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RESEARCH ARTICLE

PROVENANCE AND TECTONIC SETTING OF SOME PALEOPROTEROZOIC SEDIMENTARY ROCKS IN THE CHAGUPANA AND TARKWA AREAS OF GHANA: PETROGRAPHIC AND STRUCTURAL CONSTRAINTS

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ABSTRACT

Paleoproterozoic sedimentary rocks associated with the Man Shield of West Africa are perceived to be similar, irrespective of their locality. This research seeks to establish the provenance and tectonic setting of these rocks to ascertain any such similarity perception, based on information from two localities. The study uses modal mineral estimations to reconstruct the source, paleocurrent, paleoclimate and relief of some conglomerates and sandstones from Chagupana and Tarkwa areas in Ghana. Chagupana conglomerate has igneous and metamorphic provenances, while Kawere conglomerate has metamorphic provenance. Average mineralogical composition of Chagupana sandstone is Q_{53}-F_{45}-R_3 and classify as arkose. Tarkwa suites of Huni, Kawere and Banket sandstones are composed of Q_{48}-F_{34}-R_{18}, Q_{51}-F_{25}-R_{23} and Q_{76}-F_7-R_{17}, and classify as lithic arkose, lithic arkose-feldspathic litharenite, and sublitharenite, respectively. Detritus of all the sandstones suggest acid igneous rock source, with minor sedimentary and metamorphic imprints, with an order of maturity as Banket>Kawere>Huni>Chagupana. Detritus in the Chagupana, Huni and Kawere sandstones are from the transitional continental margin. The Chagupana is from the cold arid climate, while the Huni and Kawere are from the semi-arid/semi-humid climates. The Banket sandstone mobilises from craton interior with recycled orogenic materials in a humid environment. The angular-subangular feldspars in Chagupana sandstone indicate low relief and low-moderate recycling close to the source. Huni, Kawere and Banket sandstones derive from low-moderate reliefs with multiple recycling episodes. The Chagupana and Huni sandstones show paleo-current directions from the north and east, respectively. Similarities between the Chagupana and Tarkwa rocks can only be limited to the tectonic setting and not from source area, paleo-climate, paleo-current and relief.

KEYWORDS

Provenance, Paleocurrent, Paleoclimate, Relief, Conglomerate.

1. Introduction

Ghana lies at the eastern end of the Leo-Man shield of the West African Craton (Figure 1A) (Feybesse et al., 2006). The shield consists of the Birimian metasediments, metavolcanics, granitoid intrusives and the Paleoproterozoic sedimentary rocks that constitute the Tarkwaian rocks (Figure 1B) at the Tarkwa area in South-western Ghana (Davis et al., 1994). From the early 2000s, some conglomerates and sandstones in the Chagupana area (Figure 1C) of the Upper West Region of Ghana are reported as being similar to certain members of the Tarkwaian group (Block et al., 2015; Agyei-Duodu et al., 2009; Salvi et al., 2015).

The Tarkwaian rocks are derived from detritus of the shallow-water continental origin and in the direction of younging, consists of Kawere conglomerate, Banket series, Tarkwa phyllite and Huni sandstone (Asiedu et al., 2010). The discovery of paleo placer gold deposits in the Banket series has sparked a craze for exploration of precious metals in similar formations in neighbouring countries including Côte d'Ivoire, Mali, Burkina-Faso and Niger without critical stratigraphic correlations with the Ghana Tarkwaian (Koffi et al., 2016).

The Paleoproterozoic sedimentary rocks occurring in the Chagupana area of the Upper West Region of Ghana have been named differently by some authors. For example, Agyei-Duodu et al., (2009), after compiling the 2009 geological map of Ghana classified these sedimentary rocks as members of the Tarkwaian Group, which are made up of detrital sediments, mainly undifferentiated sandstone and conglomerate, while Salvi et al., (2015) classified the same rock types as epiclastic sediments (Agyei-Duodu et al., 2009; Salvi et al., 2015).

Block et al., (2015), who worked on the Geodynamic Evolution of the West African Craton, classified the Chagupana rocks as polymictic sediments and conglomerates, which are characterized by cross-bedding features. The Chagupana rocks share similarities with other clastic sedimentary

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units found across the craton, such as Tarkwaian sediments, or as Birimian sediments that are discordant with the older Birimian volcano-sedimentary sequences (Block et al., 2015). Such levels of varied representations of the Paleoproterozoic sedimentary rocks require some critical assessments to clarify the rocks appropriately.

Petrographic parameters such as lithic composition, mineralogy, and texture help to reveal the source area, tectonic setting, paleoclimate, paleocurrent, and transport history of the siliciclastic sedimentary rock (Khan et al., 2019; Bogss, 2006; Dickinson, 1985). According some study, pedogenesis, distance, relief, paleoclimate, depositional environment, diagenesis, among others can influence the original rock composition, however, lithological variations can cause conflicting interpretations in well-established tectono- petrographic schemes (Garzanti et al., 2013).

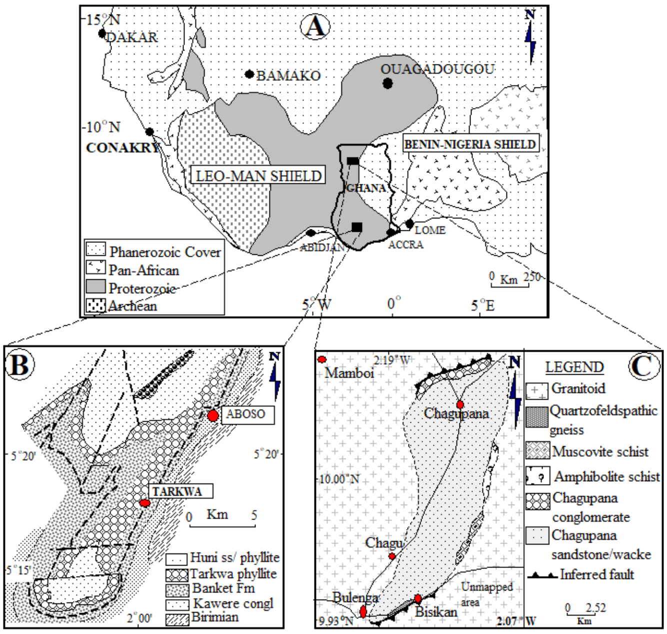


Figure 1: (A) The Leo-Man shield showing the Tarkwa and Chagupana areas (Feybesse et al., 2006); (B) Tarkwaian in Tarkwa (Davis et al., 1994); (C) The Chagupana (Ch) sedimentary basin (study area) (Block et al., 2015).

The purpose of this research is to establish the provenance and tectonic setting of the Paleoproterozoic sedimentary rocks in the Chagupana and Tarkwa areas of Ghana to ascertain the veracity of the similarity theory concerning the rock suites from the two different localities. The study uses petrography and modal estimations of mineral compositions to reconstruct the source rocks, tectonic setting, paleoclimate, relief and paleocurrent direction of deposition of some conglomerates and sandstones from the Chagupana and Tarkwa areas in Ghana for comparison.

2. Materials and Methods

2.1 Study area

The study area (Figure 1C) is bounded by two shear zones, namely, the Julie and Bulenga shear zones. The Julie shear zone is E-W trending and defined by a thrust that is consistent with N-S directed crustal shortening. The zone is observed at the northern margin of the Chagupana community (10.096°N, 2.094°W) and is underlain by basalts, granitoid, and polymictic sediments that are made of sandstones and conglomerates. The conglomerates have undergone low-grade metamorphism. According to a study, the polymictic sediments experienced early deformation (D1) which introduced volcanic materials with crystallization ages of 2129 ± 7 Ma, which depicts sediments deposition during a syn-tectonic basin formation episode (Block et al., 2015).

The Bulenga shear zone, which is an extensional detachment is observed in the southern section of the research area (9.947°N, 2.170°W). Rock types in this area include sericite schist, amphibolite schist and quartzofeldspathic rocks. Intrusives are quartz veins and basalts. The basin is surrounded by Eburnean plutonic suite characterized by hornblende- biotite- tonalite, minor granodiorite and minor quartz diorite. These intrusives normally contain biotite- amphibole- titanite and small proportions of K-feldspar which are coarse (centimetric) grained with mainly high magnetic susceptibility (1-55x10^{-3} SI) and depleted in U-Th-K. The strain is generally low and increases towards shear zones or pluton margins (Ganne et al., 2014).

2.2 Sampling strategy and procedure

Geological field mapping was conducted in the Chaqupana area. Twenty-five representative rock samples comprising 5 conglomerates and 20 sandstones were selected for petrographic analysis at the Kwame Nkrumah University of Science and Technology Geological Engineering Laboratory after critical examinations. Thin sections of 10 samples, each of the Kawere, Banket and Huni sandstones, and 5 Kawere conglomerates randomly collected from the Tarkwa area were prepared for comparison. The thin sections were prepared to a thickness of 30 microns to achieve maximum textural, mineralogical and diagenetic features of the rock types under study. The petrographic analysis was done with the petrographic microscope (LEICA-DM750P) and modal percentages estimated using the point counting machine as well as the comparison chart (Puy-Alquiza et al., 2014; Terry and Chilingar, 1955). Relative proportions of quartz (Q), feldspars (F) and lithic fragments (L) were determined from the point-counts of 300 framework grains per section, while grain sorting and roundness were estimated using the charts from Folk and Powers, respectively. The Michel Levy extinction chart was used to classify plagioclase types accordingly, while the conglomerates were classified after Boggs (Folk, 1968; Powers, 1953; Boggs, 1992). The framework parameters of detrital modes were done according to Ingersoll and Suczek (Table 1) (Ingersoll and Suczek, 1979; Whitney and Evans, 2010).

Table 1: Framework parameters of detrital modes.

Qm	monocrystalline quartz
Cht	Chert
Qp	Polycrystalline quartzose, lithic fragments (Qpq + Cht)
Q	Total (Qm non + Qm un) and Qpq used for Folk (1974) classification (Qm + Qpq)
Qt	Total quartz (Qm + Qp and Chert)
P	Plagioclase feldspar
K	Potassium feldspar
F	Total feldspar grains (P + K)
L	Unstable (siliciclastic) lithic fragments (Lv + Ls + Lsm)
R	Rock fragments
Cem	Cement
Qun	Non undulose quartz
Qu	Undulose quartz
Cal	Carbonate mineral

The QFL plots techniques used to classify the sandstones were taken from Pettijohn et al. (1987) and Folk (1974), while tectonic setting and sediment maturity ternary diagrams follow after Dickinson et al. (1983).

3. Results

3.1 Chagupana conglomerate

The Chagupana conglomerate is located in the northern margin of the study area and in contact with the E-W trending Julie shear zone. They are loosely packed, poorly sorted, well indurated, foliated, greenish-grey and indicate minor lithofacies (less than 5%) in the area. Averagely, the clasts within the Chagupana conglomerates contribute 49% to the rock mass while the remaining 51% is occupied by the matrix.

The clasts are sub-angular to rounded, ranging from 0.2-7 cm in length and composed of hornblende schist (62%), syenogranite (21%), quartz vein (10%), greenstones (2%) and quartzite (6%) all in a moderately sorted as well as silicified matrix. The syenogranite pebbles within the Chagupana conglomerates are medium-coarse grained with interlocking textures of quartz (40-45)%, plagioclase (10-15)%, orthoclase (20-30)%, muscovite (1-2)%, biotite (1-2)%, sericite (1-5)%, iron oxides (<1)%, opaque minerals (1-2)% and pyrite (1-5)% (Figure 2A). Sometimes orthoclase exhibits Carlsbad twinning whilst the majority of the polysynthetic twins of plagioclase are moderately altered.

In thin section, hornblende schist is made up of quartz (15-20)%, amphibole (60-70)%, biotite (5-10)%, chlorite (2-5)%, opaque minerals (1-2)%, feldspar (2-5)% and epidote (1-3) %. Quartz is mostly recrystallized, angular to rounded sometimes with straight edges and exhibit undulose extinction. Plagioclase (1-3)% is the predominant feldspar present even though orthoclase (0-1)% also occurs. These feldspars range from euhedral to subhedral and are moderately altered.

Biotite is dark green to brown in colour and occurs as individual grains and sometimes as aggregates that appear partially altered to interstitial chlorite aggregates. Hornblende is usually anhedral and shows inclusions of quartz grains. Elongated hornblende, muscovite, biotite and chlorite define the foliation planes, while alteration of the hornblende to chlorite and epidote grains are incipient. Isolated and deformed opaque minerals occur mainly as later overgrowths.

Quartz grains dominate the quartz veins, while the quartzites consist of interlocking grains of subhedral to anhedral quartz and feldspar. The foliated matrix framework of the Chagupana conglomerate (Figure 2B) is dominated with fine to medium-grained quartz (70-75)%, hornblende (5-10)%, plagioclase (2-5)%, orthoclase (0-1)%, chlorite (5-10)% biotite (2-5)% and opaque minerals (1-3)%. Quartz grains in the matrix are sub-angular to rounded but closely packed.

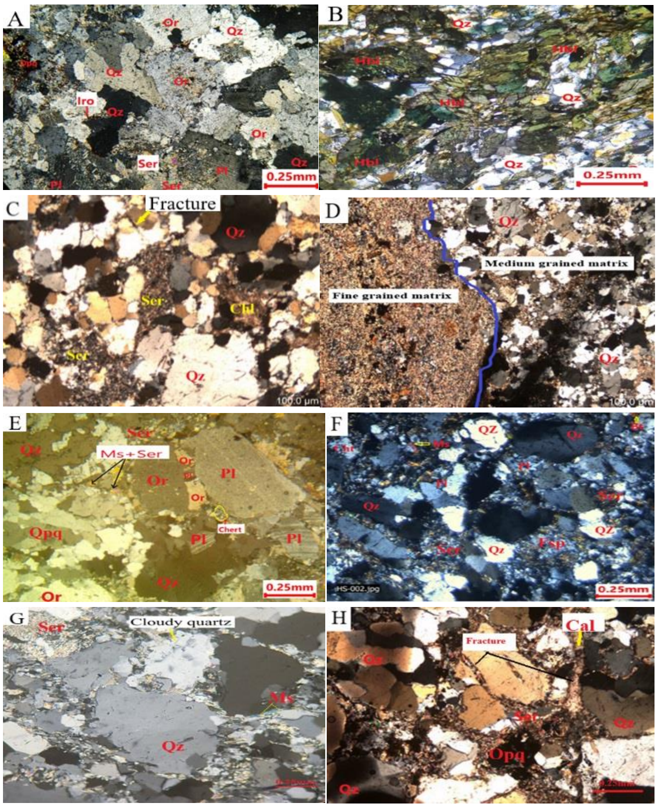


Figure 2: Photomicrographs of the conglomerates and sandstones: (A) Interlocking texture of the slightly elongated syenogranite with moderately altered plagioclase (B) Matrix of the Chagupana conglomerate showing slight alignment of biotite (C) Greenstone pebble in the Kawere conglomerate (D) Matrix of the Kawere conglomerate showing variation in grain sizes (E) Chagupana sandstone showing well to moderately preserved plagioclase and fine-grained chert (F) Huni sandstone showing rapid alteration of feldspar (G) Quartz in Banket sandstones showing sutured edges. (H) Deformed Kawere sandstone with microfractures and calcite as infill materials. Qz = quartz, Ser = sericite, Ms = muscovite, Pl = plagioclase, Bt = biotite, Or = orthoclase, Opq = opaque mineral, Cht = Chert, Hbl = hornblende, Cal=calcite (Whitney and Evans, 2010).

3.2 Kawere conglomerate

The Kawere conglomerate was sampled from the Bonsa area of the Western region of Ghana. The samples are well indurated, greenish-grey and composed predominately of closely packed, angular to rounded clasts of greenstone (36%), quartz (10%), quartzite (7%) and silicified micaceous matrix (47%). The greenstones pebbles are greenish with pyrite inclusions. Majority of the pebbles within the Kawere conglomerate are squeezed, with occasional internal micro-fractures. Arrangement of some composite pebbles suggests imbrication structures.

Petrographic analysis of the greenstone pebble shows interlocking textures of quartz (70-80)%, sericite (5-10)%, chlorite (5-10)%, and opaque minerals (1-2)%. Quartz grains usually display sutured grain boundaries (Figure 2C). The greenstone pebble is made up of fine to medium, subhedral to anhedral grains that are moderately fractured. Quartz vein and quartzite pebbles are mainly composed of quartz grains with interlocking textures. Quartz (90-95)%, chlorite (2-3)%, muscovite (2-4)% and iron oxide (<1)%, opaque minerals (<1) and sericite (1-3)% constitute the micaceous matrix of the Kawere conglomerate. The matrix demonstrates the variation in grain sizes and iron oxide appear elongated and thread-like along grain boundaries (Figure 2D).

3.3 Sandstones

Compositionally, all the sandstones under investigation are predominantly made up of detrital quartz, feldspar, opaque minerals and sedimentary rock fragments.

3.3.1 Quartz

The quartz grains are coarse to medium in the Chagupana, Kawere and Banket sandstones, and medium to fine-grained in the Huni sandstone. Proportions of quartz grains in the sandstones decreased from Banket (76%), Chagupana (53%), Kawere (51%) and Huni (48%) (Table 2).

Table 2: Recalculated average modals percentages of the sandstones (BAB= Chagupana sandstones Hs = Huni sandstones, Kw ss= Kawere sandstones, Bkt = Banket sandstones)

	Q	F	R	Qm	Qp	Q (2and3)	Q (>3)	Q non	Q un
BAB 010	51.72	45.98	2.30	20.69	31.03	10.95	25.54	14.21	39.82
BAB 421	54.88	42.68	2.44	21.95	32.93	6.95	30.54	12.20	45.12
BAB 419	47.06	49.41	3.53	18.82	28.24	8.75	27.07	10.18	40.41
BAB 001	49.41	48.24	2.35	19.76	29.65	5.92	30.49	15.53	36.24
BAB 418	55.81	40.70	3.49	22.33	33.49	5.83	30.26	17.79	41.51
BAB 411	51.72	45.98	2.30	20.69	31.03	8.95	28.54	16.21	37.82
BAB 409	52.27	45.45	2.27	20.91	31.36	10.95	25.56	18.36	36.18
BAB 015	57.47	40.23	2.30	22.99	34.48	12.98	23.61	12.93	46.84
BAB 423	53.57	42.86	3.57	21.43	32.14	10.80	25.20	14.14	43.00
BAB 006	56.47	41.18	2.35	22.59	33.88	11.96	26.58	20.65	38.18
BAB 011	54.35	43.48	2.17	21.74	32.61	6.00	29.61	18.96	45.57
BAB 021	50.56	47.19	2.25	20.22	30.34	8.95	27.54	10.84	41.97
BAB 003	48.39	48.39	3.23	19.35	29.03	5.80	30.20	15.48	36.13
BAB 412	47.19	50.56	2.25	18.88	28.31	10.92	25.49	14.83	34.61
BAB 400	53.76	43.01	3.23	21.51	32.26	15.84	20.30	17.10	39.89
BAB 036	51.72	45.98	2.30	20.69	31.03	8.95	27.54	16.21	37.82
BAB 038	52.27	45.45	2.27	20.91	31.36	10.95	25.56	16.36	38.18
BAB 045	57.47	40.23	2.30	22.99	34.48	15.98	20.61	20.31	48.84
BAB 023	53.57	42.86	3.57	21.43	32.14	8.80	27.20	17.14	40.00
BAB 005	56.47	41.18	2.35	22.59	33.88	8.96	27.58	23.65	35.18
HS 001	52.33	34.88	12.79	26.16	26.16	14.79	9.86	12.19	50.77
HS 002	50.00	31.25	18.75	25.00	25.00	13.71	8.14	20.25	47.25
HS 003	49.38	34.57	16.05	24.69	24.69	16.12	7.41	19.26	44.94
HS 004	44.30	31.65	24.05	22.15	22.15	12.54	8.36	20.13	46.96
HS 005	44.87	38.46	16.67	22.44	22.44	10.77	12.18	14.08	46.18
HS 006	50.60	36.14	13.25	25.30	25.30	14.65	9.77	18.80	43.86
HS 007	47.50	32.50	20.00	23.75	23.75	9.37	8.91	19.88	46.38
HS 008	43.21	37.04	19.75	21.60	21.60	13.13	8.75	12.52	43.21
HS 009	50.60	30.12	19.28	25.30	25.30	13.66	9.11	20.60	48.07
HS 010	50.00	31.25	18.75	25.00	25.00	16.71	7.14	20.25	47.25
Kw SS 001	50.00	22.22	27.78	15.00	35.00	9.79	22.85	21.67	50.56
Kw SS 002	55.56	24.69	19.75	16.67	38.89	5.68	29.92	21.11	49.26
Kw SS 003	47.06	29.41	23.53	14.12	32.94	8.12	26.61	19.41	45.29
Kw SS 004	53.66	24.39	21.95	16.10	37.56	10.29	24.01	21.59	50.37
Kw SS 005	50.00	25.00	25.00	15.00	35.00	8.12	25.61	20.63	48.13
Kw SS 006	52.94	29.41	17.65	15.88	37.06	10.92	25.49	19.41	45.29
Kw SS 007	46.34	24.39	29.27	13.90	32.44	9.43	22.01	21.22	49.51
Kw SS 008	48.78	26.83	24.39	14.63	34.15	12.12	21.61	20.12	46.95
Kw SS 009	55.81	23.26	20.93	16.74	39.07	8.43	26.35	21.98	51.28
Kw SS 010	46.51	29.07	24.42	13.95	32.56	10.00	23.33	19.53	45.58
Bkt SS 001	74.71	4.60	20.69	22.41	52.30	10.88	25.38	20.59	71.37
Bkt SS 002	78.31	6.02	15.66	23.49	54.82	10.33	27.43	22.11	65.25
Bkt SS 003	81.40	4.65	13.95	24.42	56.98	15.40	23.59	27.91	65.12
Bkt SS 004	81.40	5.81	12.79	24.42	56.98	11.57	27.01	37.21	53.49
Bkt SS 005	76.92	6.41	16.67	23.08	53.85	6.25	32.25	21.92	67.82
Bkt SS 006	71.43	11.90	16.67	21.43	50.00	10.25	26.25	25.00	58.33
Bkt SS 007	73.63	5.49	20.88	22.09	51.54	12.92	23.47	18.03	72.08
Bkt SS 008	76.47	5.88	17.65	22.94	53.53	11.14	26.00	10.18	80.41
Bkt SS 009	74.71	4.60	20.69	22.41	52.30	10.88	25.38	27.59	64.37
Bkt SS 010	75.00	10.00	15.00	22.50	52.50	12.25	27.25	26.25	61.25

**BAB= Chagupana sandstones Hs = Huni sandstones, Kw ss= Kawere sandstones, Bkt = Banket sandstones*

The degree of roundedness of the quartz grains ranges from angular to subangular in the Chagupana, Huni and Banket sandstones whilst in the Kawere sandstones they appear subangular to rounded (Figures 2E-H). Monocrystalline (Qm), polycrystalline quartz (Qp) and recrystallized quartz were observed in all the sandstones.

The average percentage of polycrystalline quartz to total quartz in the sandstones decreases from Banket (70%), Kawere (69%), Chagupana (60%) and Huni (50%). Usually, the polycrystalline quartz grains are fine to medium, angular to sub-rounded showing sutured edges with slight elongations whilst the monocrystalline grains mostly exhibit straight extinction (Figure 2G). Polycrystalline quartz grains with >3 crystals per grain are predominant.

3.3.2 Feldspars

The feldspars are the second dominant minerals in the sandstones and in the order; Chagupana (45%), Huni (34%), Kawere (25%) and Banket (7%). Untwined orthoclase, cross-hatched microcline and polysynthetic plagioclase are the feldspars present. Plagioclase is the predominant feldspar in the Chagupana sandstones contributing 55% of the entire feldspar composition while potassium feldspar also contributes the remaining 45%.

Plagioclase ranges from andesine to labradorite and sometimes occurs as phenoclast. Feldspars in the Chagupana sandstones are angular to subrounded (Figure 2E) and moderately weathered reflecting immature sediments as indicated by their well to moderately preserved twins (Figure 2E). In the Huni, Banket and Kawere sandstones, the predominant feldspar is orthoclase (70%) followed by plagioclase (albite 30%). The feldspars are highly altered into sericite (Figure 2F- H).

3.3.3 Opaque minerals

Amorphous to cubic opaque minerals occur in all the sandstones occasionally as overgrowths and scattered throughout the framework (Figure 2H). Banding of mafic minerals is also observed in the Chagupana and Huni sandstones. The average percentage of the opaque minerals in the sandstones decreases from the Chagupana (1-12)%, Huni (1- 6)%, Kawere and Banket (1-3)%.

3.3.4 Secondary minerals

Chlorite, sericite/saussurite, and epidote occur as secondary minerals in all the sandstones. Sericite and chlorite appear shred-like, flaky and interstitial grains to the detrital grains but in some cases anastomoses the detrital grains. These secondary minerals are sometimes weakly oriented in preferred directions in all the sandstones analyzed. In the Kawere sandstones, carbonate, sericite and muscovite fill fractures and grain boundaries (Figure 8C).

3.3.5 Rock fragment

Chert is the only rock fragment observed in all the sandstones and accounts for about 3% of the average modal composition in the Chagupana sandstone. The chert grains are subrounded and made up of fine-grained quartz (Figure 2E). Chert, and decreases from Kawere (23 %) to Huni (18%) and Banket (17 %). Chert in the Chagupana and Huni sandstones is fine-grained and subangular to subrounded while it is commonly fine to medium-grained in the Kawere and Banket sandstones.

3.3.6 Heavy minerals

Biotite (≤1)%, muscovite (1-2)%, epidote (≤1)%, zircon (1-2)% occur in the Chagupana sandstones, and in the Kawere, Huni and Banket sandstones as biotite (2-5)%, muscovite (1-2)%, epidote (≤1), zircon (≤1), garnet (≤), and tourmaline (≤1). Biotite and muscovite are subhedral to anhedral, elongated, flaky and sometimes needle-like (Figure 2E-G) and usually occur in both the matrix and along the boundaries of the quartz and feldspars (Figure 2E-G). Bending of mica flakes suggests plastic deformation or mechanical compaction of the sandstones.

3.3.7 Cement/Matrix material

Even though some detrital grains are deformed, all the sandstones have common matrix/cementing materials (quartz, quartz overgrowth, iron oxide, sericite, and chlorite). Quartz overgrowth occurs as a rim around detrital grains. The presence of sericite/saussurite and chloride indicate alteration of feldspars/muscovite and biotite respectively. The matrix composition of the Chagupana sandstones ranges from 4% to 12% while the other sandstones contribute as Huni (4-15)%, Banket (4-10)% and Kawere (4 -15)%. Carbonate is also present in the sandstones from the Tarkwa area (Huni, Banket and Kawere sandstones) as infilled material (Figure 2H).

4. Discussion

4.1 Classifications

The modal percentages of the clasts in the Chaguapana and Kawere conglomerates were recalculated and plotted on the metamorphic, igneous and sedimentary clasts ternary diagram (Figure 3A) (Boggs, 1992). On the ternary diagram, both conglomerates plot as metamorphic clast conglomerates. Folk (1974), proposed the use of recalculated grains of quartz, feldspar and rock fragments of sandstones for classification as shown in Figure 3..

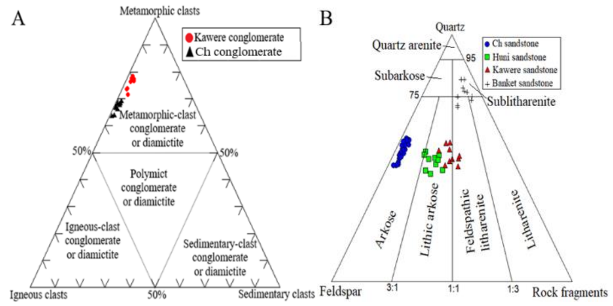


Figure 3: (A) Classification of the conglomerates based on pebble composition (Boggs, 1992), (B) Classification of the sandstones using QFR ternary plot (Folk, 1974): Quartz (Q) (mono and polycrystalline quartz without chert), Rock fragments (R) including chert.

Classification of the Chagupana, Huni, Kawere and Banket sandstones (Figure 3B) are; arkose, lithic arkose, lithic arkose-feldspathic litharenite, and predominantly sublitharenite, respectively (Folk, 1974).

4.2 Provenance studies

4.2.1 Chagupana conglomerate

The predominance of metamorphic and granitic clasts in the Chagupana conglomerate suggests that the rock is derived from metamorphic and igneous sources. Some researchers postulated that conglomerates made up of mixed populations of clasts that include moderately or weakly durable types are more likely to be first-cycle deposits and can generally be more safely used for provenance determination (Dickinson et al., 1983; Dickinson, 1988). Mineralogically, the presence of less resistant minerals (amphiboles and feldspars) in the Chagupana conglomerate suggests minimal recycling. Texturally, the clasts are subangular to rounded and occur as granules to cobbles, which is indicative of variable transport distances as well as different energy levels during deposition. Deformation of the Chagupana conglomerate is attributed to the N-S crustal shortening that resulted in the E-W Julie fault (Salvi et al., 2015).

4.2.2 Kawere conglomerate

Previous workers pointed out that the Kawere conglomerate is made up of sedimentary, metamorphic and igneous rock fragments but from this study, it is predominantly composed of metamorphic clasts (Hirdes and Nunoo, 1994; Perrouty et al., 2012). The predominant occurrence of metamorphic clasts and resistant minerals in the Kawere conglomerate suggest metamorphic provenance with multiple recycling. Texturally, the pebbles are sometimes imbricated and range from subangular to rounded, implying the long transportation distance from the source area by water media. The deformation of the Kawere conglomerate may be attributed to the N-S crustal shortening which resulted in NE-SW orientations as postulated (Perrouty et al., 2012).

4.2.3 Source rock composition of the sandstones

The possible provenance of detrital pyrite within the Kawere, Banket and Huni sandstone may include sedimentary rock successions, volcanogenic or sedimentary exhalative massive sulfide deposits, magmatic-hydrothermal deposits, and igneous rocks. The predominance of undulose monocrystalline quartz grains suggests metamorphic and igneous sources as reflected on the diamond plot (Figure 4A) (Tortosa et al., 1991). Monocrystalline quartz grains with straight to slightly undulose extinction indicate granitic source (Genne et al., 2014).

On the diamond plot (Figure 4B), quartz grains in the Huni sandstones are from granitic rocks while Chagupana, Banket and Kawere sandstones were derived from granite, gneiss and schist. Slightly elongated grains with sutured boundaries of polycrystalline quartz in all the sandstones are suggestive of a metamorphic source, most probably schistose derived from a cold working environment (Folk, 1968; Tortosa et al., 1991; Pettijohn, 1975). The high percentage of polycrystalline quartz to monocrystalline quartz is indicative of metamorphic source. On the diamond plot quartz in all the sandstones ranges from low to high-rank metamorphism (Figure 4B) (Basu et al., 1975). Generally, quartz grains within the Chagupana, Huni, Banket and Kawere sandstones can be attributed to metamorphic and igneous provenances.

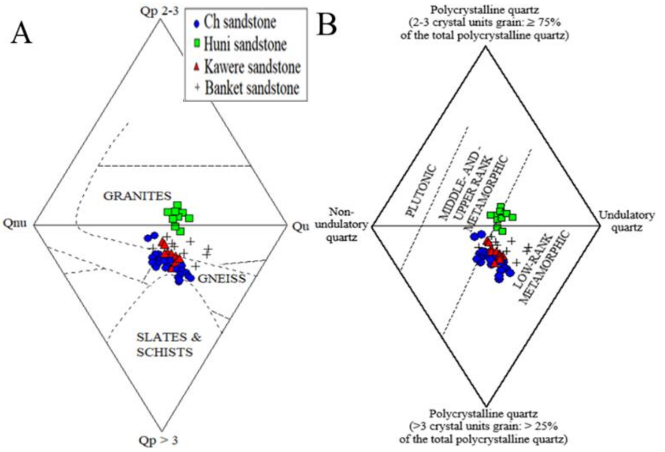


Figure 4: (A) Diamond diagram plot, after Tortosa [26] showing the source of quartz grains (B) Diamond diagram showing the provenance of quartz grains in the sandstones (Basu et al., 1975).

4.2.4 Feldspar

The abundance of less altered, subangular to angular feldspar grains in the Chagupana sandstone suggests a low-moderate degree of weathering and derivation from igneous source rocks with slow cooling magmas, high relief and closeness to the source reflecting immature sediments. The low percentage of alkali feldspar compared to plagioclase in the Chagupana sandstone suggests volcanic or hypabyssal origin, plutonic and even deeper conditions (Dickinson, 1985; Lalnunmawia and Lalhlimpuii, 2014). The abundance of alkali feldspar in the Huni, Banket and Kawere sandstones indicate slow cooling, characteristic of the plutonic sources and low-grade metamorphism. The high alteration of feldspars within the Huni, Kawere and Banket sandstones indicate mature sediments from metamorphic provenance with long transport distance, low relief and a high degree of weathering.

4.2.5 Heavy minerals

Biotite and muscovite are derived particularly from metamorphic and igneous source rocks (Ganne et al., 2014; Boggs, 2012). This association (biotite-muscovite-epidote-zircon-magnetite) of heavy minerals indicates derivation of the Chagupana sandstones from acid igneous rocks (Feo-Codecido, 1956). Also, the presence of garnet –tourmaline – biotite - muscovite - zircon - magnetite - opaque minerals and epidote in the Kawere, Banket and Huni sandstones indicates derivation from acid igneous rocks.

4.2.6 Tectonic setting

Early workers, postulated that detrital sandstone compositions can be attributed to four major provenance types namely; stable cratons, basement uplifts, magmatic arcs, and recycled orogens (Dickinson et al., 1983; Krynine, 1943; Bhatia, 1983; Seiver, 1979; Dickinson and Suczek, 1979). Using the ternary plots developed by Dickinson and Suczek (197) and Dickinson et al., (1983), all the sandstones show linear trends on the continental block, but the Chagupana, Huni, and Kawere sandstones plot as transitional continental materials whilst Banket sandstones also plot as craton interior materials (Figure 5A).

Sediments deposited within the transitional continental margin are derived from environments transitional between craton interior and basement uplift. Detritus from craton interior are mainly from uplifted basement rocks consisting largely of felsic plutonic igneous and metamorphic rocks. Craton interior environments are mostly low lying with granitic and gneissic exposures (Dickinson and Suczek, 1979). Detritus present in this environment are typically quartzose with minor feldspars, reflecting multiple recycling and perhaps intense weathering and long distances of transport on cratons of low relief (Dickinson, 1985). From Figure 5B the Chaguapana, Huni and Kawere sandstones cluster in the magmatic arc region specifically as transitional arc materials whilst the Banket sandstones plot as transitional recycled materials. From the ternary diagram, the maturity or stability of the sandstones decreases from Banket-Kawere-Huni and Chagupana (Figure 5C).

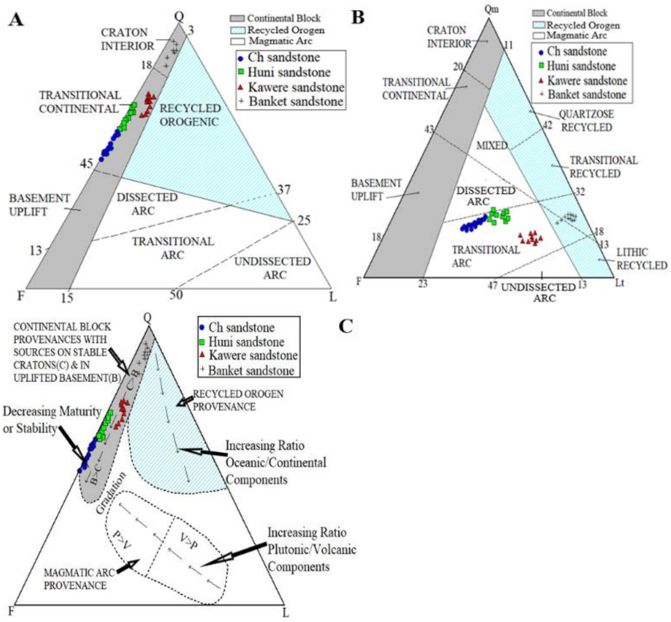
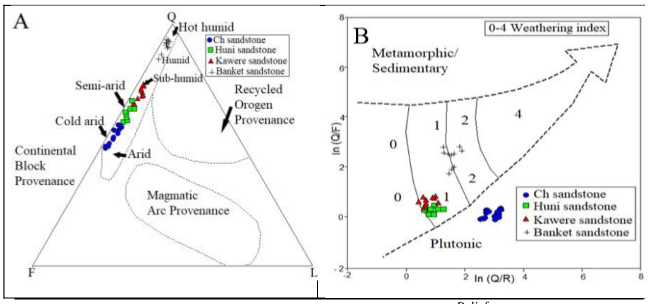


Figure 5: (A and B) are tectonic setting diagrams (A) Triangular QFL diagram showing mean framework modes of the sandstones investigated (Dickinson and Suzeck, 1979): (B) QmFLt diagram showing the mean framework modes for the sandstones investigated C) QLF plot of sediment maturity (Dickinson and Suzeck, 1979).

4.2.7 Paleoclimate and relief

Paleoclimate and relief investigations provide information about the pedogenic processes and climatic conditions present during sediment deposition (Suttner et al., 1981). Suttner and Dutta used the QFL ternary diagram to discriminate between sediments paleoclimatic conditions and tectonic setting (Suttner and Dutta, 1986). On the QFL diagram (Figure 6A) the Chagupana sandstones were derived from a cold arid climatic environment. The Huni, Kawere and Banket sandstones are derived from semi-arid, sub-humid and humid climatic conditions, respectively.

A group of researchers postulated that mineralogical components such as In (Q/R) versus In (Q/F) are sensitive indicators of climatic and relief signatures in sandstones; as such the Chagupana sandstone detritus are derived from plutonic source rocks in a low relief environment (Weltje, 1994). The Huni and Kawere sandstones have a relatively low weathering index of 1 and cluster as materials formed in a high to moderate relief region. The Banket sandstones have weathering indices 1 and 2 indicating low- moderate relief source area under tropical humid climate conditions (Figure 6B).



			Relief		
Semiquantitative Weathering Index			High mountain	Moderate hills	Low plain
			0	1	2
	Semiarid and mediteranean	0	0	0	0
Climate	Temperate subhumid	1	0	1	2
	Tropical humid	2	0	2	4

Figure 6: (A) QLF plot after Suttner and Dutta showing the paleoclimate environments of the sandstones B) ln (Q/F) and ln (Q/R) binary plot showing source rock composition, relief and paleoclimate conditions (Suttner and Dutta, 1986; Weltje, 1994).

4.2.8 Paleocurrent

Observed Sedimentary structures were used to deduce the paleocurrent of deposition. From the cross-beds, Chagupana sandstones were deposited in a north to south direction (Figure 7A) possibly by water, while the Huni sandstones show eastward depositional direction (Figure 7B).

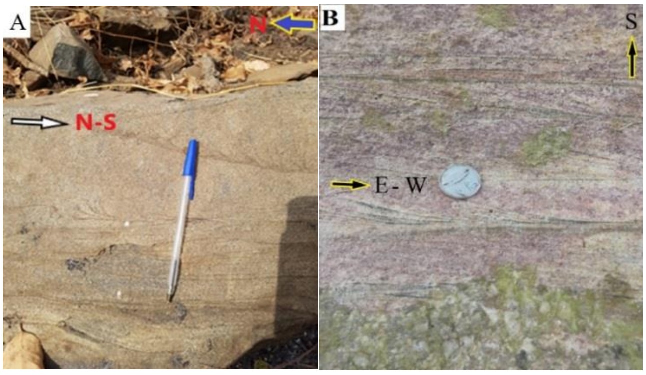


Figure 7: (A) N-S directed cross-beds occurring in the Chagupana sandstones (B) E-W directed cross-beds in the Huni sandstones.

5. Conclusion

From the petrographic study, both conglomerates classify as metamorphic clasts conglomerates. However, the Chagupana conglomerate has igneous and metamorphic provenances, while the Kawere conglomerate has metamorphic provenance; these indicate that both conglomerates sparingly differ. The Chagupana, Huni, Kawere and Banket sandstones classify as arkose, lithic arkose, lithic arkose and sublitharenite, respectively. From the mineralogical results, all the sandstones suggest detritus from acid igneous rock source with minor sedimentary and metamorphic imprints. The maturity of the sandstones decreases from Banket-Kawere-Huni and Chagupana. Detritus of the Chagupana, Huni and Kawere sandstones are from the transitional continental margin, whilst the Banket sandstones are made up of craton interior and recycled orogenic materials.

The Chagupana sandstones are derived from a cold arid region, Huni sandstones are from semi-arid climate, Kawere sandstones from subhumid climatic conditions while the Banket sandstone are from a humid environment. The angular to subangular feldspars present in the Chagupana sandstones indicates low relief and a low to moderate recycling. The Huni and Kawere sandstones are derived from moderate relief areas with multiple recycling episodes whereas the Banket sandstones form a low to moderate relief area. In terms of paleocurrent direction the Chagupana sandstones were derived from the north whilst the Huni sandstones were deposited from the east. In summary, the Chagupana, Huni, Kawere and Banket sandstones are from similar source materials deposited in a similar tectonic setting but differ in paleoclimate, relief, maturity and paleocurrent.

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References

Agyei-Duodu, J., Loh, G.K., Boamah, K.O., Baba, M., Hirdes, W., Toloczyki, M., Davis, D.W., 2009. Geological map of Ghana 1:1 000 000. Geological Survey Department of Ghana.

Asiedu, D. K., Atta-Peters, D., Hegner, E., Rocholl, A. and Shibata, T., 2010. Palaeoclimatic Control on the Composition of Palaeozoic Shales from Southern Ghana, West Africa. Ghana Mining Journal, 12, pp. 7 - 16.

Basu, A., Young, S.W., Suttner, L.J., James, W.C., Mack, G.H., 1975. Re-evaluation of the use of undulatory extinction and polycrystallinity in detrital quartz for provenance interpretation. J. Sediment. Petrol., 45, 871e882.

Bhatia, M.R., 1983. Plate tectonics and geochemical composition of sandstones. The Journal of Geology, 91 (6), 611–627.

Block, S., Ganne, J., Baratoux, L., Zeh, A., Parra-Avila, A.L., Jessell, M., Ailleres, L., Siebenaller, L., 2015. Petrological and geochronological constraints on lower crust exhumation during Paleoproterozoic (Eburnean) orogeny, NW Ghana, West African Craton. J. Metamorph Geol., 33, 463–494

Boggs, S., 1992. Petrology of sedimentary rocks. New York: Macmillan Pub. Co. 707 pp.

Boggs, S., 2012. Principles of Sedimentology & Stratigraphy, Fifth Edition. Published by Pearson Prentice Hall. All rights reserved. Pp 99-150

Boggs, S.J., 2006. Principles of Sedimentology and Stratigraphy, fourth ed. Merril Publishing Company, Toronto.

Davis, D.W., Hirdes, W., Schaltegger, U., Nunoo, E.A., 1994. U–Pb age constraints on deposition and provenance of Birimian and gold-bearing Tarkwaian sediments in Ghana, West Africa. Precambrian Research, 67, 89–107.

Dickinson, W. R., 1985. Interpreting provenance relations from detrital modes of sandstones, In: Zuffa G G (Ed.), Provenance of Arenites Dordrecht. The Netherlands, Reidel Publishing Company, NATO Advanced Study Institute Series, 148, pp. 333-361.

Dickinson, W.R., 1988. Provenance and sediment dispersal concerning paleotectonics and palaeogeography of sedimentary basins. In: New Perspectives in Basin Analysis (KL Kleinspehn & C Paola, eds), Springer-Verlag, New York, pp. 3-25.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., Ryberg, P.T.,1983, Provenance of North American Phanerozoic sandstones relating to tectonic setting: Geological Society of America Bulletin, 94, 222-235.

Dickinson, W.R., Suczek, C.A., 1979. Plate tectonics and sandstone composition. Am. Ass. Petrol. Geol. Bull., 63, pp. 2164-2182.

Feo-Codecido, G., 1956. Heavy-mineral techniques and their application to Venezuelan stratigraphy. Am. Assoc. Petroleum Geologists, Bull., 40, 984-1000.

Feybesse, J.L., Billa, M., Guerrot, C., Duguey, E., Lescuyer, J.L., Milesi, J.P., Bouchot,V., 2006. The Paleoproterozoic Ghanaian province: geodynamic model and ore controls, including regional stress modelling. Precambrian Research, 149, 149–196.

Folk, R.L., 1968. Bimodal super mature sandstones: product of the desert floor; Proc. 23rd. Intern.

Folk, R.L., 1974. Petrology of sedimentary rocks. Austin, TX: Hemphill. 182 pp.

Ganne, J., Gerbault, M., Block, S., 2014. Thermo-mechanical modelling of lower crust exhumation - constraints from the metamorphic record of the Paleoproterozoic eburnean orogeny, west African craton. Precambrian Research, 243, 88–109.

Garzanti, E., Vermeesch, P., Andò, S., Vezzoli, G., Valagussa, M., Allen, K., Kadi, K.A., AlJuboury, A.I., 2013. Provenance and recycling of Arabian desert sand. Earth Sci. Rev., 120, 1-19.

Hirdes, W., Nunoo, B. 1994. The Proterozoic paleoplacers at Tarkwa gold mine, SW Ghana: Sedimentology, mineralogy, and precise age dating of the Main Reef and West Reef, and bearing of the investigations on source area aspects. Geol. Jahrb. D., 100, 247–311.

Ingersoll, R.V., Suczek, C.A., 1979. Petrology and provenance of Neogene sand from Nicobar and Bengal Fans, DSDP sites 211 and 218. Journal of Sedimentary Petrology, 49, pp. 1217-1218.

Khan Z., Quasim M.A., Amir M., Ahmad A.H.M., 2019. Provenance, tectonic setting, and source area weathering of Middle Jurassic siliciclastic rocks of Chari Formation, Jumara Dome, Kachchh Basin, Western India: Sedimentological, mineralogical, and geochemical constraints. Geological Journal; Wiley Publication https://doi.org/10.1002/gj.3612

Koffi, Y., Wenmenga, U., Djro, S., 2016. Tarkwaian Deposits of the Birimian Belt of Houndé: Petrological, Structural and Geochemical Study (Burkina-Faso, West Africa). International Journal of Geosciences, 07, 685-700.

Krynine, P.D., 1943. Diastrophism and the evolution of Sedimentary Rocks. Pennsylvania Mining Industry Technical Paper no. 84-A, 2p

Lalnunmawia, J., Lalhlimpuii, J., 2014. Classification and provenance studies of the sandstones exposed along Durtlang road section, Aizawl, Mizoram. Sci. Vis., 14, 158–167.

Perrouty, S., Aillères, L., Jessell, M.W., Baratoux, L., Bourassa, Y.and Crawford, B., 2012. Revised Eburnean geodynamic evolution of the gold-rich southern Ashanti Belt, Ghana, with new field and geophysical evidence of Pre-Tarkwaian deformations. Precambrian Research, 204-205, 12-39.

Pettijohn, F.J., 1975. Sedimentary rocks, third edition: New York, Harper & Row: 628 pp.

Pettijohn, F.J., Potter, P.E., Siever, R., 1987. Sand and sandstone. 2nd ed. New York: Springer-Verlag. 553 pp.

Powers, M.C., 1953. A new roundness scale for sedimentary particles. Jour. Sed. Petrology, 23, Pp. 117-119.

Puy-Alquiza, M.J., Miranda-Aviles, R., Cruz-Cruz, M., Pérez-Arbizu, O., Vega-González, M., Ana-Zanor, G., 2014. Geochemistry and depositional environment of the Losero Formation in the Mesa Central, México: *Boletín de la Sociedad Geológica Mexicana,* 66 (3), Pp. 413-430.

Salvi, S., Amponsah, P.O., Béziat, D., Baratoux, L., Siebenaller, L., Nude, P.O., Nyarko, R.S., Jessell, M.W., 2015. Shear-related gold mineralization in Northwest Ghana: The Julie deposit. Ore Geology Reviews.

Seiver, R., 1979. Plate tectonic controls on diagenesis. Jour. Geol., 87, pp. 127-155.

Suttner, L.J., Basu, A., Mack, G.H., 1981. Climate and the origin of quartz arenites. Journal of Sedimentary Research, 51(4).

Suttner, L.J., Dutta, P.K., 1986. Alluvial sandstone composition and paleoclimate 1. Framework mineralogy [J]. Journal of Sedimentary Petrology, 56, pp. 326–345.

Terry, R.D., Chilingar, G.V., 1955. Summary of "Concerning some additional aids in studying sedimentary formations" by M. S. Shvetsov. Journal of Sedimentary Petrology, 25, 229-234.

Tortosa, A., Palomares, M., Arribas, J., 1991. Quartz grain types in Holocene deposits from the Spanish Central System: some problems in provenance analysis; In: Developments in Sedimentary Provenance Studies (eds) A C Morton, S P Todd and P D W Haughton, Geol. Soc. London, Spec. Publ., 57 47–54.

Weltje, G.J., 1994. Provenance and dispersal of sand-sized sediments: Reconstruction of dispersal patterns and sources of sand-sized sediments using inverse modelling techniques. PhD Dissertation. Utrecht University Geologica Ultraiectina.Geol. Cong., Prague, 8, 9–32.

Whitney, D.L., Evans, B.W., 2010. Abbreviations for names of rock-forming minerals. American mineralogist, 95(1), 185.