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Petrographic Studies of the Vihowa Formation, Sulaiman Range, Pakistan: Implications for Provenance

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Abstract: The Vihowa Formation of late to early Miocene is investigated for mineral composition and petrographic characteristics to understand the provenance, diagenesis and depositional environments. Ten representative sandstone samples were collected from various lithological units for petrographic studies. Petrographic results show that the quartz is a major constituent; while the accessory minerals are chlorite, chamosite, palagonite, sphalerite, staurolite, aragonite, hypersthene, glaucophane, monazite, kyanite, epidote, olivine, rutile, illmenite, hematite, magnetite, zircon, tourmaline and garnet. The tourmaline and rutile showing an igneous source however, the presence of epidote, staurolite and garnet expresses a metamorphic source for studied sandstones. The sandstone is medium to coarse grained having grains dominantly from the meta-sedimentary rocks whereas minor amount of grains from igneous rocks is also observed. Monocrystalline quartz is present in sands derived either from gneiss or granitic rocks, but polycrystalline quartz are from slate and schist. The inclusion of mica and garnet within quartz is observed which indicates a metamorphic source. On the QFL triangular diagram the sandstone of Vihowa Formation is mainly sub-lithic arenite and partly quartz arenite. The Qm-P-K plots indicate that feldspar and quartz are from granitic rocks along with small amount from metamorphic and volcanic rocks. The provenance of sandstone indicates that sediments were mostly deposited by transitional recycled orogeny and mixed magmatic subduction complex.

Keywords: Vihowa Formation, Petrography, Provenance, depositional environments, Sulaiman Range

1. INTRODUCTION

The late to early Miocene rocks of Vihowa Formation are exposed in the middle part of the Zindapir anticline, eastern margin of Sulaiman Fold Belt, Middle Indus Basin **(Fig. 1).** The study area lies at lat. 30^0 32' 16" N and long. 70^0 29' 18" E at Barthi Village. The Vihowa Formation is comprised of medium to coarse grained sandstone, subordinate clay and siltstone, whereas in the study area the sandstone is thick and cross bedded. The sandstone is light to dark gray, yellowish gray, light brown, reddish brown, medium to coarse grained and subangular to subrounded. The sandstones are mostly porous, loose to compact and poorly sorted. The first name Siwalik-like sediments (early to late Miocene) was given to this formation and afterwards replaced with Vihowa Formation in Sulaiman Range by Hemphill and Kidwai (1973). They investigated lithological characteristics of Siwalik Group and reported vertebrate fossils. The type section was designated at Vihowa Rud east of Charwata Post. Kazmi and Abbasi (2008) measured this formation as 700 meters thick in type section Litra Nala and 430 meters thick in Chaudhwan Zam. Kidwell and Holland (2002) observed and described that the heterogeneous sediments of this formation accommodated in shallow marine environment by the fluctuation of sea level.

The available literature review indicates that a little work on source has been done but no detailed petrographic studies have been carried out on this formation, especially in the context of source and provenance and so far, the main purpose of this paper is to provide petrographic information of the constituent sediments to interpret provenance and the nature of source rocks of Vihowa Formation.

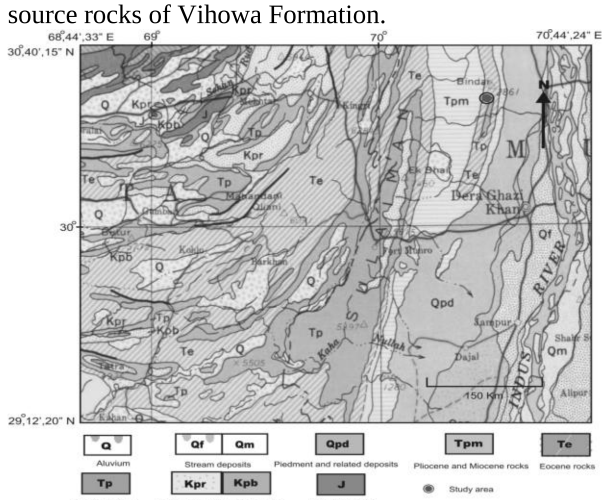

Fig. 1 Geological map of the study area (after Abu Bakar *et al.*, 1964)

2. REGIONAL GEOLOGICAL SETTING

It is now widely accepted that the detrital sediments of early Tertiary age, which have been deposited throughout the Indus basin are the result of collision between Indo-Pakistan and the Asian continental plates at about 50Ma (Garzanti *et al.*, 1996).

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Whereas, the Zhob thrust fault and Gazaband faults are formed by the Himalayan-Hindu Kush collision **(Fig. 2),** (after Hemphill and Kidwal, 1973)**.** It is generally accepted that the deposition of sediments of Chitarwata Formation within Himalayan foreland basin is the result of collision between India-Asia and eustatic sea level changes (Clift *et al.*, 2001) Moreover, the sedimentation record of Himalayan foreland basin is well preserved in the form of both Chitarwata and Vihowa formations (Downing et al. 1993). Literature review further shows that Vihowa Formation holds best exposures of fluvio-deltaic sedimentation to represent the southward progradation of Indus River system (Qayyum *et al.,* 2001). 300 m thick coastal facies of the Vihowa Formation represents the best fluvio-deltaic system in Zindapir area (Downing *et al.* 1993).

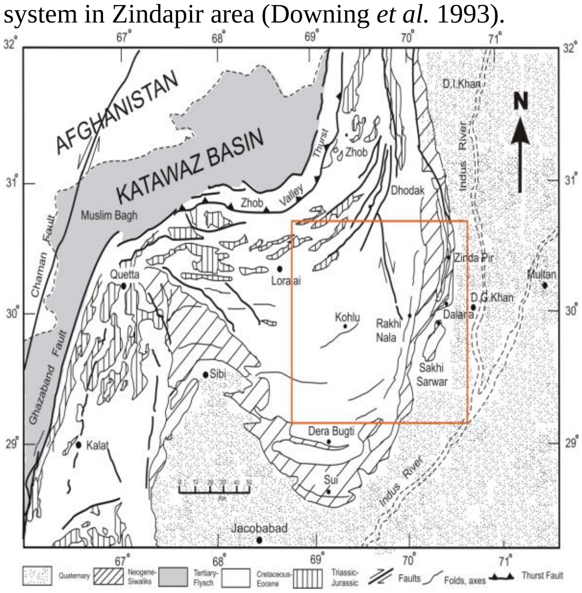

Fig. 2 Regional geological map showing the location of Sulaiman Range and the surroundings

3. MATERIAL AND METHODS

During filed work ten sandstone samples were collected from major facies of Vihowa Formation exposed along Sakhi Sarwar section. Small rock chips were cut and mounted on glass slides with resin to avoid any loss during grinding and polishing. For further binding of loose and friable particles the samples were heated in an oven. The prepared thin sections were studied under polarizing microscope for framework grains, matrix and cement. With the help of visual estimation charts of Terry and Chilingar, (1955) the relative abundance was determined. The altered grains were counted as original grains while the framework grains were counted by using the method of Gazzi-Dickinson to reduce the effect of grain size (Dickinson, 1970, Ingersoll *et al.,* 1984). Depending on grain size; greater than 300 points were counted in each section. Depending on grain size, the grid spacing was frequently changed to avoid the double counting of any grain. For present study; the method of Dickinson (1985) is followed for framework parameters that are shown in Table 1. For classification of sandstone the Folk (1980) scheme is followed and modal analysis data is recalculated and shown in Table 2. To determine the tectonic settings and provenance of sediments; the ternary diagrams of Dickinson (1985) are used. For further specific tectonic settings, all the used ternary diagrams are further classified into diverse isolated fields.

4. PETROGRAPHIC STUDIES AND PROVENANCE

Ten sandstone samples were collected from various lithological units/facies of the Vihowa Formation during the field visit for microscopic studies. The framework constituents were counted randomly following the method of Dickinson (1970), Graham *et al*. (1976), Ingersoll and Suczek (1979) and Dickinson (1985). The petrographic studies were carried out to investigate mineral composition, grain to grain contact relationship and alteration of grains in sandstone of Vihowa Formation. The results are presented in Tables 1, 2 3. The major categories of grains identified during the point counting include undulatory and non-undulatory monocrystalline quartz, polycrystalline quartz, sedimentary lithic, volcanic lithic, sedimentary-metamorphic lithic grains and chert (Tables 1, 2, 3). Heavy minerals such as rutile, ilmenite, hematite, magnetite, zircon, tourmaline, garnet and mica are also identified **(Fig. 3).**

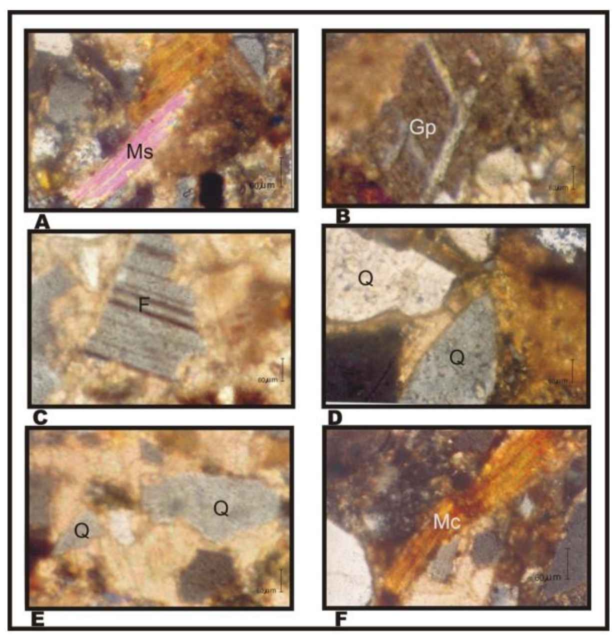

Fig. 3. Microphotographs (XPL) of different sandstones of the Vihowa Formation, (A) dark pink muscovite (Ms) flakes (B) Secondary Gypsum (Gp) grains and veins (C) Euhedral and corroded grain of feldspar (plagioclase) "F" with albite twinning (D) and (E) Quartz (Q) grains (F) Mica (Mc) grains within the sandstones

4.1 Petrography of Vihowa Formation

Sandstone types can be determined by the weight percentage of quartz, feldspar and rock fragments. Sukhtankar (2004) described depositional environment and provenance of sandstones by studying heavy minerals and rock fragments. There are various schemes to classify the sandstones but here the classification scheme of Pettijohn et al. (1987) has been utilized. The re-calculated data is plotted on Q-F-L triangular diagram (Fig. 4) which shows that nine samples drop into the field of sub-lithic arenite; whereas only one sample fall in quartz arenite field. Three types of sandstones are identified on the basis of percentage of detrital minerals and rock fragments which are quartzarenite, sublithicarenite and lithicarenite.

Thin section study indicates that quartz is the main component of sandstone of Vihowa Formation ranging from 68 to 80% which includes both mono and polycrystalline grains (Fig. 4, after Petijhon *et al.,* 1987; Tables 1, 2, 3). Monocrystalline quartz grains are abundant as compared to polycrystalline grains. It is observed that these grains have concavo-convex contact with each other and some quartz grains are fractured. It is general phenomenon that monocrystalline quartz are dominantly present in sands/sandstones resulting from granitic and gneissic rocks, while polycrystalline quartz grains are found in those sandstones originally derived from slate and schist (Tortosa *et al.,* 1991). Inclusions of mica and garnet are also found within quartz grains which indicates metamorphic source. Young (1976) pointed out that during metamorphism under the influence of increasing pressure and temperature; the monocrystalline quartz may be formed from polycrystalline quartz. Moreover, the undulatory extinction of quartz further indicates that the source rocks are metamorphic in origin and have experienced a lot of pressure. Sutured boundaries are very much clear within the studied polycrystalline quartz. Muscovite occurs as overgrowth on mono-crystalline quartz. The feldspar ranges from 4 to 15% in studied sandstones **(Tables 1, 2, 3)** and it was derived probably from uplifted oceanic island-arc terrain that had been rare source area in sedimentary record. In addition, inclusions of zircon and tourmaline are also seen within the feldspar grains.

Rock fragments are the main components, ranging from 12 to 25% in sandstone. These are predominantly chert, siltstone, limestone and schist with subordinate shale and volcanic fragments. It is probable that these fragments were derived from Cretaceous and Eocene of Sulaiman belt. Micas are also associated with some of these rock fragments and minerals. It is observed that biotite is generally altered to chlorite. Flaky minerals are mostly altered and therefore, the cleavage shape is generally wavy and broken and somewhere completely absent. Unidirectional flaky minerals indicate that the speed of water flow current was very slow during the deposition of Vihowa sandstone. The accessory minerals include; chlorite, chamosite, palagonite, sphalerite, staurolite, aragonite, hypersthene, glaucophane, monazite, kyanite, epidote, olivine, rutile, illmenite, hematite, magnetite, zircon, tourmaline and garnet **(Table 4).** Such mineral assemblage indicates a bimodal source of sediments: for example, staurolite, garnet and epidote point out a metamorphic source while the tourmaline and rutile pointing an igneous source (Tucker, 2001). The sandstone is mainly cemented by silica, ferruginous materials and minor substitutes of clay, mud, and calcite. During study, it was observed that quartz overgrowth is the most common type of silica cement and is the product of diagenesis. Along with other factors, it may also occur due to pressure dissolution. Iron and calcite are converted to ferrogeneous clay and mud by pressure solution. Ferruginous pseudo-patches have been found at some places. Reddish brown ring is developed on surrounding of ferrugeneous grains by the reaction of iron oxidized material and ferromagnesian materials. Various sizes of light dirty reddish brown patches have been observed due to alteration within iron-magnesium and mud. The ferruginous pseudo-patches, iron oxide and mud patches are found in cementing materials. Grains are bounded by pseudo-matrix, ferruginous clay and clay matrix.

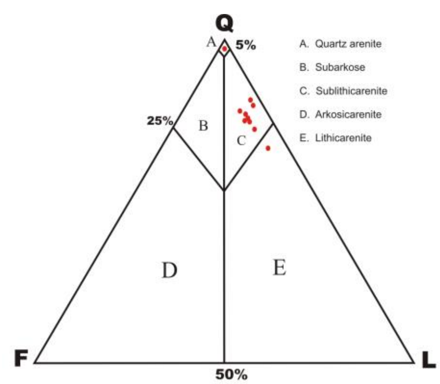

Fig. 4 QFL diagram for the sandstone samples of Vihowa Formation

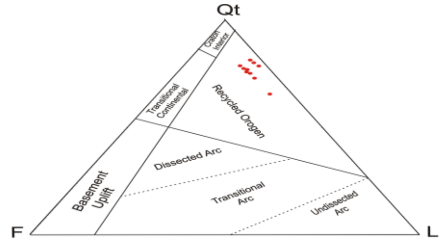

Fig. 5 QtFL diagram for the provenance of sandstones of Vihowa Formation.

Table 1 Point counting data of sandstone samples of Vihowa Formation

S. No.	Sample No	Qm un	Qm non	Qpq	Ls	Lv	Lsm	P	K	Cht
01	VF ZPD-1	14	20	75	12	06	10	02	01	03
02	VF ZPD-2	10	11	60	20	10	07	04	03	02
03	VF ZPD-3	15	24	55	09	07	03	01	02	01
04	VF ZPD-4	21	11	63	16	04	01	02	01	02
05	VF ZPD-5	17	13	45	14	01	02	06	00	00
06	VF ZPD-6	24	21	61	11	08	04	08	01	01
07	VF ZPD-7	20	15	58	15	02	01	07	01	03
08	VF ZPD-8	16	19	72	19	06	01	07	02	04
09	VF ZPD-9	22	10	66	09	09	07	01	03	01
10	VF ZPD-10	18	23	70	18	10	05	04	04	02

Note: Key for petrographic and other parameters (after Dickinson 1985). (Qm un) Undulouse monocrystalline quartz, (Qm non) Non-undulouse monocrystalline quartz, (Qpq) Polycrystalline quartz, (Ls) Sedimentary rock fragments, (Lv) Volcanic-metavolcanic rock fragments, (Lsm) Metasedimentary rock fragments, (P) Plagioclase feldspar, (K) Potassium feldspar and (Cht) Chert

Table 2 Recalculated parameters through point counting used in various triangular diagrams for provenance of sandstones of Vihowa Formation

Sample No.	Qm	Qp	Qt	Q	F	Lt	L	Acc	Cem-matx
VF ZPD-1	34	78	112	109	03	106	28	01	10
VF ZPD-2	21	62	83	81	07	99	37	05	11
VF ZPD-3	39	56	95	94	03	75	19	03	17
VF ZPD-4	32	65	97	95	03	86	21	01	14
VF ZPD-5	30	45	75	75	06	62	17	00	11
VF ZPD-6	45	62	107	96	09	85	23	10	19
VF ZPD-7	35	61	96	93	08	79	18	02	16
VF ZPD-8	35	76	111	107	09	102	26	04	12
VF ZPD-9	32	67	99	98	08	92	25	01	10
VF ZPD-10	40	72	112	110	09	105	33	03	14

Note: Key for petrographic and other parameters (after Dickinson 1985). (Qm) monocrystalline quartz, (Qp) Polycrystalline Quartzose (or chalcedonic) lithic fragments, (Qt) Total quartzose grains, (F) Total feldspar grains, (Lt) Total siliciclastic lithic fragments, (L) Unstable (siliciclastic) lithic fragments (Lv+ Ls+ Lsm), (Acc) Accessory minerals, (Cem-matx) Cementing materials and matrix.

Table 3 Percentage of various constituents of sandstones of the Vihowa Formation for plotting on the QFL diagram

Sample No.	Quartz %	Feldspar %	Rock Fragments %	Cementing Materials %	Accessory Minerals %
VF ZPD-1	72.72	01.94	18.18	06.49	0.64
VF ZPD-2	58.04	04.89	25.87	07.69	03.49
VF ZPD-3	69.34	02.18	13.86	12.40	02.18
VF ZPD-4	71.32	02.20	15.44	10.29	0.73
VF ZPD-5	68.80	05.50	15.59	10.09	0.00
VF ZPD-6	63.69	05.35	13.69	11.30	05.95
VF ZPD-7	68.57	05.71	12.85	11.42	01.42
VF ZPD-8	68.51	05.55	16.04	07.40	02.46
VF ZPD-9	69.23	05.59	17.48	06.99	0.69
VF ZPD-10	65.49	05.26	19.29	08.18	01.75

Table 4 Accessory minerals of the sandstone samples of the Vihowa Formation

Minerals	VFZD P-1	VFZDP -2	VFZDP -3	VFZDP -4	VFZDP -5	VFZDP -6	VFZDP -7	VFZDP -8	VFZDP -9	VFZDP -10
Biotite	1.5	1.5	0.5	0.5	1.9	1	1.3	1.3	1.4	0.5
Muscovite	1.8	0.8	-	0.3	-	0.2	-	-	0.4	-
Chlorite	0.2	0.1	-	-	-	-	-	-	-	-
Chamosite	1	-	-	-	-	-	0.3	-	-	-
Palagonite	0.1	-	-	-	-	-	0.5	-	0.2	-
Sphalerite	-	-	-	-	-	-	0.05	-	-	-
Staurolite	-	0.3	0.2	-	-	-	-	-	-	-
Aragonite	0.2	-	0.1	-	-	-	0.49	-	-	-
Hypersthene	-	-	0.2	-	0.1	-	-	-	0.3	-
Gypsum	-	-	-	-	-	-	-	0.2	0.8	0.2
Glaucophan e	1	-	0.5	-	-	0.4	-	-	-	-
Clay minerals	-	0.2	0.2	0.2	1	1	1.7	-	-	-
Monazite	1.5	-	-	0.3	-	-	-	-	0.3	0.1
Kyanite	-	0.1	-	-	-	-	-	0.1	0.4	-
Epidote	-	0.2	-	-	-	-	0.3	-	0.2	-
Olivine	0.1	0.1	-	-	-	-	-	0.3	-	-
Rutile	-	0.1	0.6	-	-	0.3	0.4	-	0.3	0.2
Illmenite	-	0.3	-	0.4	-	0.8	0.2	0.2	0.1	--
Zircon	-	-	0.2	0.1	0.3	0.5	0.1	-	0.2	-
Tourmaline	0.3	-	-	0.2	0.4	0.3	0.7	0.3	0.5	0.4
Garnet	0.2	0.3	1.2	-	1.3	1	0.96	0.6	0.6	0.6
Haematite	0.1	-	-	-	-	-	-	-	-	-

4.2 Provenance

Recalculated data of sandstone samples plotted on Qt-F-L triangular diagram (after Dickinson and Suczek, 1979) indicate that all studied samples fall in the field of recycled orogen **(Fig. 5).** Plot of Qm-F-Lt (after Dickinson *et al.*, 1983, 1985) (**Fig. 6a)** indicate that five out of ten samples plot on lithic recycled while the remaining five samples within the field of transitional recycled. The Lm-Lv-Ls triangular diagram (after Ingersoll and Suczek, 1979; Suczek and Ingersoll, 1985) indicates mixed magmatic and subduction complex **(Fig. 6b).** The Qm-P-K diagram (after Dickinson and Suczek, 1979) indicates detrital modes of the mineral grains alone and polycrystalline fragments only quartz and feldspar grains. It is very clear from **(Fig. 6c).** (i.e., Qm-P-K diagram) that feldspar and quartz are originally from granite with some input of metamorphic rocks and volcanics. The Qm pole shows rising maturity for detritus that is either recycled or has been derived from the cratonic blocks of orogenic parts as is reported by Dickinson and Suczek (1979) for the tectonic set up and composition of sandstones. The cluster of samples is very close to Qm pole which indicates that Vihowa sandstones are highly matured and recycled. The Qp-Lv-Ls plot (after Dickinson *et al.*, 1983, 1985) shows that two out of ten samples drop in the field of collision orogeny source; however, one sample fall between the boundary of collision orogeny and subduction complex source whereas, eight samples fall within the subduction complex source **(Fig. 6d).**

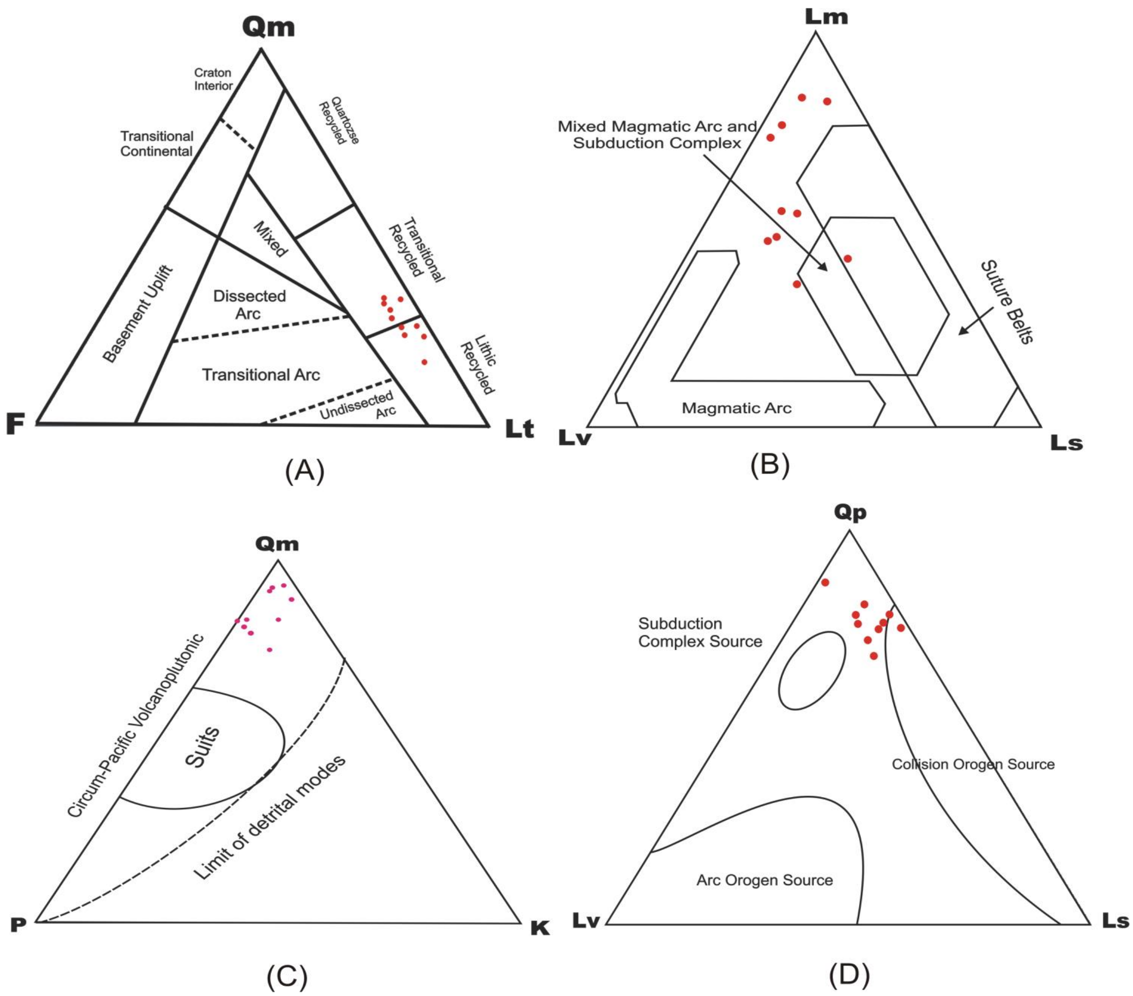

Fig. 6 Compositional diagrams of sandstones of Vihowa Formation, (A) Qm-F-Lt shows that the samples plot in transitional recycled and lithic recycled, (B) On Lm-Lv-Ls diagram, the samples plot in mixed magmatic arc and subduction complex, (C) Qm-P-K diagram showing the detritus mode of grains, (D) Qp-Lv-Ls diagram showing the source of sediments

5. DISCUSSION AND CONCLUSION

The identified types of quartz grains indicate that the source of Vihowa Formation is both metamorphic as well as plutonic in origin. The high proportion of mono-crystalline quartz of undulose and non-undulose nature (Tables 1 & 2) indicates derivation of sediments of Vihowa Formation is from a plutonic igneous source. Such types of observations have been drawn by Blatt, (1967) by studying the characteristics of quartz grains. Gallala *et al.,* (2009) described different sets of minerals and on the basis of their presence mentioned the source of sediments. In this regard, the observed minerals of Vihowa Formation such as the rutile, zircon, staurolite, and tourmaline points out that the source of sediments is from the acidic igneous rocks. Along with quartz, the lithic fragments of Vihowa Formation are meta-sedimentary in origin. Moreover, the inclusions of mica and garnet minerals within quartz grains are another indication of metamorphic source. Nowadays, it is a common mineralogical fact that during metamorphism polycrystalline quartz are formed from monocrystalline quartz because of increasing pressure and temperature. Along with others; Tucker, (2001) also proposed a set of heavy minerals, and on the basis of their presence or absence, the source lithologies can be determined. He mentioned that epidote, staurolite and garnet favour a metamorphic source terrain while tourmaline and rutile show an igneous source. The studied samples when plotted on triangular diagrams such as the Qm-F-Lt and Lm-Lv-Ls indicate transitional recycled, lithic reclyed and mixed magmatic and subduction complex, respectively (Fig 6a, b). The identified mineral assemblages and their plotting within different discrimination diagrams point out that both feldspar and quartz are derived from granitoids with some input of metamorphic and volcanic rocks. In terms of provenance; the present findings are in agreement with Garzanti *et al.*, (1996); where they discussed the detrital modes of Tertiary sandstones and mentioned that the feldspathic modes belong to active Asian mainland, whereas the sediments of quartz-arenitic are from subducting Indo-Pakistan Plate. Moreover, Downing and Goebel (1991) presented some details and pointed out the source for detrital mode of both Chitarwata and Vihowa formations. Their studies show that the detrital mode for the Chitarwata Formation is from a northern cratonic, however, the sediments of Vihowa Formation are from recycled orogenic detrital mode. They studied the sediments of above formations in the Dalana area of Zindapir Dome. In this regard, the sandstones of Litra and Chaudhwan formations fall in the typical setting of collision orogeny and suture belts (Ahmed and Khan, 1991).

In the light of above discussion, it is concluded that the sediments of the Vihowa Formation are derived from the interior of a craton and then recycled to deposit in present position. It is also probable that the rock fragments of studied sandstone may have been transported from Cretaceous Pab sandstone, exposed in Sulaiman belt in the west.

6. ACKNOWLEDGMENT

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REFERENCES:

Abu Bakr, M., R. O. Jackson, (1964). Geological map of Pakistan, Geological Survey of Pakistan.

Ahmed, W., M. J., Khan, (1991). Petrography of the Upper Litra and Chaudhwan formations, Upper Siwalik group, Zindapir Anticline, Northern Sulaiman Range. Geological Bulletin University of Peshawar, 24: 191-202.

Basu, A., (1985). Influence of climate and relief on composition of sands released at source area. In: Zuffa, G. G., ed., Provenance of Arenites. Dordrecht, the Netherlands, Reidel Publishing Company, Nato Advance Study Institute Series, 148:1-8.

Blatt, H. G., (1967). Original characteristics of quartz grains. Journal of Sedimentary Petrology, 37: 401-424.

Clift, P. D., N. Shimuzuz, G. D. Layne, (2001). Development of the Indus Fan and its significance for the erosional history of the western Himalaya and Karakorum. Geological Society of America Bulletin, 113:1039-1051.

David, A., P. Neil, A. Wells (1996). The transition from Tethys to the Himalaya as recorded in northwest Pakistan. Geological Society of America Bulletin, 108: 1295-1313.

Dickinson, W. R., L.S. Bcard, G. R. Brakenridge, (1983). Provenance of north America Phenerozoic sandstone in relation to tectonic setting. Geological Society of America Bulletin, 94:222-235.

Dickinson, W. R., (1985). Interpreting provenance relations from detrital modes of sandstone, In: Zuffa, G.G., eds. Provenance of Arenites. Advanced Study Institute Series, 148, Reidel, Dordrecht 333-361.

Dickinson, W. R., (1970). Interpreting detrital modes of greywacke and arkose. Journal of Sedimentary Petrology, 40:695-707

Dickinson, W. R., C. A. Suczek, (1979). Plate tectonic and sandstone composition. American Association of Petroleum Geology Bulletin, 63: 2164-2182.

Downing, K. F., E. H. Lindsay, W. R. Downs, S. E. Speyer, (1993). Lithostratigraphy and vertebrate biostratigraphy of the early Miocene Himalayan Foreland, Zinda Pir Dome, Pakistan. Sedimentary Geology, 87: 25-37.

Downing, K. F., and K. A. Goebel, (1991). Relationship of India-Asia convergence to sandstone depositional environments and detrital modes in early Miocene deposits of Zinda Pir Dome, Pakistan. Geological Society of America, Abstract with Programs, 23(5).

Gallala, W., M. E. Gaied, M. Montacer, (2009). Detrital mode, mineralogy and geochemistry of the Sidi Aich Formation (Early Cretaceous) in central and southwestern Tunisia: Implications for provenance, tectonic setting and paleoenvironment. Journal of African Earth Sciences, 53:159-170.

Garzanti, E., S. Critelli, R.V. Ingersoll, (1996). Paleogeography and paleotectonic evolution of the Himalayan Range as reflected by detrital modes of

Tertiary sandstones and modern sands (Indus transect, India and Pakistan). Geological Society of America Bulletin, 108: 631-642.

Gazzi, P., (1966). Le Arenarie del Flysch Sopracretaceo dell'Appennino Modenese: Correlazioni con il Flysch di Monghidoro. Mineral e Petro Acta, 12:69-97.

Graham, S. A., R. V. Ingersoll, W. R. Dickinson, (1976). Common provenance for lithic grains in Carboniferous sandstones from Ouachita Mountains and Black Warrior basin. Journal of Sedimentary Petrology, 46: 620–632.

Hemphill, W. R. and A. H. Kidwai, (1973). Stratigraphy of the Bannu and Dera Ismail Khan Area, Pakistan, United States Geological Survey, Professional Paper, 716-B:1-36.

Ingersoll, R. V., C. A. Suczek, (1979). Petrology and provenance of Neogene sand from Nicobar and Bangal Fans, DSDP sites 211 and 218. Journal of Sedimentary Petrology, 49:1217-1228.

Ingersoll, R. V., T. F. Bullard, R. L.Ford, (1984). The effect of grain size on detrital modes: A test of the Gazzi-Dickinson point-counting method. Journal of Sedimentary Petrology, 45:103-116.

Karl, P. E., (1959). Optical Mineralogy, McGraw-Hill, New York.

Kazmi, H. A., I. A. Abbasi, (2008). Stratigraphy and Historical Geology of Pakistan. Geological Survey of Pakistan, 380-385.

Kidwell, S. S., Holland, (2002). The quality of the fossil record: Implications for evolutionary analysis. Ann Rev Ecol and Syst, 33:561–588.

Pettijohn, F. J., P. E. Potter, R. Siever, (1987). Sand and sandstone. Springer, New York. 552.51

Prothero, D. R., F. L. Schwab, (2003). Sedimentary Geology, W.H., Freeman and Co, 99-126.

Qayyum, M., A. R. Niem, R. D. Lawrence, (2001). Detrital modes and provenance of the Paleogene Khojak Formation in Pakistan: implications for early Himalayan orogeny and unroofing. Geological Society of America Bulletin, 113: 320-332.

Raza, S. M., I. U. Cheema, W.R., Downs, A.R., Rajpar, S.C.Ward, (2002). Miocene Stratigraphy and mammal fauna from the Sulaiman Range, Southwestern, Himalayas, Pakistan, Palaeogeography, Palaeoclimatology, Palaeoecology, 186(3):185-197.

Suczek, C. A., R. V. Ingersoll, (1985). Petrology and provenance of Cenozoic sand from the Indus cone and the Arabian Basin. DSDP sites 211, 222 and 223. Journal of Sedimentary Petrology, 55: 340-346.

Sukhtankar, R. K., (2004). Applied Sedimentology, C.B. S Publisher., New Delhi- Bangalore. 170.

Tortosa, A., M. Palomares, J., Arribas, (1991). Quartz grain types in Holocene deposits from the Spanish Central System. Some problems in provenance analysis. Geological Society of London, Special Publication, 57.1: 47-54.

Tucker, M. E., (2001). Sedimentary Petrology, An Introduction to the origin of the Sedimentary Rocks. Blackwell Science Publisher, Oxford, 262.

Tucker, M. E., (1991). Sedimentary Petrology: an Introduction, John Wiley and Sons Ltd. 251

Young, S. W., (1976). Petrographic textures of detrital polycrystalline quartz as an aid to interpreting a crystalline source rocks. Journal of Sedimentary Petrology, 46(3): 595-603.