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PETROGRAPHIC STUDY OF SOME PALEOPROTEROZOIC SEDIMENTARY ROCKS IN THE CHAGUPANA AND TARKWA AREAS OF GHANA

Blestmond A. Brako[1+]
Gordon Foli[2]
Chiri Amedjoe[3]
Simon K.Y. Gawu[4]

[1,2,3,4]*Department of Geological Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.*
[1]*Email: bblestmond@gmail.com Tel: 0246626512*
[2]*Email: gordon.foli01@gmail.com Tel: 0248209611*
[3]*Email: chiri.amedjoe@gmail.com Tel: 0245961073*
[4]*Email: skygawu.coe@knust.edu.gh Tel: 0244067804*

(+ Corresponding author)

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ABSTRACT

This study geologically compares conglomerate and sandstone units in the Chagupana area of the Upper West Region and the Kawere conglomerate and Kawere-Huni-Banket sandstone units in the Tarkwa area of the Western Region in Ghana. Some work in the area has over time proposed that rocks from the two areas as similar based on only field relations, hence the need for more detailed work for re-classification. Macro and microscopic studies of the composition, mineralogy and texture of the rock types reveal that the conglomerates in both areas are metamorphic-clast units, greenish-grey, polymictic, foliated and texturally immature. Compositionally and mineralogically, Chagupana conglomerate is matrix-supported and immature, while Kawere conglomerate is clast-supported and mature; these constraint similarities between the conglomerates to only composition. The sandstones from both areas have similar mineralogical compositions, but with decreasing feldspar in the order of Chagupana>Huni>Kawere>Banket. Texturally, all the sandstones are sub-mature, well-indurated and angular-rounded; except the Huni sandstone, which is fine to medium-grained, while the other sandstones are medium-coarse-grained. Based on the feldspar contents, the Chagupana, Huni, Banket and Kawere sandstones classify as greywacke, feldspathic arenite, sub-litharenite and sub-feldspathic-feldspathic arenite, respectively. The greywacke and sandstones have the same cementing materials as quartz, sericite and chlorite. Concluding, the Chagupana rocks are not entirely the same as those from the Tarkwaian Group, probably due to differences in provenance.

Contribution/Originality: This study uses petrographic and structural investigations to unravel the puzzle of the Paleoproterozoic sedimentary rocks in the Chagupana area of the Upper West Region as being part, or not, of the Tarkwaian Group in the Tarkwa area of Ghana.

1. BACKGROUND

The western half of Ghana is underlain by Paleoproterozoic Birimain rocks. The Birimian rocks consist of metavolcanic belts and metasedimentary basins that are intruded by granitoids. Overlying the Birimian metavolcanics are some Paleoproterozoic sedimentary rocks that formed the Tarkwaian Group (Leube, Hirdes, Mauer, & Kesse, 1990). In a way-up stratigraphic order, the Tarkwain group consists of sequence of Kawere conglomerate and sandstones, Banket conglomerate and sandstones, Tarkwa phyllite and Huni sandstone in the Tarkwa area in the Western Region of Ghana (Kesse, 1985; Strogen, 1991). The Banket conglomerate is associated with gold mineralization (Griffis, Barning, Agezo, & Akosah, 2002; Strogen, 1991) a situation that motivated the study of similar units for possible exploration purposes. One of such areas where similarities of rock suites have been made to the Tarkwaian group is the Chagupana area in the northwestern part of Ghana (Agyei et al., 2009); (Salvi et al., 2015). A sketched geological map of Ghana showing the areas of the proposed similarity in Paleproterozoic sedimentary rock types is presented in Figure 1.

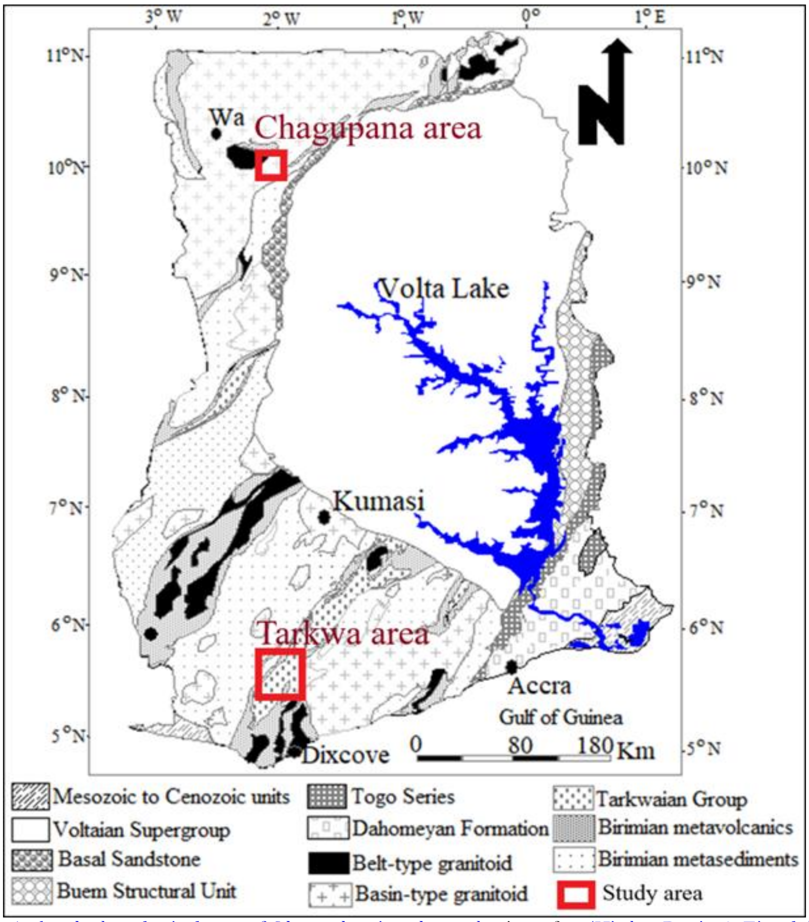

Figure-1. A sketched geological map of Ghana showing the study sites after (Hirdes, Davis, & Eisenlohr, 1992).

As stated above, in the Upper West Region of Ghana, some Paleoproterozoic rocks occurring in the Chagupana area have been likened to some members of the Tarkwaian Group based on some physical characteristics. Agyei et al. (2009) classified the Chagupana area rocks as undifferentiated, since they could not be properly correlated with similar members of the Tarkwaian Group. Block et al. (2015) in a geodynamic evolution study classified the rocks as polymictic sediments and conglomerates that are characterized by cross-bedding features; the authors then concluded that the Chagupana rocks are similar to other clastic sedimentary units across the craton, and as such, referred to them as “Tarkwa-like rocks”.

Salvi et al. (2015) also reported on shear-related gold mineralization in northern Ghana and classified the same rock types as epiclastic sediments. Based on the above inconsistencies surrounding the exact nomenclature of the Chagupana rocks, there is the need for a detailed petrographic study to unravel the apparent puzzle of the Chagupana rocks been part of the Tarkwa Group or another name will be given them. This study aims to compare the composition, mineralogy and texture of the Chagupana rocks to similar members in the Tarkwa area using petrographical investigations to appropriately classify them, thereby placing them in context with respect to the Tarkwaian group or not.

2. GEOLOGICAL SETTINGS

The West African Craton (WAC) is one of the five large cratons of the Precambrian basement rocks of the African plate, which stabilized in the Eburnean Orogeny (Abouchami, Boher, Michard, & Albarede, 1990). The eastern margin of the WAC is occupied by the Man-Leo shield and composed of Paleoproterozoic Birimian rocks, which in Ghana, consists of five evenly spaced NE-SW trending metavolcanic belts and a N-S trending belt, located at the north-western portion of the country. The metavolcanic belts and metasedimentary basins are intruded by granitoids of varying geological characteristics (Leube et al., 1990). Overlying the Birimian metavolcanics is the Tarkwaian Group which consists of shallow water continental detritus derived from the Birimian (Kesse, 1985).

3. GEOLOGY OF THE STUDY AREA

The sedimentary basin in the Upper West Region is bounded by two Shear Zones namely, the Julie belt and the Bulenga Shear Zone (9.947°N, 2.170°W). The Julie shear zone (SZ) is E-W trending and exposed at the northern margin of Chagupana community (10.096° N, 2.094°W). This Shear Zone is characterized by huge exposure of milky and smoky quartz veins, with S1 foliation dipping at 50°-70°, bears reverse, top-to-the-south kinematic indicators and carries a stretching lineation plunging down-dip towards higher-grade rocks. The Bulenga shear zone, which is interpreted as an extensional detachment that also occurs at the southern precinct is consistent with N-S directed shortening which marks D1 deformation (Block et al., 2015). This zone is characterized by metamorphic rocks such as sericite schist and quartzofeldspathic rocks intruded by quartz and basalts.

According to Block et al. (2015) the rocks at the southern part of the Julie belt also experienced D1 deformation and metamorphism. They also contain volcanic materials with crystallization ages of 2129 ± 7 Ma. This indicates that sediments must have been deposited in a syn-tectonic basin formed during ongoing D1 shortening (Block et al., 2015). However, massive outcrops of amphibolite schist, quartzofeldspathic rocks and basalts occur in the eastern margins of the basin. Most of the rock types are veined by quartz. Meanwhile, granodiorite and biotite rich granite are the main granitoids surrounding the area.

4. METHODS

Geological mapping was done in the Chaqupana area and 30 representative rock samples, comprising 5 conglomerates and 25 sandstones were selected for thin and polished section preparation. Also, thin and polished sections of 10 sandstone samples each, of Kawere, Banket and Huni, and 5 Kawere conglomerate samples, were prepared to compare with the Chagupana rocks. Analysis of thin and polished was done with the polarizing (Leica DM750P) and transmissive petrographic microscopes at the KNUST geological laboratory.

Modal estimates of quartz (Q), feldspars (F) and rock fragments (L) were calculated using the point counting machine and framework comparison chart as used by Dickinson (1970) and Terry and Chilingar (1955). Grain sorting, grain roundness and conglomerate classifications, respectively followed the criteria established by Folk (1968); Powers (1953) and Boggs (1992). The framework parameters of detrital modes, as listed in Table 1 were employed.

Table-1. Framework parameters of detrital modes (Ingersoll & Suczek, 1979).

Qm	Undulouse monocrystalline quartz
Cht	Chert
Qp	Polycrystalline quartzose, lithic fragments (Qpq + Cht)
Q	Total (Qm non + Qm un) and Qpq
Qt	Total quartz
P	Plagioclase feldspar
K	Potassium feldspar
F	Total feldspar grains (P + K)
L	Unstable (siliciclastic) lithic fragments (Lv + Ls + Lsm)
Cem	Cement

Sandstone classifications and pebble size analysis were done using QFL plots of Pettijohn, Potter, and Siever (1987). The coefficient of variation in pebble size was computed as C= s/π. Where C is the coefficient of variation in pebble size, s is the standard deviation for maximum pebble length, π is the mean of the maximum pebble length.

5. RESULTS

5.1. Petrography of the Conglomerates

5.1.1. The Chagupana Conglomerate

The Chagupana conglomerate is in contact with the E-W trending Shear Zone (10.096°N, 2.094°W) located at the southern part of the Julie belt. The conglomerates indicate a minor lithofacies (<5%). Hand specimen photographs and photomicrographs of the Chagupana conglomerate are presented in Figure 2.

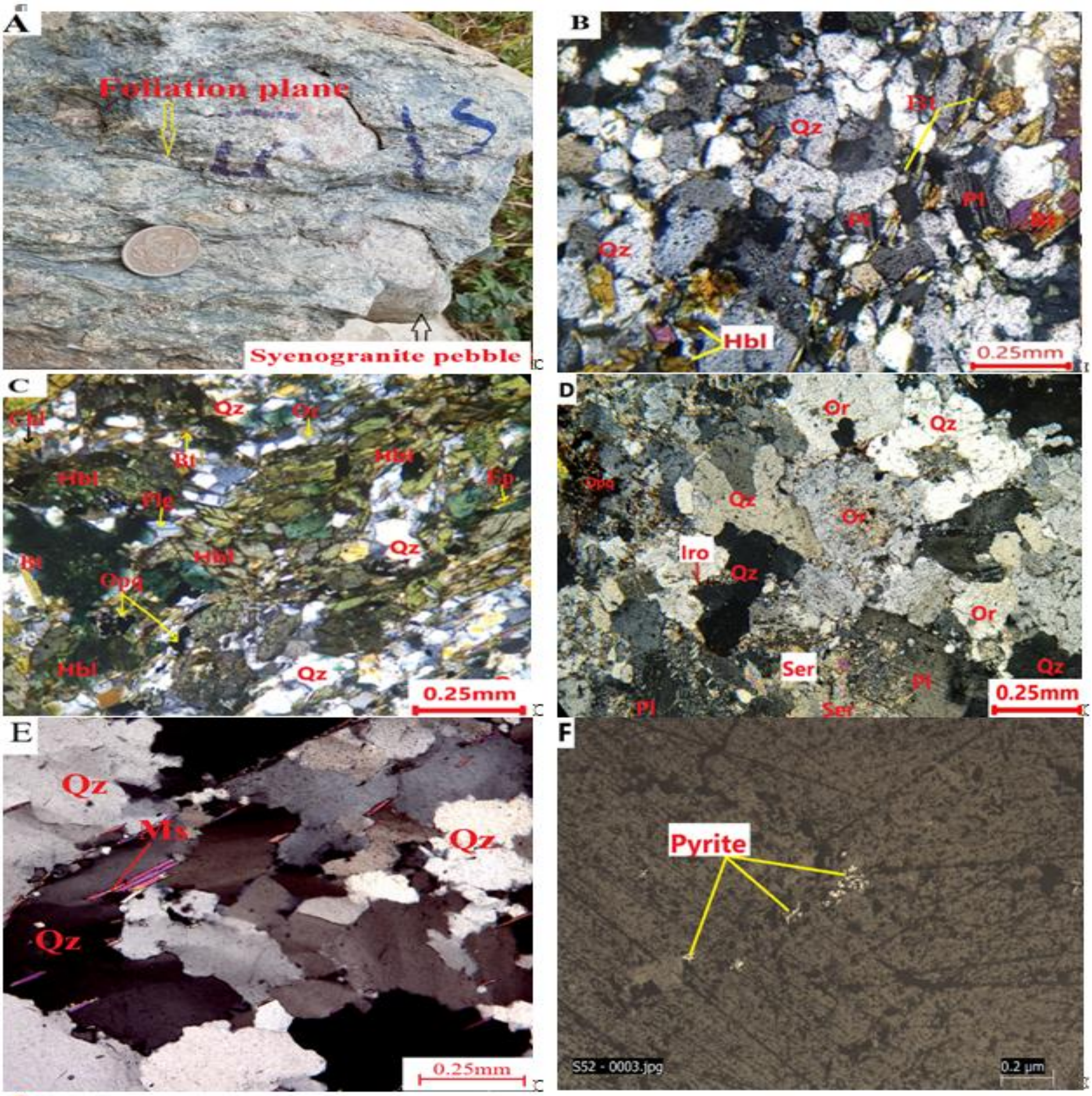

Figure-2. (A, B, C and D). Hand specimen photographs and photomicrographs of the Chagupana conglomerate: A) slightly elongated syenogranite pebbles and the foliated matrix B) Photomicrographs of the matrix showing slight alignment of biotite C) Prismatic hornblende and altered hornblende aligned in a preferred orientation D) Interlocking texture of the slightly elongated syenogranite with moderated altered plagioclase E) sutured quartz grains with flaky muscovite in quartzite F) Disseminated pyrite in polished section. Qz= quartz, Ser= sericite, Ms= muscovite, Pl= plagioclase, Bt= biotite, Or= orthoclase, Opq= opaque mineral, Cht= Chert, Iro= iron oxide, Hbl= hornblende, Ep = Epidote (Whitney & Evans, 2010).

From the petrographic analysis, the Chagupana conglomerate is loosely packed, poorly sorted, well indurated, foliated and greenish-grey but weathers into dark grey to black. Compositionally, they are made up of loosely packed clasts of hornblende schist (30%), syenogranite (10%), quartz vein (3%), greenstones (2%) and quartzite (4%), in a moderately sorted, silicified argillaceous to arenaceous matrix (51%). The syenogranite pebble is pinkish whilst hornblende schist is fine to medium-grained, platy, foliated and greenish Figure 2A. The Chagupana conglomerate clasts range from granules to cobbles (0.2-7cm) with sub-angular to rounded shapes.

In thin section, the matrix framework of the Chagupana conglomerate is dominated by fine to medium-grained quartz, hornblende, feldspars, biotite, chlorite and opaque minerals Figure 2B. In the matrix, quartz is sub-angular to rounded and closely packed. Labradorite is the dominant plagioclase in the matrix with characteristic polysynthetic twinning. Few occurrences of untwined orthoclase feldspars were also observed in the matrix. Fine-grained hornblende is predominant and occasionally anastomoses the quartz and feldspar grains whereas some are scattered throughout the framework. Biotite appears elongated in preferred orientations together with the hornblende and sometimes quartz grains. Chloritization is rapid resulting from the alteration of biotite and hornblende. The opaque minerals appear sporadic, subhedral to anhedral and sometimes as overgrowth. Hornblende is usually anhedral and has quartz inclusions Figure 2C.

The syenogranite pebble is medium to coarse-grained with interlocking texture and made up of quartz (40-45) %, plagioclase (10-15) %, orthoclase (20-30) %, muscovite (1-2) %, biotite (1-2) %, sericite (1-5) %, iron oxides (<1) % and opaque minerals (1-2) % and pyrite (1-5) %. Quartz is subhedral to anhedral and occasionally slightly elongated with predominant sutured edges Figure 2D and sometimes occurs as aggregates and sporadically as interstitial grains. Also, the plagioclase and alkali feldspars in the syenogranite pebble range from subhedral to anhedral with grains sizes ranging from 0.05mm to 0.5mm. Muscovite is shred-like, flaky and commonly as interstitial grains to the quartz and feldspar but in some cases anastomoses them. In thin section, the hornblende schist is made up of quartz (15-20) %, amphiboles (60-70) %, biotite (5-10) %, chlorite (2-5) %, opaque minerals (1-2) %, feldspar (2-5) % and epidote (1-3) %.

Majority of the quartz are recrystallized, angular to rounded and exhibit undulose extinction. Orthoclase is rare whilst polysynthetic plagioclase is moderately altered Figure 2D. Biotite is dark green to brown and occurs as individual grains or aggregates interstitial and partially chloritized. Elongated hornblende, muscovite, biotite and chlorite define the foliation planes. Chloritization and epidotization of the hornblende grains are also incipient. From Petrography, the quartzite reveals interlocking grains of subhedral to anhedral quartz, feldspar and sometimes muscovite Figure 2E. Isolated and deformed opaque minerals occur mainly as later overgrowths. In the polished section, the synogranite contains pyrite which is fine to medium grained and averagely constitutes 3% of the modal composition. It is anhedral and appears disseminated throughout the section and commonly along grain boundaries as patches Figure 2F.

5.1.2. The Kawere Conglomerate

The Kawere conglomerate forms the basal unit of the Tarkwaian group. Hand specimen photographs and photomicrographs of the Kawere conglomerate are presented in Figure 3.

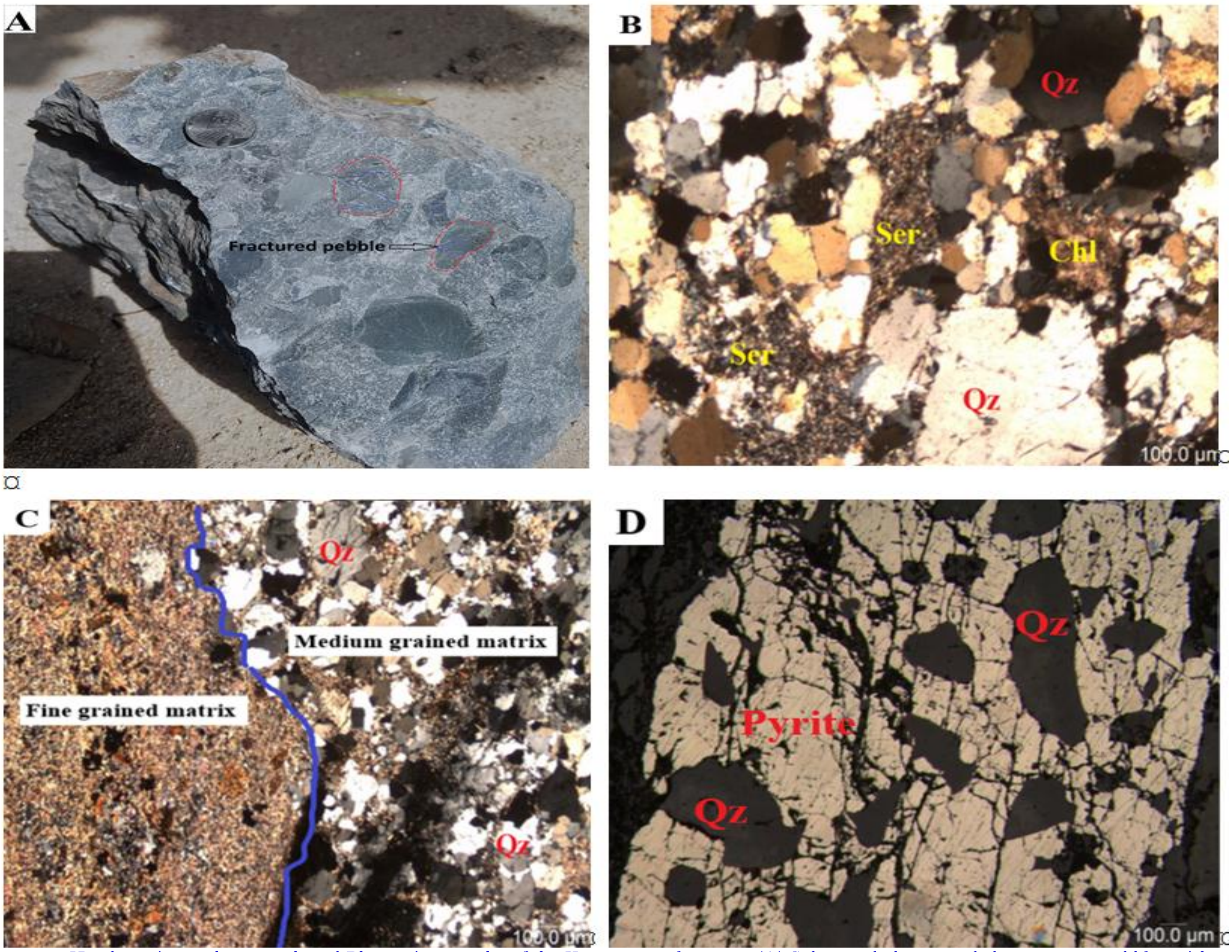

Figure-3. Hand specimen photograph and Photomicrographs of the Kawere conglomerate (A) Sub rounded to rounded greenstone pebbles with internal micro-fractures B) Photomicrograph of the greenstone pebble showing an abundance of quartz with sericite, chert and chlorite (C) Micaceous matrix predominantly quartz with variable grain sizes (D) Deformed pyrite in polished section. Qz = quartz, Ser = sericite, Opq = opaque mineral, Chl = Chlorite (Whitney & Evans, 2010).

Compared with the Chagupana conglomerate, the Kawere conglomerate is well indurated, greenish or greyish and composed predominately of closely packed, angular to well-rounded clasts of greenstone (36%), quartz (10%), quartzite (7%) all in a silicified micaceous matrix (47%). The greenstones are greenish with inclusions of pyrite. While some pebbles in the Kawere conglomerate appear squeezed, others show internal micro-fractures Figure 3A. The arrangements of some composite pebbles suggest imbrication structures Figure 4B. Petrographic analysis of the greenstone pebble shows an interlocking texture of quartz (70-80) %, sericite (5-10) %, chlorite (5-10) % and opaque minerals (1-2) %.

Texturally, the greenstone pebbles are made up of fine to medium, subhedral to anhedral grains that are moderately fractured Figure 3C, with quartz as the predominant mineral that sometimes occurs as interstitial or aggregate grains. Most of the quartz grains show undulose extinction while few display straight extinction. Both polycrystalline (Qp) and monocrystalline (Qm) quartz grains are present. Chloritization and sericitization occur as alterations of biotite and feldspars/muscovite respectively. The opaque minerals are usually anhedral and occur sporadically throughout the framework. Quartz, opaque minerals, micas and iron oxide constitute the matrix of the Kawere conglomerate. Majority of the quartz grains in the matrix are fractured, sub-angular to rounded whilst others are elongated Grain size banding is indicated by the presence of coarse and fine quartz grains. The iron oxide is elongated and thread-like along grain boundaries. In polished section, pyrite occurs as overgrowth with euhedral to anhedral shapes Figure 3 F.

5.2. Petrography of the Sandstones

5.2.1. Field and Hand Specimen Observation of the Sandstones

Field pictures of the sandstones are presented in Figure 4.

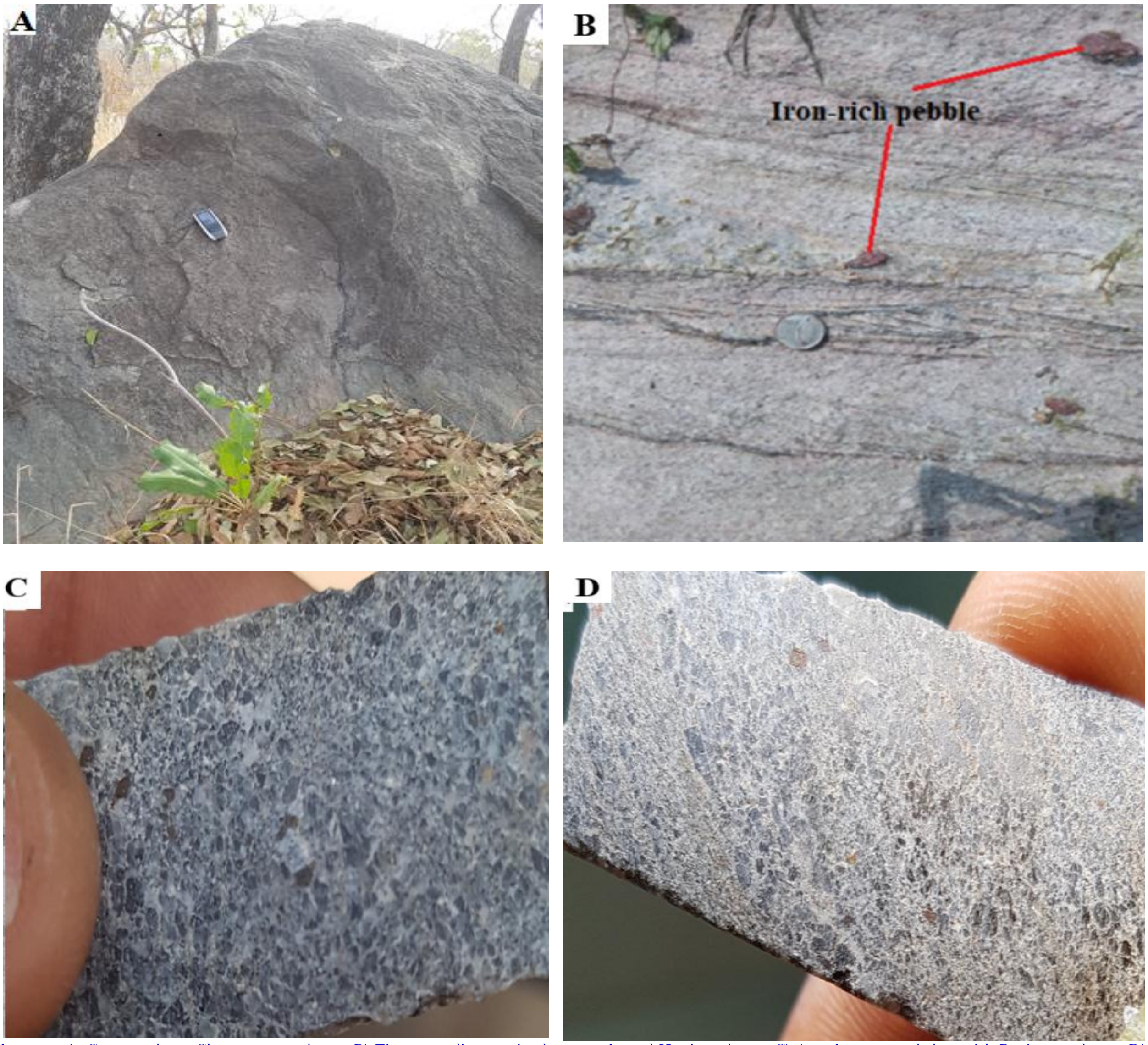

Figure-4. A. Concave-down Chagupana sandstone B) Fine to medium-grained, grey coloured Huni sandstone C) Angular to rounded greyish Banket sandstone D) Brownish grey Kawere sandstone.

The Chagupana rocks and Huni sandstones were sampled from the while core samples of the Bnaket and Kawere sandstones were collected from the University of Mines and Technology, Tarkwa. The Chagupana sandstones, occupying about 90% of the study area outcrop predominantly in the northern, central and southern precincts. They resemble granitoids displaying concave down shapes and exfoliation features though sometimes layered Figure 4A. They are well indurated and appear greyish or greenish when fresh but weathers to dark grey, brown or blackish. Quartz, feldspar and mafic minerals make up the mineral constituents of the Chagupana sandstones. Sporadic occurrences of reddish spots as well as mafic (magnetite) bands also occur in some of them. Sedimentary structures observed in the Chagupana sandstones are current bedding, flute casts and reverse grading.

The Huni sandstone is massive, fine to medium-grained, well indurated, greyish or pinkish in colour and composed of angular to subangular grains of quartz, feldspar, pyrite and mafic minerals. Phenoclasts of reddish-brown pebbles are sometimes observed. Current bedding coupled with ripple marks are the dominant sedimentary structures present in the Huni sandstone Figure 4B. Conversely, the Banket sandstone which overly the Banket conglomerate in the Banket formation is greyish, well indurated, medium to coarse-grained with phenoclasts of quartz Figure 4C. Quartz, feldspar, pyrite and mafic minerals make up the mineral constituents of the Banket sandstone. Also, the Kawere sandstone is greyish, medium to coarse-grained angular to rounded, highly indurated and slightly foliated. Minerals present are quartz, feldspar, biotite, muscovite, iron oxide, opaque minerals and pyrite Figure 4D.

5.2.2. Thin Section Analysis of the Sandstones

Compositionally, all the sandstones under investigation are predominantly made up of detrital quartz, feldspar and sedimentary rock fragments. Thin and polished sections observations indicate that all the sandstones investigated have common mineralogical associations of quartz, feldspar, chert, sericite/saussurite, chlorite, micas, zircon, and epidote. However, tourmaline and pyrite are associated with the Huni, Banket and Kawere sandstones. Photomicrographs of the various sandstone suites are presented in Figures. 5, 6 and 7.

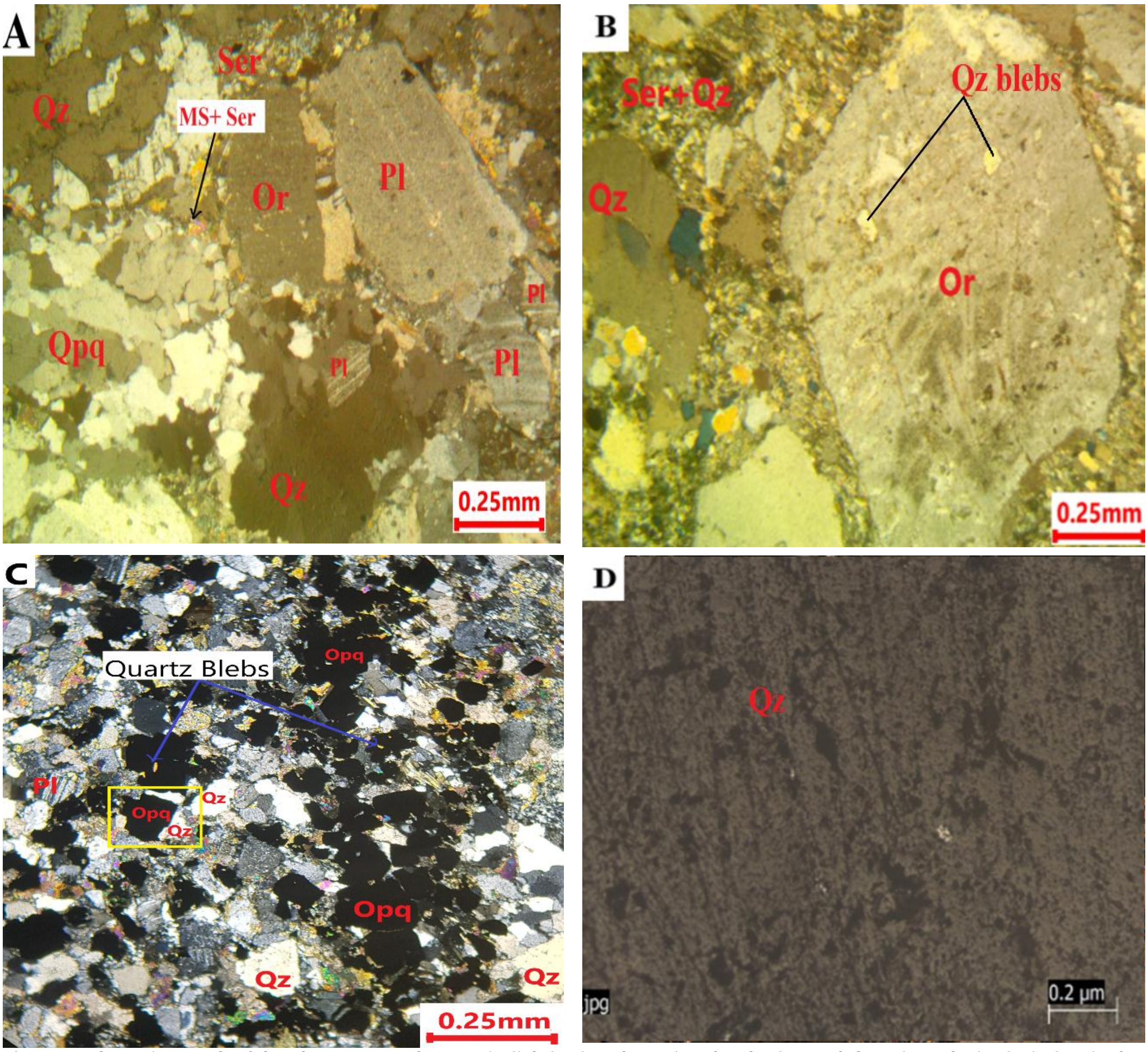

Figure-5. Photomicrograph of the Chagupana sandstone: A) Slightly altered untwinned orthoclase and the polysynthetic plagioclase in the Chagupana sandstone; B) Phenoclast of orthoclase with blebs of quartz inclusion; C) Banded magnetite in the Chaguapana sandstone; D) polished section of Chagupana sandstone showing no indication of pyrite. Qz = quartz, Ser = sericite, Ms = muscovite, Mcl = microcline, Bt = biotite, Or = orthoclase, Opq = opaque mineral, Cht = Chert (Whitney & Evans, 2010).

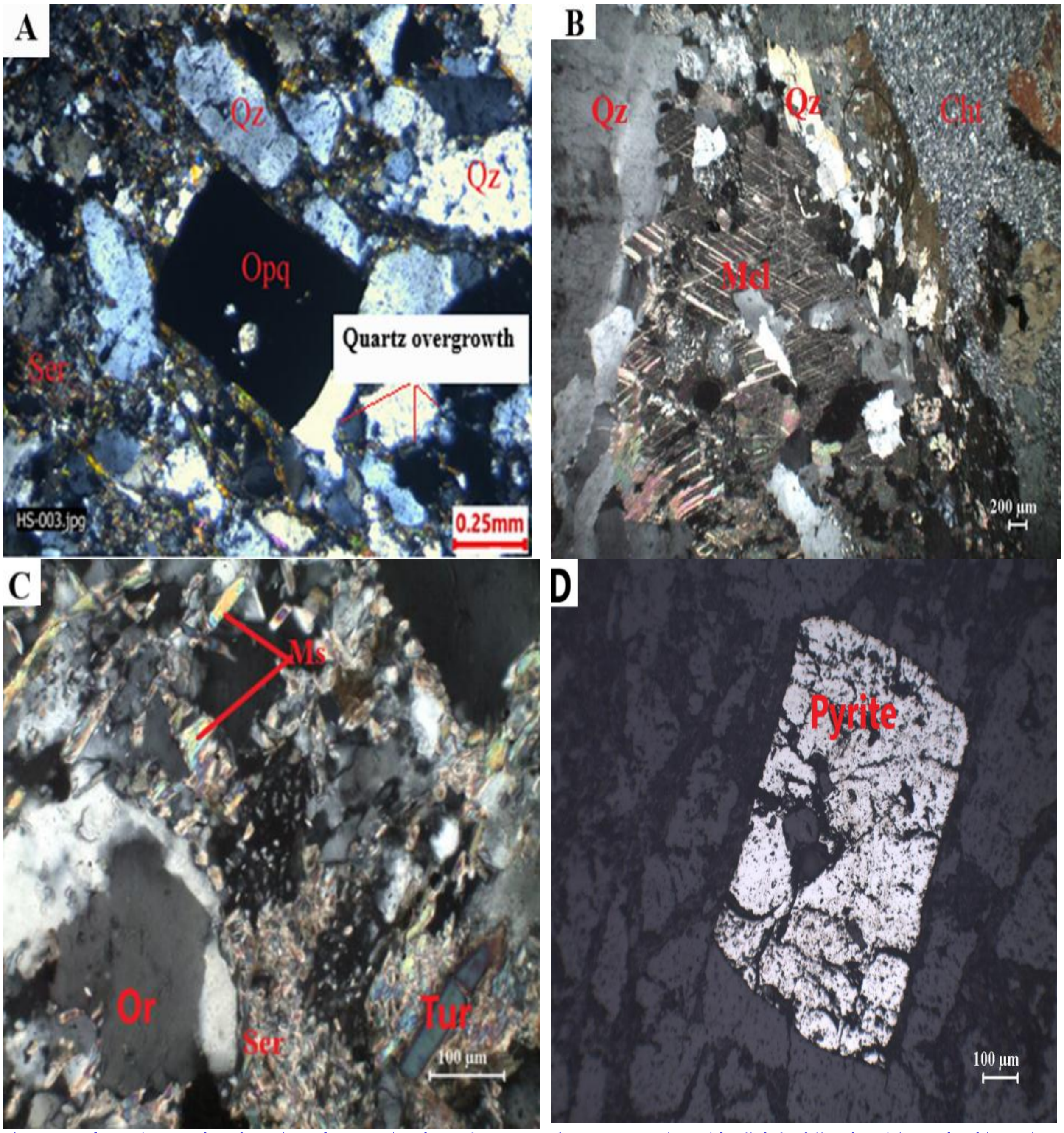

Figure-6. Photomicrographs of Huni sandstone: A) Subangular to angular quartz grains with slightly foliated sericite and cubic pyrite occurring as overgrowth; B) Untwinned orthoclase, shreds of muscovite and tourmaline; C) Skeletal microcline with inclusions of quartz; D) Deformed euhedral pyrite in polished section. Qz = quartz, Ser = sericite, Ms = muscovite, Mcl = microcline, Bt = biotite, Or = orthoclase, Opq = opaque mineral, Cht = Chert (Whitney & Evans, 2010).

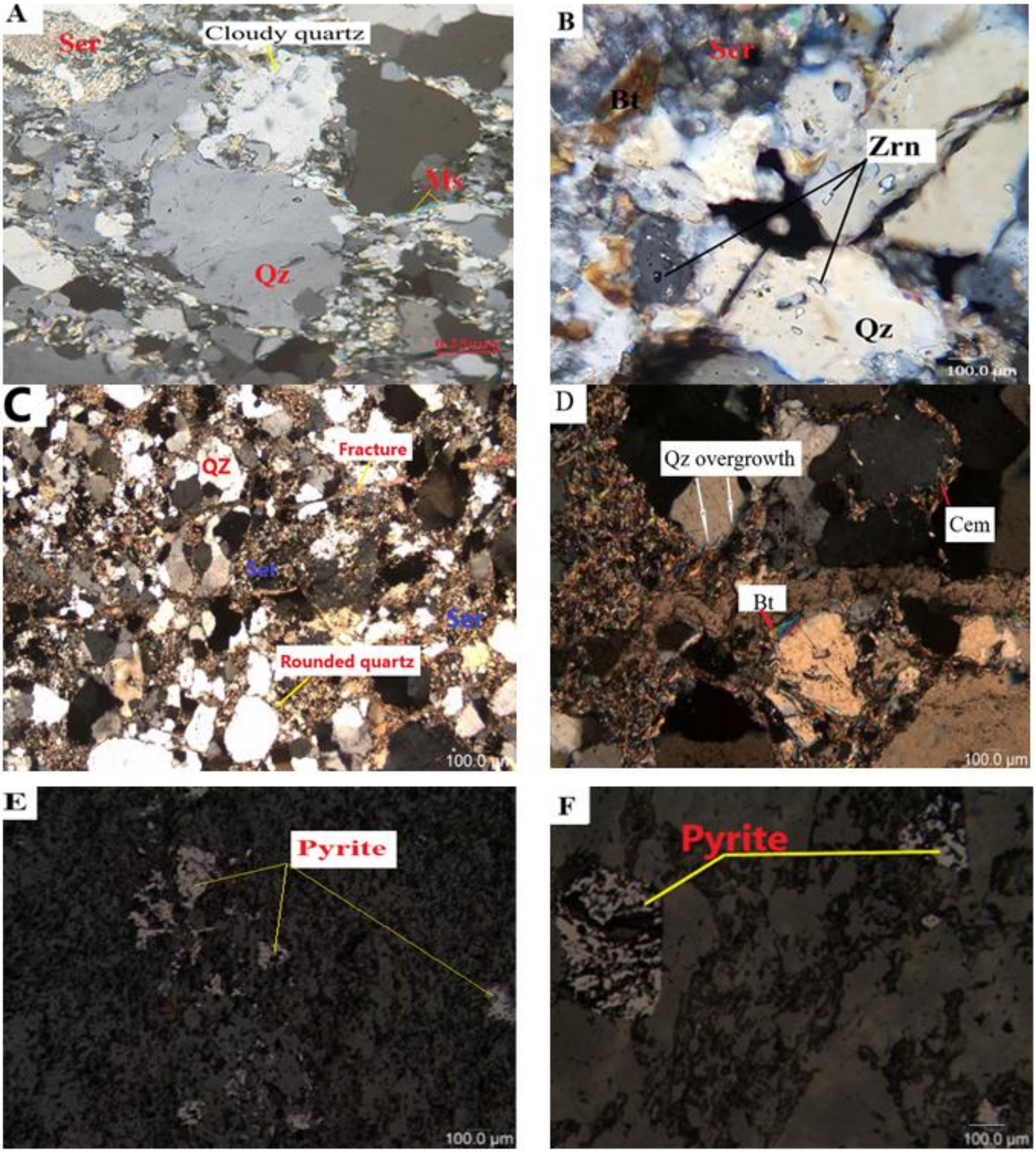

Figure-7. Photomicrograph of the Banket sandstones (C and D) are also photomicrograph of the Kware sandstone. A) Cloudy quartz with sutured contact in Banket sandstone. B) Detrital zircon in quartz and biotite altering into chlorite in the Banket sandstone C) Highly altered orthoclase feldspar and overgrowths of opaque minerals D) Sericite cement and quartz overgrowth present in the Kawere sandstone E) Disseminated pyrite in polished section of the Banket sandstone F) Sub rounded pyrite in the Kawere sandstone. Qz = quartz, Ser =sericite, Ms = muscovite, Zrn=zircon, Bt=biotite, Cem = cement (Whitney & Evans, 2010).

5.2.2.1. Quartz

The average modal analysis of the sandstones Table 2 reveals that quartz (Qz) predominate in all the samples in the following order from the highest to the lowest; Banket (78%), Chagupana sandstone (52%), Kawere (52%) and Huni (48%).

Table-2. Average point counting results of the framework grains of the sandstones (%.).

	Q	F	L	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

Note: BAB =Chagupana sandstones, Hs=Huni sandstones, Kw ss= Kawere sandstones, Bkt = Banket sandstones.

Generally, three categories of quartz grains are observed: monocrystalline (Qm), polycrystalline quartz (Qp) and recrystallized quartz. Majority of quartz grains in the Chagupana sandstones are polycrystalline (60%) followed by the monocyrstalline (40) % quartz which exhibits straight extinction. The polycyrstalline quartz is fine to medium-grained, angular to sub-rounded grains, sometimes with sutured edges and appears slightly elongated. The grains with 2-3 crystal units usually show straight crystal boundaries, whereas grains with >3 crystal units exhibit sutured boundaries Figure 5A. In the Kawere, Banket and Huni sandstones quartz grains are slightly elongated, angular to subrounded with predominant sutured boundaries and exhibit both straight and undulose extinction. The average polycrystalline and monocrystalline quartz compositions in the Kawere, Banket and Huni sandstones are; 70%, 70%, 50% and 30%, 30%, 50% respectively. However, quartz grains in the Huni sandstones are fine to medium Figure 6A, but medium to coarse in the Kawere and Banket sandstones Figure 7A.

5.2.2.2. Feldspar

The second predominant mineral in all the sandstones is feldspar with the following proportions; Chagupana (45%), Huni (34%), Kawere (25%) and Banket (7%). In the Chagupana sandstone, the feldspars present are the untwined orthoclase (43%), crosshatched microcline (2%) and polysynthetic twinned plagioclase (55%) which range from andesine to labradorite Figure 6A.

In the Huni, Banket and Kawere sandstones, averagely orthoclase (70%) is the predominant feldspar followed by the polysynthetic twinned plagioclase (albite) (30%). Rapid alteration of plagioclase and microcline are also observed in Huni, Banket and Kawere sandstones Figure 7B and C. These feldspar grains also range from angular to sub-rounded and usually show inclusions of quartz blebs.

5.2.2.3. Opaque Minerals

Amorphous to cubic opaque minerals (2 to 10) % occur occasionally as overgrowths whilst others are scattered throughout the framework of the sandstones understudy. Banding of mafic minerals (magnetite) is also observed in the Chagupana sandstone Figure 5 C. However, magnetite and pyrite are the common opaque minerals present in the Kawere, Banket and Huni sandstones. In polished thin section, pyrite is cubic but sometimes skeletal even though highly deformed Figure 5D, 6C and 7A. The percentages of detrital pyrite decrease from Huni (1-5) % to Kawere (4-5) % and Banket (2-5) % sandstones.

5.2.2.4. Secondary Minerals

The secondary minerals present in all the sandstones are chlorite, sericite /saussurite, and epidote. Commonly, sericite and chlorite appear shred-like, flaky and interstitial grains to the detrital grains but in some cases anastomoses the detrital grains. However, these secondary minerals in the Huni, Banket and Kawere sandstones are sometimes slightly oriented in a preferred direction (foliated). In the Kawere sandstones, carbonate and sericite/muscovite filled fractures and grain boundaries Figure 7C.

5.2.2.5. Rock Fragment

Chert is the only rock fragment (sedimentary rock) observed in all the sandstones. Generally, chert in the Chagupana sandstone account for 4.58% of the average modal composition, subrounded, and made up of fine-grained quartz Figure 4A. Chert, however, decreases from Kawere sandstone (21.27%) to Huni sandstone (18.92%) and Banket sandstone (15.89%). Comparatively, chert in the Chagupana and Huni sandstones, is fine-grained and subangular to subrounded whilst in the Kawere and Banket sandstones it is commonly fine to medium-grained.

5.2.2.6. Accessory Minerals

Biotite (1-2) %, muscovite (1-2) %, epidote (1-2) % and zircon (1-2) % are the accessory minerals observed in the Chagupana sandstone. Conversely, the common accessory minerals in the Kawere, Huni and Banket sandstones are biotite, muscovite, epidote, zircon, garnet and tourmaline Figure 6C and 7C. Generally, muscovite and biotite are subhedral to anhedral, elongated and flaky Figure 6C. They usually occur in the matrix and also along the boundaries of the quartz and feldspars.

5.2.2.7. Cement/Matrix Material

Even though some detrital grains are deformed to pseudomatrix, all the sandstones have common matrix/cementing materials (quartz, quartz overgrowth, iron oxide, sericite and chlorite). Quartz overgrowth occurs as a rim of quartz cement around detrital grains Figures 7A and 8A. 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% whilst that of the Huni, Banket and Kawere sandstones ranges from 4% to 15%.

6. DISCUSSION

6.1. Classification of the Chagupana Conglomerate

The Chagupana conglomerates in the Upper West Region are in sharp contact with the E-W shear zone located at the southern margin of the Julie belt (Block et al., 2015; Salvi et al., 2015). The E-W shearing may have resulted from the N-S directed crustal shortening which might have aided the foliation. The associations of stable (syenogranite (10%) Figure 8B, quartzite (4%), greenstone (2%) and quartz (3%)) and unstable (hornblende schist 25%) rock fragments make the Chagupana conglomerates compositionally immature. The variable grain sizes of the rock fragments make it poorly sorted hence texturally immature.

Some previous workers, Block et al. (2015) on the geodynamic evolution of the West African Craton and Salvi et al. (2015) on shear-related gold mineralization in NW Ghana affirm the immature nature of the Chagupana conglomerates. The recalculated modal percentages of the rock fragments within the Chagupana conglomerate indicate they are metamorphic clasts conglomerate Figure 8A. The mean length and width of the pebbles within the Chagupana conglomerate Table 3 which are 2.44 cm and 1.78 cm respectively suggest minimal deformation. The coefficient of variation (C) in terms of pebble sorting (0.79) and pebble matrix ratio (0.96) indicate predominant matrix composition.

6.2. Classification of the Kawere Conglomerate

Boggs (2014) postulated that a conglomerate in which the clasts touch each other is called clasts supported (orthoconglomerate). Hence, the Kawere conglomerate is clasts supported and polymictic. Previous workers (Davis, Hirdes, Schaltegger, & Nunoo, 1994; Kesse, 1985) postulated that the Kawere conglomerate is polymictic and made up of silicified Birimian greenstones and hornstone together with rear ones of Jasper, quartz, quartz porphyry, tourmaline-quartz, granitoids, Birimian phyllite and schist and are free from limestone, dolomite and organic matter. From the ternary diagram, the Kawere conglomerate is a metamorphic clast conglomerate composed predominantly of stable fragments hence, compositionally mature Figure 8A.

The length of the pebbles ranges from 0.2cm to 12cm similar as reported by Tetteh and Arthur (2018) but in this study, the mean pebble length and width of the Kawere conglomerate Table 3 are 4.8 cm and 2.4 cm respectively implying the length is twice the width. Similarly, the coefficient of variation (C) in pebble sorting for the Kawere conglomerate is 0.56 and the pebble matrix ratio is 1.13. The N-S crustal compression that occurred in southern Ghana (Perrouty et al., 2012) may have caused the deformation of the Kawere conglomerate owning to several microfractures, closely packed, squeezed and jointed pebbles. The variable grain sizes exhibited by the rock fragments confirm that the Kawere conglomerate is poorly sorted and texturally immature (Boggs, 2014). The ore minerals observed in the Kawere conglomerate are pyrite (5-10) % and magnetite (1-2) %.

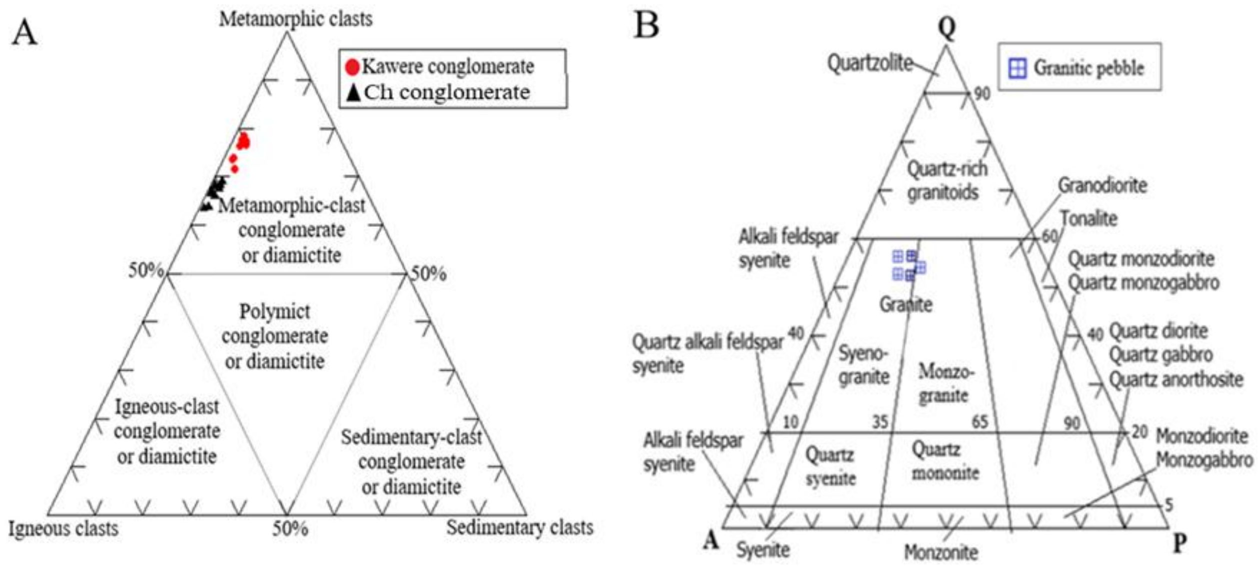

Figure-8. A. Classification of the conglomerates based on pebble composition (modify after Boggs (1992)). B) QAP diagram of granitoids classification (modified after Streckeisen (1979)): Q is quartz, A is alkali feldspar and P is plagioclase. Here, the granitic pebble in the Chagupana conglomerate is classified as granite and specifically as a syenogranite.

Table-3. Summary statistics for 200 pebbles each in the Chagupana (Ch) and Kawere conglomerates.

Statistics	Length (Ch cong)	Width (Ch cong)	Length (Kawere cong)	Width (cm) Kawere cong)
Mean	2.44	1.78	4.81	2.36
Std. Deviation	1.90	1.47	2.68	1.54
Variance	3.62	2.17	7.20	2.37
Skewness	1.45	1.08	.97	1.48
Minimum	.50	.20	1.00	.30
Maximum	7.00	6.00	13.00	8.00

6.3. Classification of the Sandstone

6.3.1. The Chagupana Sandstone

The Chagupana sandstones at first sight, resemble granitoids with concave down shapes. The framework composition was normalized Table 2 and plotted on the Pettijohns' classification ternary diagram (Figure 9A). On the quartz-feldspar-rock fragments classification diagram for greywackes, the Chagupana greywackes plot as feldspathic greywacke Figure 9A. It is evident from the thin analysis that the feldspars contribute 45% of the Chagupana greywackes and plagioclase (andesine to labradorite) is the predominant feldspar. Pettijohn et al. (1987) reported that rocks in which Na is predominant as a result of Na-rich plagioclase are greywackes. Therefore, the previously called sandstones are reclassified in this study as greywackes. Sandstones with predominant unstable framework grains are compositionally immature (Boggs, 2014). The unstable framework grains (feldspar, biotite, sericite, chlorite and muscovite) of the Chagupana sandstones make them compositionally immature. Textural maturity is determined by the relative abundance of the matrix, degree of rounding and sorting of framework grains (Boggs, 2014). The low matrix contents (4-12) % the moderate sorting and degree of roundness (subangular to rounded) renders the Chagupana sandstones texturally sub-mature. The vertically to sub vertically oriented magnetite bands may have resulted from the subsequent metamorphism.

6.3.2. The Kawere Sandstone

The mineralogical association of minerals in the Kawere sandstone makes it compositionally sub-mature. However, on the QFL ternary diagram by Pettijohn et al. (1987) it grades from sub-feldspathic to feldspathic arenite Figure 9B. According to Folk (1968) lithic arkose has feldspar/rock fragment ratio between 1:1 to 3:1;

Feldspar-rich rock with over 5% clay materials, are poorly sorted and contains angular grains, hence are classified as texturally immature. Texturally, the framework grains of the Kawere sandstone are medium to coarse-grained, angular to rounded and moderately sorted. Boggs (2014) noted that feldspathic arenites are usually medium to coarse-grained and predominantly subangular to angular. Also, the slight foliation, well indurated coupled with the mafic bands are effects of subsequent metamorphism which may have resulted from the N-S crustal shortening (Perrouty et al., 2012).

6.3.3. The Banket Sandstone

The mixture of stable and unstable framework grains indicates the Banket sandstone is compositionally sub-mature. The framework composition plots as sub feldspathic arenite on the quartz, feldspar and lithics (QLF) classification ternary diagram Figure 9B. Sub feldspathic arenite is analogous to sub-arkose but contains more rock fragments (5-25) % compared to feldspar (0- 10) % and quartz (65-95) % (McBride, 1963). The matrix /cementing composition (2%-5%) coupled with the moderate degree of sorting makes the rocks texturally sub-mature.

6.3.4. Huni Sandstone

According to Kesse (1985) the grey, greenish and bluish coloured Huni sandstone is a weathered representation of feldspathic quartzites which are usually finer than the Banket quartzites. In this study, the high feldspar (orthoclase) content (20-30) % makes the Huni sandstone feldspathic or arkosic. The framework compositions of the Huni sandstones plot as feldspathic arenites on the QFL classification ternary diagram Figure 9B. The combination of stable and unstable framework grains indicate that the Huni sandstone is compositionally immature.

Texturally, the fine to medium-grained, angular to subrounded shapes coupled with the percentage of matrix material makes the Huni sandstone immature. However, the slight foliation combined with high induration exhibited by the Huni sandstone can be attributed to the N-S crustal shortening as well as subsequent metamorphism proposed by Perrouty et al. (2012). Current bedding and ripple marks are the dominant sedimentary structures observed. The pink colour of the Huni sandstone may be due to a very fine dusting of hematite hosted in pore spaces within the feldspars, although hematite is also present as a partial or total replacement of original magnetite and as an exsolution product with rutile after ilmenite (White, Waters, & Robb, 2015).

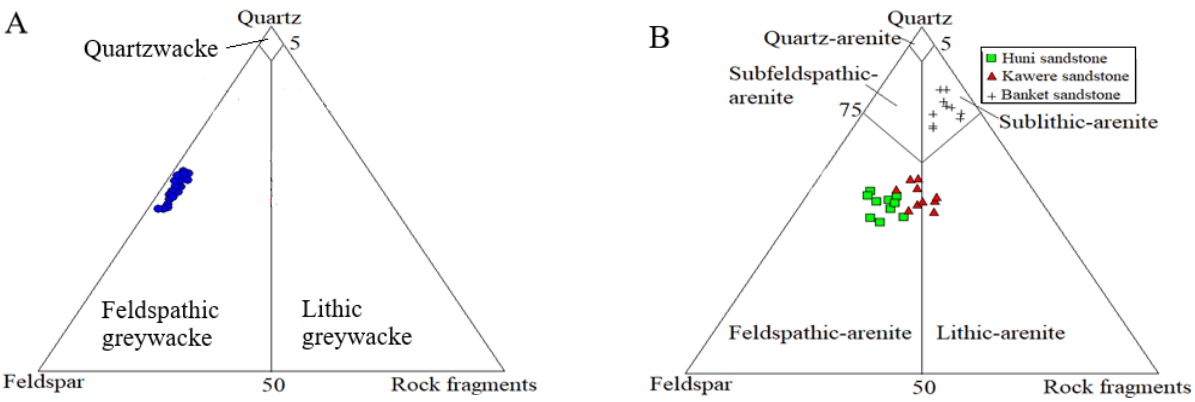

Figure-9. (A and B) Quartz–feldspar–rock fragments classification plots proposed by Pettijohn (1987) A) Chagupana greywackes B) Huni, Banket and Kawere sandstones

7. CONCLUSION

The Chagupana and Kawere conglomerates are metamorphic-clasts units, greenish-grey and polymictic. Compositionally, the Chagupana conglomerate is immature, matrix-supported and foliated while the Kawere conglomerate is clast-supported, mature and foliated. Mineralogically, the Chagupana conglomerate is immature while the Kawere conglomerate is mature. Texturally, the Chagupana conglomerate is immature while the Kawere conglomerate is sub-mature. The mean length to width ratios for the pebbles in Chagupana and Kawere conglomerates are 1.4 and 2 respectively. The coefficient of variation (C) in terms of pebble sorting for the Chagupana and Kawere conglomerates are 0.79 and 0.56 whilst the pebble-matrix ratios are 0.96 and 1.13 respectively. Geologically, the similarities between the Chagupana and Kawere conglomerates can only be limited to texture but not composition and mineralogy.

Compositionally, the greywackes and sandstones investigated have minute contribution of sedimentary rock (chert). Detrital pyrite is present in the Kawere, Banket, Huni sandstones and rare in the Chagupana sandstone. Mineralogically, feldspar contents decrease in the order from Chagupana greywackes-Huni-Kawere-Banket. The plagioclase (andesine to labradorite) is predominant in the Chagupana greywackes while orthoclase is dominant in the Huni, Kawere and Banket sandstones. Texturally, the greywackes and sandstones are sub-mature, well indurated, angular to rounded, medium to coarse-grained except for the Huni sandstone which is fine to medium-grained. The previously called Chagupana sandstones have been reclassified as greywackes in this study and the Huni sandstones are classified as feldspathic arenites whilst the Banket sandstone is a sub-feldspathic arenite. The Kawere sandstone is classified as sub-feldspathic to feldspathic arenite.

The greywackes and sandstones have the same cementing materials made up of; quartz, quartz overgrowth, sericite and chlorite. Sedimentologically, current beds, flute casts and reverse grading occur within the Chagupana greywackes whilst the Huni sandstones have ripple marks and current bedding. The Chagupana greywackes are similar to the Kawere, Banket and Huni sandstones in terms of texture but not composition and mineralogy. From this study, the petrographical properties of the Chagupana rocks are not entirely the same as similar units within the Tarkwaian Group, hence they may be attributed to a different provenance.

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