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Petrographic and geochemical evidence for determining the provenance of the Nari Formation, Pakistan

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Abstract

The geochemical and petrographic characteristics of the Nari Formation (NF) have been thoroughly examined at the Haji Haroon section in the Lower Indus Basin (LIB), located in the Northern Laki Range, approximately 20 kilometres south of Therhi village, Sehwan Sharif. The NF is predominantly composed of sandstone, multicoloured clays, shale and limestone in the Haji Haroon section. The geochemical analysis of major elements using the automated Scanning Electron Microscopy Energy Dispersive Spectrometer (automated SEM-EDS) reveals that quartz is the dominant mineral in all the studied sandstones, typically comprising over 75% and reaching up to 90%, and the second dominant phase mineral is calcite which varies from sample to sample. The basal part of the NF sample, labelled HHS-02, consists of calcitic limestone, with calcite making up more than 85% of the weight. The previous studies in the Lower Indus Basin shows that the basal part and upper part of the Nari Formation are formed in fluvial environments. However, our study contradicted the existing paradigms and revealed novel insights into the depositional environment of the NF. The current petrography, SEM-EDS, and field observations suggest that the NF at the Haji Haroon section in the Northern Laki range does not solely originate from fluvial processes. Instead, the basal part of the formation is marine in origin, while the upper part is fluvial. The basal part is characterized by transitional environments, which may be deltaic or beach deposits due to the presence of significant amounts of both quartz and calcite. The samples bear an elevated amount of quartz, classifying them as quartz arenite. Therefore, it is determined from the shape of elastic quartz grains. and based on the existent rock fragments, that the sediments presumably originated in the western highlands rather than the northern Himalayas or the Indian shield.

Key words: Petrographic, Geochemistry, Sandstone, Nari Formation, Lower Indus Basin (LIB), Oligocene.

Resumen

Las características geoquímicas y petrográficas de la Formación Nari (FN) han sido examinadas en detalle en la sección de Haji Haroon, situada en la Cuenca del Bajo Indus (LIB), en la Cordillera Laki del Norte, aproximadamente a 20 kilómetros al sur de la aldea de Therhi, en Sehwan Sharif. La FN está compuesta predominantemente por arenisca, arcillas multicolores, lutita y caliza en la sección de Haji Haroon. El análisis geoquímico de los elementos mayores mediante Microscopía Electrónica de Barrido con Espectrometría de Energía Dispersiva automatizada (SEM-EDS automatizado) revela que el cuarzo es el mineral dominante en todas las areniscas estudiadas, alcanzando entre un 75% y un 90% en su composición. El segundo mineral en abundancia es la calcita, cuya proporción varía entre muestras. En la parte basal de la FN, la muestra etiquetada como HHS-02 consiste en caliza calcítica, con un contenido de calcita superior al 85% en peso. Los estudios previos en la Cuenca del Bajo Indus sugieren que las partes basal y superior de la Formación Nari se formaron en ambientes fluviales. Sin embargo, nuestro estudio contradice estos paradigmas previos y proporciona nuevas perspectivas sobre el ambiente deposicional de la FN. Los análisis petrográficos, SEM-EDS y las observaciones de campo indican que la FN en la sección de Haji Haroon, en la Cordillera Laki del Norte, no es exclusivamente de origen fluvial. Más bien, la parte basal de la formación tiene un origen marino, mientras que la parte superior es de origen fluvial. La parte basal se caracteriza por ambientes transicionales, que podrían corresponder a depósitos deltaicos o de playa, debido a la presencia significativa tanto de cuarzo como de calcita. Las muestras presentan un alto contenido de cuarzo, lo que permite clasificarlas como arenitas cuarzosas. A partir de la morfología de los granos clásticos de cuarzo, se ha determinado que los sedimentos probablemente se originaron en las tierras altas del oeste en lugar del Himalaya septentrional o del escudo índico, con base en la identificación de fragmentos de roca preexistentes.

Palabras clave: Petrografía, Geoquímica, Arenisca, Formación Nari, Cuenca del Indus Inferior (LIB), Oligoceno.

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1. Introduction

The petrography of clastic sedimentary rocks is crucial to determine different geological aspects, such as provenance, tectonic background, and paleo-weathering. It can also be used in conjunction with other techniques to decipher paleogeographic records and inferences about paleoclimate (Armstrong-Altrin *et al.*, 2004; Quasim *et al.*, 2017; Paryal, 2020). The petrography of sandstones has been broadly used to evidence their provenance (Dickinson *et al.*, 1983; Donahue *et al.*, 1990; Khan *et al.*, 2020). Petrographic parameters of sedimentary rock such as mineralogy, lithic composition, and texture, can be used to determine paleocurrent, paleoclimate and source of siliciclastic sedimentary rocks (Ali and Barrufet, 1995; Quasim *et al.*, 2017; Paryal, *et al.* 2020).

In addition, petrography provides useful information that supplement geochemical data. For example, the presence of specific minerals, e.g., quartz, feldspar, or clay minerals, can be linked with the geochemical data to determine the general composition of sedimentary rock. (Armstrong-Altrin *et al.*, 2004; Ghosh *et al.*, 2012; Garzanti., 2019). The geochemical compositions of detrital sedimentary rocks represent a highly valuable tool to identify the characteristics of their source rocks (McLennan *et al.*, 1993; Armstrong-Altrin *et al.*, 2004), weathering and erosion dynamics (Nesbitt and Young, 1996), post-depositional changes (Ghosh *et al.*, 2012), and the tectonic setting of the depositional basins (Armstrong-Altrin *et al.*, 2015; Paryal, 2020). The distribution and abundance of some major elements (i.e., calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na)) in certain environments can also be a valuable tool for reconstructing past climates (Rajabzadeh *et al.*, 2019).

The clastic rocks of the Lower Indus Basin mountains are arranged in a chronological order spanning from Cretaceous (Pab Sandstone) to Pleistocene (Dada Conglomerate) (Brohi *et al.*, 2014; Khokhar *et al.*, 2016; Rajabzadeh *et al.*, 2019). The deposition of Pab Sandstone preceded the Himalayan orogeny while, the other clastic rocks of the Laki Range are the result of Himalayan orogeny (Dott, 1964; Bhatia and Crook, 1986; Ali and Barrufet, 1995; Brohi *et al.*, 2014). All of these formations are being investigated by various researchers from numerous prospects, yet only a slight understanding has been gained about their provenance lithology, exclusively in the Lower Indus Basin (LIB) (Figure 1A) (Ibrahim, 1977; Pilbeam *et al.*, 1977; Kazmi and Jan, 1997) .

The Nari Formation (NF) at the Haji Haroon section, near the Therhi village in Sehwan Sharif, was selected for this study due to its easy access and well-exposed outcrops (Figure 1B). The Nari Formation in this section primarily consists of fossiliferous limestone, weathered shale, calcareous and ferruginous sandstone, as well as other minerals, gypsum mineralization, and stranded clastic dykes formed by the burrows, fossils which are collected at the study area, echinoderms, gastropods, and nummulites. There is a presence of a honeycomb structure filled with gypsum mineral at the contact between the Nari Formation and the Khirthar Formation. (Figure 2B).

Previous study shows that the basal and upper parts of the NF formed in a fluvial environment (Mahmud and Sheikh, 2009; Khokhar *et al.*, 2016; Shar *et al.*, 2021), but the current petrography, automated Scanning Electron Microscopy Energy Dispersive Spectrometer (SEM-EDS) and field study indicate that that the Nari Formation of Haji Haroon section, Northern Laki range is not purely fluvial in origin, the basal part of the Nari Formation is marine by the appearance of the siliceous limestone, the upper part is fluvial by the significate of the ferruginous sandstone. This research aims to 1) identify the provenance and source of the Oligocene Northern Laki Range of Haji Haroon Section Nari Formation Lower Indus Basin Pakistan, and 2) to properly characterize lithologically, petrographically, and geochemically features of the formation's units.

2. Stratigraphy of Study Area

During the field investigation, 5 formations were observed in the area. From the older to the younger Formations are: the Khirthar Formation, the Nari Formation, the Gaj Formation, the Manchar Formation, and the Dada Conglomerate (Table 1). The upper contact is conformable between Khirthar and Nari Formations which seem the burrows, honeycomb structure, echinoderms fossil and oxidation, and gypsum mineralization at Khirthar Formation (Figure 2) and the lower conformable contact between the Nari and Gaj Formations shows stranded clastic dykes that resemble burrows in the Nari Formation (Figure 2E). The Manchar Formation ages from the Upper Miocene throughout the Pliocene epoch. It Indicates the lower contact of the Dada Conglomerate. A Pleistocene age is assigned to the formation based on its stratigraphic position.

3. Material and methods

The Haji Haroon Section is located around 20 kilometers south of Therhi village near Sehwan Sharif, Sindh, Pakistan. The typical section of the investigated formation is Nari Nai near Wahi Pandhi. The section part is located in the town of Jamshoro, Sindh, Pakistan, north of the Laki Range, and is drawn on a Pakistani survey, Toposheet No. 35 N15, with coordinates 26°14’50” N latitude and 67°49’14” E longitude.

Two days field work was carried out for outcrop observation, description and sample collection. Based on the lithological

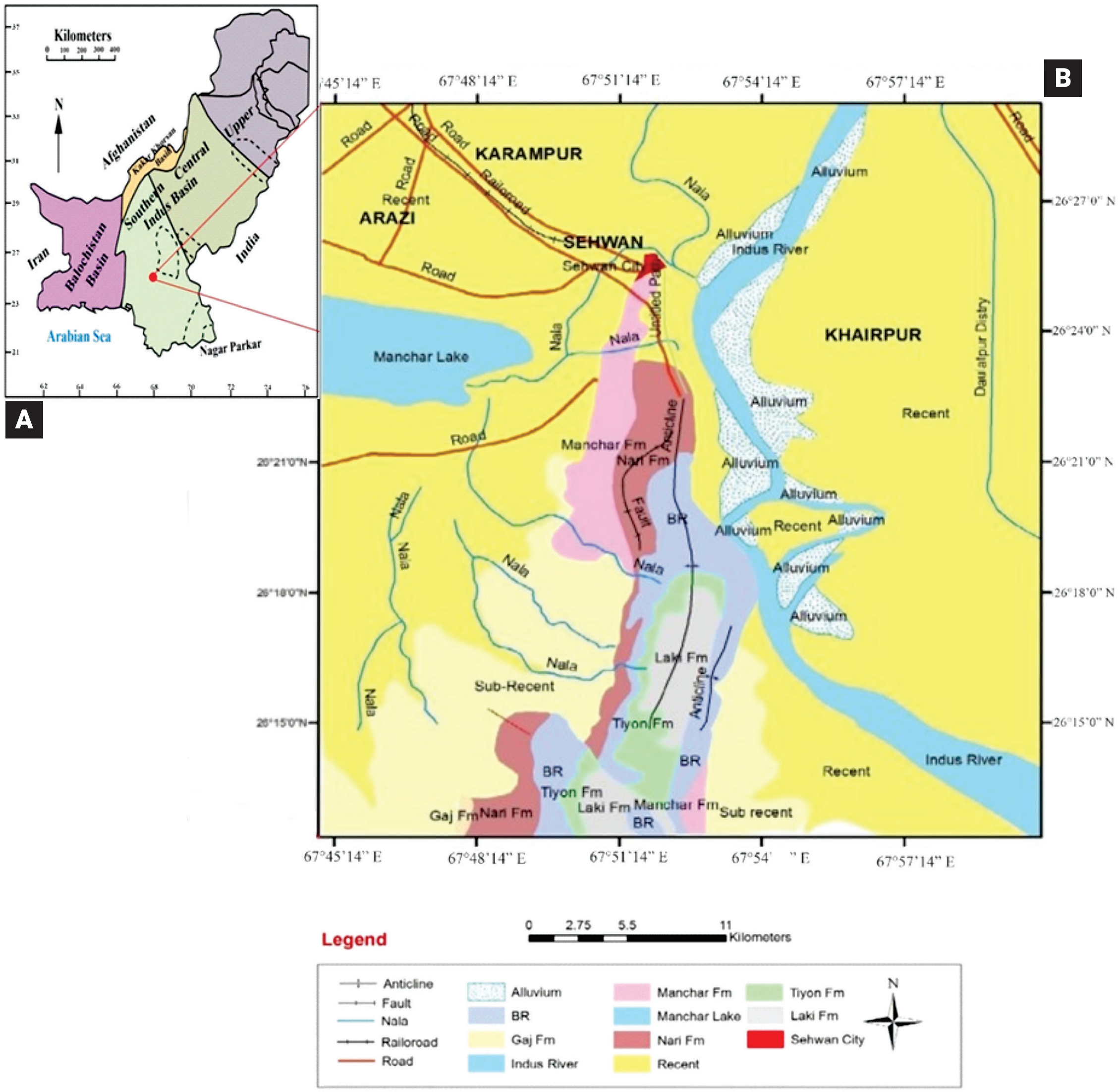

Figure 1. A) The Geological Map of Pakistan; B) the Canadian sheet of the Khirthar section Lower Indus Bisan (LIB) mark up the study area (Modify M.H Agheem *et al.*, 2020).

Table 1. Lithological composition of the study area, including the Nari Formation.

Age	Formation	Lithology
Pleistocene	Dada Conglomerate	Conglomerate
Miocene to Pliocene	Manchar Formation	Conglomerate, Sandstone and Shale
Early Miocene	Gaj formation	Shale, Sandstone and Limestone
Oligocene	Nari Formation	Sandstone, limestone and Claystone
Eocene	Khirthar Formation	Limestone

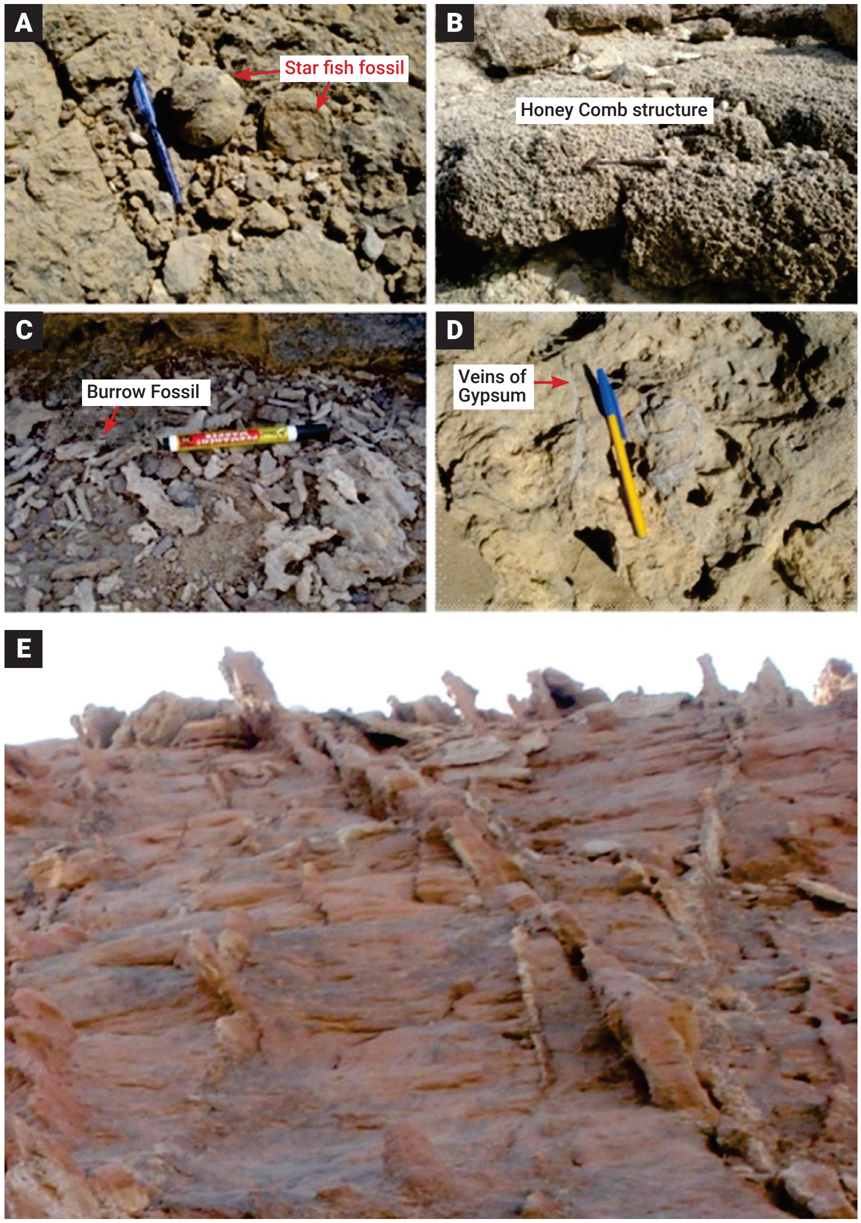

Figure 2. Field photograph showing A) the star fish fossil; B) Honey comb structure; C) the Burrow fossil; D) Veins of Gypsum mineralization, E) the stranded clastic dykes at Haji Haroon Section.

variation, sixteen (16) representative samples, with sample marking (HHS-01 to HHS-16) were collected from the Haji Haroon Section Nari Formation. Samples were collected at the contact between the Khirthar Formation and the Nari Formation, with a total thickness of 159.9 meters at the Haji Haroon section.

Petrographic analysis, which is considered one of the conventional techniques, is used to determine the source and provenance of the Nari Formation from Haji Haroon section. Micro petrographic methods were carried out with the aim to analyze the texture and mineralogy of the Haji Haroon Section Nari Formation from Northern Laki Range Lower Indus Basin.

3.1. Thin section Preparation for Petrographic Study

A total of eight representative samples out of sixteen samples were selected for petrographic examination samples. The rock samples were cut into rectangular slabs and polished on one side to create a smooth and flat surface for adhesion to glass specimen plates. The sample block was trimmed and the other side was polished again after the sample was bonded to the glass specimen plates, until an even surface (0.03mm) was created, permitting maximum light distribution across the specimen plates. The thin sections preparation and analysis were conducted at Geosciences Advance Research Laboratories, Islamabad, and Centre for Pure and Applied Geology, University of Sindh, Jamshoro (CPAG) respectively. A minimum of 300 points was determined per thin section using the point count technique on the petrographic microscope (Wahyu *et al.*, 2024). The LEICA 2500p transmitted light microscope was used for the examination and the LEICA DFC 290 camera for the photographs.

3.2. Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS)

Four samples were selected for SEM analysis to document the category, cement, shape, and size of the constituent grains. The smooth and fresh rock chips of the samples were carefully prepared and mounted on the sample stub using conductive double-sided carbon tape. The sample stub was then placed in the sample chamber of the JEOL JSM-6590LV SEM, which was equipped with an additional and crucial component, the Bruker EDS. The SEM system was controlled through the IMAGING INTERFACE software, while the EDS was operated using the QUANTAX software.

During the SEM analysis, the samples were examined under an accelerating voltage of 15 kV and a working distance of approximately 10 mm to obtain high-resolution images of the mineral grains and their textures. The imaging revealed the grain shapes, sizes, and the overall surface morphology of the rocks. To identify the chemical composition of the mineral grains, the EDS system was used, with an acquisition time of about 1-2 minutes per point to gather accurate elemental data. The EDS detected elements ranging from boron to uranium, providing insights into the mineralogy of the samples. Elemental mapping was also conducted to visualize the distribution of key minerals across the samples. All data and images were controlled and recorded through the computer system to facilitate further analysis. This analysis was performed at the Advanced Research Laboratory, Centre for Pure and Applied Geology, University of Sindh, Jamshoro.

5. Result

5.1. Petrographic Studies

The framework mineral composition of eight thin sections of Nari formation deposits (Tables 2 and 3) was determined by the point count technique on the petrographic microscope (Donahue *et al.*, 1990; Zahoor *et al.*, 2020; Wahyu *et al.*, 2024). The lowest of 300 points was calculated per thin section. The description of the samples is as follows:

HHS-1 (Compact Limestone)

Compact Limestone, fine-grained, subangular, moderately sorted, micritic calcite (microcrystalline calcite deposits of a size comparable to terrigenous clay 0.001 to 0.004 mm) and microfossils Lepidocyclina species are present (Figure 3), Calcite is dominant 90% with 3-5% of quartz (Table 2).

HHS-2 (Camel-coloured limestone)

Camel-coloured limestone, fine-grained, sub-angular to sub-rounded, poorly to moderately sorted. Micritic calcite (microcrystalline calcite deposits of a size comparable to terrigenous clay (0.001 to 0.004 mm), and calcite crystals deposited within veins, pore spaces or fissure (Figure 4). Calcite is dominant 85% with 4-5% of quartz, iron nodules 4 to 6%. (Table 2).

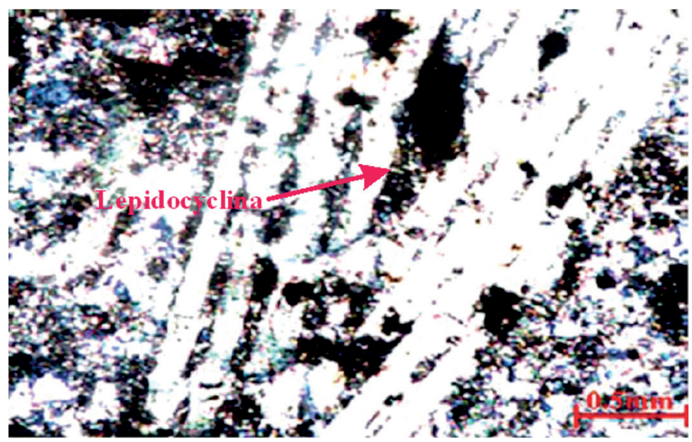

Figure 3. Microphotograph shows the Lepidocyclina in sample HHS-1.

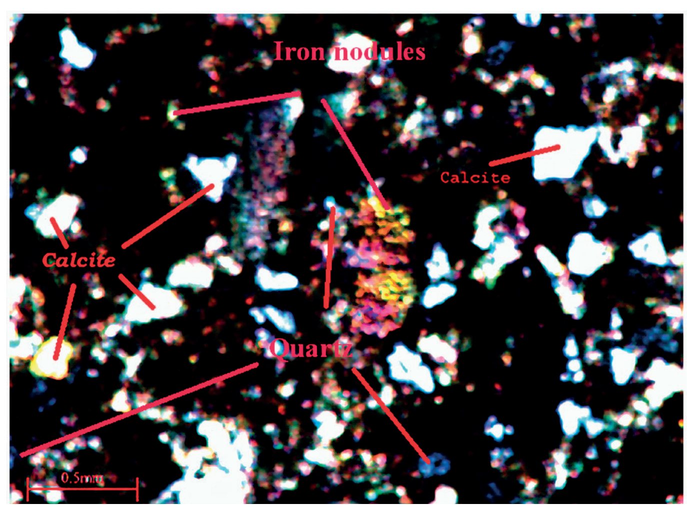

Figure 4. Microphotograph shows micritic calcite and few quartz grains in sample HHS-02.

HHS-6 (Compact sandstone)

Compact sandstone, coarse-grained, sub-angular to sub rounded, poor to moderately sorted (Figure 5). Calcite and iron oxide cement is present. Quartz is dominant 85%, Calcite 5-7%, 3-5% Iron oxide by weight percentage (Table 2).

HHS-9A (Compact sandstone)

Compact sandstone, fine-medium grained, sub-angular to angular, moderately sorted. Calcite cement is present, and iron oxides are also present. Rod shape ore bearing minerals are also present (Figure 6). Quartz is dominant 90%, no rock fragment, and 3-5% calcite (Table 2).

HHS-9B (Ferruginous sandstone)

Ferruginous sandstone, fine-grained, sub-angular to sub-rounded and moderately sorted. Iron oxide and calcite cement are present. There are also traces of muscovite flares shown in this sample (Figure 7). Quartz is dominant, 90%, and 1-2% rock fragments (Table 2).

HHS-10 (Consolidated sandstone)

Consolidated sandstone, fine grained, angular to sub-rounded, poorly to moderately sorted iron oxide with siliceous cement is present. The grains are isolated but at places the grain-to-grain contacts are also present (Figure 8). 70% quartz, 5-10% clay and 10% calcite (Table 2).

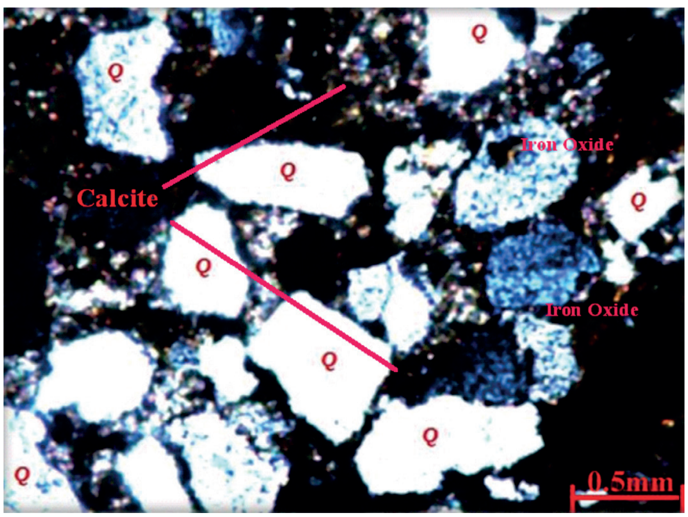

Figure 5. Microphotograph shows angular to subrounded quartz grains buried within calcite and iron oxide cements in the sample HHS-06.

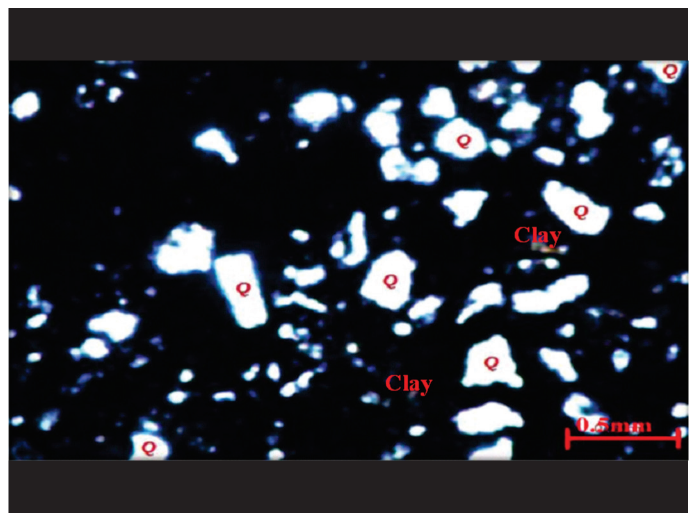

Figure 7. Microphotograph shows quartz grains are sub angular to sub rounded and moderately sorted in the sample HHS-9B

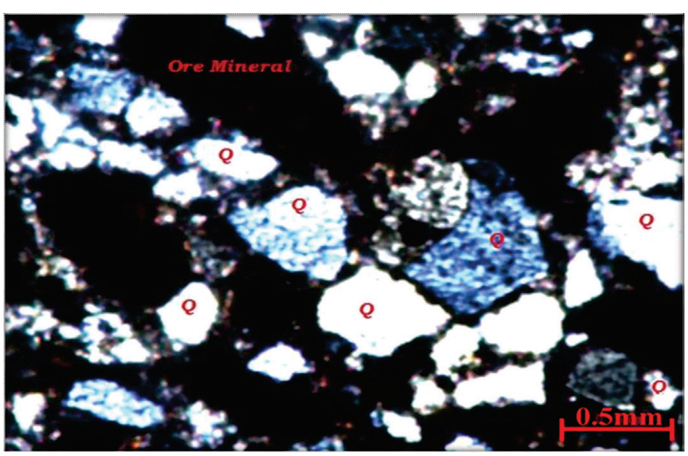

Figure 6. Microphotograph shows iron oxides calcite ore minerals and subangular to angular quartz grains in the sample HHS-9A.

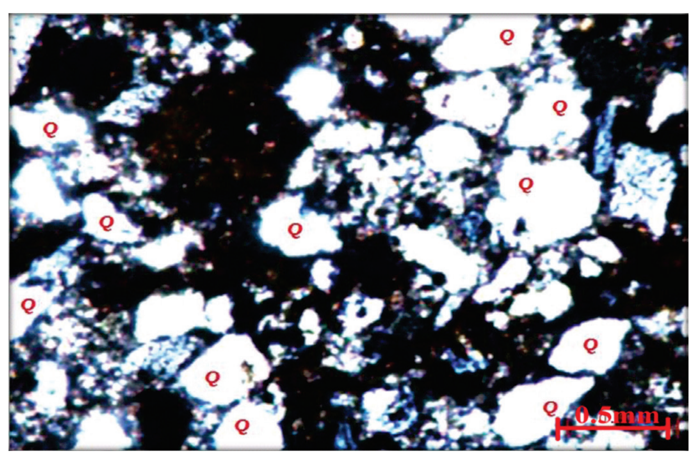

Figure 8. Microphotograph shows quartz grains sub-angular to sub-rounded and weakly to moderately graded in the sample HHS-10.

HHS-12 (Sandy claystone)

Sandy claystone, fine to medium-grained, angular to sub-rounded, and poorly sorted. Clay is dominant 40-50%, 30% quartz (Table 2), mainly grains floating but at places, point contacts are present (Figure 9).

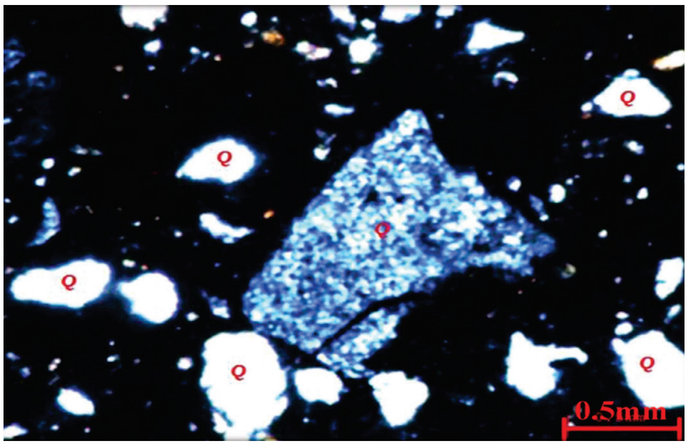

Figure 9. Microphotograph shows quartz angular to subangular, poorly sorted. Most grains are isolating in the sample HHS-12.

HHS-13 (Reddish coloured sandstone)

Reddish-coloured sandstone, Fine-grained, sub-angular to sub-rounded, moderated sorted. Calcite cement is present. Quartz is the dominant mineral, making up 80%, while calcite accounts for 7–10% (Table 2), also traces of rock fragments (quartzite / polycrystalline) and at places pressure shadows on quartz grains (Figure 10)

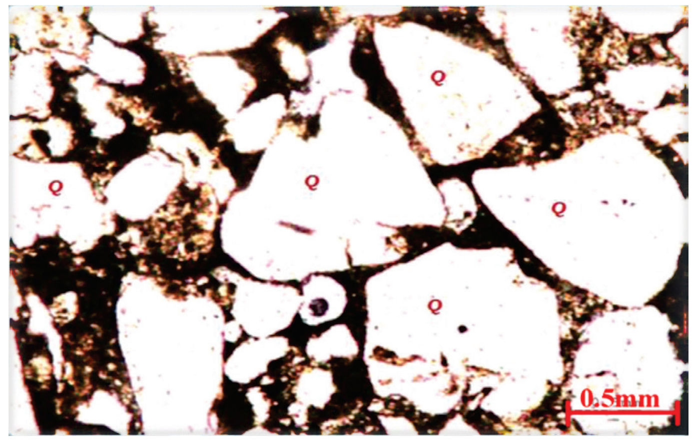

Figure 10. Microphotograph shows sub angular to sub-rounded Quartz grain is embedded within iron oxide in the sample HHS-13.

Table 2. visual estimate framework of minerals along with other sedimentological characteristics.

S.No.	Sample No.	Petrographically Observation		
		Shape	**Sorting**	**Mineral Composition (visual estimate)**
01	**HHS-01 (Camel coloured Limestone)**	fine-grained and sub-angular	Moderately sorted	3-5% quartz, 90% calcite,
02	**HHS-02 Sub-angular to sub-round.**	Sub-angular to sub-round.	Poorly to moderately sorted.	4-5 quartz, 85% calcite
03	**HHS-06 (Coarse-grained sandstone)**	Sub-angular to sub-rounded	Poorly to moderately sorted	85% quartz, 5-7% calcite 3-5% iron oxide
04	**HHS-09A (Compact Sandstone)**	Angular to sub-angular	Moderately sorted	90% quartz, 3-5% calcite
05	**HHS-09B (Compact Sandstone)**	Sub-angular to sub-rounded	Moderately sorted	90% quartz, 1-2 % rock fragments
06	**HHS-10 (Consolidated sandstone)**	Angular to sub-rounded	Poorly to moderately sorted	70% quartz, 5-10% clay and 10% calcite
07	**HHS-12 (Sandy claystone)**	Angular to sub-rounded	Poorly sorted	40-50% Clay and 30% quartz
08	**HHS-13 (Reddish coloured Sandstone)**	Angular to sub-rounded	Moderately sorted	80% quartz, 7-10% calcite

5.2. Scanning Electronic Microscope & Energy Dispersive X-ray-Spectroscopy

Sample HHS-01A (Limestone)

The SEM-EDS investigation reveal that oxygen (52%) and calcium (35%) are abundant compared to silicon (5.32%) (Figure 11A, Table 3). The SEM microphotograph observations revealed that the sample is composed of dominantly very fine calcite mineral grains (Figures 12A). As a result of the high amount of calcium, which is evident that calcite is the most abundant mineral, followed by quartz. Clays are found in the matrix (Figure 12A, Table 3). Throughout, the investigation of the EDS, SEM and general elemental cleared that HHS-01A is limestone.

Sample HHS-06 (Coarse- grained sandstone)

The SEM-EDS analysis displayed that the oxygen (58%), silicon (19.38%) and calcium (8.5%) are the most abundant elements in this sample (Figure 11B Table 3). The SEM microphotograph revealed that the sample is composed of dominantly quartz grains and cementing minerals calcite along with iron oxide (Figure 12B). Both cementing minerals are associated with each other. Due to presence of these secondary mineral, the deposits primary porosity and permeability has been completely reduced. The same characteristics can be observed also from the SEM microphotograph (Figure 12B, Table 3).

Sample HHS-9A (Compact sandstone)

The SEM-EDS investigation indicate that the major elements in this sample are oxygen (57.8%), silicon (25.6%) and calcium (10.1%) (Figure 11C, Table 3). The SEM image shown that the sample is composed of dominantly quartz grains and cementing minerals calcite (Figure 12C). it also observed that the quartz crystals embedded within fine calcite cement.

Sample HHS-12 (Sandy-claystone)

The SEM-EDS investigation demonstrated that the silicon (26.9%), aluminium (11.58%) and oxygen (54.2%) are the most abundant elements along with traces of potassium (2.67%) and iron oxide (Figure 11D, Table 3). The SEM microphotograph revealed that the sample is composed of quartz grains and cementing minerals (iron oxide) (Figure 12D). Throughout the investigation, it was observed that the clays were the most abundant materials forming a matrix (Figure 12D).

6. Discussion

6.1. Geochemistry of Haji Haroon Section

The geochemical analysis of the samples' weight percentages reveals an abundance of silicon and calcium. The lower part of NF sample labelled HHS-12 contains varying amounts of Al, K, and Mn indicating the presence of clay minerals (Figure 13). It is also indicating that the Nari sands are not clean. The geochemistry, SEM-EDS and petrographic studies revealed that calcite and iron oxide cements occur together in the samples. The cementing phases completely reduced the primary porosity. The surface geochemistry, SEM-EDS and petrographic data of Nari Formation of Haji Haroon section demonstrated that the upper part is composed of clastic rocks interbedded with clays that were deposited in fluvial environment, while the lower part, composed of lithic sandstone and quartz arenite, is interpreted as marginal marine or deltaic deposits.

The Dott's classification method for sandstone relies on the mineralogical composition, specifically the relative abundance of quartz, the minor presence of rock fragments, and feldspar grains (Dott, 1964). Based on the DOTT'S classification, the upper part of the Nari Formation can be classified as the quartz arenite. (Figure 14; Table 2). The high occurrence of the quartz arenite and lack of matrix indicate that the part of the Nari

Table 3. Major-Element concentration in weight percent (wt. %) of Nari Formation.

Sample ID	Si	Al	Fe	Mg	Ca	K	P	S	O	C	Total
HHS-O1A (Limestone)	5.32	2.36	2.66	0.35	35.4	1.91	0.39	----	52	0.35	100.7
HHS-06 (Compact sandstone)	19.38	1.34	10.59	2.64	8.5	0.62	----	1.39	58	0.46	101
HHS-09A (Compact sandstone)	25.26	2.41	1.1	0.35	12.3	0.88	----	----	57.8	----	100
HHS-12 (Sandy-claystone)	26.92	11.58	3.44	0.64	----	2.67	----	----	54.2	0.59	100

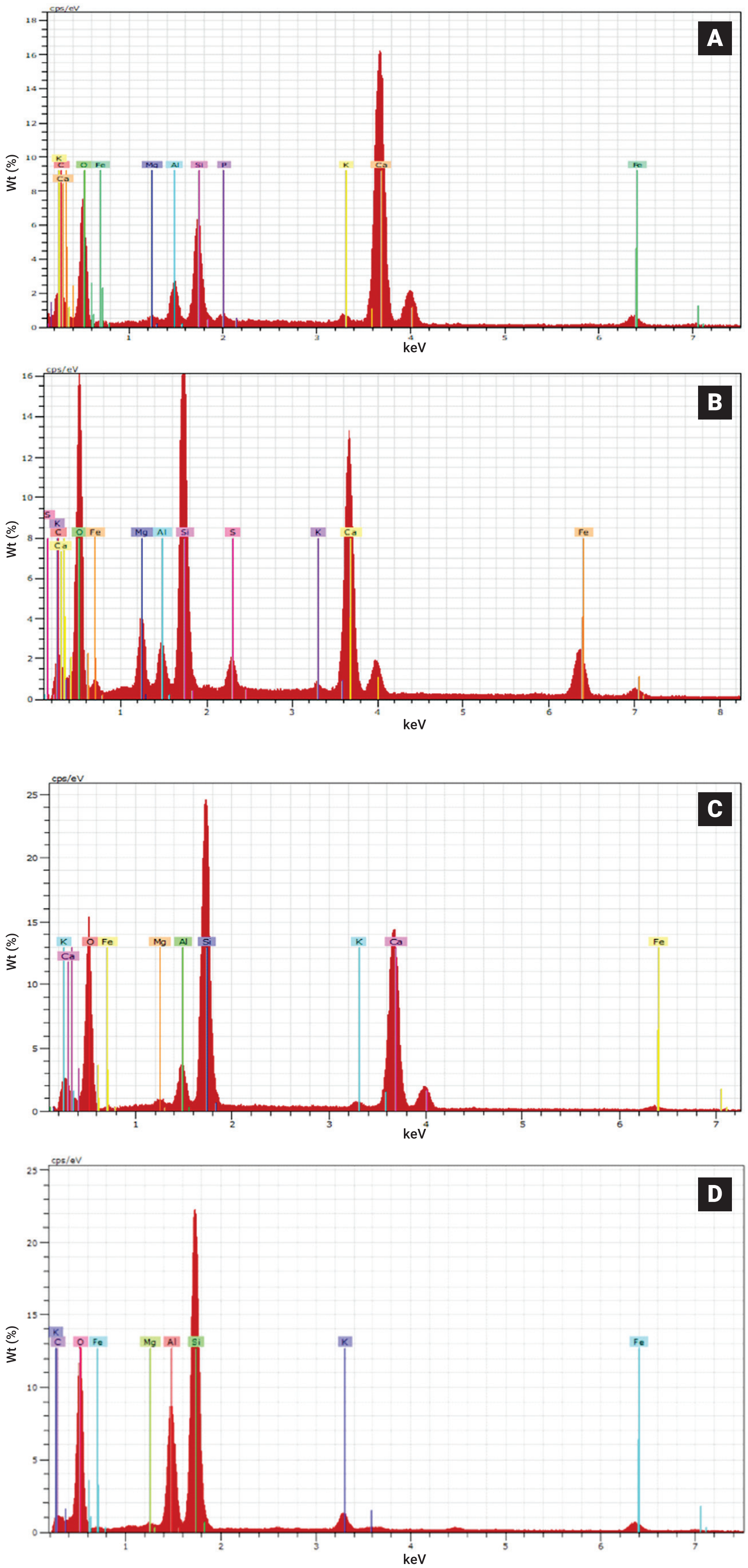

Figure 11. The general graphical presentation of elements A) HHS-O1A, B) HHS-06, C) HHS-9A and D) HHS-12 samples.

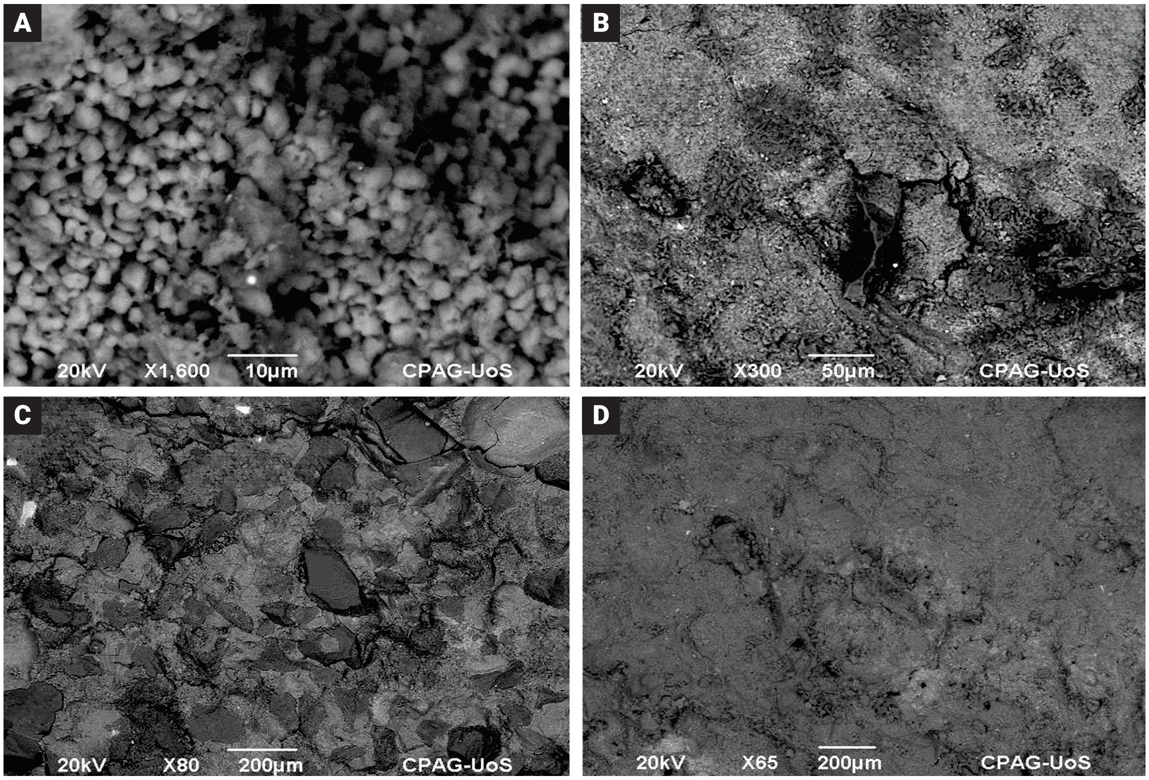

Figure 12. The SEM microphotograph images show A) fine calcite mineral grains, B) the cementing mineral calcite and iron oxide, C) the quartz crystals embedded within fine calcite cement D) the quartz grains are embedded within the clay.

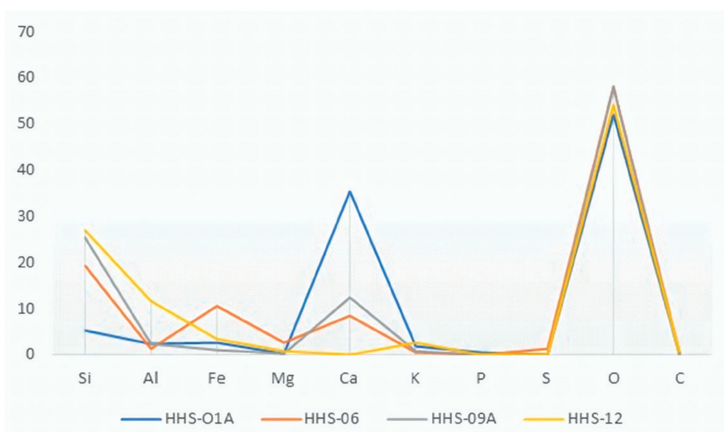

Figure 13. Geochemistry of the Haji Haroon Section Nari Formation.

Formation has a potential for good reservoir. The lower part of the studied area is composed of sub-lithoarenite to lithic arenite (Figure 14). The occurrences of 5-10% matrix and the presence of the limestone bed which is a significant sign of the deposition in a marginal marine or deltaic depositional environment of the upper part of the Nari Formation.

Based on the gathered petrographic, and geochemical data, the provenance and depositional environments of Nari Formation are proposed by (Zahoor *et al.*, 2020; S, Shah, 1977). Nari Formation is also being intensively investigated by numerous companies for the exploration of hydrocarbon (Mahmud and Sheikh, 2009; Paryal et al 2020; Shar *et al.*, 2021). Until recently, no geochemical investigation has been conducted from any part of the Nari Formation. The current research is an effort to explain the geological record of this formation.

The Nari Formation is composed of mixed lithofacies: limestone, sandstone, shale and multi colored clay (Mahmud and Sheikh, 2009; Khokhar *et al.*, 2016; Shar *et al.*, 2021).

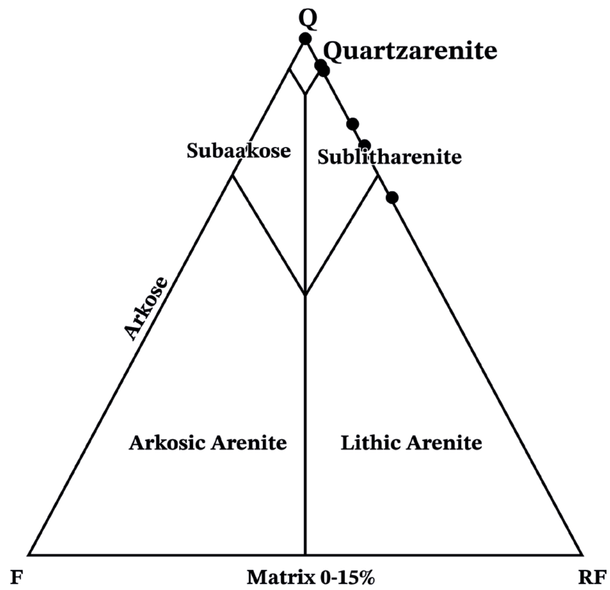

Figure 14. QFRF Diagram of the Nari Formation at Haji Haroon Section

Previous studies revealed that the lower, middle and central parts of the Nari Formation Lower Indus Basin, were generally deposited in a fluvial environment (Ibrahim, 1977; Brohi *et al.*, 2014; Khokhar *et al.*, 2016; Gardezi *et al.*, 2021). During the fieldwork, it was observed that the lower part consists of fossiliferous limestone, iron oxidation along with iron nodules (Naseem *et al.*, 1996). The upper part of Nari Formation is characterized by transgression and regression of the sea level (Paryal et al 2020). The basal part is composed mainly of limestone, whereas the central part is made out of sandstone followed by limestone exhibiting different erosional features (such as iron nodules, oxidation, and gypsum mineralization. These erosional features indicate that sea level fluctuation was occurring during the Oligocene epoch (Ameen., 2009), early studies suggested that the basal part of the Nari Formation is marine, while the upper part is fluvial (Mahmud *et al.*, 2009; Brohi *et al.*, 2014; Khokhar *et al.*,2016). The present petrographic study indicates somewhat different depositional environments, as the entire lower part is not completely deposited in marine areas. The basal part belongs to transitional environments and these may be deltaic, because of presence of both quartz and calcite in significant amounts (Pietro *et al.*, 2006; Maria, Haugen, 2017; Sadaf *et al.*, 2018).

The selected samples from major rock units/lithofacies were investigated based on different petrographic analyses (Table 2). The utilized methods such as the petrographic and SEM-EDS show that the leading mineral of all the studied sandstones is quartz and calcite, while feldspar was not observed (Table 2 and Table 3). The sandstone shows great compositional maturity and is moderately sorted with sub-angular to sub-round, but somewhere grains rounded to subrounded, which implies textural sub-maturity (Figure 5, 6, 7, 8, 9 and 10).

7. Conclusions

The Petrography and Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-EDS) indicate that the dominant mineral of all the studied sandstone is quartz, no feldspar and several percentages of lithic particles were observed which described that the Nari Formation is pure sand and the significant sign for decent reservoir potential.

During field work it was noticed that the lower contact of Nari Formation with Khirthar Formation "whereas" the lower part consists of fossiliferous limestone, iron oxidation along with the iron nodules but present petrographic results show the few amounts of quartz grains as shown in Figure 4 and Figure 11B. In the Nari Formation, a transition from limestone-dominated basal layers to sandstone-interlaced and reveals distinct erosional features, reflecting dynamic sea level fluctuations during the Oligocene epoch, encompassing both transgressive and regressive phases.

The predominance of calcite as the cementing material in sandstone, coupled with iron oxide and the sub-angular to subround shape of the grains, suggests that the grains may have not travelled very long distance and it is possibility that these sediments of the Nari Formation came from near source. Moreover, it is also concluded that the sediment source likely originates from the western highlands rather than from the Indian shield or the northern Himalayas.

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9. Author's contribution

Mr. Aftab Ali Panhwar conducted fieldwork and acted as a MS scholar, he undertook laboratory work and drafted the initial manuscript under the supervision of Dr. Zhong Jianhua and Mr. Muhammad Paryal. Mr. Chander Pirkash helped in SEM analysis, funding acquisition, reviewing article, technical input and project management. Dr. Agheem Muhammad Hassan and Gulfam Hussain conducted technical review, scientific merit, critical editing of the article and contributed in Conceptualization. Mr. Rizwan Ali Shar and Mr. Irfan Ali Siyal conducted the petrographic analysis.

10. Conflict of Interest

There is no clonflict of interest to declare.

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