

# Sandstone Composition and Provenance of the Nari Formation, Central Kirthar Fold belt, Pakistan



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## Abstract:

The Oligocene-Early Miocene Nari Formation is widely distributed in the Kirthar thrust-fold belt. The formation in the study area is mainly consist of sandstone and shale. Field observations and detailed petrographic study reveal that these sandstones are mostly fine to medium grained, subangular to subrounded and poorly to moderately sorted. Detrital grains are dominantly quartz ranging in proportion 36-76%, feldspar 7-17% and lithic grains 1-13%, reflecting that these sandstones are compositionally submature. Quartz is mostly monocrystalline with some polycrystalline grains. Feldspar is dominantly plagioclase (albite) with some alkali feldspar (orthoclase and microcline). Lithic fragments are siltstone, mudstone and chert. Biotite and muscovite are present as accessory minerals. Heavy minerals such as apatite, tourmaline, and zircon are present in trace amount. The QFL diagrams show that the sandstones of the Nari formation are subarkose and lithic subarkose. The QtFL, QmFLt ternary diagrams and paleocurrent direction suggest that the sediments were transported from the Indian shield exposed to the northeast of the Nari Basin.

**Keywords:** Petrography; Provenance; Nari Formation; Kirthar Fold Belt; Indian Sheild

## 1.0. Introduction:

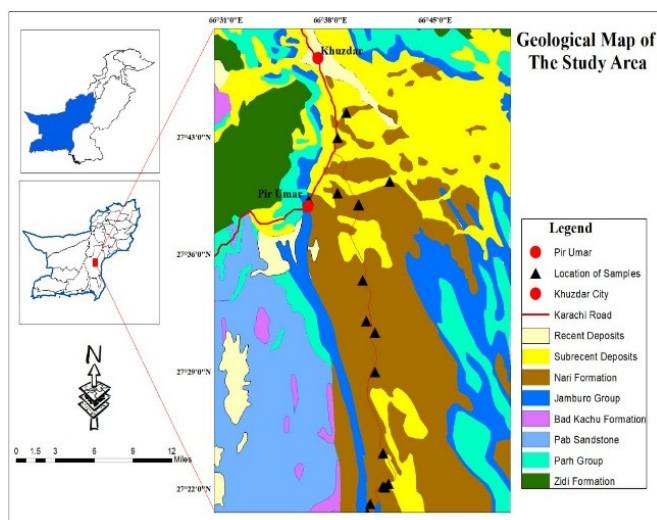
Petrographic analysis can be used to classify siliciclastic sedimentary rocks and to trace provenance. Since detrital mineral components of such rocks preserve good information useful for interpretation of source rock characterization [1-7]. The original mineral composition of siliciclastic, particularly sandstones is the function of interaction of many factors like parent rock lithology, weathering, topography, climate, transportation, depositional environments and diagenetic processes [5, 8-11]. Other factor like recycling and mixing of sediment from multiple sources also influence the composition of sandstones. Different tectonic basins provide specific mineral components unique to that tectonic environment [5]. The present study was carried out to provide detailed petrographic analysis in order to determine mineral composition and construct provenance of the Nari Sandstone exposed in the Central Kirthar Fold-Belt, Balochistan, Pakistan. Previously no detailed petrographic study of the sandstones of the Nari Formation in the study area have been undertaken for classification and provenance of these sandstones.

## 1.1. Geological Setting of the area

The Kirthar range is characterized mostly by sedimentary successions, starting from Jurassic Ferozabad group to Holocene recent-sub recent rocks (Table 1). The Jurassic Ferozabad Group, was introduced [1]. The Jurassic Ferozabad Group is consist of three formations [1]. These are Kharrari Formation, Malikhorre Formation and Anjira Formation. The Kharrari Formation is mainly composed of limestone, dolomite, sandstone, siltstone and shale [2]. The Malikhorre Formation is mainly consist of thick-bedded limestone with subordinate shale and marl [2]. The Anjira Formation is consist of limestone thin to thick bedded locally interbedded with thin marl and shale beds [2]. Early-late Cretaceous Mona Jhal group unconformably overlies the Anjira Formation and is divided into Sembar, Goru, Parh and Maghal Kot Formations [1]. Sembar Formation is dominantly shale with subordinate siltstone and limestone [1].

Goru Formation is characterized by rhythmic alternation of limestone and shale [3]. Parh Limestone is predominantly composed of argillaceous and occasionally platy to slabby limestone [3]. The Maghal Kot Formation is composed of marl, shale and quartz rich sandstone [4]. Pab sandstone of Maastrichtian age is dominantly composed of quartzose sandstone with minor marl and mudstone [5,6]. The Khadro Formation, conformably overlying the Pab sandstone is consist of sandstone, shale and minor limestone beds [4,7]. Bara Formation of the Rani Kot group is dominantly composed of sandstone with minor shale and volcanic debris [8]. Lakhra Formation of Rani Kot group conformably overlies the Bara Formation is dominantly composed of limestone, sandstone and shale [3]. The Ghazij Formation dominantly is composed of mudstone, shale with subordinate sandstone, conglomerate and coal [4,7].

The Kirthar Formation overlying the Ghazij Formation is dominantly limestone with minor shale and marl [3,7]. The Nari Formation is mainly consist of sandstones and interbedded shales [4]. The sandstone is fine to medium grained, in places coarse grained. Sandstone beds are thin to thick, displaying cross lamination, parallel lamination, grading and various types of sole marks. Shale shows intense bioturbation and burrows mostly horizontal. Early Miocene Gaj Formation conformably overlies the Nari Formation. It is composed of mudstone, limestone, sandstone and minor beds of conglomerate. The Pliocene Manchar Formation, uncomfortably overlying the Gaj Formation is predominantly sandstone, mudstone with minor conglomeratic beds [7]. The Pleistocene Dada conglomerates contains some sandstone intercalations.



**Figure 1:** Geological map of the study area modified after [9]

**Table 1:** Stratigraphy of the Kirthar fold belt modified after [1,3,9].

AGE		GROUP	FORMATION	LITHOLOGY
Holocene			Recent-Subrecent	Mixture of clay, sand and gravel
Unconformity				
Pleistocene			Dada Formation	Conglomerates with subordinate coarse grained sandstone
Pliocene			Manchar Formation	Sandstone, shale interbedded with subordinate conglomerate
Unconformity				
Miocene			Gaj Formation	Shale and sandstone with subordinate limestone and conglomerate
Oligocene			Nari formation	Sandstone interbedded with shale
Eocene			Kirthar Formation	Fossiliferous limestone interbedded with shale and marl
			Ghazij Formation	Shale is dominant with minor sandstone
Paleocene	Rani Kot Group		Lakhra Formation	Intraclastic limestone and shale
			Bara Formation	Sandstone and shale
			Khadro Formation	Sandstone, shale and marl
Cretaceous	Maastrichtian-Campanian		Pab Sandstone	Sandstone intercalated with marl and mudstone
	(Early-Late)	Mona Jhal Group	Maghal Kot Formation	Marl, arenaceous limestone, mudstone and sandstone
			Parh Limestone	Biomicroite limestone
			Goru Formation	Micrite limestone with shale, siltstone and sandstone
			Sembar Formation	Shale, siltstone and marl
Unconformity				
Jurassic	(Early-Late)	Ferozabad Group	Anjira Formation	Limestone interbedded with shale and marl
			Malikhore Formation	Oolitic limestone with subordinate shale and marl
			Kharri Formation	Limestone, shale, marl and minor sandstone

## 2.0. Materials and Methods

Six stratigraphic sections of the Nari Formation were measured in the study area, and were described in detail, noting their sedimentary structures, texture and other features. 25 samples were collected from different horizons of Nari Formation for detailed petrography (Table 2). Petrographic analysis of 20 representative samples were carried out using the Leica petrographic microscope equipped with digital camera and automatic point counter. Minimum 300 points in each thin section were counted for the comparative proportion of mineral composition using Gazzi-Dickinson method [10-12]. Nomenclature of was used to determine the framework grains for siliciclastic sandstones (Table 3) [7]. For classification of sandstone ternary diagrams were used (Figure 3) and for provenance and tectonic settings of sandstone of the Nari Formation, ternary diagrams and were used (Figure 4) [10-14].

## 3.0. Results

### 3.1. Texture

Field observations and petrography of the Nari Formation reveal that the formation in the study area is consist of dominantly sandstone and shale. Limestone beds are present in the southern part of the Basin [15]. The sandstone is fine to medium grained, in places coarse grained, thin to thick bedded, in places massive, moderately sorted, framework grains are mostly subangular to subrounded (Figure 2A) with low to medium sphericity. Common sedimentary structures are parallel lamination, cross lamination, normal grading, flutes, load casts and grooves. It is mainly grain supported, with calcite cement 2-35% and ferruginous cement 1-9%.

### 3.2. Sandstone Composition

The sandstones of the Nari Formation are mainly composed of quartz, feldspar and lithic grains. Biotite and muscovite present as accessory minerals and heavy minerals such as apatite, epidote, tourmaline and zircon are present in trace amount (Table 2).

### 3.3. Quartz

Quartz is found as the most common detrital mineral in sandstones of the Nari Formation, ranging from 36% to 76%. Quartz is mostly monocrystalline and shows uniform extinction (Figure 2B). Some of the quartz grains show undulose extinction. Polycrystalline Quartz are also present in minor amount (Figure 2B). The Quartz grains are commonly subangular to subrounded in shape.

### 3.4. Feldspar

Feldspar is the next abundant mineral in these sandstones ranging from 7 to 17%. It is mostly plagioclase with minor amount of alkali feldspar (orthoclase and microcline). Plagioclase feldspar is characterised by perfect albite twinning (Figure 2C), low relief and some show zoning whereas orthoclase and microcline feldspar show cross hatch and Carlsbad twinning (Figure 2C). The orthoclase grains are usually cloudy and dirty. Some grains with perthitic and myrmekitic intergrowth texture were also observed in some thin sections (Figure 2D). The shape of feldspar grains are mostly subangular to subrounded, partially to completely altered to sericite and calcite.

### 3.5. Lithic grains

Lithic grains are less common, ranging from 1 to 13% with an average of 6% (Table 2). Among the lithic fragments mudstone is the most common with minor amount of sandstone, siltstone, mudstone, limestone, volcanic igneous rocks and bioclasts. Bioclasts of foraminifer are also present most probably derived from older formations.

### 3.6. Mica

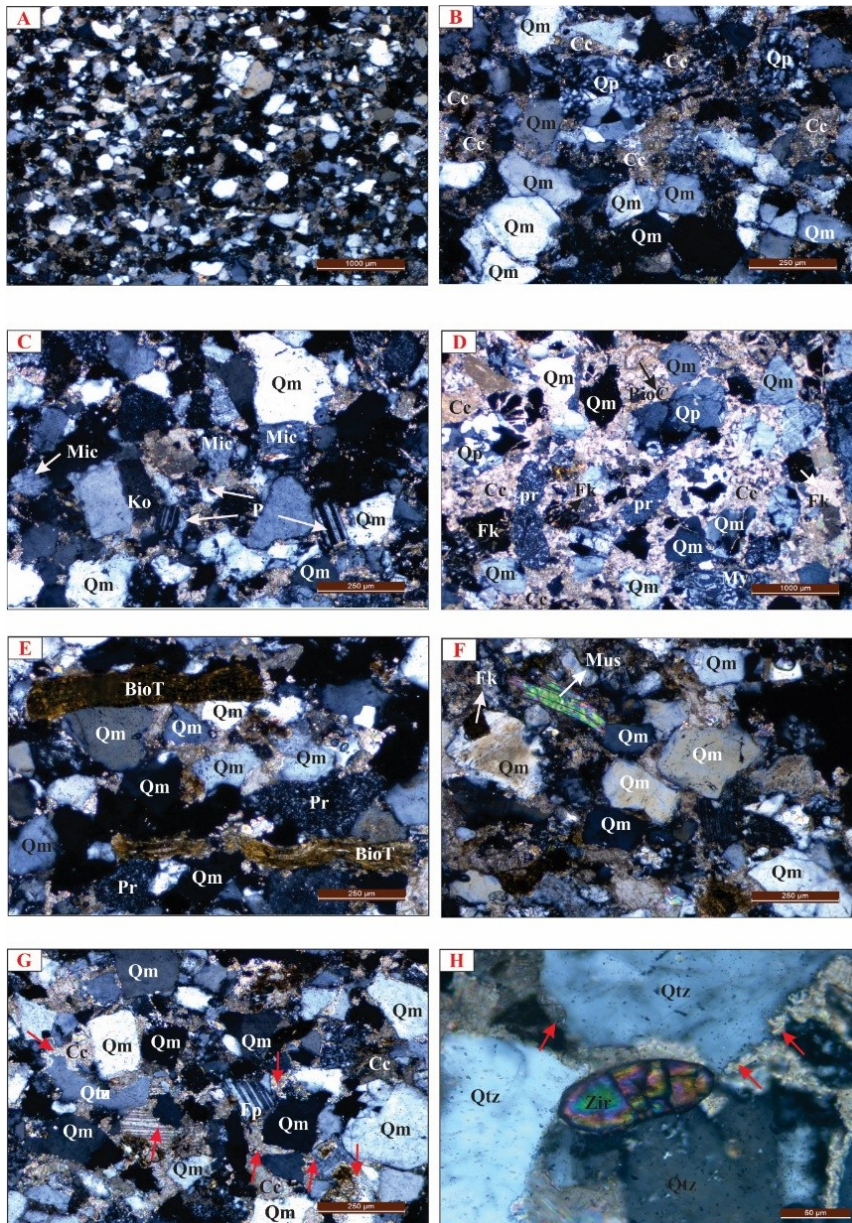
Mica in the form of biotite and muscovite are present up to 4%. Biotite is more common than muscovite. They are present in the form of elongate and bended flakes. (Figure 2E, F). Some grains of muscovite are strained and altered to chlorite.

### 3.7. Cement

Calcite, quartz and hematite cement (Figure 2) is present ranging from 5-14%, Calcite cement is more abundant, while one sample (ZA-33) contains 37% cement. Quartz overgrowth has also been observed in several thin section. Calcite replacing quartz and feldspar grains is common (Figure 2G).

### 3.8. Heavy minerals

Heavy minerals such as Zircon (Figure 2H), tourmaline, apatite and epidote are present as accessory minerals. Brown leached material may indicate the presence of iron oxide.



**Figure 2:** Photomicrographs of sandstones of the Nari Formation showing (A) moderately sorted, subangular to subrounded grains of quartz, (B) monocrystalline-Qm and polycrystalline-Qp quartz grains, (C) Albite-Al, Orthoclase-Or and Microcline-Mic grains, (D) perthitic-Pr and myrmekitic-My texture, (E) Biotite-BioT, (F) Muscovite-Mus, (G) Calcite replacing quartz and feldspar grains-red arrow, (H) Zircon grain, also note calcite replacing quartz.

**Table 2:** Mineral composition of the Nari Sandstone.

Sample Name	Mineralogy															Percentage
	Quartz		Feldspar		Lithic Fragments			Mica		Bio-clast	Cement		Heavy Mineral		Op	
	M	P	Pl	Mic	Ig	Mt	Sed	Bi	Mu		Ca	He	Zir	Ap		
ZA-1	58	4	11	1	2	1	5	1	4	3	6	3	P	P	1	100
ZA-2	68	3	7	2	0	0	2	2	1	2	12	1	P	P		100
ZA-3	37	8	13	1	1	0	8	2	0	19	7	3	P		1	100
ZA-4	73	3	6	1	0	0	1	3	0	0	4	9	P	P		100
ZA-5	67	2	14	3	0	0	4	2	1	2	4	1	P			100
ZA-6	71	2	6	1	0	0	9	1	0	2	5	1	P		2	100
ZA-7	58	10	13	0	2	0	4	2	1	1	7	2	P	P		100
ZA-7	56	9	15	1	0	0	3	4	2	1	8	1	P			100
ZA-9	65	6	12	2	1	0	6	2	0	1	4	1	P			100
ZA-10	62	3	11	1	1	0	9	3	1	1	8	0	P	P		100
ZA-11	67	2	10	1	0	0	7	2	3	2	4	1	P		1	100
ZA-12	64	4	14	2	0	0	2	2	1	1	7	1	P		2	100
ZA-13	70	2	11	0	1	0	5	2	1	0	5	2	P		1	100
ZA-14	67	3	9	1	2	0	5	2	1	2	6	1	P		1	100
ZA-15	63	1	16	1	1	0	6	1	1	1	7	2	P	P		100
ZA-16	28	8	8	0	1	0	12	0	0	6	35	2	P			100
ZA-17	62	4	6	1	0	0	4	3	2	1	14	3	P	P		100
ZA-18	57	2	13	1	1	0	8	6	3	2	5	2	P	P		100
ZA-19	67	3	14	1	1	0	2	2	1	3	2	4	P			100
ZA-20	66	2	16	0	1	0	3	2	1	2	5	1	P		1	100

### 3.9. Sandstone Classification of Nari Formation

The values of recalculated detrital mineral composition of the studied thin sections (Table 3) were plotted into the ternary diagrams for classification of sandstones (Figure 3) fall in the field of subarkose and few samples fall in the field of lithic subarkose, indicating that the sandstones of the Nari Formation are mostly subarkose and with minor lithic suarkose, reflecting that these sandstones are compositionally submature [13,14].

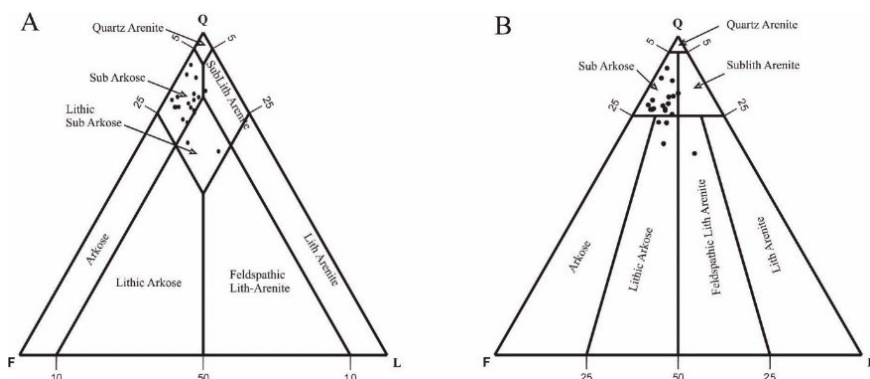
**Table 3:** Recalculated modal point count data of sandstone of the Nari formation in the study area.

S.No	Qm-F-Lt (%)				Qt-F-L (%)				Lm-Lv-Ls (%)				Qm-P-K (%)		
	Qm	F	Lt		Qt	F	L		Lm	Lv	Ls		Qm	P	K
ZA-1	74	15	10		76	15	10		12.5	25	63		86	13	1
ZA-2	86	11	3		87	11	2		0	0	100		91	7	2
ZA-3	62	23	15		66	21	13		0	11	89		81	17	1
ZA-4	90	9	1		90	8	1		0	0	100		93	6	1
ZA-5	76	19	5		77	19	4		0	0	100		82	15	3
ZA-6	82	8	10		82	8	10		0	0	100		92	7	1
ZA-7	75	17	8		78	15	7		0	33	67		85	15	0
ZA-7	75	21	4		77	19	4		0	0	100		82	17	1
ZA-9	76	16	8		77	15	8		0	14	86		84	13	2
ZA-10	74	14	12		75	14	11		0	10	90		86	13	1
ZA-11	79	13	8		79	13	8		0	0	100		88	11	1
ZA-12	78	20	2		79	19	2		0	0	100		83	15	2
ZA-13	80	13	7		81	12	7		0	17	83		88	12	0
ZA-14	80	12	8		80	11	8		0	29	71		89	10	1
ZA-15	72	20	8		73	19	8		0	14	86		81	18	1
ZA-16	57	16	27		63	14	23		0	8	92		88	12	0
ZA-17	85	10	5		86	9	5		0	0	100		92	7	1
ZA-18	71	18	11		72	17	11		0	11	89		84	15	1
ZA-19	79	18	4		80	17	3		0	33	67		84	15	1
ZA-20	77	19	5		77	18	5		0	25	75		83	17	0



**Table 4:** Framework grain parameters [10].

$Qt = Qm + Qp$	Qt = Total quartzose Grains. Qm = Monocrystalline Aphanitic Quartzose Graines. Qp = Polycrystalline Aphanitic Quartzose Graines.
$F = P + K$	F = Total Feldspar Graines. P = Plagioclase Feldspar Graines. K = Orthoclase Feldspar Graines.
$Lt = Lm + Lv + Ls$	Lt = Total Unstable Aphanitic Lithic Graines. Lm = Metamorphic Aphanitic Lithic Graines. Lv = Volcanic And Hypabasal Aphanitic Lithic Graines. Ls = Sedimentary Aphanitic Lithic Graines + Extrabasinal Carbonate Graines.



**Figure 3:** QFL ternary diagrams (A-Pettijhone, 1975 and B-Folk, 1980) for sandstone classification of Nari Formation.

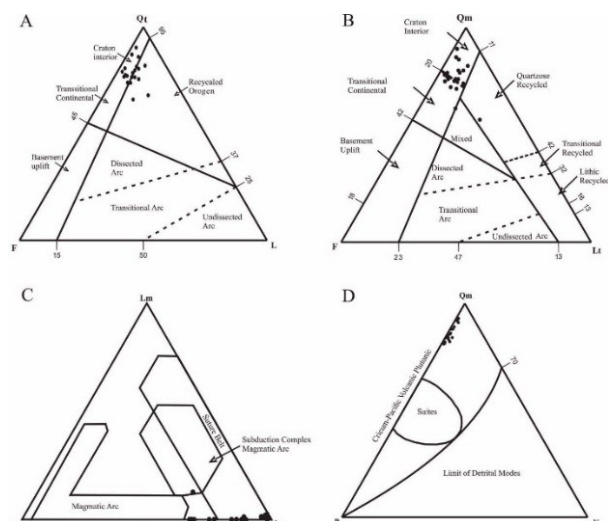
#### 4.0. Interpretation and Discussion

##### 4.1. Provenance and Tectonic Settings

To interpret sandstone provenance and tectonic setting of the ancient sedimentary basins with the help of the quantitative detrital modes, calculated from point counts of thin section is well established [10,11,16]. Sandstone composition is greatly affected by parent rock type, tectonic setting, climate, topography of the source area, mechanism of transport, depositional environment and diagenesis [10-17]. Prolong weathering produces sandstone depleted with unstable minerals such as feldspar and mafic minerals and enriched with stable minerals such as quartz. Sandstone composition is also modified during transportation from source to depositional site by eliminating the unstable minerals. Mixing of sediment from multiple source and addition of sediment like bioclast, glauconite within basin followed by diagenesis further modify final composition of sandstone [17-20]. Major categories of provenance include Craton Interior, Transitional Continental, Basement Uplift, Magmatic Arc (Dissected Arc and Undissected Arc) and recycled orogen [10,11,16].

Using the QtFL plot, the detrital mineral composition of sandstone of the Nari formation fall in craton interior and recycled orogen field (Figure 4A) and the data plotted in the QmFLt ternary diagrams, fall in the field of craton interior and transitional continental block provenance (Figure 4B) indicating that the sandstones of the Nari formation were derived mostly from shield areas and some from uplifted basement and recycle orogens provenance [16]. The shield areas, commonly composed of granitic and gneissic rocks with low topography, usually provide quartz rich and subarkose sandstones. In the LmLvLs plot, the samples fall in suture belt field (Figure 4C) indicating that some sediments have also been derived from the uplifted older sedimentary strata exposed in the kirthar fold belt [11]. In the QmPK plot it falls near to Qm end (Figure 4D) indicating derivation of the detritus from continental block [11]. The abundance of monocrystalline quartz with uniform extinction indicates that these sandstones were derived from granitic source [17,18].

The presence of some of polycrystalline quartz consisting of more than 3 grains and undulose quartz grains suggest derivation from plutonic igneous and metamorphic rocks [14]. The presence of zircon inclusion in the quartz grains indicates derivation from plutonic felsic igneous rocks. The presence of albite plagioclase and alkali feldspar (orthoclase) suggest derivation of sediments from plutonic felsic igneous rock. The presence of microcline indicates that derivation of the sediments from felsic plutonic igneous and metamorphic rocks. The presence of mica (biotite and muscovite) indicates derivation from metamorphic and igneous plutonic felsic rocks [21-25]. The presence of some lithic fragments such as siltstones, limestones chert indicate derivation of some sediment from older sedimentary rocks. The paleocurrent direction recorded from the flutes show that the flow was from southwest. This indicates that source area was to the northeast of the Nari Basin. It is envisaged that the Indian Craton to the NE have provided sediments for the Nari Formation with minor contribution from nearby exposed sedimentary rocks [26,27].



**Figure 4:** A- QtFL, B-QmFLt, C-LmLvLS and D-QmPK ternary diagrams for provenance tectonic setting of the Nari Formation [16].

## 5.0. Conclusions

Following conclusions can be drawn from the petrographic analysis of sandstones of the Nari Formation:

1. The sandstones are texturally and compositionally submature and moderately sorted indicating high relief, rapid erosion in the source area and short transport distance from source area.
2. The sandstones are subarkose and lithic subarkose. These sandstones are rich in quartz (36% to 76%) with subordinate feldspar (7-17%) and minor amount of lithic fragment (1-13%). The absence of distinctive variation in the composition of these sandstones indicate homogenous source.
3. The detrital mineral components indicate that these sandstones mostly were derived from acidic igneous granitic source with partial contribution from metamorphic and sedimentary rocks.
4. The Ternary Tectonic diagrams and paleocurrent direction reveal that the Indian Craton present to the northeast of the study area is believed to be the major source area with minor contribution from locally exposed sedimentary rocks.

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## 7.0. Conflict of Interest

There is no conflict of interest among the authors

## 8.0. References

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