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PETROGRAPHIC INVESTIGATIONS OF THE SANDSTONE OF THE DHOK PATHAN FORMATION, SOUTH EASTERN HAZARA, NORTH PAKISTAN, IMPLICATIONS FOR THE PROVENANCE

PETROGRAFICKÝ VÝZKUM PÍSKOVCE SOUVRSTVÍ DHOK PATHAN, JIHOVÝCHODNÍ HAZARA, SEVERNÍ PÁKISTÁN, PŮVOD KLASTICKÉHO MATERIÁLU

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Abstract

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Petrographic investigations of the sandstone of the Dhok Pathan Formation, South Eastern Hazara, North Pakistan, Implications for the Provenance

In this study, the sandstone of the middle part of the Dhok Pathan Formation was studied in detail for the petrographic-based provenance at the South Eastern Hazara. The outcropping clastic sequence of the area reveals complex braided fluvial depositional conditions dominated during Pliocene period. The interbedded channel facies (sandstones) and floodplain facies (shales and some specific sandstone units), in varying proportions, differentiate individual formation in the Siwalik Group. The watercourse sediments are the product of aggrading fluvial sedimentation and are distinguished by a succession of upward-fining sandstones overlain by mudstones. Most of the sandstone units in the study area have been observed as multistoried and comprised of composite sand bodies reflecting a mixed fluvial depositional mechanism. The petrographic analyses of different samples collected from the study area of the middle sandstone horizon of the Dhok Pathan Formation reveals abundant quartz, feldspar, rock fragments along with variable amounts of several accessory minerals such as epidote, garnet, jarosite and clay minerals. The feldspar grains show alteration to chlorite, kaolinite and other secondary minerals. Calcite, clay minerals, silicious and iron oxide are present as cementing material and their grains show poor to moderate sorting. Rock designated on the basis is lithic arkose to Feldspathic litharenite considering the Folk's classification of sandstone. Rock fragments observed in the petrographic analysis provide indications about provenance. These assemblages of rock fragments also suggest that the source rocks were rich in igneous to metamorphic ensemble in addition to sedimentary assimilation. By plotting the provenance diagram of Dickenson, showing that the source rocks fit in the zone of recycled orogen.

Key words: Southeastern Acronym of the Azad Jammu Kashmir, Middle Dhok Pathan Formation, Lithic Arkose, sedimentological, petrographic, provenance analysis, Recycled orogen, Pakistan

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1. INTRODUCTION

Sedimentological and petrographic studies of sandstone often bestow imminent into the nature of source rocks and the evolution of the orogenic belts. Sediment grains size and composition is also controlled by the grade of weathering and transport (Dorsey 1988; Kassi *et al.* 2015). In the settings of active orogeny, the nature of source rock largely accountable for the sediment's composition. However, climate and relief play critical role in the formative composition and grain size of sediments in areas of diminutive tectonic activity (Ullah *et al.* 2006). Plentiful investigative studies have been executed on the Neogene Siwalik Group of Pakistan, especially in the Kohat-Potwar plateaus (Johnson *et al.* 1992; Cerveny *et al.* 1989). However, inadequate work has been done to characterize the Siwalik Group rocks of the South Eastern Hazara area. The molasses sequence of this area is divided into four lithological units Chinji, Nagri, Dhok Pathan, and Soan Formation. In this efforts were made to establish the sedimentological and petrographic composition along with the provenance studies of the middle Dhok Pathan in the southeastern AJK. Based on biostratigraphy, Pilgrim (1913) first used the term "Dhok Pathan" to refer to the upper section of the "Middle Siwalik" in the northeastern Punjab. The unit was renamed "Dhok Pathan Formation" by Cotter (1933), and the Stratigraphic Committee of Pakistan used it in the Kohat-Potwar Province. The formation is consisting of light grey to dark grey friable sandstone interbedded with brownish to light red mudstone and intraformational conglomerates. The formation is designated late Pliocene age on the basis of magneto stratigraphic studies and the presence of Mammalian fossils such as Hipparion [8]. The study area falls in the Survey of Pakistan Topographic maps Nos. 43-G/12, 43-G/16, 43-K/4, 43-L/1, and 43-L/5 and demarcated along the geodetic coordinates of Longitude 73° 00/ E to 74° 15/ E and Latitude 32° 55/ N to 33° 55/ N. Overall this study has been conducted in 300 km^2 area.

2. GEOLOGICAL SETTING

During the Early Jurassic era, Gondwanaland's disintegration caused the separation of the Indo-Pakistan and African portions, and the Indo-Pakistan Plate began to move northward. The Indo-Pakistan Plate and the Eurasian Plate collided in the Paleocene and Eocene, and from Oligocene forward, the Indo-Pakistan Plate continued to push beneath the Eurasian Plate (Nazeer *et al.* 2012; Solangi *et al.* 2014; Ullah *et al.* 2020, 2022). Structural and stratigraphic framework is the major controlling parameter of geological setting of the area. General elevation is about 450 meters and ranging between 300 m to 800 m from the existing ground level. Due to lithological variance along trend and the formation of dendritic drainage patterns, most outcrops having rocky terrain are cut by deep nalas including the Bhundar Kas, Bhimber, and Suketar nalas. These nalas system emerge from the northern periphery of mountain belts, transverse stratigraphic strikes, and eventually empties into the Chenab River. The research region is located in the tectonically most southern reaches of the Main Boundary Thrust (MBT) and Pir Panjal Range, which together comprise the southern foothills of the Lesser Himalayas (figure 1). The MBT-delineated northern limb of the research area extends southwestward towards the eastern Potwar plateau. All structural components are seen to have a broad structural trend that is orientated in the NW-SE and mildly dipping in the southwest. The structural development of the region, which is the northeastern (back limb) of a significant anticline, is disturbed by the exhumation of the MBT. The Neogene Siwaliks Group rocks are exposed in the area as shown in (table 1). The older strata overlying the basement rocks are not exposed in the area.

Tabulka 1. Content of major and minor minerals (%) in Dhok Pathan Formation.
Table 1. Obsah hlavních a vedlejších minerálů (%) ve souvrství Dhok Pathan.

Sr. No	Quartz	Plagioclase	Orthoclase	Perthitic Feldspar	Rock Fragments	Biotite	Muscovite	Chlorite	Clays (A.P)	Ferruginous Clay	Garnet	Jarosite	Detrital Calcite	Epidote/ Zoisite	Magnetite	Hematite	Hornblende	Accessory Minerals	Voids/ empty spaces	Calcite Cement	Clay Cement	Hematite Cement	Rock Name
1	24	2	25	2	10	4	2	1	2					2	2	1	1	3	2	17			**Lithic Arkose**
2	22	2	24	1	12	3	2	1	3		1			2	2		2	2	1	20			**Lithic Arkose**
3	17	2	18	2	23	2	2		3		1			2	2		2	2	2	20			**Feldspathic Litharenite**
4	16	3	17	2	22	3	1		4					2	1		2	2	2	23			**Feldspathic Litharenite**
5	18	2	20	1	23	2			4					3	2		2	3	7	13			**Feldspathic Litharenite**
6	17	3	17	2	24	3	1		4		1			2	1		2	3	3	17			**Feldspathic Litharenite**
7	18	2	20	1	22	3	1	1	4					1	2		2	3	4	16			**Feldspathic Litharenite**
8	22	2	24	1	14	3	2		4					2	1	1	2	3	13	6			**Lithic Arkose**
9	17	3	18	2	22	3	1		1					2	1		2	2	1	25			**Feldspathic Litharenite**
10	23	2	25	1	16	3	1	2	3					2	1	1	2	2	10	6			**Lithic Arkose**
11	15	2	17	2	21	1		1	2					2	1		2	2	Ac	32			**Feldspathic Litharenite**
12	16	2	18	1	23	2	1	1	2		1			2	1		2	1	1	26			**Feldspathic Litharenite**
13	19	2	20	2	23	2			3		2	6	6	3		8	2	2					**Lithic Arkose**
14	5	Ac	9		74	1				6				2				3					**Lithic Arenite**
15	20	3	20	2	24	3		3	3				5	3		9	2	3					**Lithic Arkose**
16	18	2	21	2	25	3		2	3					2		2	2	3	5	1	7	2	**Feldspathic Litharenite**
17	16	2	15	3	22	1		1	2					2	1		2	2	Ac	32			**Feldspathic Litharenite**
18	22	3	26	2	11	3	2	2	2					3	2	1	2	4	2	16			**Lithic Arkose**
19	24	2	19	1	21	4	1	1	3					1	2		2	3	4	18			**Feldspathic Litharenite**
20	21	3	23	1	15	2	2		3					3	1	1	2	3	14	7			**Lithic Arkose**

Ac = Accessory, A. p = Alteration product

3. METHODOLOGY

A total of twenty representative rock samples of sandstone were collected from the Palang, Jangar and north-northwest of Bhimber from the middle horizon of the Dhok Pathan Formation. General features observed in in lower middle to middle part of the formation as limonitic/hematitic alteration, reiteration of hard bands, volcanic matter, conglomeratic channel, friable and thick sandstone beds, organic matter and bone fossils in the sandstone bodies along with thick shale beds (figure 1).

Thin section slides were prepared, and petrographic studies were carried out with the help of a standard petrographic polarizing microscope with a fitted DP12 Camera. Folk's classification of sandstone was used for the classification of rock type based on major framework grains and modal composition (FOLK 1980). The triangular plot of DICKINSON and SUCZEK (1979) was used to determine the provenance of sandstone.

Fig. 1. Digital elevation model showing major tectonomorphic terrains of North Pakistan, red inset shows the location of the study area.

Obr. 1. Digitální výškový model zobrazující hlavní tektonomorfní terány severního Pákistánu; červené pole ukazuje vymezení studované oblasti.

3.1 Stratigraphic and Sedimentological Study

Late Neogene to Quaternary clastic sequence is well exposed to northeast and northwest of Bhimber city of South Eastern Hazara. The upper Siwaliks are exposed along the northern fringes of the Bhimber and getting older further north where Chinji, Nagri and Dhok Pathan formations are exposed towards the Pir Panjal Range (figure. 2). Top of the Cenozoic sequence is occupied by the Soan sediments overlain by sequence of the Siwalik Group. This non-marine, time-transgressive molasse facies represent an erosional stuff of southward advancing of the Himalayan thrust front. The Paleo and Siwalik-Indus River, which were sourced from the higher Himalayas throughout late Paleogene to early Neogene till the present, were among the southeast-flowing continental braided fluvial systems that were found in the outcrops in the area, which are exclusively made up of Siwaliks.

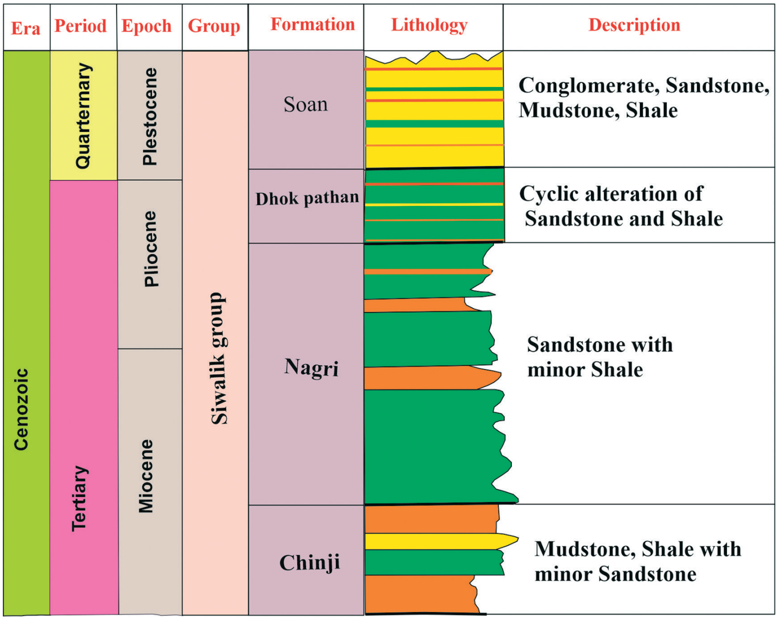

Fig. 2. Generalized exposed stratigraphic sequence of the study area.
Obr. 2. Generalizovaná odkrytá stratigrafická sekvence studované oblasti.

4. RESULTS AND DISCUSSIONS

4.1 Palang Area

4.1.1 Sample Description and Texture

The sandstone samples are whitish to light grey in color. They are soft, friable in nature, coarse to medium grained and they did not show reaction when treated with 10% HCl. However, few samples are hard, compact and massive in nature. The microscopic texture of the sandstoneis clastic.

4.1.2 Framework Components

Analysis of thin sections of sandstone showed quartz, feldspar and rock fragment as the dominant framework grains. Minor amounts of biotite, muscovite, clays, epidote, magnetite, hematite, chlorite and hornblende were observed in the samples (figure 2). The detrital constituents are cemented with calcite cement.

The content of quartz varies from 15% to 24% of the framework grains and is mostly monocrystalline with few polycrystalline grains. While majority of its grains are subrounded while some rounded grains have also been observed. The grain boundaries are diffuse to well-defined. The grains have normal extinction but tectonic quartz grains with undulatory extinction have also been observed in some samples (figures. 3–4). Undulatory extinction shown by quartz grains is probably caused due to strain-induced crystallographic dislocation. In quartz found in metamorphic rocks, lattice dislocation is common. Statistically a higher proportion of both moderately to strongly undulose mono-crystalline quartz grains and higher proportion of polycrystalline quartz grains with four or more sub-grains characterize a metamorphic source (Basu 1985).

Feldspar is the most common detrital constituents and makes 21% to 29% of the framework components. Feldspar grains are sub rounded to sub angular and occurs predominantly as orthoclase with few grains of perthitic feldspar and plagioclase (figures 3, 4). Few orthoclase grains exhibit Carlsbad twinning as shown in fig. 4a. Microcline and plagioclase are identified by their characteristic cross-hatched and polysynthetic twinnings respectively. The relatively high proportion of feldspar with moderate angularity and sorting indicates textural immaturity of sandstone.

The percentage of rock fragments ranges from 10% to 23% in the sandstone. The rock fragments are comparatively less than quartz and feldspar grains. Particles of igneous rocks are mainly composed of granitic fragments and a few devitrified volcanic rock fragments. The metamorphic lithic fragments include quartz mica schist/ phyllite, quartzite fragments, gneissic fragments, and carbonaceous schist. Sedimentary lithic consists of siliceous fragments/chert, sandstone, limestone, claystone and siltstone fragments. Sandstone

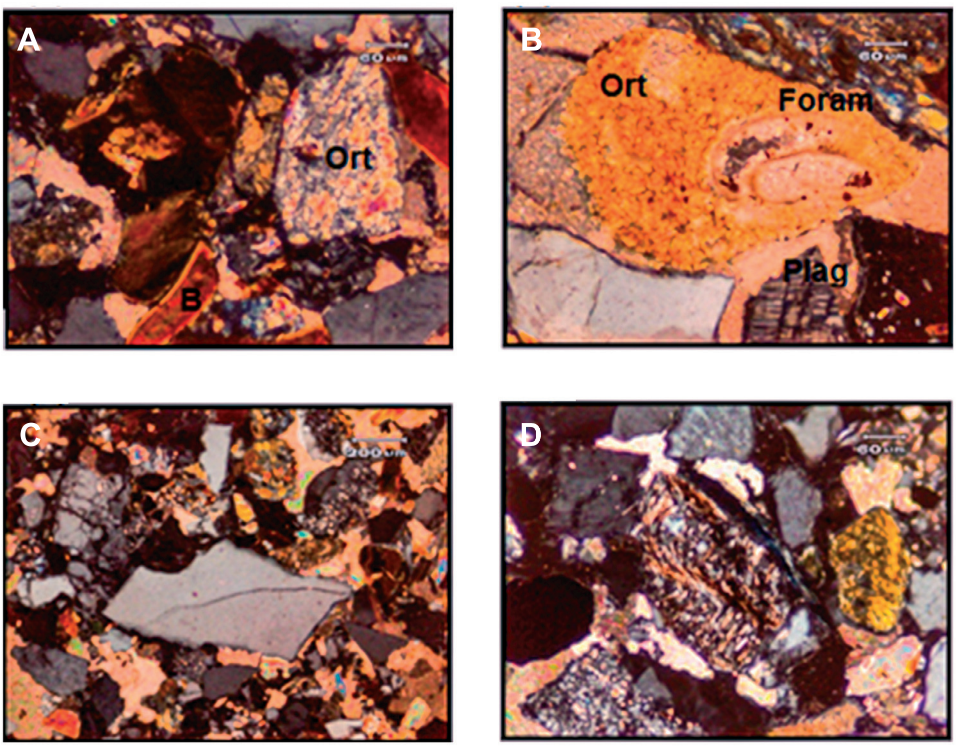

Fig. 3. Photomicrograph: (a) alterations of feldspar into muscovite and clays, biotite flake alters to chlorite (XPL); (b) limestone fragment enclosing benthic foram (Nummulitie) with preserved skeletal structure, orthoclase grain is also visible. (XPL); (c) detrital grains are weakly sorted and moderately rounded. (XPL); (d) Crenulations schistosity developed in quartz mica schist by compaction or later tectonics (XPL).Whereas XPL is crossed polarized light, Ort – orthoclase, B – Biotite, Plag – plagioclase.

Obr. 3. Mikrofotografie: (a) přeměny živce na muskovit a jílové minerály, lupínky biotitu se mění na chlorit (XPL); (b) úlomek vápence obklopující bentický otvor (Nummulitie) se zachovanou kosterní strukturou, patrné je i zrno ortoklasu. (XPL); c) drobná zrna jsou slabě vytříděná a středně zaoblená (XPL); (d) Břidličnatost (kliváž) vyvinutá v křemenném svoru zhutněním nebo pozdější tektonikou (XPL). XPL = zkřížené polarizátory, Ort – ortoklas, B – biotit, Plag – plagioklas.

fragments are most probably derived from Cretaceous Pub Sandstone exposed in the Sulaiman belt. The Limestone fragments containing Nummulitie shells come from the Eocene limestone rocks of the Sulaiman Range (figure 3b) Crenulations schistosity has been observed in a few quartz mica schist fragments (figure 3d).

4.1.3 Other Minor and Accessory Minerals

The biotite grains exhibit brown and pale greenish color and are mostly elongated in shape (figures 3c, 4b). The percentage of pores ranges from 1% to 13%. In a few thin sections voids are interconnected as shown in figure 3d. Chlorite grains are mostly alteration product of biotite (figure. 5b). Accessory minerals include garnet, microcline, sphene, enstatite, hematite, chlorite, tourmaline and rutile. A prominent feature of the Dhok Pathan Formation is the presence of garnets which occur as sub-rounded grains and can easily be identified by its isotropic behavior under cross-polarized light and high relief.

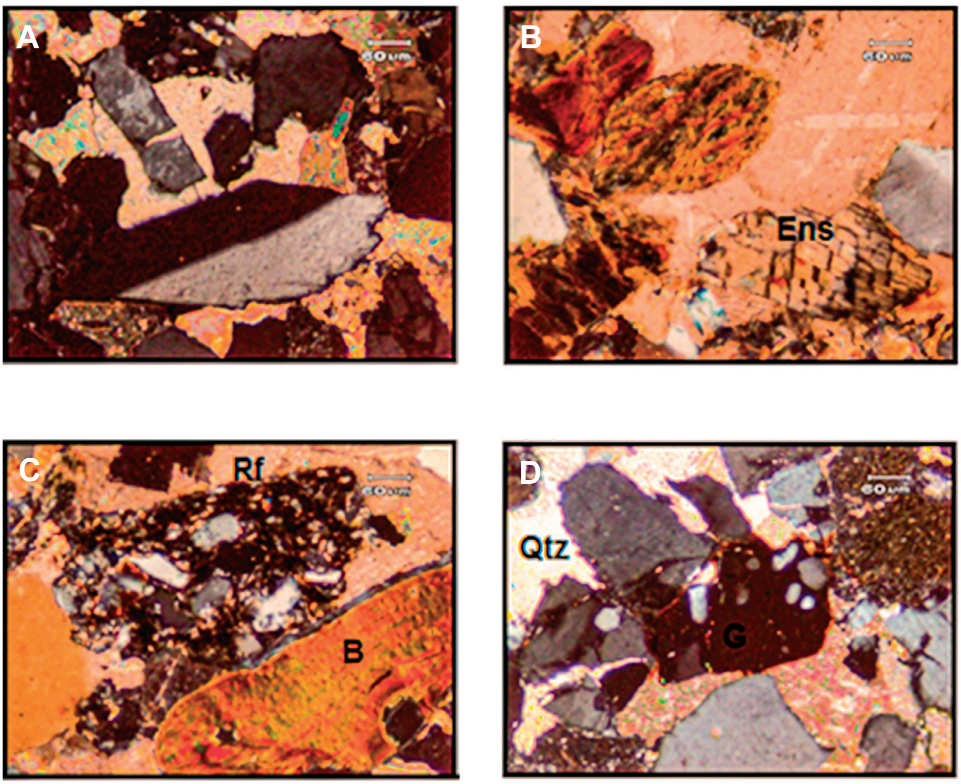

Fig. 4. Photomicrograph: (a) Carlsbad twinning in orthoclase grains. (XPL); (b) Enstatite, biotite and sparry calcite (XPL); (c) Pre-existing sandstone fragment and biotite flake (XPL); (d) quartz inclusions in garnet grain. (XPL). Ens = enstatite, Rf = rock fragment and Qtz = quartz.

Obr. 4. Mikrofotografie: (a) karlovarské dvojčatění v ortoklasových zrnech (XPL); (b) Enstatit, biotit a kalcit-sparrit (XPL); (c) úlomky a lupínky biotitu v pískovci ; (d) inkluze křemene v granátu (XPL). Zatímco Ens = enstatit, Rf = klast horniny, Qtz = křemen.

Figure 4d shows the quartz inclusions of garnet grains. Garnets indicate considerable input from the northern provenance of Kohistan Island Arc (KIA) and adjoining areas (Johnson *et al.* 1992).

4.1.4 Alteration Studies

Clays are the product of sericitization and kaolinitization of feldspar (figures 3a, 3b, 5a). The feldspar grains demonstrate moderate level of alteration into clays (sericite, kaolinite), muscovite, epidote, and chlorite and a weak degree of alteration into calcite (figure 3a, 3b, 5a). The flakes of biotite moderately alter to chlorite as seen in figure 3a.

5. JANGAR AREA

5.1.1 Sample Description

All but one hand specimen sample were loose sandy material; therefore, grain-mounted sections were prepared for petrography. It is understood that cementing material and voids are not taken into account in case of grain-mounted sections.

5.1.2 Framework Components

The petrographic study reveals that major detrital constituents are quartz, feldspar, and rock fragments. Calcite, hematite, jarosite, clays (alteration product such as sericite and kaolinite), epidote/zoisite, biotite, amphibole (hornblende) and garnet occur in minor amount (table 2). The quartz grains make up from 5% to 19% of the framework components. They are mono-crystalline and angular to sub angular in shape. They have normal extinction but strained quartz grains with undulatory extinction have also been observed in few thin sections. Their grain boundaries are diffuse to well-defined. Feldspar grains make 9% to 25% of the framework components. They are sub rounded to sub angular and untwined orthoclase is the dominant feldspar. Plagioclase, and perthitic feldspar grains occurs in minor amounts.

Rock fragments range from 23% to 75% of the total framework components. Igneous fragments include mainly granitic fragments and basalt fragments while metamorphic lithics are mainly quartz mica schist/ phyllite with some gneissic fragments and carbonaceous schist. Sedimentary lithics consist of siliceous fragments/ chert, pre-existing sandstone and limestone fragments/ shell fragments and claystone fragments.

5.1.3 Other Minor and Accessory Minerals

Detrital calcite is sperry as well as micritic in nature. Hematite occurs in the form of detrital grains. Jarosite occurs in the form of crystal aggregates; it is yellowish brown in color and shows high relief (figure 5c). Clays are the product of sericitization and kaolinitization of feldspar. Epidote grains are mostly alteration product of feldspar. Biotite is mostly elongated in shape and having brown and pale greenish colors. Kinking in few mica flakes can be seen in fig 4d. Amphibole is green in color and strongly pleochroic. It frequently displays well developed cleavages. Accessory minerals comprise magnetite, muscovite, chlorite, microcline, tourmaline, garnet, muscovite, titanite and myrmekite (figures 5, 6). The garnet grains happen as subrounded grains and can simply be recognized due to their isotropic manners under cross-polarized light and high relief. Its few grains hold inclusions of quartz. Muscovite flakes are colorless in nature and elongated in shape. Chlorite grains are typically alteration product of biotite and feldspar. In solid samples three types of cementing material have been observed, i.e. primarily clay minerals, minor hematite and calcite (figures 5, 6). Some of the interstitial spaces are empty.

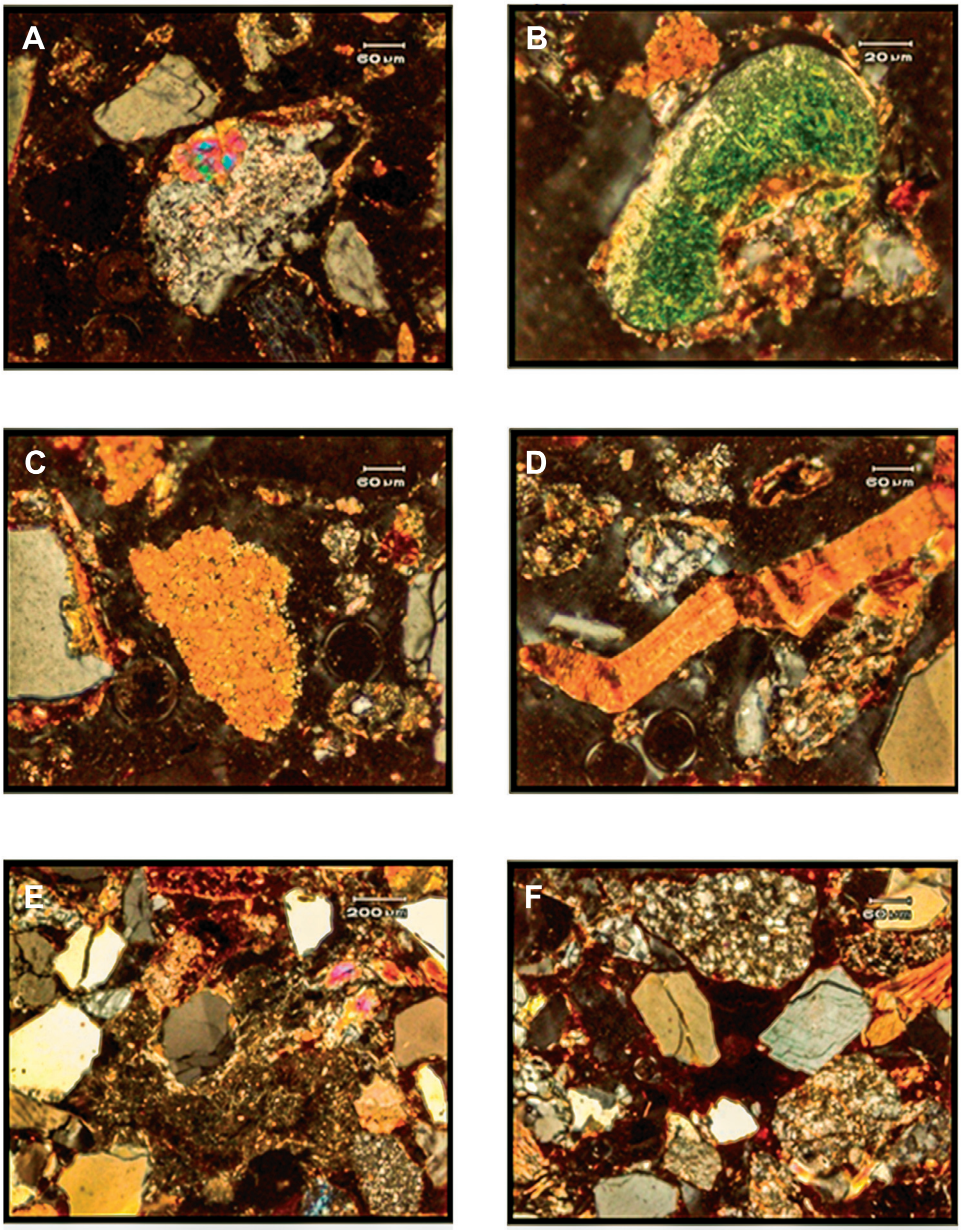

Fig. 5. Photomicrograph: (a) alteration of feldspar into clays (sericite) and epidote. (XPL); (b) alteration of feldspar into chlorite (XPL); (c) Jarosite and other detrital constituents (d) kinking in biotite flake (XPL), (e) detrital constituents are cemented with clays (XPL) (f) detrital constituents are cemented with hematite (XPL).

Obr. 5. Mikrofotografie: (a) přeměnu živce na jílové minerály (sericit) a epidot (XPL); (b) přeměna živce na chlorit (XPL); (c) Jarosit a další detritické složky (d) kinking lupínků biotitu (XPL); (e) částice detritu jsou tmeleny jílem (XPL); (f) částice detritu jsou tmeleny hematitem (XPL).

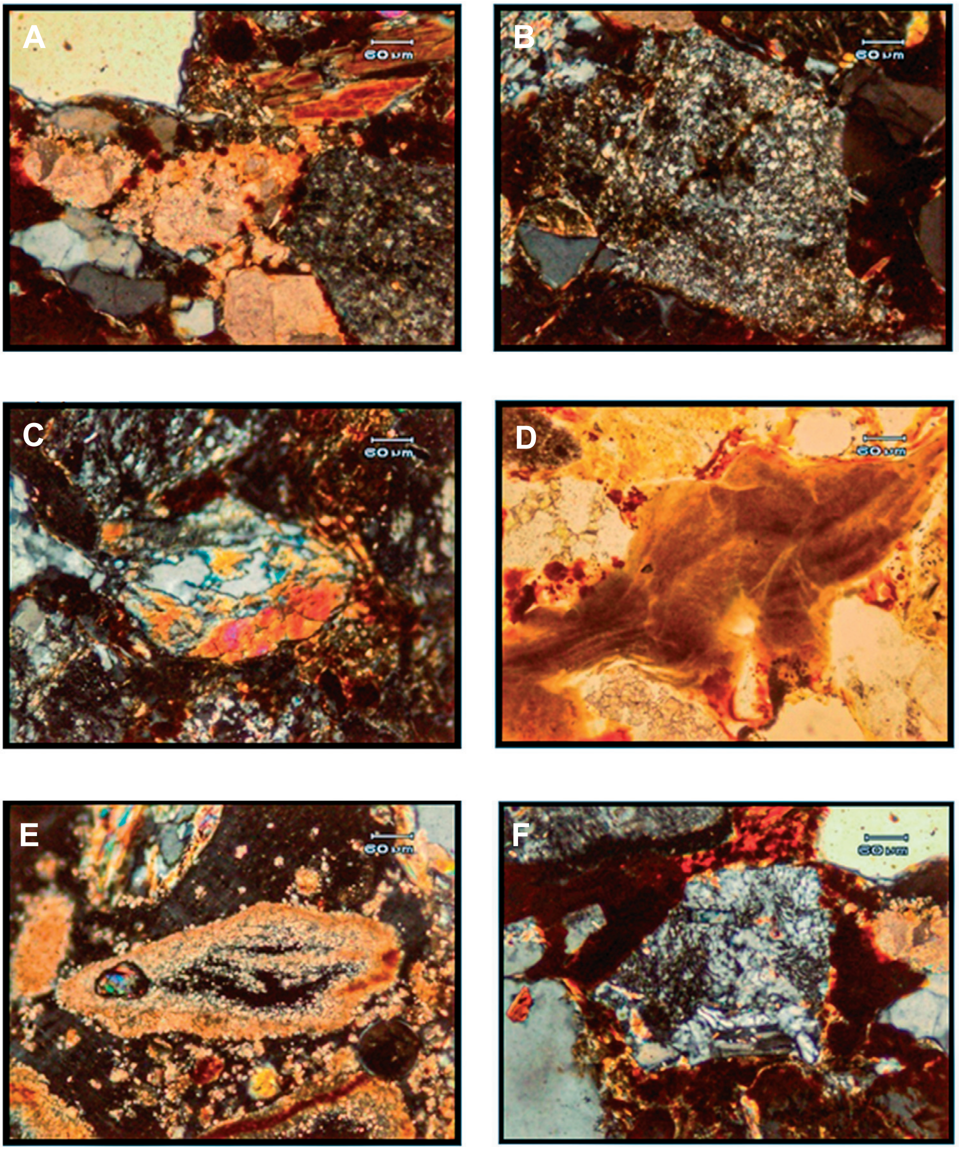

Fig. 6. Photomicrograph: (a) detrital constituents are cemented with calcite (XPL); (b) alteration of feldspar into clays (sericite) (XPL); (c) alteration of feldspar into epidote (XPL); (d) alteration of biotite into chlorite (PPL); (e) fossil cast seems to be of Nummulitie foram whose internal part has been dissolved (XPL); (f) myrmekite (XPL).

Obr. 6. Mikrofotografie: (a) detritální složky jsou tmeleny kalcitem (XPL); b) přeměna živce na jílové minerály (sericit) (XPL); (c) přeměna živce na epidot (XPL); (d) přeměna biotitu na chlorit (PPL); e) fosilní odlitek pochází z části nummulitu, jejíž vnitřní část byla rozpuštěna (XPL); (f) myrmekit (XPL).

6. ALTERATION STUDIES:

Feldspar grains show moderate to the weak degree of alteration into clays (sericite, kaolinite), epidote, muscovite, and chlorite and biotite flakes weakly alter to chlorite (figures 5, 5d).

7. SANDSTONE CLASSIFICATION

The results of petrographic studies were used to classify sandstone of middle horizon Dhok Pathan Formation using QFL diagram of Folks' classification of sandstone (Folk 1980). In this classification scheme, QFL diagram is used and percentages of quartz, feldspar and rock fragments are plotted on it. The chert fragment is integrated in the pole of the rock fragment while the feldspar pole consists of granite and gneiss fragments. The percentages in 100% of three end-members were calculated and plotted according this classification scheme in figure 7. The sandstone samples of the Dhok Pathan Formation belong to Lithic Arkose and Feldspathic litharenite.

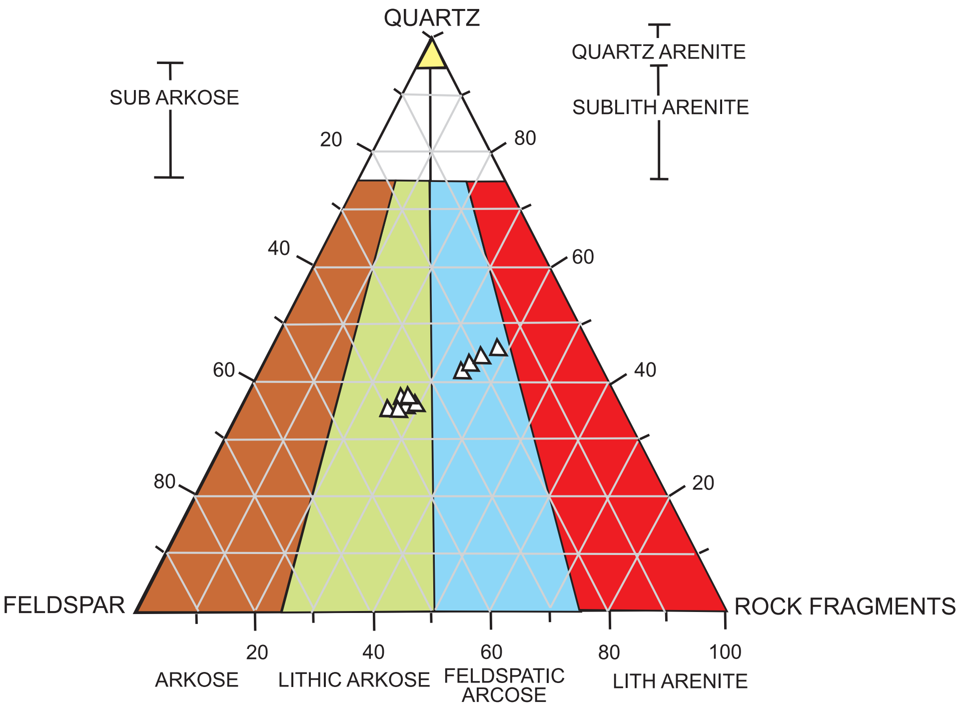

Fig. 7. Triangular QFL diagram (Folk 1980) for the studies sandstone showing that sandstone of Dhoke Pathan Formation belongs to Lithic Arkose and Feldspathic Lith-Arenite category.

Obr. 7. Trojúhelníkový diagram QFL (Folk 1980) pro studium pískovců ukazující, že pískovec souvrství Dhoke Pathan patří do kategorie litických arkóz a živcového lithoarenitu.

8. PROVENANCE OF SANDSTONE

Based on the triangular plot of DICKINSON and SUCZEK (1979) sandstone of the middle part of the Dhok Pathan Formation shows recycled orogen provenance in the South Eastern Hazara area (figure 8). Quartz is a stable detrital mineral; it is not only chemically inert but also mechanically durable. Mono-crystalline quartz grains were frequently derived from quartz-bearing plutonic rocks, but polycrystalline quartz grains show frequently metamorphic origin. The presence of feldspar minerals such as microcline and orthoclase indicates plutonic igneous and metamorphic sources of sediments. The probability of volcanic source is ruled out due to the absence of sanidine. Moreover, zoned plagioclase has not been observed which is considered to be derived from a volcanic source.

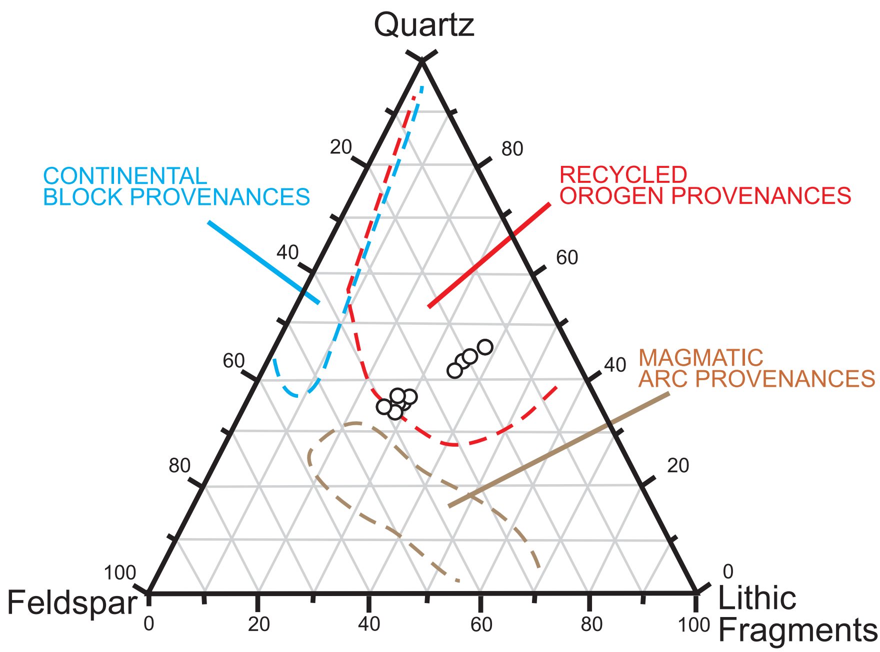

Fig. 8. The triangular QFL plot showing relationship between plate tectonics and sandstone composition.
Obr. 8. Trojúhelníkový graf QFL ukazující vztahy mezi deskovou tektonikou a složením pískovce.

The rock fragments offer direct evidence of the provenance; the collection of rock fragments advocates that the source of the rock was affluent in igneous-metamorphic as well as sedimentary rocks. A substantial quantity of rock fragments reveals that the source area had high topographic relief. Limestone fragments were derived from the limestone horizon as indicated by the presence of "Nummulite shells", Epidote, garnet and hornblende show metamorphic sources. Crenulations schistosity shows compaction during burial or after burial. Kinking in a few mica flakes and some fractured grains indicate that the rock was subjected to tectonic strain.

The presence of undulatory quartz and fragments of igneous, metamorphic and sedimentary rock intends that source area was experiencing orogenic movement and rapid exhumation due to which deep-seated igneous and metamorphic rocks were exposed to the surface.

The relative abundance of lithic fragments and feldspar suggest elevated relief fast erosion in the source area. The textural immaturity, due to moderate angularity and sorting along with the high content of feldspar, indicates little transportation distances from source area to the deposition basin.

9. CONCLUSIONS

The middle horizon of the Dhok Pathan Formation consists of whitish-grey to light grey sandstone interbedded with reddish mudstone and conglomerate. The Formation represents the middle to upper molasse sequence of the Siwalik Group in the study area. The petrographic analysis of sandstone shows that it contains feldspar, rock fragments and quartz as framework grains and garnet, biotite, chlorite, enstatite etc. as accessory minerals. Three kinds of cementing material, calcite, clays and iron oxide were observed in the thin section studies of sandstone. Compositionally, sandstone falls into the arkose and feldspathic litharenite. The feldspar grains have been subjected to some degree of alteration and formation of other secondary minerals such as chlorite, epidote, sericite and other clay minerals. The provenance of sandstone inferred as recycled orogeny. The high presence of feldspar and lithic fragments indicate high relief and short transportation distances during the deposition of middle horizon of the Dhok Pathan Formation in the southeastern Kashmir.

SOUHRN

Bylo podrobně studováno složení pískovce střední části souvrství Dhok Pathan (JV Hazara, severní Pákistán) pro diskusi provenience klastického materiálu. Sedimentární sekvence v této oblasti odhalují komplikované fluviální depoziční poměry, které dominovaly v období pliocénu. Facie mezilehlých kanálů (pískovce) a facie niv (břidlice a některé specifické pískovcové jednotky) v různém poměru odlišují jednotlivá dílčí prostředí sedimentace. Sedimenty vodních toků jsou produktem agradující sedimentace a vyznačují se sukcesí vzestupně se zjemňujících pískovců překrytých jílovci. Většina pískovcových facií byla charakterizované jako vícestupňová, složená z kompozitních pískovcových těles odrážejících smíšený fluviální depoziční mechanismus. Petrografické analýzy středního pískovcového horizontu souvrství Dhok Pathan určily ve složení pískovců hojný klastický křemen, silně alterované živce a úlomky hornin spolu s proměnlivým množstvím akcesorických minerálů jako je epidot, granát a jílové minerály. V tmelu je přítomen kalcit, jílové minerály, Fe-silikáty a oxidy. Horniny petrograficky odpovídají lithické arkóze až živcovému litharenitu. Z geotektonického hlediska má klastický materiál studovaných pískovců původ v prostředí recyklovaného orogenu.

AUTHOR CONTRIBUTION

Iftikhar Alam conducted the field and analytical work while Nazir ur Rehman and Afrasiab prepared the maps of the study area and proofreading of the manuscript. Shuja Ullah and Muhammad Waqar Azeem helped in laboratory work and petrographic study of the samples. Shahid Iqbal, Muhammad Saad Rehan and Khalid Khan assisted in drafting the manuscript.

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