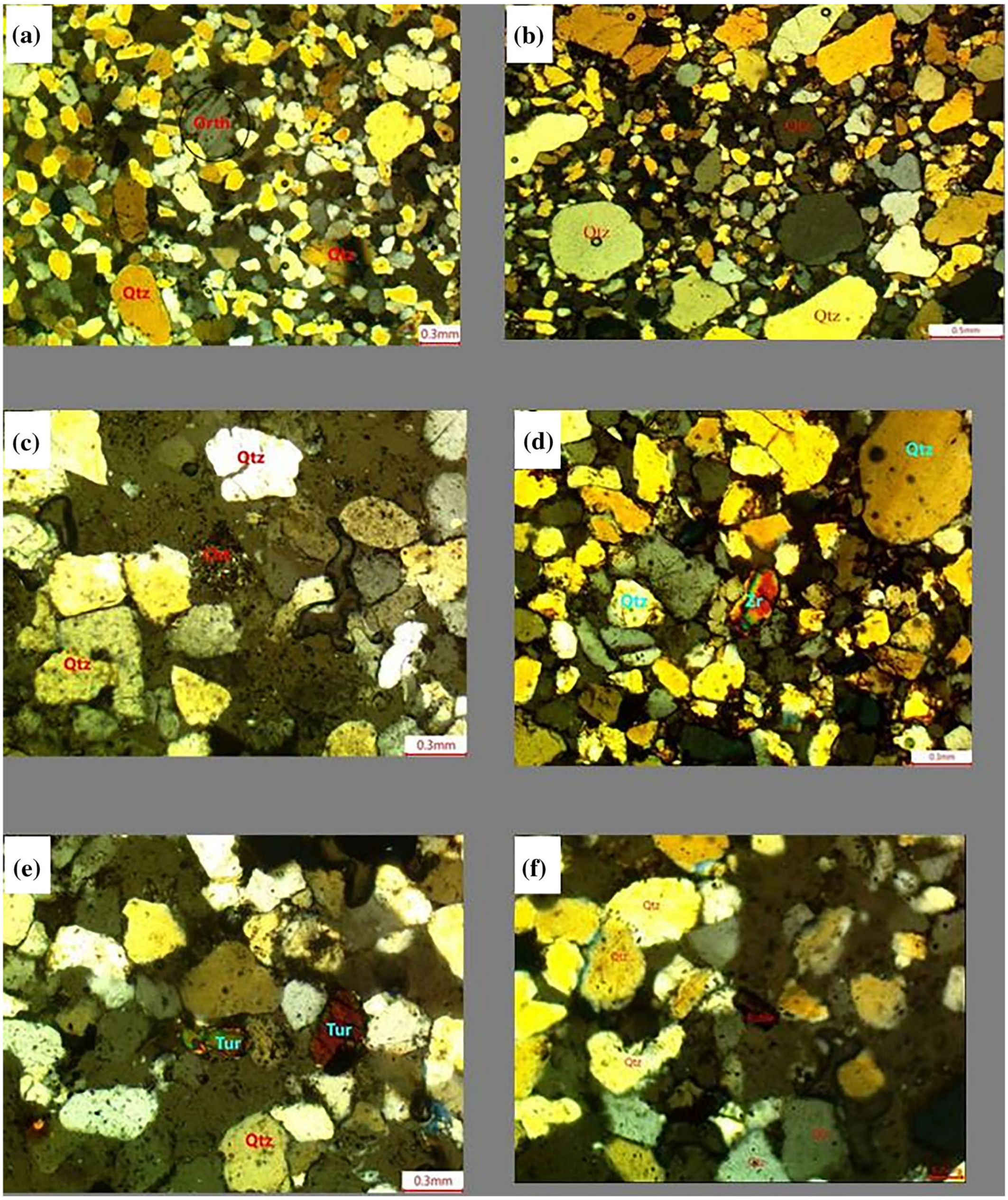


FIGURE 7 Photomicrographs of the Accraian sandstone showing (a) an orthoclase mineral, (b) general texture of poorly sorted grains (Bimodal texture), (c) a sedimentary lithic fragment (chert), (d) a zircon mineral, (e) a tourmaline mineral, and (f) a rutile mineral at the centre [Colour figure can be viewed at wileyonlinelibrary.com]

4 | RESULTS

4.1 | Petrography

4.1.1 | Quartz

Results of the modal analysis of the medium-grained sandstones are presented in Table 1. These sandstones exhibit compositional maturity (Figures 7a–e). Framework grains consist of a few polycrystalline quartz and mostly monocrystalline quartz, consisting of two modes (bimodal), one in the coarse or medium sand range and the other in the fine sand range (Figure 7b). Generally, the modal quartz content ranges between 99.4% and 100%. The grains are subangular to rounded.

4.1.2 | Feldspar

The feldspar content is extremely low, and in some cases, absent (0%–0.4%). K-feldspars mostly orthoclase, dominate over plagioclase (Figure 7a; Table 1). Most of the feldspars have been altered into clay minerals (sericites).

4.1.3 | Lithic fragments/heavy minerals

The lithic fragments are mainly sedimentary in origin (0%–0.6%), composed of chert and shale (Figure 7c; Table 1)? The heavy minerals include zircon, tourmaline, and rutile (Figures 7d–f).

The petrographic evidences suggest grain-supported sandstones within the Lower Accraian rocks. On the basis of their mineralogical contents based on the point counts (Table 1), the Lower Accraian sandstones are classified as quartz arenites (Figure 8), according to Folk (1974).

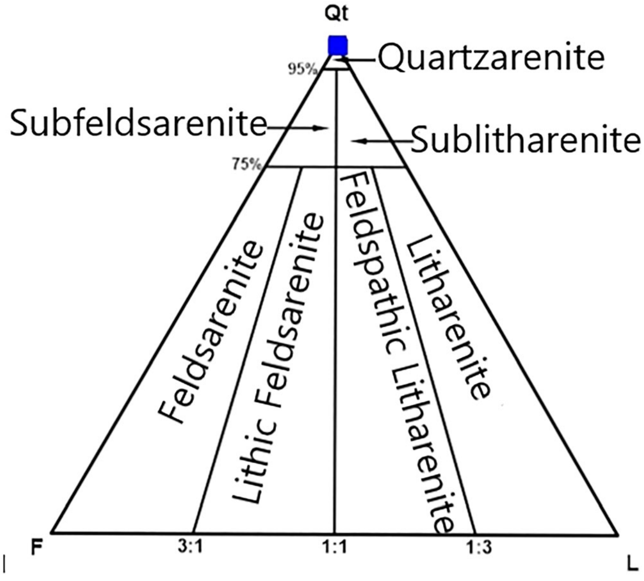


FIGURE 8 QtFL diagram modified after Folk (1974), showing the sandstone classification of the Lower Accraian Sandstone Formation where: Qt, total quartz including monocrystalline and polycrystalline quartz; F, feldspar; L, lithic fragments. The square symbols represent the plotted sandstone samples of the Lower Accraian [Colour figure can be viewed at wileyonlinelibrary.com]

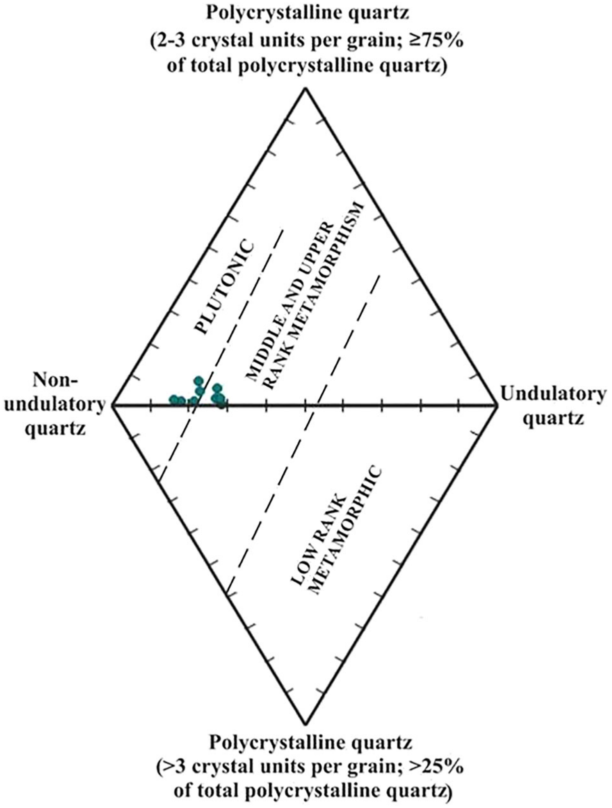


FIGURE 9 Varietal quartz diamond plot used to discriminate sands sourced by different types of crystalline rocks, on the basis of the extinction pattern and polycrystallinity of quartz grains (Basu et al., 1975) [Colour figure can be viewed at wileyonlinelibrary.com]

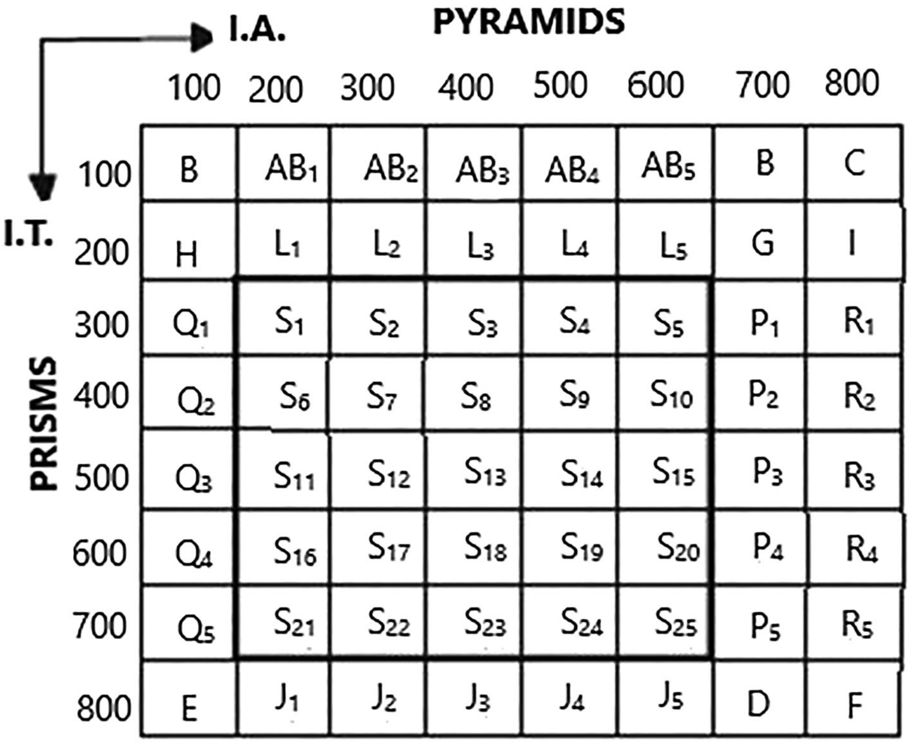
4.2 | Quartz-type analysis of the quartz arenites

Detailed investigation into the characteristics of quartz grains to help constrain their potential sources was undertaken. To evaluate the relative importance of plutonic and metamorphic rocks as quartz sources, we plotted polycrystalline quartz versus nonundulatory and undulatory monocrystalline quartz in a double-triangular diagram (Figure 9) following the technique of Basu et al. (1975).

The Accraian sandstone samples are mostly monocrystalline quartz with 91.2% to 98.8% of the quartz grains showing either undulose or nonundulatory extinction. Polycrystalline grains make up between 1.2% and 8.8% (Table 2) of the total quartz. When plotted on a diamond diagram of Basu et al. (1975) (Figure 9), the Accraian sandstone samples plot mostly in the plutonic field with a few straddling around the middle and upper rank metamorphic field.

4.3 | Zircon typology

On the typology diagram (Figure 6), two indices were used to characterize each type or subtype. Index A (I.A.) corresponds to the degree of development of pyramidal forms and is controlled by an



I.T. \ I.A.	100	200	300	400	500	600	700	800
100	B	AB$_1$	AB$_2$	AB$_3$	AB$_4$	AB$_5$	B	C
200	H	L$_1$	L$_2$	L$_3$	L$_4$	L$_5$	G	I
300	Q$_1$	S$_1$	S$_2$	S$_3$	S$_4$	S$_5$	P$_1$	R$_1$
400	Q$_2$	S$_6$	S$_7$	S$_8$	S$_9$	S$_{10}$	P$_2$	R$_2$
500	Q$_3$	S$_{11}$	S$_{12}$	S$_{13}$	S$_{14}$	S$_{15}$	P$_3$	R$_3$
600	Q$_4$	S$_{16}$	S$_{17}$	S$_{18}$	S$_{19}$	S$_{20}$	P$_4$	R$_4$
700	Q$_5$	S$_{21}$	S$_{22}$	S$_{23}$	S$_{24}$	S$_{25}$	P$_5$	R$_5$
800	E	J$_1$	J$_2$	J$_3$	J$_4$	J$_5$	D	F

FIGURE 10 Simplified main types and subtypes of the typology classified from Pupin, 1980

anticorrelation (Loi & Dabard, 1997) between aluminium and alkalis. Index T (I.T.) corresponds to the development of prismatic forms and is controlled by crystallization temperature.

A careful analysis of the 298 zircon grains based on Figure 10, established that seven subpopulations or morphotypes of zircon grains were found to be abundant (Figure 11). These are subtypes AB$_1$, AB$_2$, S$_5$, S$_{10}$, S$_{15}$, P$_1$, and P$_2$. Examples from the Lower Accraian Sandstone samples are captured in Figure 12. Further examples shown in Figure 13 are subtypes not susceptible to typological analysis because of their rounded nature.

5 | DISCUSSION

5.1 | Source area rocks and sediment recycling

The detrital framework grains of the Accraian sandstones are quartz, feldspar, and lithic fragments. The quartz grains form the most dominant framework grains of the sandstones. Some of the sandstones contain ~100% quartz grain minerals (Table 1). The Lower Accraian sandstone grains, generally, are medium-grained; however, the bottom part (older beds, Figure 4) are quite pebbly. The petrographic study suggests bimodal texture of the sandstones (Figure 7a,b). According to Blatt (1992), the presence of more than a single mode in a size distribution can be a strong indicator of depositional environment. Blatt (1992) had indicated that sandstones composed entirely of quartz and consisting of two modes (bimodal), one in the coarse or medium sand range and the other in the fine sand range, are quite common in early Palaeozoic rocks. Such textural compositions, as captured in Figure 7a, are found in the lower part of the Lower Devonian Accraian Sandstone Formation. This assertion seems to emphasize the Devonian age of the Accraian sandstones as evidenced by the fossils recorded in McCallien (1962). The depositional environment of such textures is beyond the scope of this study and therefore, not captured.

Following the definition of Murawsky and Meyer (2010), roundness is the smoothening of crystal edges caused by abrasion. It is supposed to be the main indicator determining the energetic dimension affecting zircon grains during the entire transport process (Dietz, 1973; Köster, 1964). It is a parameter for the already realized distance of transport (Gärtner et al., 2013). Detrital zircon provenance studies are an established tool to develop palaeogeographical models, mostly based on zircon of siliciclastic rocks and isotope data (Gärtner et al., 2017). The refractive nature of zircon constraints it in a category of more than just isotopes but features well-definable morphological characteristics. The latter may indicate single-grain transport histories independent of the individual grade of concordance (Gärtner et al., 2017). This additional tool for palaeogeographical reconstructions was tested on zircon from siliciclastic sedimentary rocks of Palaeozoic age from sandstones of the Lower Accraian Formation. This study adopted Murawsky and Meyer (2010) definition of roundness in zircons. Therefore, the smoothness of crystal edges of 298 zircon grains from the Lower Accraian sandstones were critically observed. Results of this study have shown that ~71.7% (Figure 14b) of zircon mineral grains are rounded (Average deduced from Table 3 and Figure 14a). Thus, the rounded nature of most Accraian sandstone sediments as observed with the quartz grains suggests provenance from a recycled orogen.

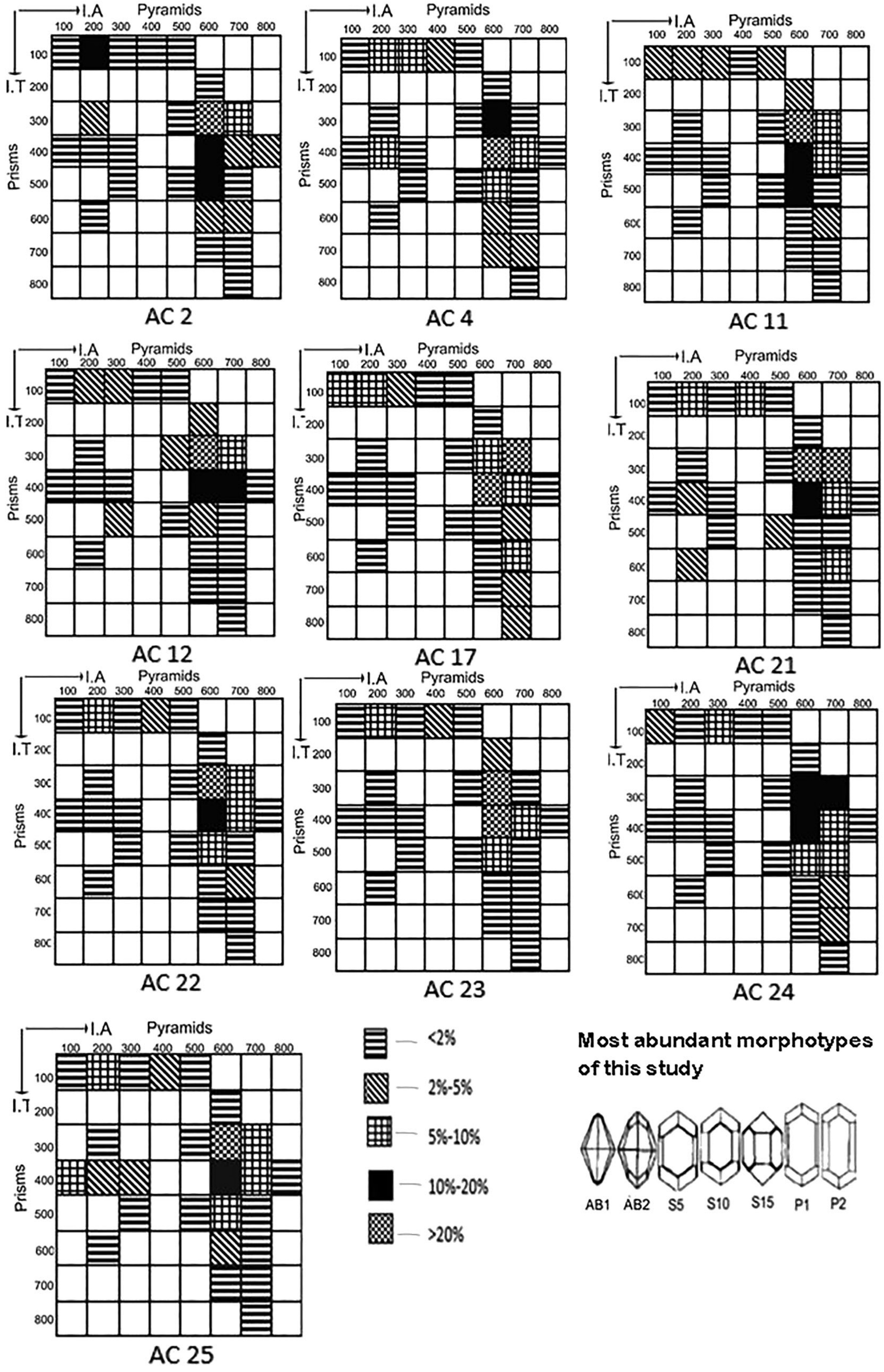


FIGURE 11 Results of the Lower Accraian Sandstones zircon typology analysis based on the I.A–I.T diagram of Pupin (1980)

Sedimentary rocks derived predominantly from pre-existing sedimentary rocks are characterized by zircon enrichment which can be reflected by relationships between Th/Sc and Zr/Sc (McLennan, Hemming, McDaniel, & Hanson, 1993). Th/Sc versus Zr/Sc diagram of the Accraian sandstones defined a trend suggestive of heavy mineral accumulation by sediment recycling and/or sorting (Anani

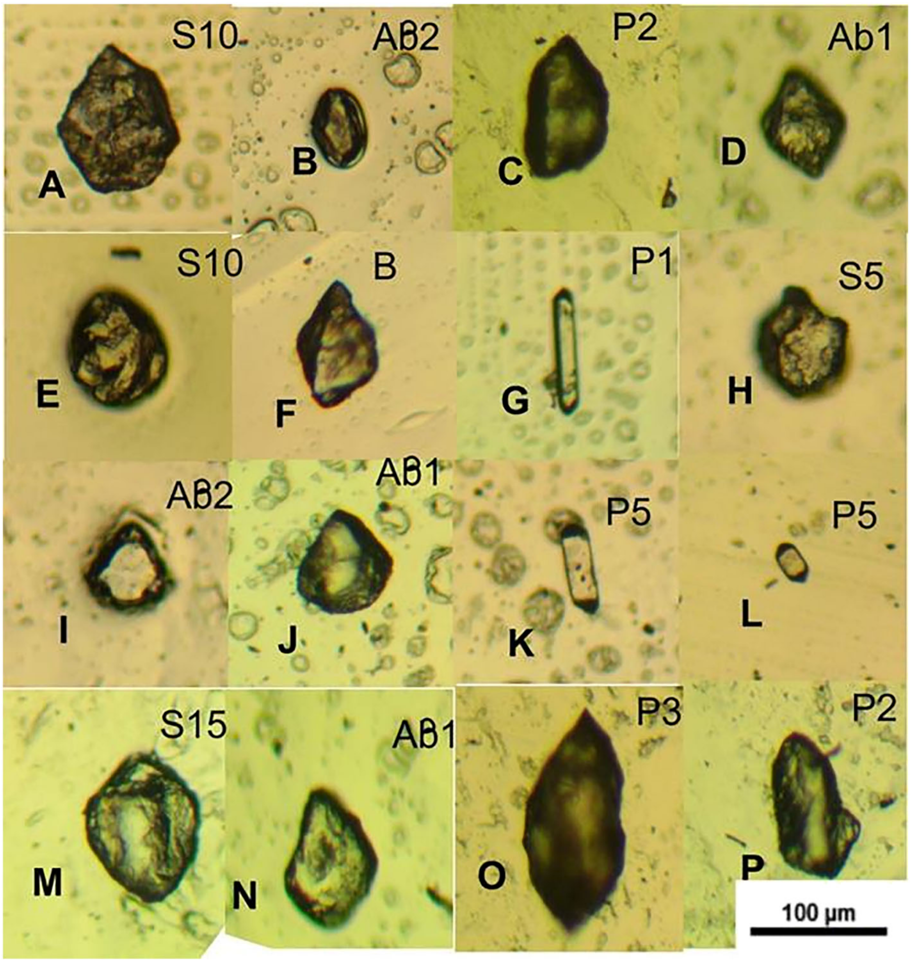


FIGURE 12 Examples of Lower Accraian detrital zircons susceptible to typological analysis. Letters with index correspond to subtypes of the classification found according to the categories proposed by Pupin (1980) [Colour figure can be viewed at wileyonlinelibrary.com]

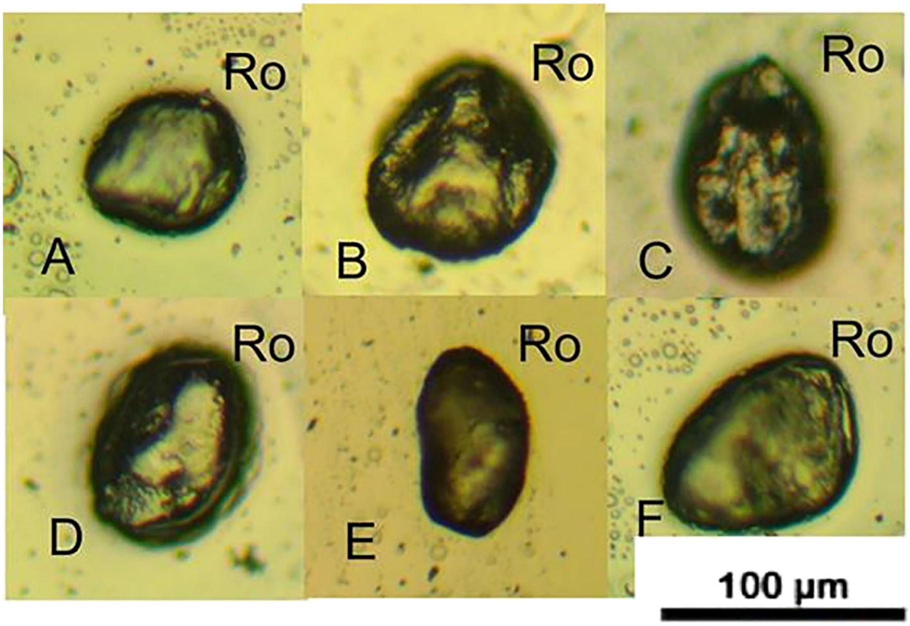


FIGURE 13 Examples of rounded (Ro) Zircons not susceptible to typologic studies [Colour figure can be viewed at wileyonlinelibrary.com]

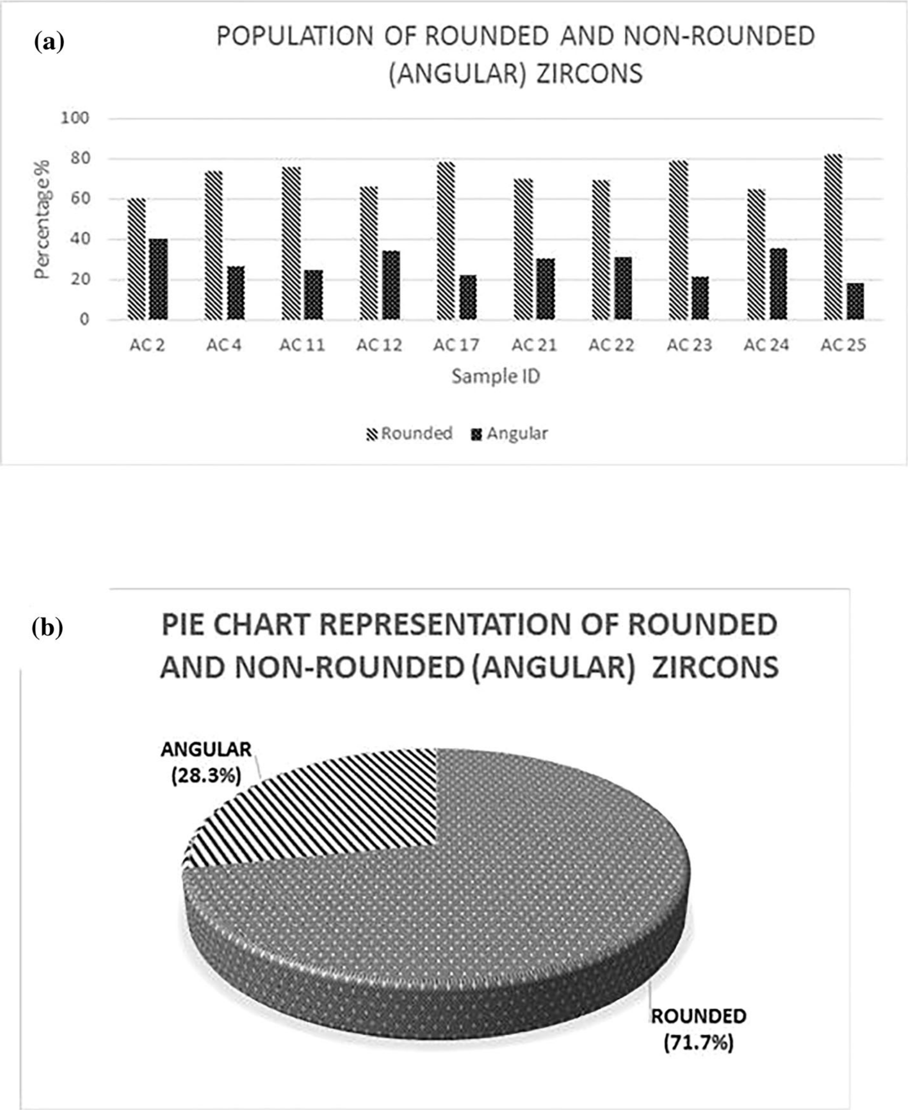


FIGURE 14 Showing (a) a bar chart representation of percentage populations of rounded and nonrounded zircons and (b) a pie chart representation of percentage populations of detrital zircons

TABLE 3 Modal composition of shapes of detrital zircons

Sample ID	Rounded (%)	Nonrounded (%)	Total count
AC 2	59.8	40.2	82
AC 4	73.6	26.4	159
AC 11	75.6	24.4	287
AC 12	65.7	34.3	99
AC 17	78.2	21.8	317
AC 21	69.6	30.4	92
AC 22	69.0	31.0	200
AC 23	78.8	21.2	269
AC 24	64.6	35.4	65
AC 25	82.0	18.0	150

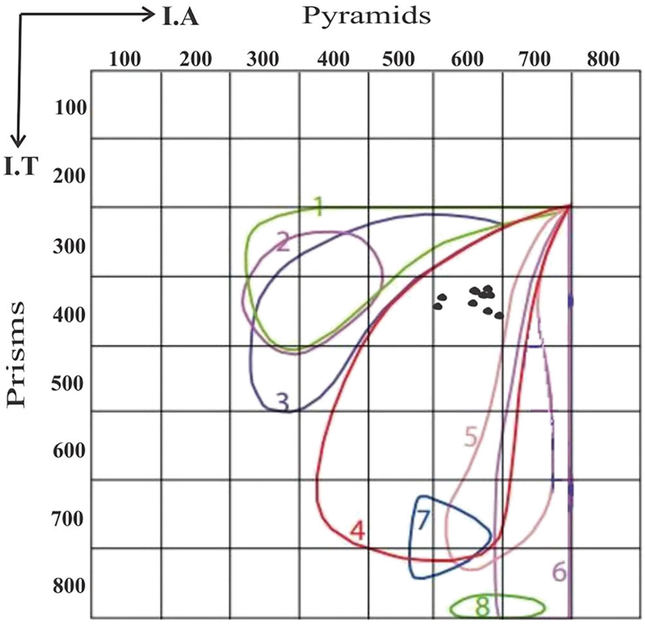


FIGURE 15 Distribution of granitic rocks in the typology diagram derived from the mean value of I.A and I.T (Pupin, 1988): (1) alumina leucogranites, (2) monzogranites-granodiorites (sub)autochthonous, (3) monzogranite-granodiorite aluminium intrusives, (4) calc-alkaline and K-rich calc-alkaline series granites, (5) subalkaline series granites, (6) alkaline series granites, (7) tholeiitic continental granites, and (8) tholeiitic series oceanic granites. The black points represent the results of zircons analysed in this study [Colour figure can be viewed at wileyonlinelibrary.com]

et al., 2018). However, an additional interpretation of the zircon typology analysis of the Accraian sandstone is indicative of other additional sources. Previous studies used elongation (nonrounded or angular zircons) as an indicator for possible host rocks (e.g., Hoppe, 1963; List, 1966; Poldervaart, 1955, 1956). Furthermore, zircons of granitic origin usually are more elongated (nonrounded) than those of sedimentary origin (Finger & Haunschmid, 1988).

Findings from this study as presented in Table 3 and Figure 14a,b, indicate that ~28.3% of the zircon grains are nonrounded, suggestive of a direct parent source rock. Zircons are particularly ubiquitous in silicic and intermediate igneous rocks (Mange & Maurer, 1992). Investigation on quartz types (Figure 9) in this study suggests supply of sediments and thus the direct supply of zircons from plutons into the catchment area of the Lower Accraian Sandstone Formation.

The typology diagram (Figure 15) derived from the mean values of I.A. and I.T. (Pupin, 1988; Table 4) shows that the zircons are originally from calc-alkaline and K-rich calc-alkaline series granites.

Calc-alkaline and K-rich calc-alkaline series granites have been reported to occur within the Birimian Supergroup of Ghana. Nyarko et al. (2012), particularly, have indicated that the granites of the Winneba belt (Figure 2) within the Birimian Supergroup of Ghana show calc-alkaline affinity. These granites and their associated metasedimentary rocks are positioned proximally to the northwest of the Accraian Group and relatively very close to the study area and therefore a very probable source of sediment supply to the Accraian Group. This assertion of sediment supply from the Birimian Supergroup to form these coastal sedimentary rocks has also been indicated by Asiedu et al. (2005) in the Sekondian Group (Figure 2), which are of similar age as the Accraian Group. According to Asiedu et al. (2005), the Sekondian Group is about 1,200 m. It consists of a predominantly fine-grained basal unit, shale unit, overlain by six predominantly arenaceous lithologic units in decreasing order of age. Micropaleontological results from the group indicate that it ranges from late Ordovician to early Cretaceous in age and that it is broadly correlative with formations in the Maranhao Basin of Brazil (Bär & Riegel, 1980).

Quartz-type analysis in Figure 9 suggests supply of sediments from a source which had experienced intermediate to high grade metamorphism. The Birimian is reported to have experienced greenschist-facies metamorphism (Hirdes et al., 1996). However, the third of three zones of the Dahomeyide belt (Figure 2), being the “internal zone” to the east-northeast of the study area had experienced a very

TABLE 4 Calculated mean points for I.A–I.T values

Sample ID	I.$\bar{A}$	I.$\bar{T}$
AC 2	558	345
AC 4	506	350
AC 11	573	333
AC 12	580	324
AC 17	580	357
AC 21	563	328
AC 22	583	333
AC 23	560	326
AC 24	597	363
AC 25	513	337

$\mathrm{I.}\bar{A} = \sum_{\mathrm{I.A}=100}^{800} \mathrm{I.A} \times n_{\mathrm{I.A}}$ $\mathrm{I.}\bar{T} = \sum_{\mathrm{I.T}=100}^{800} \mathrm{I.T} \times n_{\mathrm{I.T}}$

Note. Where $n_{\mathrm{I.A}}$ and $n_{\mathrm{I.T}}$ are the respective frequencies for each value of I.A and I.T ($\sum n_{\mathrm{I.A}} = \sum n_{\mathrm{I.T}} = 1$). I.A. = Index A corresponds to the degree of development of pyramidal forms and is controlled by an anti-correlation (Loi & Dabard, 1997) between aluminium and alkalis. I.T. = Index T corresponds to the development of prismatic forms and is controlled by crystallization temperature.

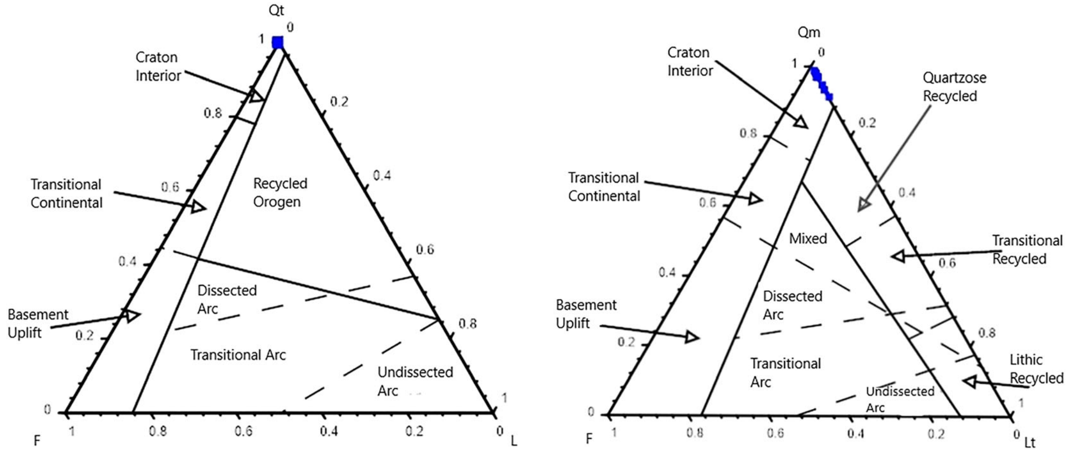


FIGURE 16 Quaternary plots after Dickinson et al. (1983) showing the following: (a) QFL plot of detrital modes of quartz arenites from the Lower Accraian sandstone samples and (b) QmFLt plot of detrital modes of quartz arenites from the Lower Accraian sandstone samples. Abbreviations: Q, total quartz, F, feldspar, L, lithic fragments, Qm, monocrystalline quartz, Lt, lithic fragments + polycrystalline quartz [Colour figure can be viewed at wileyonlinelibrary.com]

complex and strong metamorphism and consists of rocks that include Neoproterozoic sedimentary assemblages, Archean to Paleoproterozoic basement, and Pan-African granitoids with calc-alkaline affinity (Deynoux, Affaton, Trompette, & Villeneuve, 2006). Deynoux et al. (2006) further reported a lateral equivalence between the rocks of the internal zone and the upper portion of the Volta Basin referred to as the Tamale or Obusum Formation. It is therefore suggested that some of the Accraian sediments showing medium- to high-grade metamorphism (by the diamond diagram plot in Figure 9) and of calc-alkaline affinity (indicated by the zircon analysis) were derived as follows: the sediments were initially derived from the internal zone of the Dahomeyide belt, and deposited in the upper part of the Volta Basin, referred to in Deynoux et al. (2006) as the Tamale or Obusum Formation. These sediments then picked up the signature of a craton interior/recycle orogeny (Figure 16b) characteristic of the Volta Basin, some of which were part of the sediments supplied into the Accraian catchment area. According to Asiedu et al. (2005), the Sekondian Group, which is of similar age as the Accraian Group and positioned also on the coastline of Ghana, but situated further west of the Accraian Group (Figure 2), is reported to have received supply of sediments from the Dahomeyide rocks. Anani et al. (2018) has also indicated the Dahomeyide as a possible source of additional sediment supply for the Accraian Group.

5.2 | Tectonic setting

Petrographic modal analyses allow plotting of two types of triangular discrimination diagrams for provenance determinations, thus the QFL and QmFL diagrams (Dickinson et al., 1983; Dickinson & Suczek, 1979), Figure 16 and Table 1. In the Q-F-L plot, where all quartz grains are plotted together, the emphasis is put on grain stability and then on weathering, provenance, relief, and transport mechanism as well as source rocks, whereas in Qm-F-Lt, where all lithic fragments are plotted together, the emphasis is shifted towards the grain size of source rocks, because fine-grained rocks yield more lithic fragments in the sand-size range.

The samples which are predominantly rich in quartz and poor in both feldspar and lithic fragments plot in the craton interior field in both ternary plots. However, the sediments trend or show some affinity towards the quartzose recycled field in the QmFLt ternary diagram (Figure 16b) and may therefore contain an admixture of sediments from a recycled orogen. This latter circumstance is indicated by the subangular to rounded nature of quartz grains in Figure 7.

6 | CONCLUSIONS

The petrographic analysis of the sandstones (quartz arenites) suggests continental block provenances with source on a stable craton, recognized as the West African Craton (WAC). Some of the sediments, however, show strong affinity towards a recycle provenance. The investigation reveals that the basin received a mixture of debris derived from proximal sources. A further integrated analysis of petrographic and quartz-type analyses coupled with zircon typology characteristics suggests the following: (a) the sand detritus was probably derived from the granites of the proximal Birimian granites and their associated metasedimentary basin and (b) additional sediment supply from an admixture of Voltaian Basin sediments which consist of an earlier supply from the Dahomeyide belt at the time of the Pan-African Orogeny.

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CONFLICT OF INTERESTS

We the authors of this article which is to be published in the Geological Journal wish to declare that we have no conflict of interest.

ORCID

Chris Y. Anani https://orcid.org/0000-0002-9153-9807

Patrick Asamoah Sakyi https://orcid.org/0000-0002-7536-6264

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