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Sedimentology and Economic Significance of Hangu Formation, Northwest Pakistan

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Abstract: The Hangu Formation (Paleocene) consists of sandstone, siltstone, carbonaceous shale, coal and laterite. It is well exposed in the Trans Indus Surghar range and the southern Hazara basin. The sandstone is yellowish brown, fine to coarse grained and medium to thick bedded. The sandstone of the Hangu Formation is classified as quartz arenite on the Q-F-L diagram. It is mostly grain supported and are cemented by silica cement. The study of different stratigraphic sections reveal that Hangu Formation can be sub-divided into a number of lithofacies on the basis of sedimentary structures and lithological variations. These include lateritic lithofacies, coal and carbonaceous shale, cross-bedded sandstone, bioclastic limestone and bioturbated sandstone. All these lithofacies are well-developed in the Baroch Nala section of the Surghar range except the lateritic lithofacies which contains a thin bed of ferruginous clay. In the studied sections of the Hazara basin, the lateritic lithofacies is the only well-developed lithofacies present in the area. The coal occurs at two stratigraphic levels in the Baroch Nala section. The lower coal seam is thick and its chemical study indicates higher calorific value and carbon content than the upper coal seam and with low moisture/ash content. On the basis of the calorific value, the coal of the Hangu Formation is characterized as high volatile bituminous. The degree of laterization is strong in the Langrial and Khanpur sections and moderate in Baroch Nala section.

Keywords: Trans Indus Surghar range, Paleocene, laterization, calorific value.

Introduction

The Hangu Formation of Paleocene age has been studied in detail in the Baroch Nala section of the Trans Indus Surghar range and the Khanpur and Langrial sections in the Hazara basin. The Trans Indus Surghar Range is the western continuity of the Salt range and represents the southern boundary of the Kohat basin in the foreland fold and thrust belt (Powel, 1979). They have stratigraphic rock record ranges from Permian Wargal Formation to Siwaliks (Shah, 2009). The eastern extremity of Surghar range is the Kalabagh strike slip fault which separates it from the youngest southernmost foreland thrust known as Salt Range Thrust (SRT) (McDougall and Khan, 1990). The east-west structural trend of the Trans Indus Surghar Range changes along the eastern flank of Bannu basin and became north-south aligned (Khan and Opdyke, 1993) (Fig 1). The Hazara basin is an east-west oriented piggy back basin in the intensely deformed fold and thrust belt with 7-8 km of sedimentary cover above the metamorphosed basement and merges into Hazara-Kashmir syntaxis (Lillie et al., 1987). It is a part of Lesser Himalayas and is bounded by Main Boundary Thrust (MBT) in the north and Panjal Thrust in the south (Ghazanfer et al., 1987).

The Hangu Formation of Makarwal Group is well exposed in the Trans Indus Surghar range and in the Hazara basin (Latif, 1969; Shah, 2009). The Paleocene succession in the Surghar range and Hazara region consists of both clastic and non-clastic rocks. The Hangu Formation comprises of clastic rocks. Its lower contact in the Surghar Range is unconformable with the Lumshiwal Formation of the Cretaceous age while in the Hazara region; the lower contact is conformable with the Kawagarh Formation. The upper contact with the Lockhart Formation in both the area is sharp and conformable (Shah, 2009). An age of Early Paleocene has been assigned to it (Hangu Formation) on the basis of faunal presence (Haque, 1956; Iqbal 1972). However, an age of middle to late Paleocene has been assigned to it on the basis of presence of nanofossils, dinoflagellates and pollen and spores' data (Kothe, 1988; Danilchik and Shah, 1987). The proposed study section at Baroch Nala, Surghar Range (Lat. 32˚ 50′ 41.1", Long. 71˚ 08′ 44.5"), Khanpur Dam (Lat. 33° 50' 32.14"N, Long. 72° 59' 8.34"E) and Langrial (Lat. 33° 55' 7.82"N, Long. 73° 7' 29.74"E) contain excellent exposure of the Paleocene Hangu Formation of Makarwal Group (Fig. 1). The Makarwal Group comprises of the Hangu, Lockhart and Patala formations (Table 1).

The first study and description of the coal of the Hangu Formation is done in the Makarwal area (Simpson, 1904; Gee, 1948). The detailed study of the Makarwal coal fields is done by Danilchik and Shah (1987). Also, the study describing the petrographic characteristics of the coal in the Makarwal area is done by various researchers (Abid and Abbasi, 1984; Ghaznavi, 1988). However, an integrated study to describe the

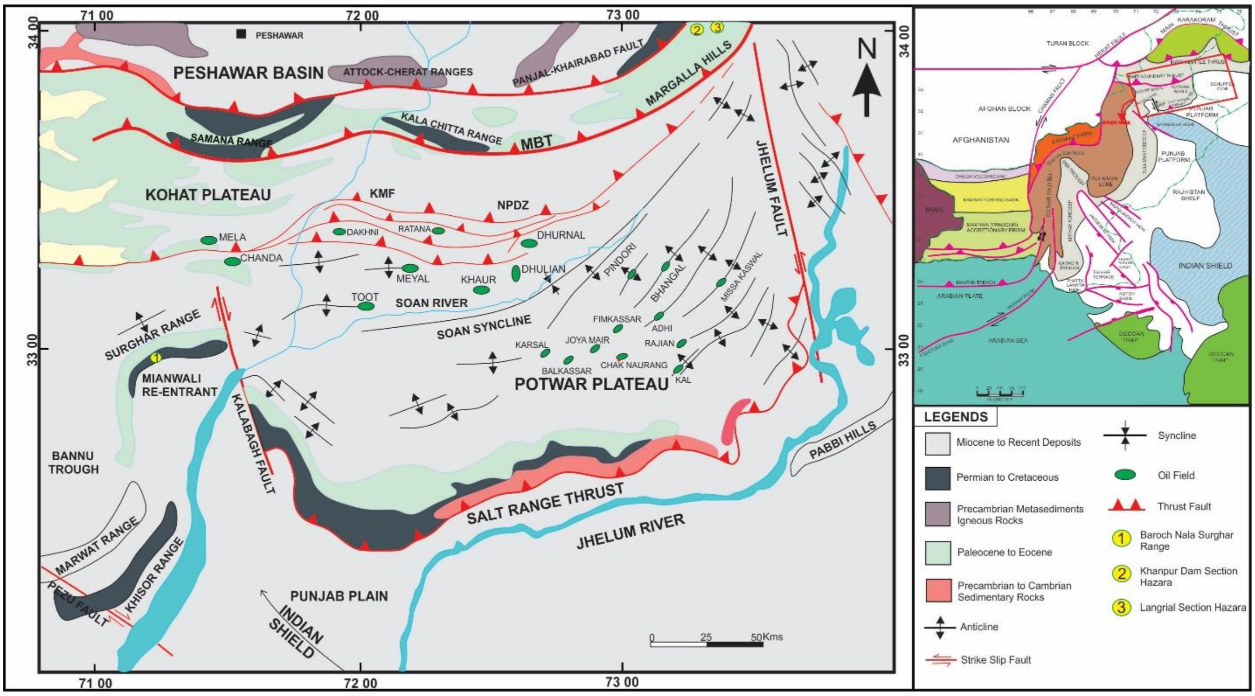

Fig. 1 Location map of the studied sections in the Trans-Indus Surghar Range and the Hazara Basin (modified after Gee, 1989).

lithological variation, petrographic description, geochemical character of the coal and laterite as well as their economic significance and comparison in both the Trans Indus Surghar Ranges and Hazara Basin is still lacking. The current study describes the lithofacies identification and lateral variation, sandstone petrography and economic deposits i.e. coal and laterite geochemistry in the Baroch Nala, Khanpur dam and Langrial Section.

Regional Geology of the Western Himalayas

Pakistan has a complex geological history as a result of collision of Indian and Eurasian plates. The collision of these major tectonic plates resulted in Himalayan orogeny and formed major suture zones in North Pakistan i.e. Main Karakoram Thrust (MKT) and Main Mantle Thrust (MMT). The deformation associated with Himalayan orogeny opened further thrust systems in Pakistan known as Main Boundary Thrust (MBT) and Salt Range Thrust (SRT). The Main Boundary Thrust (MBT) or Panjal-Khairabad fault divided the Himalayan fold and thrust belt into the hinterland zone which is towards north and the foreland zone is towards south (Pivnik and Wells, 1996; DiPietro et al., 1999). The foreland zone consists of Hazara-Kashmir syntaxis, Kohat-Potwar fold belt, Salt Range and Kurram-Cherat-Margalla thrust belt while Himalayan crystalline nappe and thrust belt is a part of hinterland zone. The current study is a part of foreland zone (Fig. 1).

Sampling and Geochemical Analysis

A 46 m thick section of the Hangu Formation was measured and logged in the Baroch Nala (Surghar range), Khanpur Dam and Langrial Section (Hazara Basin) and 22 samples were collected for carrying out petrographic and geochemical studies. The sample intervals were based on both lithological and textural variations.

Results and Discussion

Lithofacies Analysis of the Hangu Formation

The detailed sedimentological studies of the Hangu Formation show wide variation in the lithology. The principal lithology is sandstone with carbonaceous shale, coal, siltstone, laterite and a minor limestone bed. The Hangu Formation is interpreted to be deposited in shallow marine and deltaic depositional environment on the basis of the sedimentary structures and its lithology (Danilchik and Shah, 1987; Shah, 2001). The Baroch Nala section is considered as a principal section to designate the main lithofacies present in the Hangu Formation and is compared laterally with the Khanpur and Langrial sections. From bottom to top, there are five lithofacies recognized in the Hangu Formation.

a) Lateritic lithofacies
b) Coal and carbonaceous shale lithofacies
c) Cross-bedded sandstone lithofacies
d) Bioclastic limestone lithofacies
e) Bioturbated sandstone lithofacies

a) Lateritic lithofacies

This lithofacies marks the base of the Hangu Formation in the Baroch Nala, Langrial and Khanpur dam section and comprise of laterite, ferruginous clay and sandstone. According to Valeton (1983), tropical areas with seasonal variations in the weather (wet and dry) developed laterite most commonly. Laterite shows their longer exposure to changing weathering conditions (Abbasi et al., 2011). The appearance of laterite at the base of the Hangu Formation marks a depositional break and also an evidence of Cretaceous-Tertiary (K-T) boundary. It is 0.2 m thick in the Baroch Nala section of the Surghar Range and consists of ferruginous clay while its thickness in the Langrial and Khanpur areas of Hazara Basin are 5 m and 6 m respectively and consists of laterite, ferruginous clay and sandstone (Fig. 2).

Table 1 Generalized stratigraphic column of the Surghar Range and the southern Hazara (modified after Danilchik and Shah, 1987; Latif, 1970).

Era	Period	Group	Surghar Range	Southern Hazara
Cenozoic	Pliocene	Siwalik	Soan	-
			Dhok Pathan	-
	Miocene		Nagri	-
			Chinji	-
		Rawalpindi	Kamlial	-
			Murree	Murree
	Unconformity			
	Eocene	Chharat	Chorgali	Kuldana
			Sakesar	Chorgali
			Nammal	Margala Hill
	Paleocene	Makarwal	Patala	Patala
			Lockhart	Lockhart
			Hangu	Hangu
	Cretaceous-Tertiary Boundary			
Mesozoic	Cretaceous	Surghar	Kawagarh	Kawagarh
			Lumshiwal	Lumshiwal
			Chichali	Chichali
	Jurassic	Baroch	Samana Suk	Samana Suk
			Shinawri	-
			Datta	Datta
	Triassic	Musa Khel	Kingriali	-
			Tredian	-
			Mianwali	-
	Permo-Triassic Boundary			
Paleozoic	Permian	Zaluch	Chhidru	-
			Wargal	
Precambrian	-	-	-	Hazara

b) Coal and Carbonaceous Shale Lithofacies

This lithofacies overlies the laterite and comprise of coal, carbonaceous shale and sandstone. This lithofacies is well developed in the Baroch Nala section of Surghar range while it laterally pinches and is absent in the Khanpur and Langrial sections. In the Baroch Nala, coal lithofacies is present at two stratigraphic levels i.e. lower stratigraphic level (C1) and upper stratigraphic level

(C2). The C1 coal seam lies above the carbonaceous shales in the lower part of the formation and is the main coal layer with variable thickness (0.5-1.5 m). The C1 coal is dull to shining black, soft and powdery. The C2 coal seam lies in the upper part of the formation and is less in thickness than C1 i.e. 1 m thick in the Baroch Nala (Fig. 2). It is bounded on top and bottom by thin parallel laminated sandstone beds. The coal facies are deposited in humid vegetated swamp area. Specially, along the beach ridge barrier which is occupied by marshland and swamps. These are the ideal conditions for the accumulation of peat, coal and carbonaceous shales (Abbasi et al., 2011).

c) Cross-bedded Sandstone Lithofacies

This lithofacies overlies the coal and carbonaceous shale lithofacies and consist of sandstone, shale and siltstone (Fig. 2). The sandstone is brown to dark grey in color and medium to thick bedded. The shale is grey to brown in color and contain thin layers of coal. The sandstone has low angle cross-bedding with some bioturbation at the top. These facies show fining upward sequence. The thickness of this lithofacies in the Baroch Nala is 20 m while it is absent in the Khanpur and Langrial sections of the Hazara region. It shows deposition in the high energy fluvial settings.

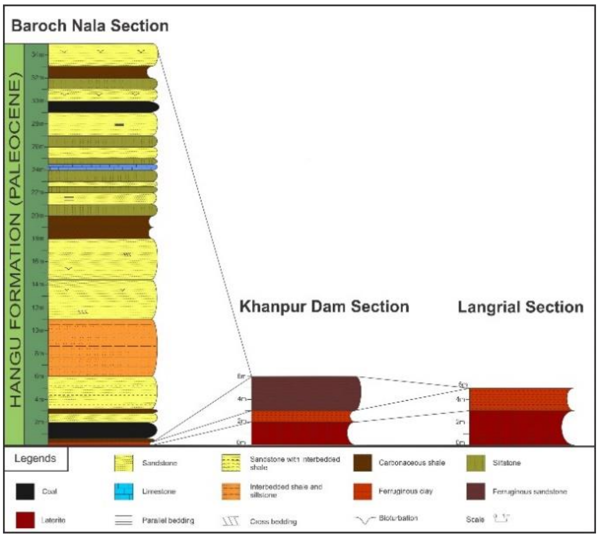

Fig. 2 Lithologic log of the Paleocene Hangu Formation.

d) Bioclastic Limestone Lithofacies

This lithofacies overlies the cross-bedded sandstone lithofacies and is grey to light grey in color. It is thin to medium bedded and is highly fossiliferous. The fossils include brachiopods, gastropods and foraminifera. It is deposited in shallow marine depositional environment. It is 0.5 m thick in the Baroch Nala section and is developed in the form of lenses showing lateral discontinuity. However, it is absent in the Khanpur and Langrial sections of the Hazara Basin (Fig. 2).

Table 2 Percentage modal proportions of framework elements in the Hangu sandstone.

SN	S#	Quartz			Feldspar		Lithic	Mica	Cement	Ore	Acces. Miner.	Classification
		Qt	Qm	Qp	AlkFel	Plg.						Pettijohn (1975)
1	H1	90	89	1	2	1	1	0.5	5	0	0.5	Qtz-Arenite
2	H2	94	91	3	1.8	0.2	1	0	2	0	1	Qtz-Arenite
3	H3	91	91	0	2.4	0.6	0	1	3	1.8	0.2	Qtz-Arenite
4	H4	90	89.5	0.5	3	0	2	1	2	1	1	Qtz-Arenite
5	H5	88	88	0	2.5	0.5	1.5	2.5	2	3	0	Sub-Felds. Arenite
6	H6	92	90	2	4	1	1	0	1	0.4	0.6	Qtz-Arenite
7	H7	91	90.5	0.5	2.7	0.3	3	0	2	2	0	Qtz-Arenite
8	H8	89	89	0	2	0	0.5	1	6	0.5	1	Sub-Felds. Arenite
9	H9	95	92	3	1	0	0	0.5	3	0.5	0	Qtz-Arenite
10	H10	90	89	1	3	1	1	0	4	1	0	Qtz-Arenite
11	H11	88	87.8	0.2	2.8	0.2	2	1	3	2	1	Sub-Felds. Arenite
12	H12	93	92	1	1	0	0.5	0	5	0.5	0	Qtz-Arenite

e) Bioturbated Sandstone Lithofacies

This lithofacies comprises of sandstone, siltstone and shale (Fig. 2). It marks the middle and the topmost beds of the Hangu Formation at contact with the overlying Lockhart limestone. The sandstone is light grey to grey, medium to thick bedded, medium grained and is highly bioturbated. The upper part of the formation is highly bioturbated as compared to the middle part of the formation. Both vertical and horizontal style of bioturbation is present. The presence of burrows/bioturbation indicate deposition in the tidal flat environment (Reading, 1986). This lithofacies is 5 m thick in the Baroch Nala section of the Surghar Range while it is absent in the Khanpur and Langrial sections of the Hazara basin.

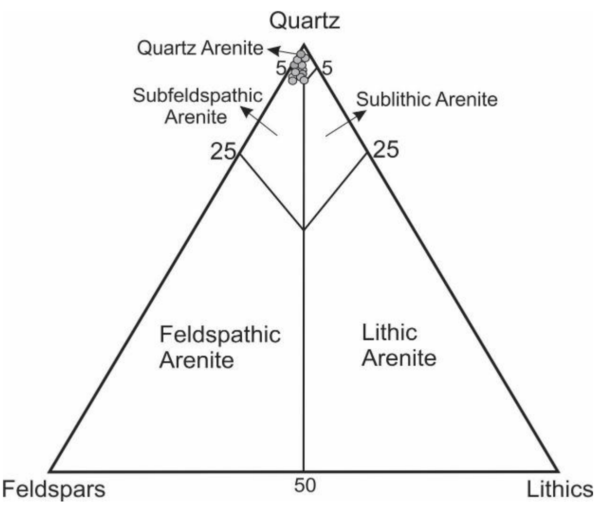

Fig. 3 QFL diagram of the Hangu Formation sandstone after Petti john (1975) based on framework element proportions.

Petrography of the Hangu Sandstone

The petrographic study of sandstone of the Hangu Formation shows it as dominantly grain supported and moderately sorted. The principal cement is silica/quartz along with calcite and ferruginous cement. The grain contact ranges from point to concavo-convex through sutured. The average modal abundance of framework grains is 91 (quartz), 2.75 (feldspar) and 1.13 (lithics) volume percent, respectively (Table 2). The framework grains are sub-angular to sub-rounded. Quartz grains with its typical varieties i.e. monocrystalline and polycrystalline are present. The monocrystalline quartz grains are more abundant than polycrystalline grains. Some of the grains have developed quartz cement as overgrowth and mica is present as inclusions in some quartz grains.

Feldspar is second most dominant framework grains in the Hangu sandstone. Both alkali feldspar and plagioclase are present. The average abundance of alkali feldspar is more than plagioclase (Table 2). Microcline and orthoclase are the two varieties of alkali feldspar observed in the Hangu sandstone. Lithics (volcanics) are also present in the studied sandstone. Mica (biotite/muscovite) is present with modal abundance of 0.63. Muscovite is more abundant than biotite. The heavy minerals observed in the Hangu sandstone are tourmaline, zircon, rutile and sphene. Major diagenetic signatures observed are chemical and mechanical compaction, cementation, replacement and grain fracturing. The petrographic study of the Hangu Formation sandstone classified it as quartz arenite on the basis of framework grains (Petti john, 1975) (Fig. 3).

Economic Significance

The Paleocene Hangu Formation is economically rich as it contains coal and laterite. These deposits are economically viable and can be used for various industrial purposes. The shales of the Hangu Formation are important as a hydrocarbon source rock. In order to determine the economic grade of the coal and laterite/iron ore, geochemical analysis was carried out which are discussed below.

Geochemical Analysis of Coal

Coal is defined as an organo-clastic sedimentary rock which is composed of lithified plant debris. Peat is the starting moist material which becomes dry, compressed and undergoes modification both in texture and composition during the process of diagenesis associated with burial (Ward, 1984).

In Pakistan, the coal beds are generally characterized as lignite-A to sub-bituminous-C, lenticular bodies (generally 2 m thick or less) that are early Tertiary in age (Warwick and Javed, 1990). Most of the coal beds in Pakistan show high ash (7-33 %) and sulphur (2.5-6.5 %) Warwick and Javed, (1990). The grade of Pakistan coal deposits is poorer and relatively younger in age because of the particular environment of deposition and the short time of putrefaction (decay) (Ahmed, 1986). The mining of coal in the Makarwal area of Surghar Range dates back to 1903 (Ball and Simpsons, 1913). According to Danilchik and Shah (1987), the coal reserves of Makarwal coal field are estimated to be 21.6 million tons. The coal of Makarwal is ranked as high volatile B to C bituminous (Landis et al., 1971; Ghaznavi, 1988).

Two coal samples from the Baroch Nala section of the Surghar range are selected for geochemical analysis. One sample is from the lower coal seam (C1) and the other from the upper coal seam (C2). The C1 coal seam is the main seam where mining is carried out in Makarwal coal field (Baroch Nala). This seam lies just above the lateritic bed and ranges in thickness from 0.5 to 1.5m. It is dull to black in appearance, soft and break easily into pieces or powder. The C2 coal seam is 1m thick and present in the form of lenses bounded by parallel laminated sandstone. The gross calorific and fixed carbon value of C1 is greater than C2 while moisture and ash content is less than C2 (Table 3) which makes it a good quality coal than C2. The gross calorific value of sub-bituminous coal is 4000-5800 kcal/kg while the calorific value of bituminous coal is more than 5800 kcal/kg. The gross calorific value of coal in the Baroch Nala (Surghar Range) ranges from 6500-6700 kcal/kg and is ranked as high volatile bituminous coal.

Table 4 shows the comparison of the Paleocene Hangu Formation in the Baroch Nala (Surghar range) with different coal mines belonging to various formations and ages with respect to fixed carbon, moisture, ash, total sulphur, volatile matter and the heat values (Ahmed et al., 1986; Kazmi et al., 1990; Hussain et al., 1990). The Paleocene Hangu Formation in the Hangu and Makarwal coal mines shows higher heat value (BTU/lb) as compared to Paleocene Bara Formation of the Sindh and the Eocene Ghazij Formation in the Baluchistan.

Table 3 Chemical analysis of Lower (C1) and Upper Coal (C2) seam.

Parameters	Result (C1)	Result (C2)
Moisture content	2.49%	2.88%
Ash	16.82%	18.65%
Volatile matter	50.36%	48.93%
Fixed carbon	30.33%	29.54%
Sulphur	1.31%	0.92%
Gross calorific value (Kcal/Kg)	6724.16	6539.16

Table 4 Comparative analytical data of the various coal fields of Pakistan (after Ahmed et al., 1986; Kazmi et al., 1990; Hussain et al., 1990).

Coal field	Hangu	Attock Cherat	Makar wal	Salt Range	Sindh	Baluchi stan
Age	Paleoc	Paleoc	Paleoc.	Paleoc	Paleoc	Eocene
Fm	Hangu	Hangu	Hangu	Patala	Bara	Ghazij
Fixed C	53	51.2	40.3	34.6	25.2	58.1
Moist.	0.3	7.1	5.5	7.6	28.5	9.6
Ash	14.9	9.3	11.2	24.3	6.1	13.6
Total S.	4.2	1.3	5.14	5.58	4.78	4.99
Volatile matter	30	20	43.1	33.39	27.98	40.29
BTU/lb	12918	9386	11237	9115	6680	9816

Geochemical Analysis of Laterite

Laterite is a soil/rock rich in iron and aluminium and is more common in the tropical region which experiences alternating dry and wet seasons periodically (Alexander et al., 1956). During laterization, parent rocks undergo removal of magnesia, silica, soda, potash and lime and the enrichment in iron and aluminium oxides (Fuchtbauer and Richt, 1988). In Pakistan, laterites are present stratigraphically in the time period of Cambrian, Devonian, Jurassic, Cretaceous-Paleocene and Oligocene (Ahmad, 1969). However, the most important and widespread laterites are associated with Cretaceous-Paleocene and occur at the base of the Hangu Formation in Kohat-Potwar and Hazara Basin (Shah, 1984). Laterites are also well developed in the Hazara basin and poorly developed in the Surghar range.

During the current study, two samples of laterite from each studied section (Baroch Nala, Khanpur and Langrial section) are analyzed chemically to infer its enrichment relative to iron oxide/bauxite. The geochemical results are also analyzed for their comparison in both study areas. The major element geochemistry of the laterite ore indicates that it is enriched relative to iron and depleted in terms of silica and aluminium contents (Table 5). Alkalis show low values as these elements are highly mobile and may leached out during chemical weathering. The concentration of Fe_2O_3 in the Langrial area ranges from 20.09-58.54 wt%. The sample L-1 is iron rich with low silica and aluminum contents while sample L-2 is iron and aluminium poor and shows silica enrichment.

Table 5 Geochemical data of laterite.

Oxides	L-1	L-2	K-1	K-2	SR-1	SR-2
SiO_2	16.04	60.37	13.99	18.41	25.25	20.85
TiO_2	0.26	1.11	0.33	0.43	0.72	4.07
Al_2O_3	11.04	8.61	8.90	11.91	9.42	25.57
Fe_2O_3	58.54	20.09	62.38	50.87	54.33	31.81
MnO	0.07	0.10	0.16	0.43	0.04	0.08
MgO	2.75	2.02	1.93	2.58	0.39	0.00
CaO	2.41	0.48	1.79	2.26	2.41	1.38
Na_2O	0.45	0.36	0.68	0.46	0.38	0.39
K_2O	0.01	0.02	0.03	0.03	0.03	0.02
P_2O_5	1.37	0.09	0.71	0.44	0.26	0.17
LOI	7.09	6.77	9.09	12.19	6.77	15.76
Al_2O_3/ Fe_2O_3	0.18	0.42	0.14	0.23	0.17	0.80
Al_2O_3/SiO_2	0.68	0.14	0.63	0.64	0.37	1.22

The silica rich sample represents poor or weak degree of laterization. Similarly, the Fe_2O_3 concentration in the Khanpur area ranges from 50.87 - 62.38 wt%. These two samples are iron rich and depleted relative to silica and alumina. Moreover, the samples from the Surghar range shows Fe_2O_3 concentration which ranges from 31.8 - 54.3 wt%. Both of these samples are silica and alumina poor. Hence, it can be concluded on the basis of geochemical study that the laterite ore in the Hazara region have higher iron content as compared to the one present in the Surghar range.

Schellmann (1982) used the ternary plot of SiO_2, Al_2O_3 and Fe_2O_3 to determine the degree of laterization. The plotted data indicate strong degree of laterization in the Khanpur and Langrial sections while laterite of the Baroch Nala (Surghar range) indicates moderate laterization (Fig. 4).

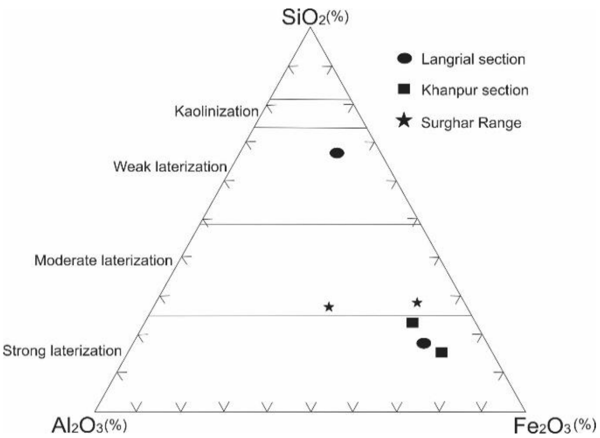

Fig. 4 Ternary plot of SiO_2, Al_2O_3 and Fe_2O_3 to determine the degree of laterization (after Schellmann, 1982).

Conclusion

The Paleocene Hangu Formation comprises of sandstone, siltstone, carbonaceous shale, limestone, coal and laterite has been studied in detail to identify the lithofacies and its lateral variation in the Surghar and Hazara Ranges. The five lithofacies are classified as laterite lithofacies, coal and carbonaceous shale lithofacies, cross-bedded sandstone lithofacies, bioclastic limestone lithofacies and bioturbated sandstone lithofacies. On the basis of framework grains, the sandstone has been classified as quartz arenite. The Surghar Range has well developed coal lithofacies, limestone lithofacies and cross bedded and bioturbated sandstone lithofacies while the laterite lithofacies is well-developed in the Hazara Basin. On the basis of geochemistry, it is concluded that Hangu Formation has potential of economic deposits both in the Surghar Range (coal deposits) and the Hazara Basin (Laterite deposits) which can be extracted and use for commercial purpose.

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