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Petrography and Geochemistry of late Cretaceous Pab Sandstone, Laki range, Southern Indus Basin, Pakistan: implications for Provenance and Paleoclimate

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Abstract

Geochemistry and petrography of the late Cretaceous Pab sandstone exposed at the Laki Range, Southern Indus basin has been carried out in order to acquire better understanding of source rock, paleoclimate and the tectonics. The unit in the study area dominantly comprises of sandstone with some conglomeratic sandstone and mudstone beds. The petrographic studies of Pab sandstone reveal the quartz as the major mineral constituent in almost all analyzed samples. The monocrystalline variety of quartz was seen dominant than the polycrystalline; with dominant non-undulatory extinction, the undulation was also noticed. In addition, studied samples reflect medium to coarse size grains, angular to subangular to subrounded shape characterized with the grain to grain contacts as point to straight and sutured. Iron oxide is observed to be leading cement with calcareous as the second most abundant cementing material, the matrix was also observed in minor amount. The monocrystalline quartz abundance in Pab sandstone indicate the existence of granitic rocks in the source region. The lesser fragments of feldspar and lithics suggest of their alteration to various clay minerals. The Pab sandstone is composed mainly of monocrystalline quartz derived dominantly from craton interior as revealed through plots of model composition on Quartz -Feldspar- Lithics (QFL) and Quartz Monocrystalline-Feldspar-Lithics (QmFLt) plots as per the petrographic characterization. The major element geochemistry of Pab sandstone indicates that the samples comprised of abundant SiO2 (56.21 to 69.93 wt.%), Al2O3 (12.56 to 22.98 wt.%), CaO (1.68 to 6.38 wt.%) and Fe2O3 (3.87 to 14.12 wt.%), the rest of the major oxides are <2 wt.%. Additionally, major element compositions suggest the sediment derivation from a granitic source. The Chemical Index of Alteration (CIA) values ranging from 61.12 to 83.75 and the values of Plagioclase Index of Alteration (PIA) ranging from 59.94 to 89.44 suggests that studied sediments underwent the weathering conditions being moderate to intense in warm and humid climate regime.

The present petrographic findings and geochemical data suggest the sediment derivation from huge Cratonic landmass (Indian Shield). The similar rock types in the form of Nagar Parkar Igneous Complex are still exposed in the southeast of study area in Pakistan and Malani Igneous Suite in India.

Keywords: Pab Sandstone, Laki Range, Provenance, Paleoweathering

1. Introduction

The term Pab sandstone, derived from the Pab Range, was first introduced by Vredenburg (1908). The Williams (1959) labelled the location at Latitude 25°31' 12” N and Longitude 67°00'19” E lying west of Wirahab Nai as the type section for the unit exhibiting the thickness of 490 meters. In the Northern Laki Range, the Pab Sandstone unit is remarkably thick succession of sandstone as dominant lithology with some gravel beds and less volume of fine lithologies including silt and mud. The sandstone units are generally red to reddish brown, medium to coarse grained, moderate to highly compacted reflecting abundant cross bedding (both planar and trough). The trough cross bedding is more common than planar cross bedding. The other structures such as asymmetrical ripple marks and mud cracks are also found in the sandstone and mudstone beds. The gravel beds portray visible fining up lithologic trend at certain places in the Pab outcrops. The unit is overlain by Khadro Formation whereas, it is underlain by the non-clastic sequences of Fort Munro Formation. Based on fauna, Maastrichtian age is assigned to the Pab sandstone strata (Vredenburg, 1908; HSC, 1960).

The provenance analyses using various properties of strata are generally carried out to determine the sediment source area. The different suits of detrital minerals are produced from various kind of source rocks thus they reveal the character of the particular source rock from which they have originated. However, the geochemical compositions of siliciclastic rocks are extensively used to recognize the composition, weathering history, and helps to ascertain the paleogeographic reconstruction of source terrains. In sedimentary provenance analysis of siliciclastic rocks, the sandstone petrographic investigation is amongst the extensively used methodology to deduce source composition, tectonic setting, transportation mechanism, and even deposition of sediments (Dickinson, 1970, 1985; Dickinson and Suczek, 1979; Dickinson et al., 1983; Ingersoll and Suczek, 1979; Le Pera and Arribas, 2004; Le Pera et al., 2001; Zuffa, 1985, 1987). Likewise, their geochemical composition also provides information about the provenance, tectonics and paleoclimate (Kamp and Leake, 1995; Cingolani et al., 2003; Armstrong and Verma, 2005; Nagarajan et al., 2007; Jafarzadeh and Hosseini, 2008; Umer et al., 2011; Pandey and Parcha, 2017; Khokhar, 2019).

The exposures of Pab sandstone strata of late Cretaceous are present in different areas of the Sulaiman and Kirthar Fold-Thrust belts of Middle and Lower Indus Basin. This important lithostratigraphic unit has been extensively studied in aforesaid regions particularly in Middle Indus Basin for facies analysis, provenance and reservoir characteristics (Kasi et al., 1991; Sultan and Gipson, 1995; Khan et al., 2002; Umar, 2007; Umar et al., 2011). Though the above studies cover considerable information about the deposition, sedimentary source, transportation, and diagenetic character of Pab sandstone but its exposures in Laki Range, Southern Indus Basin require more attention in terms of discourse on geochemistry and petrography. The present work attempts to deduce the provenance, tectonics, and paleoclimate through modal composition and geochemical analysis of two well exposed stratigraphic sections of the Pab sandstone i.e, the Beezen (BZN) and the Cheephat (CHPT) in the Laki Range (Fig. 1).

2. Geology of Study Area

The study area geologically is part of the Laki Range in Southern Indus Basin, Sindh, Pakistan. The Pab sandstone from two stratigraphic sections exposed in the Northern extremities of the Laki Anticline of the Laki Range (Survey of Pakistan Topographic sheet number 35 N/16 part of Hunting Survey Corporation geologic map number 35 J-N) are selected for present study. This anticline is part of the Laki Range; which in turn is a fold and thrust belt, oriented in North – South direction at the regional scale. Moreover, this anticline has steep eastern flank and moderately dipping western flank, thus it is asymmetrical in nature. The steep eastern limb is intersected by north-south trending thrust fault system which may record the 1000 m displacement (Schelling, 1999). The crest height of this anticline is maximum towards northern extremities of the Laki Range thus the oldest rocks in the base got exposed that later are being eroded by ephemeral rivers. The deformation activity of this anticline prevailed even after Miocene upto Pleistocene as demonstrated by the uplift of Manchhar Formation (Miocene-Pliocene) and the recent sediments (Schelling, 1999). The region comprises of exposed Cretaceous to recent sedimentation record; the oldest unit is of Fort Munro limestone whereas, Dada Conglomerate is the younger most unit in the area. Other than that, Cretaceous to recent sedimentary sequences are not exposed anywhere else in the Southern Indus Basin. This entire sedimentation stack reveal the episodic fluctuations of sea level as indicated by presence of the several lithologic characters in the region. The basaltic flows in the strata of Paleocene age are also witnessed in this region (Agheem et al., 2011). The study area is bounded by the Thar desert and Nagar Parker igneous complex (NPIC) in the East and the Kirthar Range and Axial Belt comprising Bela ophiolites in the West.

3. Materials and methods

The rock samples from field were collected along the two stratigraphic sections i.e., the Beezen (BZN) and Cheephat (CHPT) Nala sections; targeting the Pab strata. A total of twenty-six (26) samples were collected from

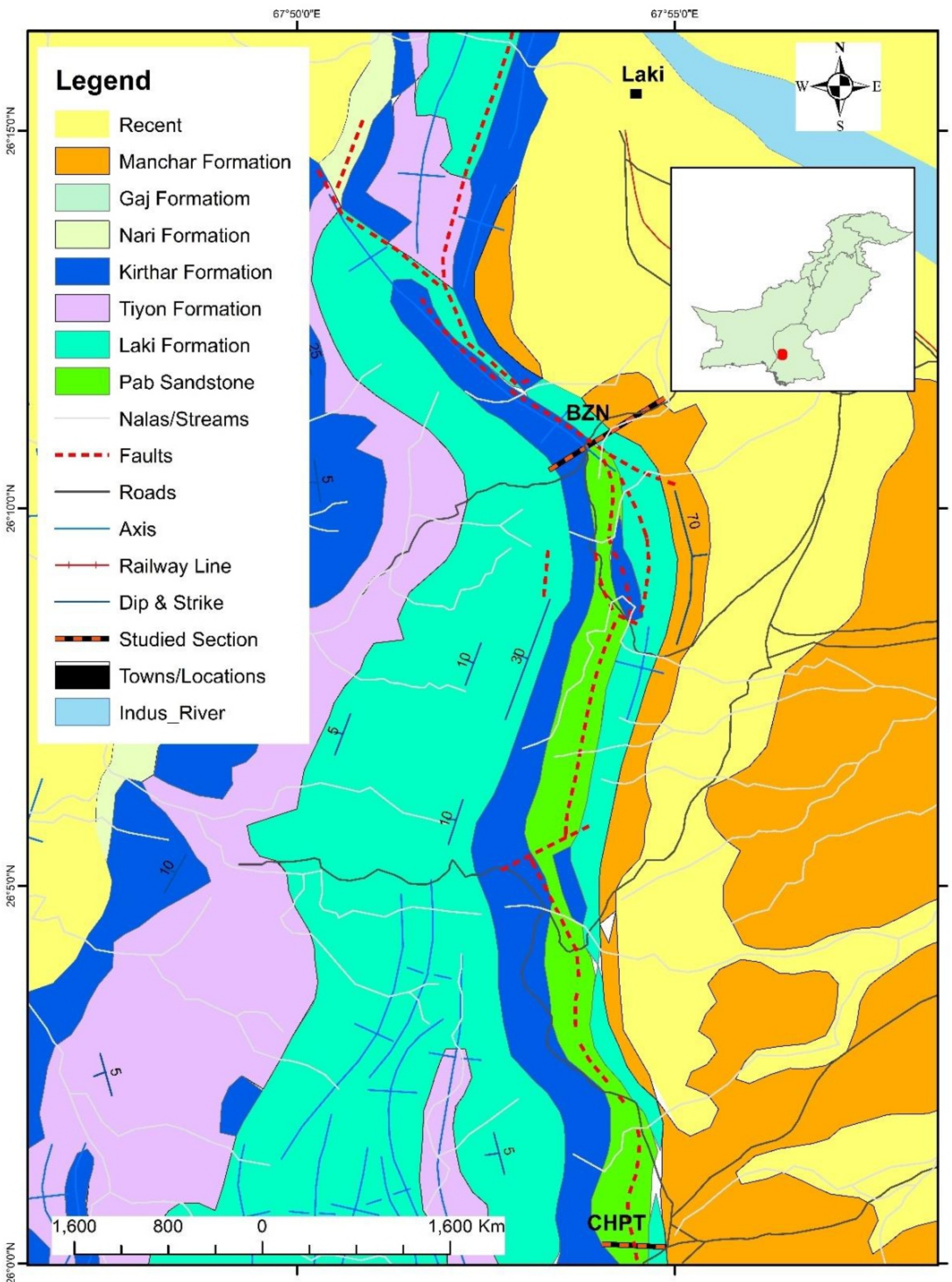

Fig.1 The geological map the studied sections showing the lithologies, in the inset the index map of Pakistan marking the study area is given (Redrawn after HSC, 1960).

both the sections. While sampling, special care was taken to document all the lithological variations. From total collected samples, ten (10) representative samples were selected for the petrographic investigation whereas, sixteen (16) samples were chosen for the geochemistry particularly the major oxide concentrations. These samples were labelled with the prefix of BZN and CHPT prior to the number denoting the name of the section sampled.

For the petrographic investigations the standard thin section preparation procedures were adopted. The prepared thin sections were examined under the Leica DM 2500 petrographic microscope available at the Advanced Research Labs of Centre for Pure and Applied Geology (CPAG), University of Sindh (UoS), Jamshoro. During the thin section examination, in each thin section a total of 300 points were counted adopting the Gazzi-

Dickinson method (in Ingersoll et al., 1984).

The framework components in the thin sections were counted and the grid spacing was adjusted in a way allowing the count of >300 framework components per thin section avoiding repeated count of any single component. The quartz grains both the mono-crystalline (Qm), polycrystalline (Qp), Lithic fragments (L), and Feldspar (F), along with other minerals such as Muscovite (M), Glaucon3ite (G) Zircon (Zr) Biotite (B) and Chert (Ch), were counted. The geochemical analyses focused mainly on the major elements (major oxides) for the selective samples; investigations were carried out on the S4 Pioneer X-Ray Fluorescence Spectrometer of the Bruker AXS, Germany. The provenance characteristics, were determined using the major oxides such as CaO, K_2O, MgO, Na_2O, and SiO_2, on the ternary diagram of Taylor and Mclennan (1985). The Chemical Index of Alteration (CIA) calculation is adopted after Nesbit and Young (1989) using oxide values such as Al_2O, CaO, Na_2O and K_2O. The Plagioclase Index of Alteration (PIA) suggested by Fedo et al., (1995) is adopted, the calculations involve the measurements of Al_2O_3, CaO, K_2O and Na_2O.

4. Results and Discussions

4.1 Petrography

The quartz is found to be the leading mineral constituent in the studied Pab sandstone samples. Both varieties monocrystalline and polycrystalline were noticed (Fig.2). The monocrystalline phase was observed as dominant with non-undulation and rare undulation (Fig.3). The sandstone is medium to coarse grained, subrounded, angular to sub angular having grain to grain contact as point to straight and sutured (Fig.2); this suggests that the studied sediments have experienced moderate to slightly intense compaction. The other framework grains such as some plagioclase feldspar with noticeable lithics, particularly the chert grains were observed (Fig. 2). The quartz ranging from 85% to 96% is the leading component among the framework grains; averaging 93% in population. The rock fragments and feldspar are observed in lesser quantity. Iron oxide was the leading cementing material with some calcareous cement and minor matrix was also observed. The detailed analysis of petrographic characters is given in Table 1.

The composition of parent rock greatly influence the composition of sandstone; accordingly, the modal analyses of framework particles are useful for the identification of provenance (Dickinson, 1970; Dickinson and Suczek, 1979; and Dickinson et al., 1983). Dickinson and Suczek (1979) and Dickinson et al., (1983) used ternary diagram to show the compositional fields characterized with different provenances. The modal point counting data of Pab sandstone from Laki Range was plotted on Quartz-Feldspar-Lithics (QFL) and Quartz monocrystalline-Feldspar and Lithics (Qm-FLt) ternary diagrams proposed by Dickinson et al., (1983). These ternary diagrams distinguish fields such as Craton, Transitional, Basement uplift, Quartzose recycled, Dissected arc etc. Nearly all the plotted sandstone samples of Pab are seen in the craton field (Figs. 4 and 5). This kind of plotting may be related to higher proportion of quartz in the investigated samples.

4.2. Geochemistry

The major element geochemistry of the sandstone is very useful in discerning the provenance type and tectonics of the ancient basin (Bhatia, 1983). Other than that, the major element composition also help in determining the weathering history of sediments (Nesbitt and Young, 1982, 1984, and 1989; Fedo et al., 1995; McLennan, 2001; Lee et al., 2005). In order to assess the provenance type and paleoweathering conditions experienced by Pab sediments a total of sixteen (16) samples (eight from each section) were selected for geochemical analysis (Table 2). The studied samples of Pab sandstone collected from Laki Range abundantly comprise of SiO_2, Al_2O_3, CaO and Fe_2O_3. The other major oxides are <2 wt.%. Majority of samples show much variation in major oxide values. The higher percentage of SiO_2 along with K_2O reflects the origin of sediments from uplifted basement (Bhatia, 1983). Besides, the SiO_2 and Al_2O_3 ratios are helpful in identifying quartz richness in sandstone (Bhatia, 1983). In addition, the values of SiO_2 and ratios of K_2O and Na_2O help to distinguish sandstone types (Middleton 1960; Crook, 1974; Schwab, 1975).

The values of SiO_2varies from 56.21% to 70.11% averaging 66.5%. After SiO_2, the $Al_2O_3$is the second most abundant oxide with average values of 15.18%. The Fe_2O_3 content ranges from 3.87 to 14.12%, averaging 6.42 %. The concentration of TiO_2 varies from 0.38 to 0.89 with average values of 0.70%. The CaO concentration in Pab sandstone varies from 1.68 to 6.23 % averaging 4.68 %. The concentration of Na_2O ranges from 0.43 to 1.08 % averaging 0.65 %. The K_2O content ranges from 1.88 to 2.91 % averaging 2.07 %. Other oxides such as MnO, MgO, TiO_2 and P_2O_5 are present in less than 1 wt.%. The diagram of Taylor and Mclennan (1985) was used with the intention of ascertaining the provenance of Pab sandstone (Figs. 6 and 7). The fields identified in this model are granitic, basaltic and ultramafic distinguished by the relative abundance of SiO_2, CaO, MgO, Na_2O and K_2O. The plotting of samples in this ternary diagram indicates that virtually majority of the samples are scattered close to the granitic source though some of them are plotted in between basaltic and granitic fields; this could be due to the minor or comparatively little contributions from the mafic sources. The mafic dykes along with basement rocks are also found in significant volumes of exposures besides the dominant lithologies of granitic rocks in the Neoproterozoic NPIC (Jan et al., 2022).

4.3 Paleoweathering

The major oxides content can be affected by the diagenetic processes therefore, the weathering conditions at source region should be taken into account prior to mobility or transportation (McLennan, 2001). The weathering conditions of the source region are mainly governed by composition of the source rock, climatic conditions, and the tectonics which expose the source rocks and also provide information about the relief (Roser and Korsh, 1988). The weathering history of sediments can be evaluated through examination of alkali and alkaline earth elements (Nesbit and Young, 1989). The depletions of alkali and alkaline earth elements occur during the weathering (Roser and Korsh, 1988). The CIA and PIA has been carried out to assess the paleoweathering trend of Pab sediments.

The values of CIA calculated below 50 indicate slight effect of chemical weathering whereas the values above 75 indicate high weathering conditions. The studied sediments yield the values of CIA between 57.83 – 83.75 (Table 2) suggesting the prevalence of moderate to high weathering conditions.

Table 1. Point counting petrographic data of the Pab sandstone samples from BZN and CHPT sections.

Sample	Qm	Qp	Feldspar	Lithics	Other Min.	Total
BZN-01	278	10	2	4	6	300
BZN-03	280	12	1	3	4	300
BZN-05	277	14	2	2	5	300
BZN-06	274	12	2	7	5	300
BZN-08	284	10	2	3	1	300
CHPT-01	271	16	2	6	5	300
CHPT-03	271	16	2	6	5	300
CHPT-04	280	13	1	3	3	300
CHPT-06	276	17	1	3	3	300
CHPT-07	274	14	2	7	3	300

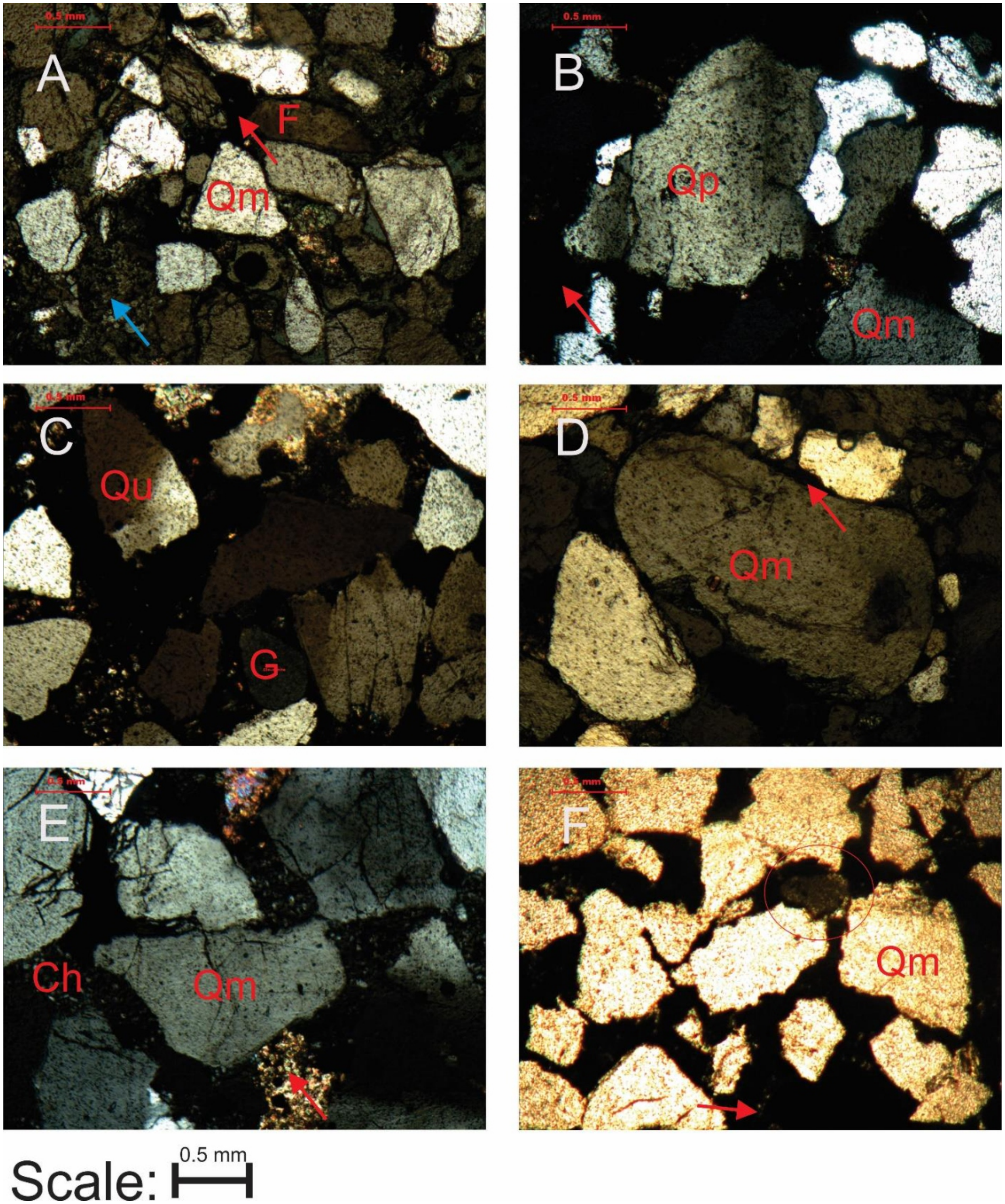

Fig.2 Representative photomicrographs of Pab sandstone from Beezen Nala Section (BZNS), A) monocrystalline quartz with moderate sorting, ferruginous cement and matrix is shown with red and blue arrow respectively (XPL), B)Very-coarse polycrystalline grain cemented with iron oxide (XPL), C) Qu grain surrounded by iron oxide cement, glauconite is present at bottom center (XPL), D) Very-coarse quartz sub rounded quartz , arrow showing straight contact , (XPL), E) Fractured quartz showing embedded chert, arrow showing calcite cement (XPL), F) Sub angular to angular grains floating in ferruginous cement with a few point contacts, arrow marking ferruginous cement and tourmaline is shown in circle (PPL),

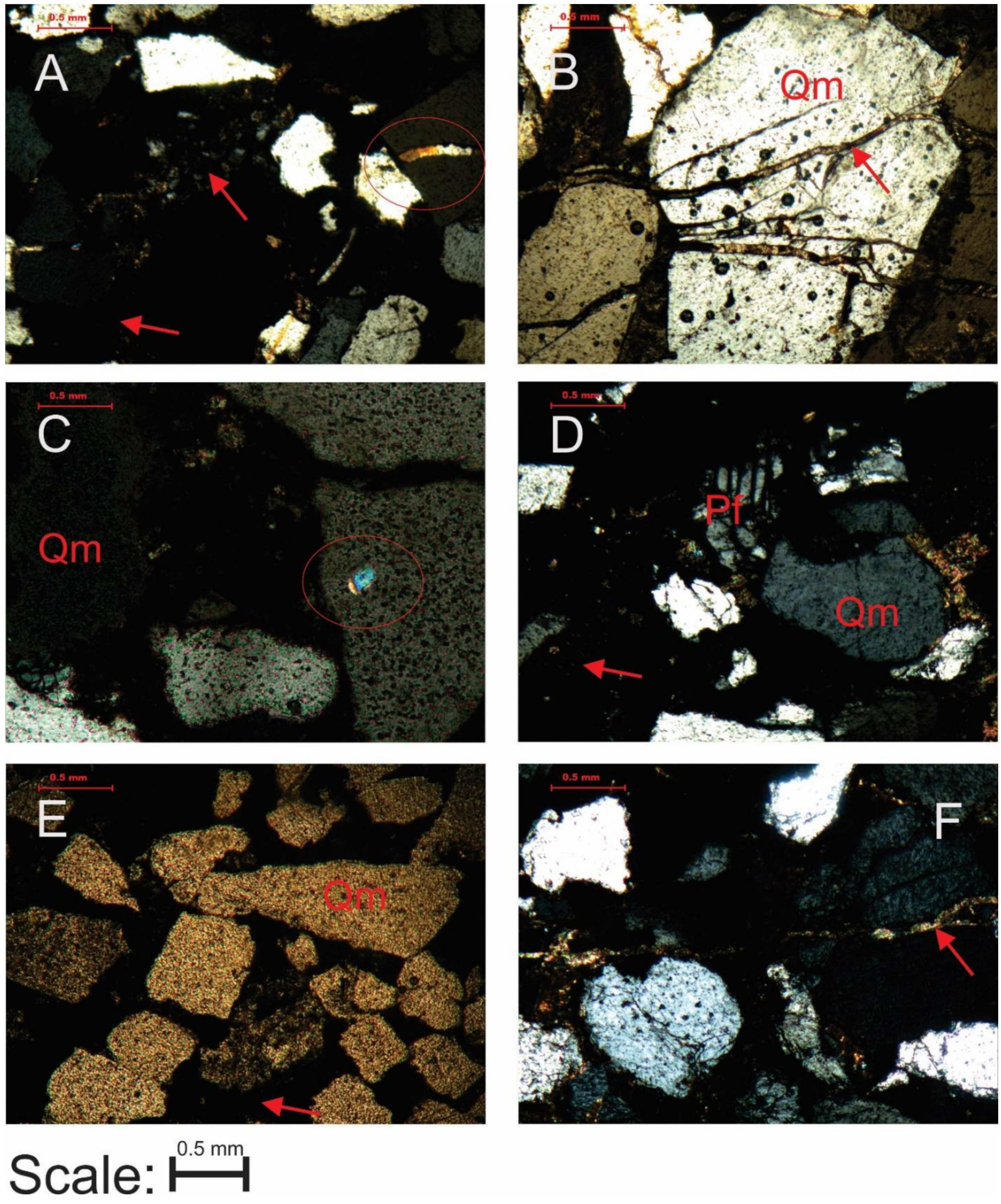

Fig.3 Representative photomicrographs of Pab sandstone from Cheephat Nala Section (CHPTNS), A) arrow in the center showing matrix and in the bottom ferruginous cement with biotite shown in circle (XPL), B) Very coarse fractured quartz showing point to straight grain contact, the fractures are filled with secondary material (XPL), C) Monocrystalline quartz with zircon inclusion (XPL), D) Monocrystalline quartz and feldspar, arrow in the bottom left showing iron oxide cement (XPL), E) Moderately sorted sub angular to angular quartz grains floating in iron oxide cement, F) Arrow showing calcareous vein oriented in left to right direction in the photomicrograph (XPL).

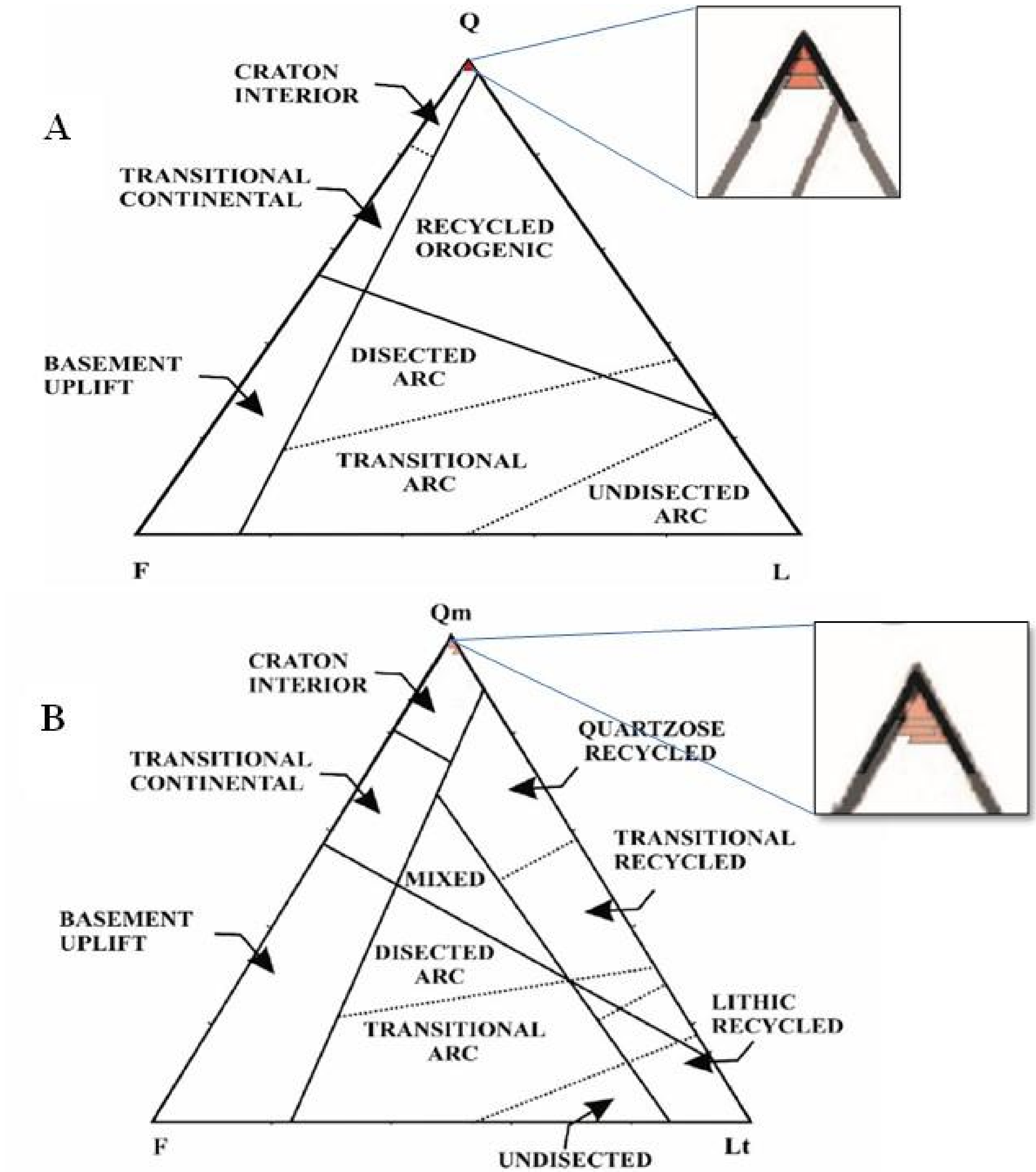

Fig. 4. A) QFL and B) Qm-FLt diagrams for Pab sandstone samples from Beezen Nala Section, (after Dickson et al., 1983).

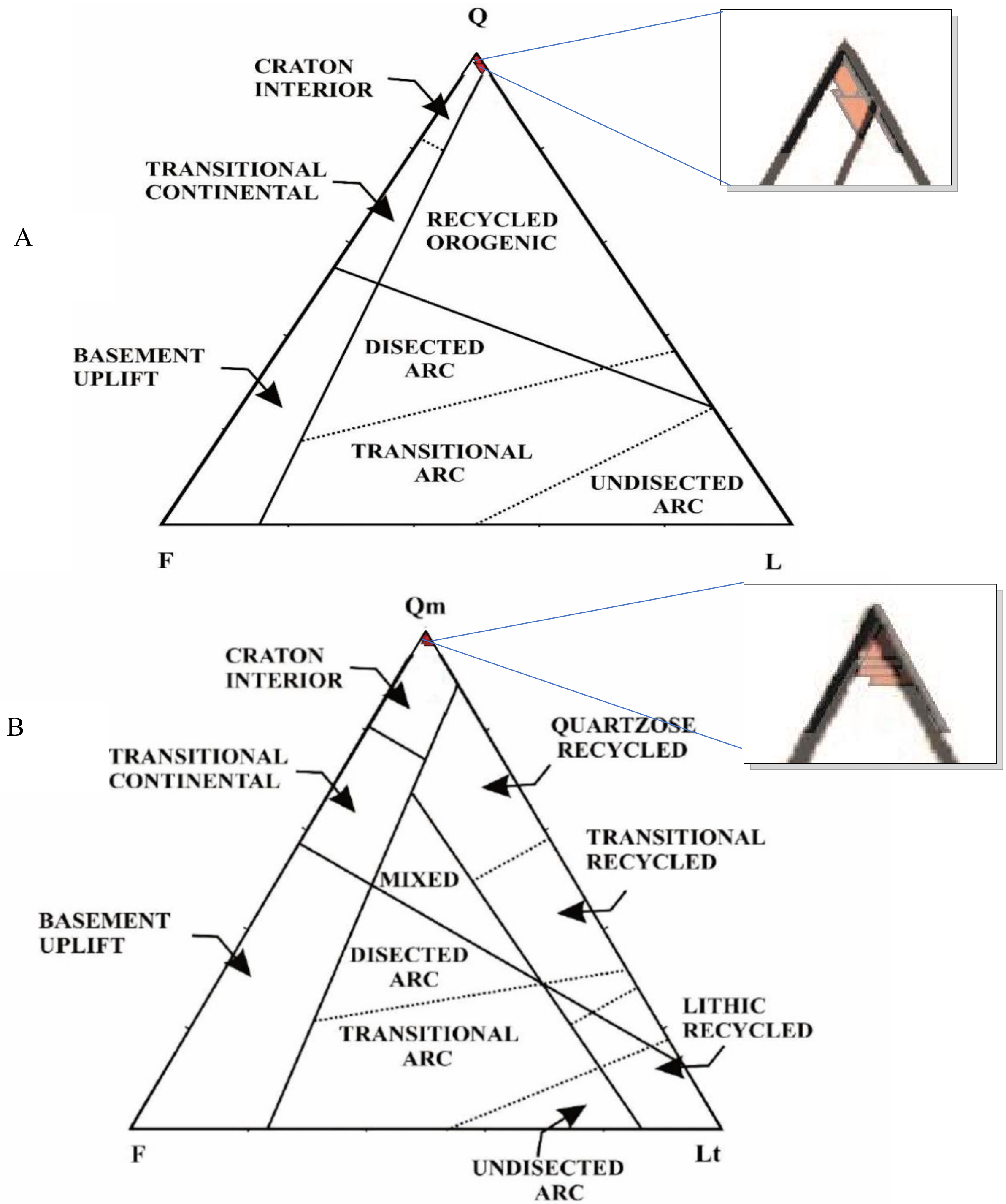

Fig. 5. A) QFL and B) Qm-FLt diagrams for Pab sandstone samples from Cheephat Nala Section, (after Dickson et al., 1983).

Table 2. Major element oxide concentrations (wt.%) of selected samples from BZN and CHPT sections.

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	MnO	MgO	Na_2O	K_2O	P_2O_5	LOI	Total	PIA	CIA
BZN-1	69.78	14.18	4.96	5.74	0.75	0.88	0.32	0.63	2.13	0.29	2.11	101.77	65.42	62.52
BZN-2	68.84	12.84	5.87	4.9	0.62	0.84	0.66	0.62	1.97	0.47	2.9	100.53	66.32	63.16
BZN-3	70.11	13.18	6.22	3.88	0.38	0.74	0.84	0.59	1.99	0.65	1.65	100.23	71.46	67.11
BZN-4	56.21	22.98	11.87	1.68	0.89	0.63	0.46	0.8	1.98	0.68	1.18	99.36	89.44	83.75
BZN-5	66.89	12.92	6.71	5.66	0.67	0.89	0.65	0.61	1.95	0.48	2.14	99.57	63.63	61.12
BZN-6	67.12	18.35	4.88	4.71	0.74	0.51	0.42	0.43	1.88	0.39	1.54	100.97	76.21	72.33
BZN-7	65.82	14.65	5.64	6.38	0.78	0.74	0.63	0.49	1.89	0.48	2.68	100.18	65.00	62.58
BZN-8	66.92	15.66	5.63	3.98	0.68	0.81	0.74	0.46	1.99	0.43	2.68	99.98	75.48	70.89
CHPT-1	68.12	15.12	4.91	5.74	0.7	0.64	0.35	1.08	1.98	0.31	1.15	100.1	65.83	63.21
CHPT-2	69.93	13.65	3.87	5.54	0.53	0.77	0.65	0.64	1.91	0.44	1.89	99.82	65.51	62.79
CHPT-3	68.92	14.48	4.78	5.12	0.69	0.83	0.8	0.71	1.89	0.33	1.48	100.03	68.35	65.23
CHPT-4	64.91	17.16	6.98	3.91	0.82	0.58	0.37	0.76	2.11	0.43	2.1	100.13	76.32	71.68
CHPT-5	67.32	13.41	5.69	5.42	0.73	0.82	0.71	0.61	1.89	0.51	2.91	100.02	65.64	62.87
CHPT-6	58.11	17.9	14.12	2.15	0.78	0.81	0.31	0.64	2.91	0.38	1.9	100.01	84.31	75.85
CHPT-7	67.11	12.56	4.98	6.23	0.72	0.84	0.65	0.62	2.31	0.19	3.99	100.2	59.94	57.83
CHPT-8	67.91	13.98	5.74	3.98	0.74	0.68	0.74	0.71	2.29	0.41	3.1	100.28	71.37	66.70

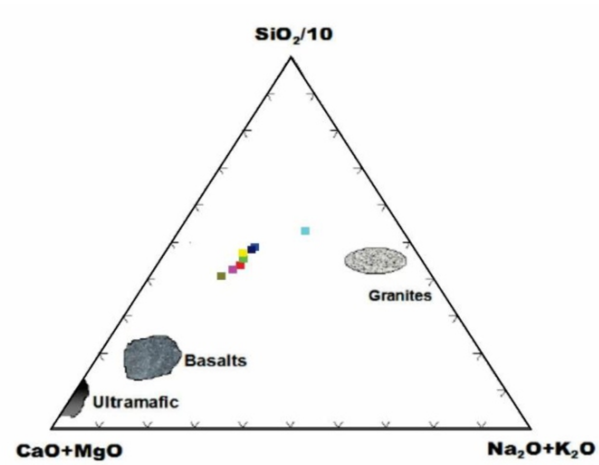

Fig. 6. $Na_2O + K_2O$ - $SiO_2/10$ – $CaO + MgO$ diagram of Pab sediments at BZN section (after Taylor and McLennan, 1985).

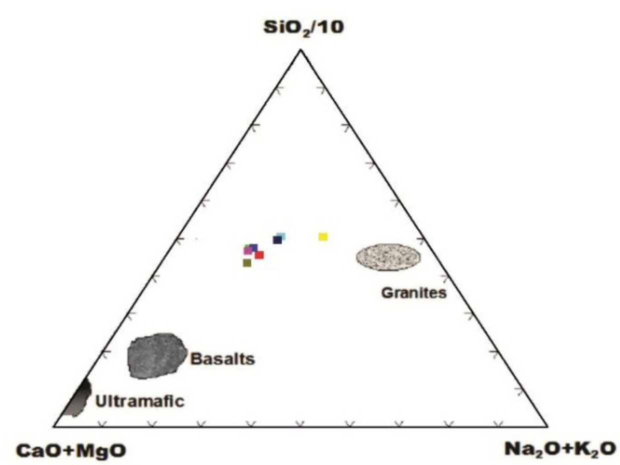

Fig. 7. $Na_2O + K_2O$ - $SiO_2/10$ – $CaO + MgO$ diagram of Pab sediments at CHPT section (after Taylor and McLennan, 1985).

5. Discussion

The petrographic results suggest that the Pab sandstone is rich in monocrystalline quartz while other frame work minerals such as feldspar and lithics were in minor amount. The abundant ferruginous cement hold together the framework grains. The point counting data plots suggest the derivation of sediments from cratonic source. The monocrystalline quartz abundance in the studied sections reveal existence of acidic plutonic rocks in source region. In addition, the abundance of Qnu over the Qu suggests acidic plutonic and volcanic source rocks (Blatt, 1967). Along with present findings, the Pab strata exposed in Balochistan have also been derived mainly from the Cratonic source (Kassi et al., 1991; and Kakar, 2010).

The less amount of feldspar and the lithic fragments suggest erosion from the low relief area and their alteration to different clay minerals, in addition, the abundance of ferruginous cement in Pab sediments indicate humid and warm conditions. Additionally, low relative amount of feldspar in sandstone may be related with factors such as transportation, chemical weathering, and diagenesis. Umer (2007) reported slightly intense chemical weathering conditions were experienced by Pab sediments in the Kirthar and Sulaiman area. Later on, Umer et al., (2011) reported abundant kaolinite as an altered product of feldspar. The studied sediments have considerable concentration values of Al_2O_3 potentially highlighting presence of certain clay minerals as the alteration product of feldspar. The major oxide contents of studied sediments are also consistent with petrographic findings. The studied sediments have higher values of SiO_2 due to overall abundance of quartz. The Al_2O_3 is the second most abundant oxide in sandstone, ranging from 12.56 wt.% to 22.98 wt.% which may link with the presence of clay minerals since studied sediments are deficient in feldspar content which potentially may have altered to certain clay minerals. According to Khanehbad et al., (2012) the K_2O content are related with the orthoclase feldspar and mica content whereas, the Na_2O is related with the plagioclase feldspar. The studied sediments are deficient in both the K_2O and Na_2O, these values are in agreement with the petrographic findings. Nevertheless, the K_2O content is higher than Na_2O suggesting the presence of potassium feldspar, muscovite, biotite and illite (Osae et al., 2006). The sediments of Pab contain Fe_2O_3 and CaO from 3.87 - 14.12 wt.% and 1.68 - 6.23 wt.% respectively, where higher Fe_2O_3 is related with iron oxide cement and the CaO represents the calcite cement. The increased values of iron, alumina, and calcium oxide could be attributed to abundant cement and clay matrix. To discourse provenance of Pab sandstone measurements of the major oxides such as SiO_2, CaO, MgO, Na_2O and K_2O were plotted on ternary diagram of Taylor and Mclennan (1985). The majority of samples in this ternary diagram are scattered close to granitic source though some of them are plotted in between basaltic and granitic fields; this could be due to the minor contributions from the mafic sources. The CIA and PIA values indicate the rate of chemical weathering at the source region as moderate to slightly intense.

5. Conclusions

The present and past geographic position of the study area represents the presence of Indian Shield exposures in the southeastern direction dominantly comprised of granitic rocks. The petrographic findings reveal the quartz as the major mineral constituent being the monocrystalline, polycrystalline, and non-undulatory with minor undulations. The feldspar and the lithics were observed in minor amount. The iron oxide is noticed as the dominant cement along with some calcareous cement and minor matrix. The detritus of Pab sandstone based on present findings were contributed from cratonic source dominantly composed of granites along with some input of mafic rocks. The ternary diagrams based on the major element geochemistry also reveal their agreement with the petrographic findings. The studied sediments underwent the weathering conditions being moderate to intense in warm and humid climate regime as revealed by CIA and PIA. The present petrographic findings and geochemical data suggest the sediment derivation from huge Cratonic landmass (Indian Shield). The similar rock types in the form of Nagar Parkar Igneous Complex are still exposed in the southeast of study area in Pakistan and Malani Igneous Suite in India.

Authors' Contribution

Ghulam Mustafa Thebo, proposed the main concept and involved in field activity, laboratory analyses and write up. Sarfraz Hussain Solangi, assisted in establishing and supervising the research methodology. Muhammad Hassan Agheem, collected field data, geochemical analyses and thin section petrography. Muhammad Ali Solangi, did provision of relevant literature, and preparation of maps and discrimination diagrams. Akhtar Hussain Markhand, did technical review before submission and proof read of the manuscript. Kashif Ahmed Memon, helped in write up.

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