ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-5035 (Print)
ISSN: 2521-5043 (Online)
CODEN: ESMACU

Earth Sciences Malaysia (ESMY)

DOI: http://doi.org/10.26480/esmy.02.2021.93.103

CrossMark

RESEARCH ARTICLE

PETROGRAPHIC AND PROVENANCE OF THE SANDSTONE OF RAWALPINDI GROUP IN LESSER HIMALAYAS

Sayed Mushahid Hussain[a]*, Syed Khaliq Hussain[b], Enayatollah Emami Meybodi[b]

[a]Department of Earth Sciences, COMSATS University Islamabad, Abbottabad, Pakistan
[b]Department of Geology, Yazd University, Yazd, Iran
**Corresponding Author E-mail: mushahidabdi@gmail.com*

ARTICLE DETAILS

Article History:

Received 05 September 2021
Accepted 10 September 2021
Available online 21 October 2021

ABSTRACT

In the present work, we deal with the petrographic and provenance of the sandstone of the Rawalpindi group in the lesser Himalayas. The formations present in the project area are Murree and Kamlial Formations of the Rawalpindi group. The petrological studies of Murree and Kamlial Formations determine the minerals composition prospect, which minerals have high proportion and which one is less proportion. Which aim to determine the petrological characteristic of these rock formations for the use of scientific studies or in engineering projects. Both of these two formations are Siwalik molasse deposits, the same orogeny correlation, same age from the same group. Determine the difference in such kind of similar rock formations are very important and also challenge in the field of geology. With highly advance petrographically analysis, it shows that Kamlial formation consists of heavy minerals such as garnet, tourmaline, etc., as compared with Murree formation consists of light minerals such as quartzite, Felice and feldspar, etc. And the provenance analysis of the sandstone of the Rawalpindi group is performed by the QFL ternary diagrams method. All the plots in the QFL diagram plot on recycled orogeny provenance field.

KEYWORDS

Petrography, Provenance, Rawalpindi group, sandstone, lesser Himalayas

1. INTRODUCTION

The project area lies in the core of Hazara Kashmir Syntaxis in the Lesser Himalayas. For present study, the Neogene molasse sequence of the Rawalpindi group in Bagh and Rawalakot area is selected. The formations present in the project area are Murree and Kamlial Formations of the Rawalpindi group. Geological work on Rawalpindi group had done by various geoscientist (Abbasi, 1994; Critelli and Garzanti, 1994; Guillot et al., 2003; Kazmi and Abbasi, 2008; Najman et al., 2002). The Himalayan Basin is divided into several sub-basins classified by certain pre-tertiary basement highs (Raiverman, 2013). This series of the foreland basin describes the post-Eocene sedimentary record of the collision of the Indian and Eurasian plates preserved in northern Pakistan, India, and Nepal(Valdiya, 2011). The high uplift rates of the Himalayan orogenic belt throughout Miocene time(Zeitler et al., 2001). Himalayan drainage system related to the present-day river systems of Indus, Ganges, and the Brahmaputra began flowing axially within their particular basins that deposited thick detrital sediments commonly known as the "molasse deposits"(Abbasi and Friend, 2000). Certain molasse sediments contribute data regarding the lithologies uplifted in the source area, the type of drainage system, the condition of the depositional site relevant to the orogenic belt, and basin subsidence(Morad et al., 2010). These sediments become progressively younger southward as the deformational front and resultant depocenter are transferred away from the collision belt (DeCelles et al., 2014) . The Neogene molasse sequence of the Kohat Plateau includes the Rawalpindi group held by the marine sequence of the Eocene age. These rocks have been tightly folded and make narrow ridges due to tectonic activity(Siyar et al., 2018). The Rawalpindi Group exposed in the Himalayan foreland Basin consists of the Murree and Kamlial formations, and the Siwalik Group comprises Chinji, Nagri, Dhok Pathan, and Soan formations(Abir et al., 2017; Naseer et al., 2019). Despite this, the study region comprises frequently lies in the Rawalpindi Group. In certain groups, the formations are included sandstone, siltstone, shales, and conglomerates. As usual, the foreland sequence of the Rawalpindi and Siwalik groups describes less than 18 million years of fluvial deposition, several likely with the ancestral Indus River(Yar et al., 2021). The Murree and Kamlial Formation of Miocene consists of sandstone inter-bedded with shales. They are generally light grey to grey in fresh color while dark grey to purple and dark grey to greenish grey in weathered colors. The sand stone is medium to coarse-grained high tenacity, and compact calcite veins are present at some places. Cracks and fractures are present and filled with calcareous and clayey material(Naseer et al., 2019; Rahim et al., 2020; Yasin et al., 2017). According to stratigraphic sequence, the sandstone of Murree and Kamlial Formation are of Miocene age(Bilal and Khan, 2017).Ashraf and Chaudhry (1985) have worked on the petrology of the Murree Formation in the lesser Himalayas. They explained the petrographic examination of sandstone and shale. Based on grain size in the field, they divided the Murree formation into upper and lower Murree Formation. The purpose of this study is to carry out detailed petrographic investigation of sandstone of Rawalpindi group.

2. GEOLOGICAL SETTING

The study area is located in Rawalakot district Ponch, Azad Kashmir and has ranges from latitudes 34^0 48' 15"E to 34^0 60' 50" E and longitudes 73^0 34' 40"E to 73^0 54' 50" N. The current study falls in toposheet no 43-G/9

Quick Response Code	Access this article online	
	Website: www.earthsciencesmalaysia.com	**DOI:** 10.26480/esmy.02.2021.93.103

Cite The Article: Sayed Mushahid Hussain, Syed Khaliq Hussain, Enayatollah Emami Meybodi (2021). Petrographic and Provenance of The Sandstone of Rawalpindi Group in Lesser Himalayas.*Earth Sciences Malaysia, 5(2): 93-103*.

to G/13 of Geological survey of Pakistan. The site is at an elevation of 1798 m above mean sea level. Rawalakot is one of the most beautiful valleys of KASHMIR which is located 80 km away from Rawalpindi and Islamabad. Rawalakot weather is quite erratic. The average temperatures in summer is 25°C to 35°C and in winter drops to 8^{0}C. The geological map of Pakistan and Tectonic map of Northern Pakistan is shown in (Fig.1 a & b). The geological and samples Location map of Study Area is shown on (Fig. 1c). The stratigraphy of the Kashmir Basin ranges from Precambrian to recent which shown in (Table 1) (Craig et al., 2018; Malkani and Mahmood, 2017).The Rawalpindi Group represent Mollase deposits of the Himalayan Orogeny.The core of HKS is occupied by sedimentary rocks of Cambrian Abbottabad Formation. The formation unconformable overlain by Paleocene and Eocene rock formations.

Table 1: Stratigraphic sequence of the Poonch and surrounding areas

Formation	Age	Lithology
Alluvium	Quaternary	Greenish sandstone, reddish shale, mudstone, jointed and cracked, calcite and quartz veins are common.
------------Unconformity-----------		
Soan Formation	Late Pliocene	Massive conglomerate with subordinate interbeds of sandstone, siltstone and clay.
Dhok Pathan Formation	Middle Pliocene	Monotonous cyclic alternations of sandstone and clay beds
Nagri Formation	Early Pliocene	Sandstone with subordinate clay and conglomerate.
Chinji Formation	Late Miocene	Red clay with subordinate ash grey or brownish grey sandstone
Kamlial Formation	Late Miocene	Purple-grey and dark brick-red sandstone which is medium to coarse grained and contains interbeds of hard purple shale.
Murree Formation	Miocene	Cyclic deposition of siltstone, sandstone and clay. Fine to medium grained.
------------Unconformity-----------		
Kuldana Formation	Late Eocene	Variegated shales, clays with subordinate sandstone.
Chorgali Formation	Middle Eocene	Shales and lenses of limestone
Margalla Hill Limestone	Early Eocene	Nodular limestone with subordinate marl and shales. Nummulites and Assilina.
Patala Formation	Late Paleocene	Shales and marls with subordinate limestone and sandstone.
Lockhart Formation	Middle Paleocene	Nodular, fossiliferous limestone with massive beds.
Hangu Formation	Early Paleocene	Shales, ferrogenous sandstone, laterite and bauxite.
------------Unconformity-----------		
Panjal Formation	Carboniferous to Permian	Volcanic greenstone metamorphosed lava flow.
------------Unconformity-----------		
Abbotabad Formation	Middle Cambrian	Dolomitic, quarzitic and sandy facies
------------Unconformity-----------		
Mansehra Type Granitic Intrusion	Cambrian	Granites and Granitic Gneisses.
Tanol Formation	Precambrian	Biotite, muscovite, quartz and andalusite staurolite schist.
Salkhala Formation	Precambrian	Slates, Phyllite, Garnet mica schist, kyanite Gneisses, quartz feldspathic Gneiss calcareous quartz mica Gneisses, graphitic gneisses, amphibolite and sheet granite.
Hazara Formation	Precambrian	Slates, phyllite and shales with minor occurrence of limestone.

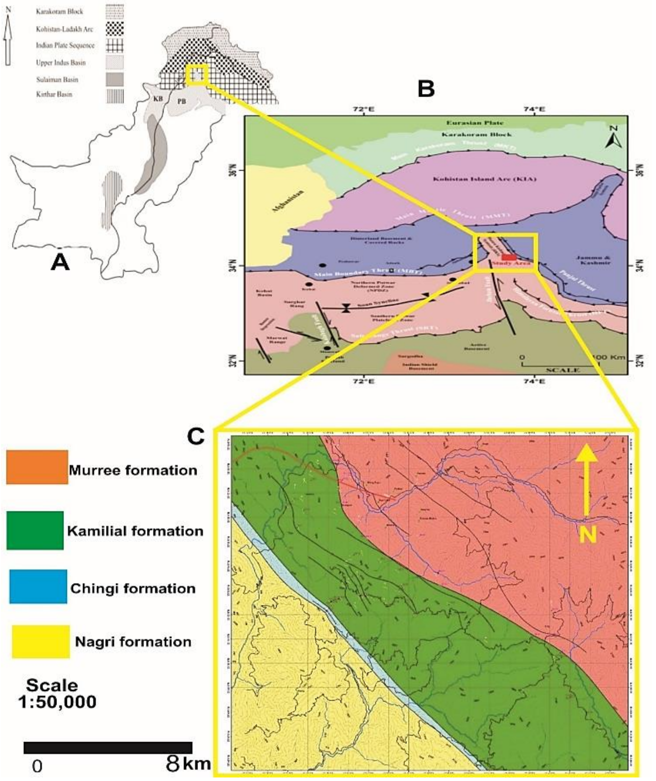

Figure 1: (a) Geological map of Pakistan. (b)Tectonic map of Northern Pakistan, (c)Geological map of Study Area

3. METHOD AND TECHNIQUES

A vast area of District Poonch, Azad Kashmir at latitudes 340 48' 15" to 340 60' 50" E and longitudes 730 34' 40" to 730 54' 50" N, has been mapped at a scale of 1:50,000. It extends from Bagh to Rawalakot and the surrounding side of Rawalakot, mostly covered with vegetation and alluvium. The main objective of this study was to investigate the Petrographic properties of Rawalpindi group sandstone, because Murree & Kamlial sandstone is extensively used in construction for preparing concrete blocks, road construction, and other civil engineering structure, and to establish the relationship between different properties for proper utilization of the rocks. However, a researcher described the geology of the area (Yin, 2006). Another researcher has also worked on the geology of the area and described the petrography of the rocks (Umar et al., 2015). A geological map has been prepared on 1:50000 scales Samples of sandstone have been marked on the map. The four-times enlargement of the relevant portion of the toposheets numbers 43 G/9, 43 G/13 of Survey of Pakistan were used as a base map at a scale of 1: 50,000. During the fieldwork, traverses were made across the strike to note the maximum variations. Field observations were plotted on the base map. Samples were taken based on color, texture, structure, joints, and thickness of the rock bed. The 63 samples were prepared for petrological studies. The name of the sample is given according to the rock type, locality and the number indicates the position of the sample collected in the field. E.g. KS-1, where S stands for sandstone, K stands for Kamlial Formation. The samples were collected from the fresh outcrops and were not taken from highly weathered places either chemical or mechanical. Dip, strikes, joints and cracks were plotted on site for the preparation of geological map.

4. RESULTS

4.1 Petrography

The petrographic examination carried defined to the sedimentary rocks. Fresh and representative samples of sandstone of the research field were preferred of well-exposed rock units in the project region. The thin section was made in the laboratory and examined under the microscope. The model mineralogical results of rocks are shown in tables (Tables 2, 3, 4, 5, 6, and 7). Some Murree and Kamlial sandstones obtain fine-grained, although most of them are medium to coarse-grained. The grains transpire frequently from sub-rounded to sub-angular. The cast is formed of clay, sericite, small grain, and accessory minerals. The binding and cementing material comprises calcareous, argillaceous, ferrogenious, and siliceous. Sandstone is dense and greenish-grey, grey to dark grey and reddish-brown in appearance.

The mineralogy of Rawalpindi Groups is sandstone composed of quartz, feldspar, rock fragment, calcite, clays, muscovite, biotite, tourmaline, and iron minerals, etc. These minerals are observed in various scales in the matrix and modify in the composition of the site to site. Their interest inside the matrix is presented in (Tables 2, 3, 4, 5, 6, and 7). The quartz grains are sub-angular to sub-rounded and show twining at some places. Calcite has seen cloudy in the thin section. The interference color is light grey to white. It is the main binding and cementing material in a thin section. It has a cubic crystals structure and displays rhombohedral cleavage. Muscovite and sericite usually occur in a connected pattern. Sericite is fine-grained whereas muscovite is commonly fine to medium-grained. Some muscovite should be observed as grains and the rest of the muscovite is a part of the matrix. Sericite with clay also occurs as an alteration outcome of feldspar. Hematite and other iron minerals occur as grains from the sub-angular to sub-ground in shape. The rock fragments have been observed in an unstable form. They are mostly medium to coarse-grained and sub-angular to sub-rounded. Their distribution is found throughout the area of Rawalpindi group sandstone. Clays occur as specks of fine microcrystalline minerals. It may also occur as an alteration outcome of feldspars. It is a significant component of the matrix.

In Khaigala area quartz percentage ranges from 38% to 40%, calcite ranges from 15% to 25%, muscovite/sericite ranges from 3% to 4%, iron minerals range from 5% to 10%, rock fragment ranges from 20% to 30% and clays up to 2% to 4% (Tables 2, 3, 4, 5, 6, and 7).

In Chottagala area quartz percentage ranges from 37% to 38%, calcite ranges from 15% to 20%, muscovite/sericite ranges from 3% to 4%, iron minerals range from 2% to 4%, rock fragment ranges from 0% to 3% and clays up to 2% to 3% (Tables 2, 3, 4, 5, 6, and 7).

In Arja area quartz percentage ranges from 32% to 38%, calcite ranges from 15% to 20%, muscovite/sericite ranges from 2% to 4%, iron minerals from 2% to 4%, rock fragments range from 15% to 25% and clay ranges up to 2% to 7% (Tables 2, 3, 4, 5, 6, and 7).

In Benjosa area quartz percentage ranges from 34% to 35%, calcite ranges from 10% to 15%, muscovite/sericite ranges from 3% to 4%, iron minerals from 3% to 4%, rock fragments range from 15% to 20% and clay ranges up to 1% to 6% (Tables 2, 3, 4, 5, 6, and 7).

Table 2: Model mineralogy of Lithic Arenite of Murree Formation.

Model Mineralogical Composition			Sample										
			MS-1	MS-2	MS-3	MS-4	MS-5	MS-6	MS-7	MS-8	MS-9	MS-10	MS-11
Quartz	Monocrystalline		37	35	30	32	30	25	25	30	29	30	35
	Polycrystalline		3	5	6	4	5	5	7	6	5	3	8
Feldspar	Orthoclase		2	2	1		1	1					1
	Microcline		2	2		1	2	2	2	1	1		1
	Perthite		2	1			3	1	1				3
	Plagioclase			8	3	3	10	4	5	2	2	4	7
Rock Fragments	Igneous	Plutonic											
		Volcanic	6	5	5	6	7	10	7	5	6	5	8
	Metamorphic	Quarzite	12	4	1	1	3	3	2	2	2		5
		Gneisses		1			1	2	1		2		1
		Slate		2	1	2	3	4	2	3	1		2
		Phyllite		3		2	2		1		1	1	
		Biotite schist		4	4	6	4	2	5	6	5	4	5
		Chlorite schist		1		2	2		2	2	2	2	2
	Sedimentary	Sandstone	7	3		4	2	5	2	4	4	2	3
		Siltstone		2		4	1	4	1	2	2		1
		Limestone		5	15	8	5	10	7	8	6	10	2
		Dolomite											
Accessory Minerals	Muscovite		2	2	2	2	2	4	2	2	3	5	3
	Biotite		2	1	2	1	2	4	1	2		2	2
	Tourmaline				1	1	1		1		1		
	Zircon					1			1	1			
	Hornblend						1			1		1	
	Epidote		1		2		1		2		2		
	Sericite		1	1	1	1			1		1		
	Apatite												
	Chlorite		1	1	1				1			2	
	Hematite									3	2		
Cement	Calcite		20	6	20	4	5	7	10	9	5	20	7
	Quartz			2		2	2	2		4	4		1
	Hematite			2	3	7	2	3	5		7	5	2
	Silica									1			1
	Clay					1	1		1	2	1		
Opaque minerals			1	1	3	2	1	2	1	2	3	1	
Matrix			1	1		3	1		2	2	3	3	
Calcite veins									2				
Total			100	100	100	100	100	100	100	100	100	100	100

Table 3: Model mineralogy of Lithic Arenite of Murree Formation.

Model Mineralogical Composition			Sample											
			MS-12	MS-13	MS-14	MS-15	MS-16	MS-17	MS-18	MS-19	MS-20	MS-21	MS-22	MS-23
Quartz	Monocrystalline		32	30	30	35	37	32	27	33	37	27	25	25
	Polycrystalline		6	10	10	7	5	6	5	7	7	6	3	9
Feldspar	Orthoclase		2	1	1		1	1	2		1		1	1
	Microcline		1		1	1		1	1	2		2		1
	Perthite		1	2	3	1	1		1					1
	Plagioclase		6	8	5	4	3	3	6	6	5	5	1	5
Rock Fragments	Igneous	Plutonic												
		Volcanic	7	9	6	6	5	5	8	5	5	6	5	8
	Metamorphic	Quarzite	1	2	3	1	2	2	2	2	1	1	3	1
		Gneisses				1	1	1	1	1	3	1		
		Slate	2	3	3	1	2	2	1	1			2	2
		Phyllite						3	2			2		
		Biotite schist	3	2	3	2	1	3	4	2	5	5	2	6
		Chlorite schist	2	1	1	2	2	1	2	1	2	2		
	Sedimentary	Sandstone	4	2	4	3	4	3	4	3	3	2	4	3
		Siltstone	1	1	2	2	1	1	2	1	1	1		1
		Limestone	8	5	5	4	7	5	9	7	5	10	12	10
		Dolomite												
Accessory Minerals	Muscovite		3	2	3	2	2	2	3	2	2	3	2	3
	Biotite		2	2	2	2	1	2	2	2	1	2	2	3
	Tourmaline				1	1	1							
	Zircon					1	1		1					1
	Hornblend									1		1		
	Epidote		1	2	1	1	2	1	1	2	1	1		1
	Sericite		2		1	1	2		1	1		1		1
	Apatite													
	Chlorite		2		1			2	1	1	1	1	1	1
	Hematite					1	1	1	1	1	1		1	
Cement	Calcite		5	9	3	6	3	7	8	7	8	8	20	4
	Quartz		3	2	1	2	1	3			1	1		1
	Hematite		1	4	6	8	9	5	2	6	7	3		5
	Silica							1		2		1		
	Clay		1		1	1		1		1	1	1		1
Opaque minerals			1	1	1	1	2	2	2	2	1	3		3
Matrix			3	2	2	2	1	3	1	1	2	4	3	2
Calcite veins						1	2	1						1
Total			100	100	100	100	100	100	100	100	100	100	100	100

Table 4: Model mineralogy of Lithic Arenite of Kamlial Formation.

		Model Mineralogical Composition	*Sample*									
			KS-1	KS-2	KS-3	KS-4	KS-5	KS-6	KS-7	KS-8	KS-9	KS-10
Quartz		Monocrystalline	35	30	32	32	30	32	30	28	33	30
		Polycrystalline	4	10	5	8	8	6	10	7	6	7
Feldspar		Orthoclase			1		2		2	1		3
		Microcline	1	2	1	1	3	2	2		1	2
		Perthite	1	1	2		1		2	3		1
		Plagioclase	3	6	5	3	7	4	9	8	4	9
Rock Fragments	Igneous	Plutonic										
		Volcanic	6	7	6	6	6	4	7	5	6	8
	Metamorphic	Quarzite	3	2	1	2	1	3	2	4	2	2
		Gneisses		1	1	1			1		1	3
		Slate	3	1	1		2	3	2	3	2	
		Phyllite		2	3	2		1		1		
		Biotite schist	6	8	5	2	6	3	4	4	4	3
		Chlorite schist	1	2	1	2	2	2	1	2	3	2
	Sedimentary	Sandstone	5	4	6	1	2	3	2	4	2	1
		Siltstone	2	1	2	1	2	2	1	1	1	1
		Limestone	8	6	5	12	4	10	4	4	6	3
		Dolomite										
Accessory Minerals		Muscovite	2	2	5	3	3	2	4	2	2	4
		Biotite	2	2	2	2	1	3	5	2	2	2
		Tourmaline		1	1	1	1		1	1	1	1
		Zircon	1					1				
		Hornblend	1			1		1			1	
		Epidote		1	1	1	1					
		Sericite				1		1		1		
		Apatite										
		Chlorite				1	1	1		1		
		Hematite	3	1	1	1		2			1	
Cement		Calcite	5	5	5	4	7	4	3	5	8	6
		Quartz		1	2	1	1		2	2	2	2
		Hematite	2	2	3	5	2	4	2	7	6	7
		Silica	1			1	1			1	1	
		Clay	2				1	1		1	1	
		Opaque minerals	2	1	1	2	2	3	2	1	2	1
		Matrix	1	1	2	2	3	2	2	1	2	2
		Calcite veins									1	
		Total	100	100	100	100	100	100	100	100	100	100

Table 5: Model mineralogy of Lithic Arenite of Kamlial Formation.

Model Mineralogical Composition			*Sample*									
			KS-11	KS-12	KS-13	KS-14	KS-15	KS-16	KS-17	KS-18	KS-19	KS-20
Quartz		Monocrystalline	24	30	35	28	30	32	25	32	25	25
		Polycrystalline	14	7	5	5	6	4	6	4	5	8
Feldspar		Orthoclase	2		2	2	1		3		2	2
		Microcline	1	2	3	1		2		2	2	1
		Perthite	3		2	1	1		1		1	1
		Plagioclase	9	3	5	5	5	4	3	4	10	7
Rock Fragments	Igneous	Plutonic										
		Volcanic	6	4	8	6	5	4	2	4	8	6
	Metamorphic	Quarzite	3	2	2	3	1	2	1	2	3	2
		Gneisses			1		1				1	1
		Slate	3	1	2	4	4	1	2	1		4
		Phyllite		2	1		1					
		Biotite schist	1	5	3	3	5	3	8	3	2	3
		Chlorite schist	1	2	1	1	3	2		2	1	2
	Sedimentary	Sandstone	6	3	3	4	4	4		4	3	4
		Siltstone	1	2	1	1	1	2		2	1	1
		Limestone	5	9	4	6	8	8	6	8	4	4
		Dolomite					1					
Accessory Minerals		Muscovite	3	1	2	4	3	3	5	3	2	2
		Biotite	2	2	1	3	2	3	3	3	2	3
		Tourmaline	1		1	2	1	1	2	1		1
		Zircon			1						1	1
		Hornblend		1								
		Epidote			1			1	1	1	1	1
		Sericite		1			1	1		1		
		Apatite										
		Chlorite		1		2			2			
		Hematite			1	1		1		1		
Cement		Calcite	7	7	7	7	7	8	12	8	10	8
		Quartz	2		3		2				3	3
		Hematite	4	6	2	5	1	7	8	7	5	5
		Silica		2			1	2		2	1	1
		Clay		1							1	2
Opaque minerals			1	2	1	2	2	2	6	2	2	2
Matrix			1	4	2	4	3	3	4	3	1	
Calcite veins												
Total			100	100	100	100	100	100	100	100	100	100

Cite The Article: Sayed Mushahid Hussain, Syed Khaliq Hussain, Enayatollah Emami Meybodi (2021). Petrographic and Provenance of The Sandstone of Rawalpindi Group in Lesser Himalayas.*Earth Sciences Malaysia, 5(2): 93-103.*

Table 6: Model mineralogy of Lithic Arenite of Kamlial Formation.

Model Mineralogical Composition			*Sample*									
			KS-21	KS-22	KS-23	KS-24	KS-25	KS-26	KS-27	KS-28	KS-29	KS-30
Quartz		Monocrystalline	35	30	35	30	35	30	35	34	31	34
		Polycrystalline	7	7	5	7	7	6	4	6	8	7
Feldspar		Orthoclase	1		2	1			1		1	1
		Microcline		1	1	1	2	2	1	1	1	1
		Perthite			2			1	2			2
		Plagioclase	4	3	5	5	3	5	4	5	4	5
Rock Fragments	Igneous	Plutonic										
		Volcanic	5	7	7	6	9	7	6	8	6	4
	Metamorphic	Quarzite	1	2	2	2	1	3	2	1	2	1
		Gneisses	2		1			1	1	1	3	2
		Slate	1	1	1		2					5
		Phyllite			2			1	1	1	1	1
		Biotite schist	5	5	3	4	4	6	5	3	4	4
		Chlorite schist	1	2	2	3	2	2	1	3	2	3
	Sedimentary	Sandstone	3	4	3	4	3	3	4	4	5	2
		Siltstone	1	1	2	2	1	1	1	1	2	1
		Limestone	4	6	6	5	10	5	3	5	2	4
		Dolomite							1		1	1
Accessory Minerals		Muscovite	2	2	2	1	2	2	3	4	5	2
		Biotite	2	2	2	2	1	1	2	2	3	
		Tourmaline		2	1	1		1	4	1	2	1
		Zircon										
		Hornblend					1	1	1		1	1
		Epidote						1	2	1	1	1
		Sericite	1	1		1	1			1	1	1
		Apatite									1	
		Chlorite	1		1	1	1	2	2		1	
		Hematite	2	2		1	1		1	1		2
Cement		Calcite	6	7	7	7	6	7	6	7	4	6
		Quartz	3	2	1	2			1		2	1
		Hematite	7	6	3	6	4	5	3	5	4	3
		Silica				1						
		Clay	2		1	2	1	1	1		1	1
Opaque minerals			2	2	2	2	1	2		2	1	2
Matrix			2	4	1	3	2	4	2	3	1	1
Calcite veins				1								
Total			100	100	100	100	100	100	100	100	100	100

Table 7: Model mineralogy of Lithic Arenite of Kamlial Formation.

Model Mineralogical Composition			Sample									
			KS-31	KS-32	KS-33	KS-34	KS-35	KS-36	KS-37	KS-38	KS-39	KS-40
Quartz	Monocrystalline		37	30	29	35	32	34	32	35	30	26
	Polycrystalline		4	5	8	4	6	10	8	5	7	5
Feldspar	Orthoclase		2	1		2		1		1	2	
	Microcline		1		1	1	1	2	1	1	1	1
	Perthite		1	1		2			1		1	1
	Plagioclase		6	4	5	6	3	6	4	4	6	3
Rock Fragments	Igneous	Plutonic										
		Volcanic	6	6	5	4	7	4	6	5	10	8
	Metamorphic	Quarzite	1	2	1	2	1	1	3	3	4	2
		Gnesis		1		1	2	2	2	1	1	1
		Slate	1			1			1		3	
		Phyllite	1				1			1		1
		Biotite schist	4	6	5	5	4	3	5	6	5	6
		Chloride schist	2	4	3	2	2	2	3	3	2	2
	Sedimentary	Sandstone	2	2	3	3	3	3	3	3	2	3
		Siltstone	1	1	3	1	2	2	2	1	1	1
		Limestone	6	5	7	3	4	6	6	5	3	8
		Dolomite										
Accessory Minerals	Muscovite		3	2	2	2	3	2	3	2	1	3
	Biotite		3	1	2	2	3	3	2	1	1	2
	Tourmaline		1	1	1	1	1	1	1	1		1
	Zircon			1	1							
	Hornblend			1	1		1	1				1
	Epidote		1					1	1			1
	Sericite			1	1		1		1			1
	Apatite											
	Chlorite		2	1	1	1		1				1
	Hematite					2	1	1		1		
Cement	Calcite		8	7	8	8	8	6	6	8	8	9
	Quartz			1	1	2	2	1	1	1	2	
	Hematite		4	6	5	6	6	5	6	7	5	4
	Silica			1	1		1					
	Clay			2	1		1			1	2	1
Opaque minerals			2	2	3	2	1	1	1	1	2	3
Matrix			1	1	2	2	3	1	1	3	1	4
Calcite veins												1
Total			100	100	100	100	100	100	100	100	100	100

4.2 Provenance and Tectonic Setting

QFL ternary diagrams plotted for the provenance analysis are based on triangular diagram of a study which shown in (Fig 2 & 3) (Dickinson et al., 1983). Most of the plots in QFL diagram plot on recycled orogeny provenance field. The detritus of rock fragments strongly suggests mixed sources of the Rawalpindi Groups of sandstones as metamorphic, igneous and sedimentary lithics occur dominantly.

4.3 Microscopic feature of Lithic Arenite

Sandstone of Rawalpindi Groups mainly comprised of angular (Figure 4(a) to sub-angular and rounded (Figure 4(b) to sub-rounded quartz grains. Few quartz grains are stretched (Figure 4(c, d), strained (Figure 4(e), sutured (Figure 4 (f, g), show non-uniform extinction. Quartz grains are mostly monocrystalline (Figure 4(h) show uniform extinction and few quartz grains are polycrystalline (Figure 4(i, j). In quartz the dissolution feature of styolitic (Figure 4(k) is also found. Some quartz grains are fractured (Figure 4 (l) due to intense tectonic activities. Feldspar in Murree and Kamlial Formations is dominantly plagioclase (Figure 5(a, b, c, d), (Albite to Oligoclase in composition) and alkali feldspar microcline

(Figure 5(e, f) and perthite (Figure 5 (g) also shows in Murree & Kamlial formations.

The clasts of rock fragments found in sandstone of Murree and Kamlial Formations are both interformational and intraformational. The interformational clasts in sandstone of Murree and Kamlial Formations include metamorphic, igneous and sedimentary rocks i.e. slates (Figure 6 (a ,b),phyllite (Figure 6 (c), chlorite schist, biotite schist (Figure 6 (d, e, f, g, h, i, j), garnet schist, graphitic schist (Figure 6 (k), gneisses, quartzite (Figure 6(l, m, n,), and limestone (Figure 6 (o). The intraformational clasts in sandstone of Murree and Kamlial Formations includes clasts of both sandstone (Figure 7 (a, b, c, d, e, f) and siltstone (Figure 7 (g). The accessory minerals include besides zircon (Figure 8 (a, b, c), garnet (Figure 8(d),tourmaline (Figure 8(e), epidote (Figure 8(f, g, h), biotite (Figure 8 (i, j), muscovite (Figure 8 (k, l, m), hematite, and chlorite (Figure 8 (n).The cementing material is mostly calcite (Figure 9 (a, b), hematite (Figure 9(c, d, e), silica, chlorite, clay. Quartz and calcite veins are also found in sandstone. Based on microscopic features, the sandstone of Murree & Kamlial Formations is mostly poor in matrix and enrich in arenite facies. Mineralogically it is composed of quartz 25-45%, feldspar 4-16%, rock fragment 11-30%, tourmaline 0.5-1%, epidote 1-2, biotite 1-4%, muscovite 1-05%, hematite 1-3%, opaque 1-5%, chlorite 1-2%, apatite, zircon 1-2%, chlorite 1-3% and sericite 1-2% (Tables 1, 2, 3, 4, 5, and 6). In lithic arenite cementing materials are calcite 2-21%, hematite 1-19%, clay 5-5%, dolomite 01%, quartz 1-4%, chlorite 01-05% and silica 01-03% (Tables 2, 3, 4, 5, 6, and 7).

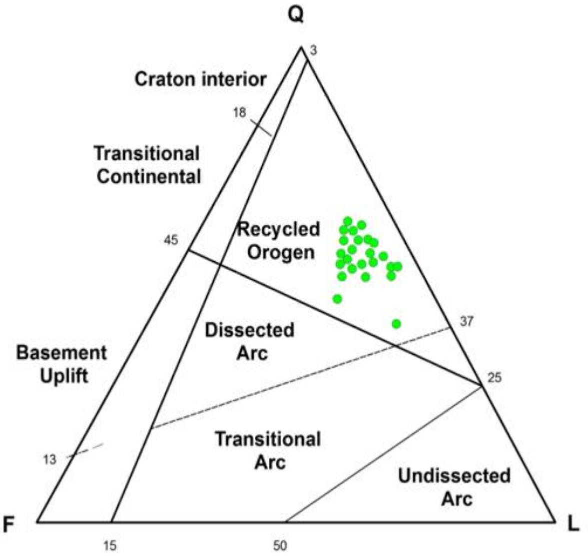

Figure 2: Standard triangular plot (QFL) for provenance interpretation of sandstone samples of Murree Formation (after (Dickinson et al., 1983).

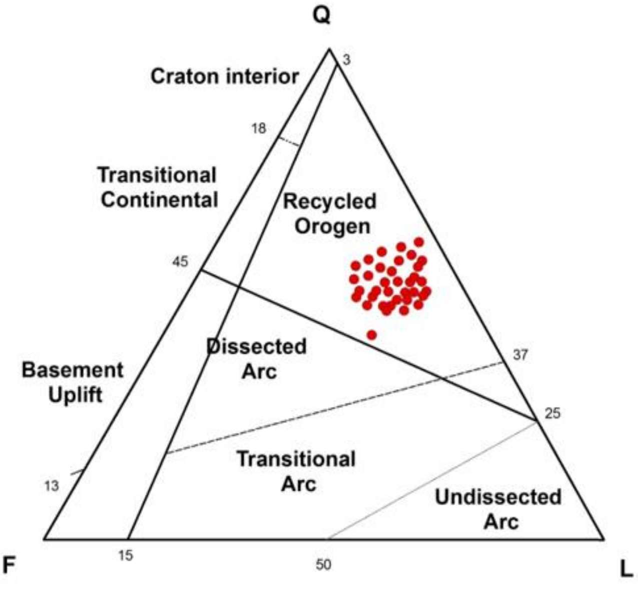

Figure 3: Standard triangular plot (QFL) for provenance interpretation of sandstone samples of Kamlial Formation (after (Dickinson et al., 1983).

Figure 4: Shown the quartz grain of Sandstone of Rawalpindi Group (a) sub-angular and rounded (b) sub-rounded quartz grains. stretched (c, d), strained (e), sutured (f, g), monocrystalline (h) polycrystalline (i, j) (PPl; 10X).

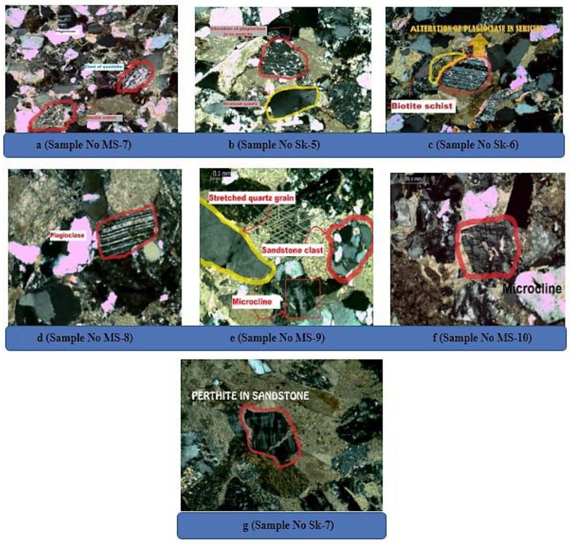

Figure 5: Shown the feldspar and plagioclase of Murree and Kamlial formations (a, b, c, d), (Albite to Oligoclase in composition) and alkali feldspar microcline (e, f) and perthite (g) (PPl; 10X).

Figure 6: Shown the interformational clasts in sandstone of Murree and Kamlial Formations include metamorphic, igneous and sedimentary rocks i.e. slates (a, b), phyllite (c), chlorite schist, biotite schist (d, e, f, g, h, i, j), garnet schist, graphitic schist (k), gneisses, quartzite (l, m, n,), and limestone (o).

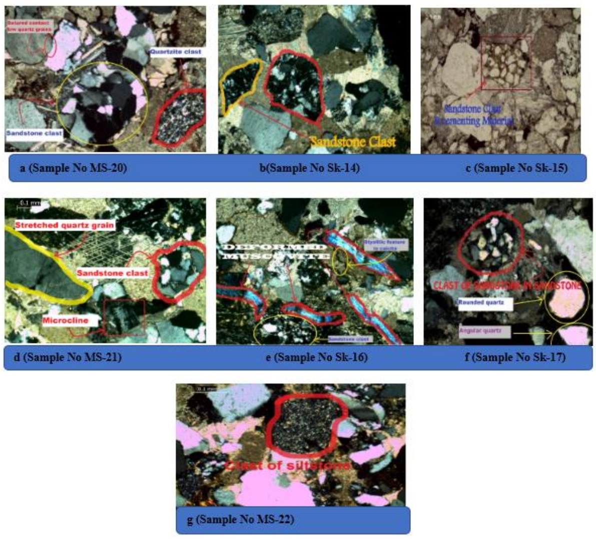

Figure 7: The intraformational clasts in sandstone of Murree and Kamlial Formations includes clasts of both sandstone (a, b, c, d, e, f) and siltstone (g).

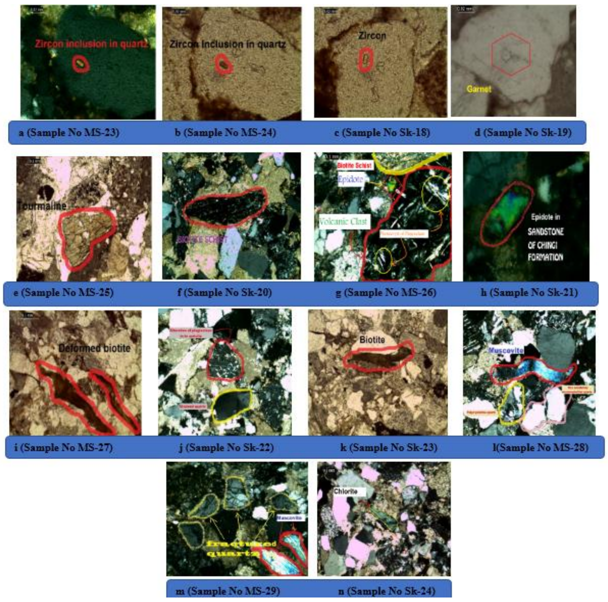

Figure 8: The accessory minerals include besides zircon (a, b, c), garnet (d), tourmaline (e), epidote (f, g, h), biotite (i, j), muscovite (k, l, m), hematite, and chlorite (n).

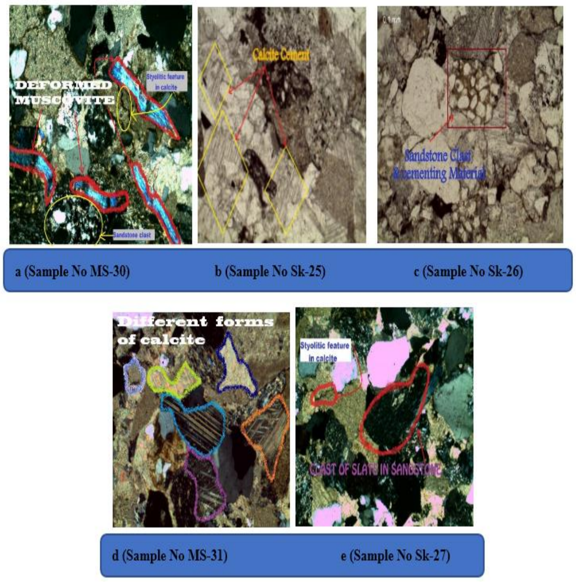

Figure 9: The cementing material is mostly calcite and hematite (a, b) and (c, d, e), silica, chlorite, clay.

5. DISCUSSIONS

Himalayan molasses deposits were formed in the foreland basin during Himalayan orogeny due to collision between Indian and Eurasian plates. Foreland basin was developed in front of Himalayan orogeny due to sinking. Murree Formation was the oldest cyclic sequence of Himalayan molasses deposits. Himalayan orogeny starts during Tertiary, as a result of this, area was uplifted due to folding and thrust faulting developed by compressional stresses between two continental plates. Once the area was uplifted its erosion take place and the eroded sediments were deposited in the Himalayan foreland basin.

The sandstone of Rawalpindi Group is fine to medium grained in texture. Hematite concretion in mud rocks is also found in Rawalpindi Group. The alteration of hematite into calcite are found in sandstone of Rawalpindi Group which shows different levels of oxidizing conditions in Himalayan foreland basin. Based on microscopic features, the sandstone of Rawalpindi Group is subdivided into two facies lithic arenite and lithic wacke but mostly the study area comprised of lithic arenite. The sandstone of Rawalpindi Group mainly composed of angular to sub-angular and rounded to sub-rounded, stretched, non-uniform extinction, uniform extinction grains, and polycrystalline quartz grains. In Feldspar plagioclase (Albite to Oligoclase in composition having Albite twining) and alkali feldspar of Microcline and Perthite are found in sandstone. The clasts or rock fragments found in sandstone of Rawalpindi Groups are both Interformational and Intraformational. The Interformational clasts in sandstone of Rawalpindi Group includes Metamorphic, Igneous and Sedimentary rocks i.e. Slates, Biotite Schist (, Quartzite. Volcanic clast, Limestone. The accessory minerals include Tourmaline, Epidote, biotite, muscovite, garnet, hematite concretion, apatite, and chlorite. Zircon are found as inclusion in Quartz grains. The cementing material is mostly Calcite veins are also found in Siltstone. Mineralogically lithic arenite are composed of Quartz 25-40%, Feldspar 2-8%, Rock fragment 15-35%, tourmaline 0-2%, epidote 0-1%, biotite 1-6%, muscovite 1-6%, hematite 0-5%, garnet 0-1%, hornblende 0-2%, opaque 1-6%, chlorite 0-4%, sericite 0-0.1%, zircon 0-0.5%. In lithic arenite cementing materials is calcite 10-25% and hematite 5-15%.

Frequency of the non-undulatory monocrystalline quartz (Qnu) is larger in the Sandstone of Rawalpindi Groups as compared to the frequency of the undulatory monocrystalline quartz (Qnu) and polycrystalline quartz (Qp). The greater abundance of Qnu may suggest plutonic provenance for the sandstones of Rawalpindi Group. Increasing amount of muscovite and biotite content in the Middle sandstones of Murree Formation can be related to the unstable tectonic setting of the MCT and uplift of the Higher Himalaya. The MCT activation and the Higher Himalaya uplift and its denudation probably had caused increase in biotite detritus to the Middle sandstones of Rawalpindi Group.

6. CONCLUSIONS

Based on microscopic features and matrix content in the sandstone of Rawalpindi Groups is subdivided into two facies namely lithic wacke and lithic arenite but the study mostly comprised of lithic arenite. Angular to sub-angular quartz grains of sandstones of Rawalpindi Groups indicate these grains were derived from nearby source, whereas rounded to sub-rounded quartz grains indicates their source was at large distance and these grains become rounded during long transportation. Non undulatory monocrystalline quartz grains indicate their source was acidic plutonic igneous rock such as granite, whereas undulatory monocrystalline and stretched quartz grains and polycrystalline quartz grains indicate their source was metamorphic such as slate, phyllite, schist, gneiss and quartzite. In feldspar; plagioclase and alkali feldspar of Microcline and Perthite in sandstones of Rawalpindi Groups indicate their source was granites and granite gneisses while plagioclase was fractured during diagenesis or due to local tectonic activity. Overall, less amount of feldspar in most sandstones; 1-8% in lithic arenite indicate semi humid conditions during its deposition whereas very slightly high amount of feldspar in few sandstones indicate semiarid conditions during its deposition. During semi humid conditions heavy rain fall causes alteration or weathering of feldspar into sericite whereas in semiarid conditions slight rain fall causes less weathering of feldspar into sericite. The accessory minerals of sandstones of Rawalpindi Groups such as tourmaline, biotite, muscovite, garnet are secondary minerals formed due to alteration of pyroxene and feldspar respectively. Epidote is also secondary mineral formed due to alteration of Ca rich plagioclase (albite and epidote). QFL ternary diagrams plotted for the provenance analysis are based on triangular diagram. All of the plots in QFL diagram plot on recycled orogeny provenance field of Murree and Kamlial Formations. The detritus of rock fragments strongly suggests mixed sources of the Rawalpindi Group sandstones as metamorphic, igneous and sedimentary lithic occur dominantly.

REFERENCES

Abbasi, I. and Friend, P. 2000. Exotic conglomerates of the Neogene Siwalik succession and their implications for the tectonic and topographic evolution of the Western Himalaya. Geological Society, London, Special Publications, 170(1): 455-466.

Abbasi, I.A. 1994. Fluvial architecture and depositional system of the Miocene molasse sediments, Shakardarra Formation, southeastern Kohat, Pakistan. Geological Bulletin, University of Peshawar, 27: 81-98.

Abir, I.A., Khan, S.D., Aziz, G.M. and Tariq, S. 2017. Bannu Basin, fold-and-thrust belt of northern Pakistan: Subsurface imaging and its implications for hydrocarbon exploration. Marine and Petroleum Geology, 85: 242-258.

Ashraf, M., Chaudhry, M.N. 1985. Petrology of Murree formation of Poonch District, Azad Kashmir. Kashmir J Geol 3:13–36.

Bilal, A., Khan, M.S. 2017. Petrography of paleogene carbonates in Kalamula and Khursheedabad area, Kahuta, Azad Kashmir. Earth Sciences Malaysia (ESMY), 1(1): 36-41.

Craig, J., Hakhoo, N., Bhat, G., Hafiz, M., Khan, M., Misra, R., Pandita, S., Raina, B., Thurow, J. and Thusu, B. 2018. Petroleum systems and hydrocarbon potential of the North-West Himalaya of India and Pakistan. Earth-science reviews, 187: 109-185.

Critelli, S. and Garzanti, E. 1994. Provenance of the lower Tertiary Murree redbeds (Hazara-Kashmir Syntaxis, Pakistan) and initial rising of the Himalayas. Sedimentary Geology, 89(3-4): 265-284.

DeCelles, P.G., Kapp, P., Gehrels, G.E. and Ding, L. 2014. Paleocene-Eocene foreland basin evolution in the Himalaya of southern Tibet and Nepal: Implications for the age of initial India-Asia collision. Tectonics, 33(5): 824-849.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A. and Ryberg, P.T. 1983. Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geological Society of America Bulletin, 94(2): 222-235.

Guillot, S., Garzanti, E., Baratoux, D., Marquer, D., Mahéo, G. and de Sigoyer, J. 2003. Reconstructing the total shortening history of the NW Himalaya. Geochemistry, Geophysics, Geosystems, 4(7).

Kazmi, A.H. and Abbasi, I.A. 2008. Stratigraphy & historical geology of Pakistan. Department & National Centre of Excellence in Geology Peshawar, Pakistan.

Malkani, M.S. and Mahmood, Z. 2017. Stratigraphy of Pakistan. Geological Survey of Pakistan, Memoir, 24: 1-134.

Morad, S., Al-Ramadan, K., Ketzer, J.M. and De Ros, L. 2010. The impact of diagenesis on the heterogeneity of sandstone reservoirs: A review of the role of depositional facies and sequence stratigraphy. AAPG bulletin, 94(8): 1267-1309.

Najman, Y., Pringle, M., Godin, L. and Oliver, G. 2002. A reinterpretation of the Balakot Formation: Implications for the tectonics of the NW Himalaya, Pakistan. Tectonics, 21(5): 9-1-9-18.

Naseer, S., Ahmad, D. and Hussain, Z. 2019. Petrographic, Physical and Mechanical Properties of Sandstone of Mirpur District Area State of AJ&K, Pakistan. Earth Sciences Malaysia (ESMY), 3(2): 32-38.

Rahim, Y., Lia, Q., Jadoona, U.F., Lutfia, W., Khanb, J. and Akhtarc, S. 2020. Microfacies Analysis of Late Jurassic Samana Suk Formation, Hazara Basin Lesser Himalaya North Pakistan. Earth Sciences Malaysia (ESMY), 4(2): 102-107.

Raiverman, V. 2013. A brief account of the continuum from Karakoram and Himalayan ranges to foreland and ocean basins. Journal of the Geological Society of India, 81(3): 337-349.

Siyar, S., Awais, M., Zafar, M., Waqas, M. and Faisal, S. 2018. Reservoir characterization of Paleocene clastics and carbonates in Chanda-01 well, Kohat Basin, Khyber Pakhtunkhwa, Pakistan: a petrophysical approach. The Nucleus, 55(1): 27-32.

Umar, M., Sabir, M.A., Farooq, M., Khan, M.M.S.S., Faridullah, F., Jadoon, U.K. and Khan, A.S. 2015. Stratigraphic and sedimentological attributes in Hazara Basin Lesser Himalaya, North Pakistan: their role in deciphering minerals potential. Arabian Journal of Geosciences, 8(3): 1653-1667.

Valdiya, K. 2011. Some burning questions remaining unanswered. Journal of the Geological Society of India, 78(4): 299.

Yar, M., Hanif, M. and Sajid, M. 2021. Lithofacies and petrography of Miocene Murree Formation, Peshawar basin, NW Pakistan: implications for provenance and paleoclimate. Arabian Journal of Geosciences, 14(8): 1-14.

Yasin, M., Ali, S.M.K., Munir, H. and Ishfaque, M. 2017. The Sedimentary Geology, Remote sensing, Geomorphology and Petrology of Miocene to Late Pliocene sediments in District Sudhunhoti and Poonch, Azad Jammu and Kashmir, Pakistan. Earth Sciences Malaysia (ESMY), 1(1): 8-14.

Yin, A. 2006. Cenozoic tectonic evolution of the Himalayan orogen as constrained by along-strike variation of structural geometry, exhumation history, and foreland sedimentation. Earth-Science Reviews, 76(1-2): 1-131.

Zeitler, P.K., Koons, P.O., Bishop, M.P., Chamberlain, C.P., Craw, D., Edwards, M.A., Hamidullah, S., Jan, M.Q., Khan, M.A. and Khattak, M.U.K. 2001. Crustal reworking at Nanga Parbat, Pakistan: Metamorphic consequences of thermal-mechanical coupling facilitated by erosion. Tectonics, 20(5): 712-728.