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Provenance, tectonic setting and palaeoclimate of Proterozoic Jiran Sandstone, Southeastern Rajasthan, India: A petrographic approach

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Abstract

Proterozoic Jiran Sandstone rests unconformably on Binota Shale and Khori-Malan Conglomerate. The Jiran Sandstone is comprised mainly of fine to medium-grained, varicolored, thickly bedded sandstones, showing diverse primary sedimentary structures such as ripple marks, planar, and trough cross-bedding. Petrographically, Jiran Sandstone is of mainly quartzarenite which is composed of varieties of quartz with ultra-scarcity of feldspar, lithic fragments, micas, and heavy minerals. Quartz is more abundant mineral shown by X-ray Diffraction Analysis. The provenance, tectonic setting, and paleoclimatic condition of the Jiran sandstone were evaluated using integrated petrographic studies. Analysis pursuant, monocrystalline and polycrystalline quartz grains and heavy minerals are driven primarily from metamorphic and plutonic Precambrian basement source rocks of a craton interior setting with a minor quartzose recycled sedimentary source material. Intensive chemical weathering in warm and humid paleoclimate is indicated by lack of feldspar and rock fragments.

Keyword: Jiran sandstone, Petrography, X-ray Diffraction, Provenance, Tectonic setting

INTRODUCTION

Provenance, tectonic setting, weathering conditions, sediment transport processes, and depositional environment greatly influence the mineralogical composition of siliciclastic rocks (Armstrong-Altrin, 2015; Dickinson, 1988; Johnsson and Basu, 1993; Boggs, 2006; Critelli, 2018). Siliciclastic rock provenance analyses often aims to determine the composition and geological evolution of the sediment source area, as well as constrain the tectonic setting of the basin (Verma and Armstrong-Altrin, 2013 & 2016; Dickinson, 1985). Classification, tectonic setting, provenance, and paleoclimatic condition of Jiran Sandstone investigated by the study of quantitative mineralogical evolution of quartz, feldspar, rock fragments, and undulosity in detrital quartz. The frequency of several types of quartz grains was utilized to evaluate the source rock type (Basu et al., 1975; Tortosa et al., 1991), the framework mineralogical composition reflects the tectonic setting of sandstone (Crook, 1974; Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985) and type of sandstone classified by Folk (1980) classification scheme. Suttner et al. (1981) model is used to explain the paleoclimatic conditions that occurred during the weathering of the source rock. Two analytical approaches for determining the mineralogical composition of sandstone have been investigated in this study: (i) Petrography (optical examination of thin sections), (ii) X-ray Diffraction (XRD). The principal objectives of this research are to determine the composition of the source area, the tectonic setting, and interpret paleoclimatic conditions during the deposition of the Jiran Sandstones of Southeastern Rajasthan.

Geologic Background of the Study Area

The Vindhyan Supergroup forms an unmetamorphosed succession in an intracratonic sedimentary basin exposed in the form of an arcuate belt that is locally affected by folding and faulting and is one of the best-preserved Meso-Neoproterozoic sequences in India (Singh et al., 2020). On the basis of its diverse tectonic settings, the Vindhyan Supergroup is divided into two major successions. The Lower Vindhyan deposited in an intracratonic rift basin (Bose et al., 1997) and Upper Vindhyan in an intracratonic sag basin (Sarkar et al., 2002). On the basis of lithology, carbonate dominant sedimentary rocks of Lower Vindhyan is overlain by siliciclastic dominant sedimentary rocks of Upper Vindhyan (Sen et al., 2014). Lower Vindhyan succession in Rajasthan constitutes the Satola, Sand, Lasrawan, and Khorip groups in ascending stratigraphic order can be correlated with the Semri Group of lower Vindhyan in Son valley (Auden, 1933; Malone, 2008). The Upper Vindhyan Supergroup comprises from base to top are Kaimur, Rewa, and Bhander groups (Gopalan et al., 2013). Unconformity was identified between the Semri and succeeding groups of Upper Vindhyans (Soni et al., 1987). The generalised stratigraphy of Vindhyan

Supergroup, southeastern Rajasthan is given in figure 1. The Vindhyan basin in Rajasthan is bordered on the northwest by the Delhi-Aravali orogenic belt and on the southeast by the Satpura orogenic belt. The Aravali and Satpura mobile belts are tectonic in nature, with intrinsic disturbances marked by the presence of large zones of displacement in the west, such as the Great Boundary Fault Zone (GBFZ), and the Central Indian Tectonic Zone (CITZ) in the south. The Great Boundary Fault is a significant lineament with a NE and SW trend that separates the Aravali-Delhi orogen from the Vindhyan basin (Khan, 2013). The Vindhyan Supergroup rests over Palaeoproterozoic Delhi-Aravali Supergroup and Archean Berach granite (Raza et al., 2012). The geological map of the Lower Vindhyan in Rajasthan is given in figure 2. Khorip Group of Lower Vindhyan consists of Khori-Malan Conglomerate (Fig. 3a) at the base, followed by Jiran Sandstone (Fig. 3b), Bari Shale (Fig. 3c), Nimbahera Limestone, and Suket Shale formations successively overlying Binota Shale of Lasrawan Group. The Jiran Sandstone unconformably overlies the Binota Shale and Khori-Malan Conglomerate, occurring as the long ridges and hillocks. The Jiran Sandstone is consisting mainly of sandstone with shale intercalation at some places (Fig. 3d). These sandstones mostly show gradational contact with underlying Binota Shale and overlying Bari Shale.

Sampling and Analytical Procedures

For the petrographic analysis total 24 fresh and unweathered samples were collected from the tectonically undisturbed outcrop of Jiran Sandstones. Thin sections were prepared and subjected to petrographic investigation under the petrological microscope. Thin sections were stained with sodium cobaltinitrite solution for K-feldspar identification during microscopic analysis. For Modal analysis, about 250-300 grain per thin section were counted by the point-counting method (Dickinson, 1985). Grain size counting was done using Gazzi Dickinson point counting method (Ingersoll et al., 1984). The definition of raw and recalculated parameters used in the investigation is presented in table-1 and relative proportions of quartz, feldspar, and rock fragments were determined. The counted grains were recalculated into percentage as summarized in table-2 and these tabular data were plotted in the diagrams suggested by Folk (1980), Suttner et al. (1981), and Dickinson et al. (1985) to interpret the type of sandstone, paleoclimate, provenance and tectonic setting of Jiran sandstone respectively. Sandstones were characterized by Folk (1980) classification.The source rock composition of Jiran Sandstone was determined by Basu et al. (1975) model.

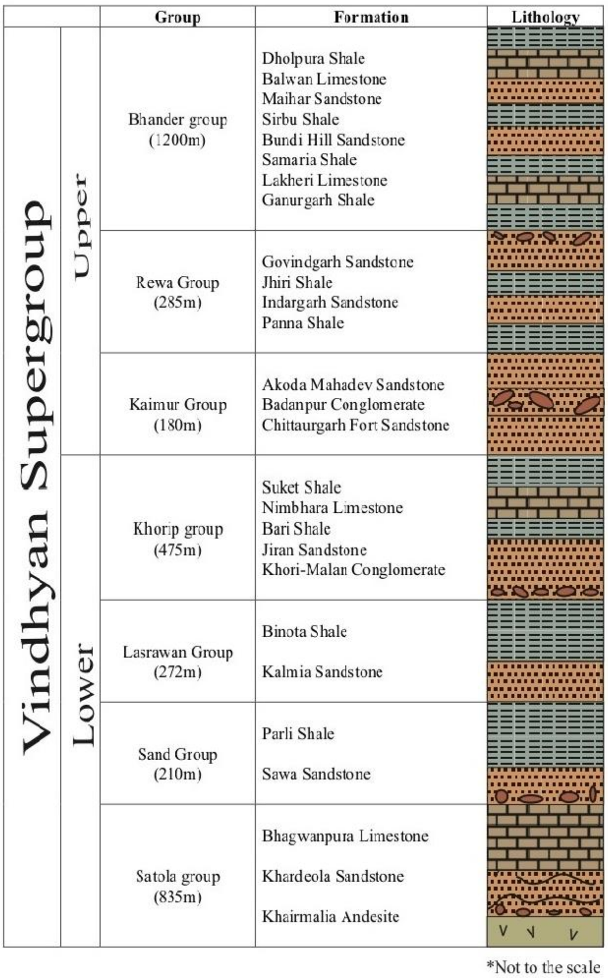

Fig. 1: Generalized stratigraphy of Vindhyan Supergroup, southeastern Rajasthan, modified after Malone et al. (2008) and Khan (2013).

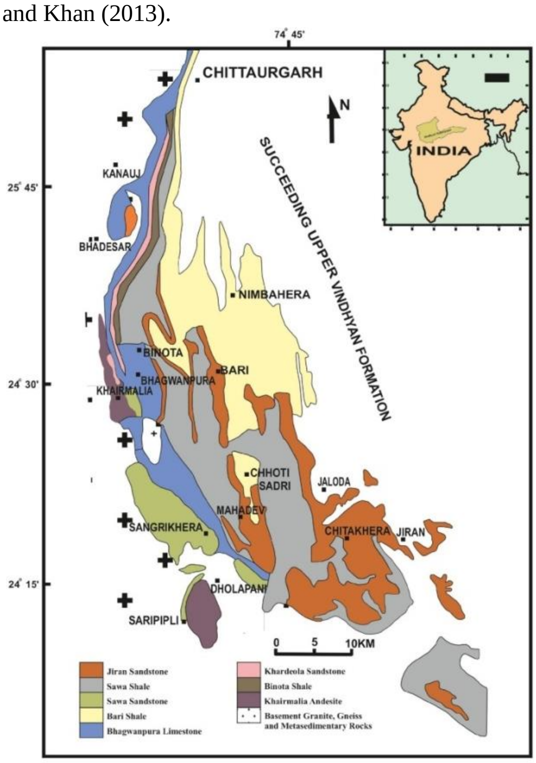

Fig.2: Geological map of Lower Vindhyan Basin (Along western margin), Southeastern Rajasthan.

Fig.3: Field Photographs of the study area, (a) Khori - Malan conglomerate, (b) Jiran Sandstone, (c) Bari Shale, (d) Intercalation of Jiran Sandstone and Bari Shale.

Table 1: Key for counted and recalculated petrographic framework grain parameters of sandstones, after Folk (1980), Dickinson and Suczek (1979), Suttner and Dutta (1986).

QFR	QtFL	QmFLt
Q = Total quartz grain (Qm+Qp), where Qm = Monocrystalline quartz Qp= Polycrystalline quartz F = Total feldspar (P+K), where P = Plagioclase, K = K-feldspar R = Total rock fragments including chert	Qt = Total quartz grain (Qm+Qp), where Qm = Monocrystalline quartz Qp = Polycrystalline quartz including chert F= Total feldspar (P+K), where P = Plagioclase, K = K-feldspar L= Total lithic fragments	Qm = Monocrystalline quartz F = Total feldspar (P+K), where P = Plagioclase, K = K-feldspar Lt = Total lithic fragments + Polycrystalline quartz

After useful thin section screening, five representative samples were selected for X-ray diffraction analysis. Bulk powder samples of Jiran Sandstones were quantitatively analyzed by X-ray diffractometer (XRD in Lab, Department of Physics, AMU, Aligarh) for their mineral composition. The samples were scanned in 2θ range of 5°- 40° with X-rays using Cu (λ=1.540598) target source for crystalline phase identification. Obtained “Intensity vs. 2 θ” data were plotted and identified minerals peaks.

RESULTS

Petrographic study and X-ray Diffraction of sandstone

Jiran Sandstones are pinkish white to dirty white quartzarenite, the significant proportion of detrital grains of the sandstone are showing subangular to sub-rounded, moderately to well sorted with fine to medium grain size. The detrital grains of sandstone are composed mainly of varieties of quartz (97.02 %) with ultra-scarcity of feldspar (0.3 %), lithic fragments (1.74 %), micas (0.35 %), and heavy minerals (0.32 %). All of the sandstone samples data shown in the QFR triangle diagram indicate close distribution in the quartzarenite field, indicating that sandstone is mostly quartzarenite with little variance in mineralogy (Fig. 4a). Quartz is the most dominant detrital grain in sandstone. Among dominant quartz grain, monocrystalline quartz is dominant over polycrystalline quartz (Fig. 5a).

Table 2: Recalculated percentages of detrital grain modes of Jiran Sandstone, Southeastern Rajasthan.

Sample	QFR			QtFL			QmFLt		
	Q	F	R	Qt	F	L	Qm	F	Lt
JJST – 1	100.00	0.00	0.00	100.00	0.00	0.00	98.33	98.33	98.33
JJST – 2	97.48	0.25	2.27	98.75	0.25	1.00	96.16	96.16	96.16
JJST – 3	99.69	0.00	0.31	100.00	0.00	0.00	96.07	96.07	96.07
JJST – 4	99.26	0.20	0.54	99.26	0.20	0.54	98.73	98.73	98.73
JJST – 5	99.70	0.00	0.30	99.70	0.00	0.30	89.42	89.42	89.42
JJST – 6	99.05	0.32	0.63	99.39	0.32	0.28	97.47	97.47	97.47
JJST – 7	99.80	0.00	0.20	99.80	0.00	0.20	97.98	97.98	97.98
JJST – 8	97.10	0.45	2.44	97.97	0.46	1.57	95.67	95.67	95.67
CJST – 1	91.22	1.21	7.57	97.01	1.28	1.71	91.22	91.22	91.22
CJST – 2	97.40	0.00	2.60	98.44	0.00	1.56	95.50	95.50	95.50
CJST – 3	98.52	0.00	1.48	98.52	0.00	1.48	94.50	94.50	94.50
CJST – 4	99.74	0.00	0.26	99.74	0.00	0.26	97.30	97.30	97.30
CJST – 5	98.85	0.56	0.58	99.43	0.57	0.00	96.98	96.98	96.98
CJST – 6	97.58	0.49	1.93	97.58	0.49	1.93	94.18	94.18	94.18
CJST – 7	100.00	0.00	0.00	100.00	0.00	0.00	95.83	95.83	95.83
CJST – 8	99.15	0.44	0.40	99.37	0.45	0.18	96.78	96.78	96.78
BJST – 1	99.19	0.32	0.49	99.47	0.32	0.20	95.78	95.78	95.78
BJST – 2	95.95	0.61	3.43	98.01	0.63	1.37	95.82	95.82	95.82
BJST – 3	96.83	0.36	2.81	97.65	0.37	1.98	95.13	95.13	95.13
BJST – 4	95.08	0.66	4.25	98.56	0.69	0.75	95.07	95.07	95.07
BJST – 5	98.33	0.32	1.34	99.67	0.33	0.00	98.59	98.59	98.59
BJST – 6	95.08	0.42	4.50	95.63	0.43	3.95	93.80	93.80	93.80
BJST – 7	97.94	0.60	1.46	98.99	0.61	0.40	95.12	95.12	95.12
BJST – 8	97.59	0.00	2.41	98.38	0.00	1.62	95.84	95.84	95.84

Monocrystalline quartz has undulose as well as nonundulose variety and polycrystalline quartz grains are mainly composed of randomly oriented crystallites with straight to undulose extinction. Some of the monocrystalline quartz grains show the inclusions of heavy minerals (Fig. 5b). Some of the quartz grains show silica overgrowth and most of the quartz grains show triple junction, dominant long, concavo-convex contacts are common (Fig. 5c). The framework grains of sandstone are cemented by mainly silica, ferruginous (Fig. 5d) cement, and matrix (Fig. 5e). Feldspar grains population is rarely present in thin sections; microcline is the common variety of k-feldspar dominates over plagioclase. Rock fragments are absent in many thin sections, identified rock fragments mainly are of volcanic (Fig. 5f), chert (Fig. 6a), shale, and metamorphic (phyllite, schist) rocks (Fig. 6b). Sparkling color of muscovite (Fig. 6c) and heavy minerals mainly rounded zircon (Fig. 6d), tourmaline (Fig. 6e), and rutile (Fig. 6f) are present in sandstones.

Using bulk X-ray diffraction spectrum analysis, mineralogical investigations of Jiran Sandstone revealed a high intensity and dominating quartz (Fig. 7). As a result, the principal binding materials and dominant framework grains are silica.

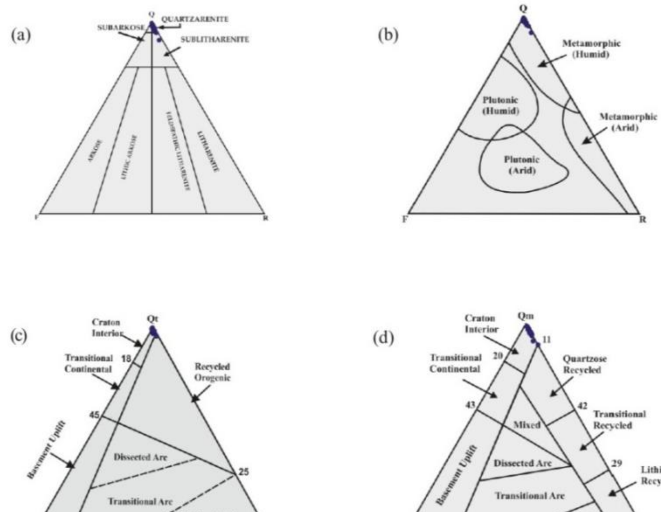

Fig. 4: Ternary plots of Jiran Sandstone, (a) QFR diagram, after Folk (1980), (b) QFR diagram after Suttner et al. (1981), (c & d) QtFL & QmFLt diagrams, after Dickinson et al. (1985).

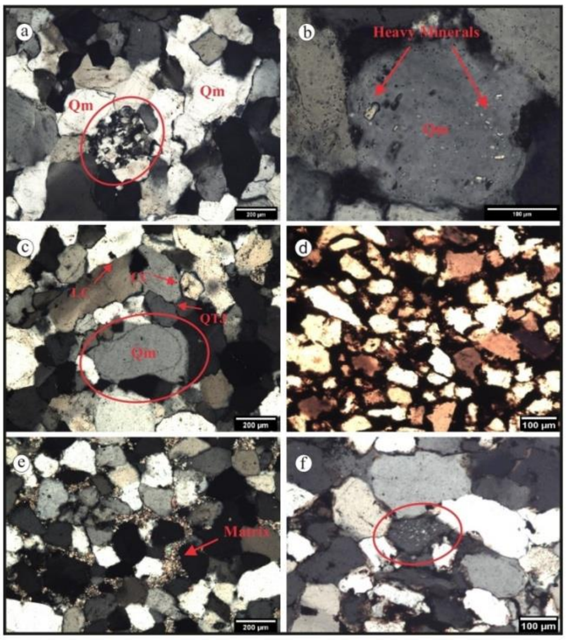

Fig. 5: Photomicrographs of Jiran Sandstones, (a) Medium size polycrystalline quartz grain, (b) Heavy mineral inclusions in monocrystalline quartz grain, (c) Grain of monocrystalline quartz with silica overgrowth and arrows show quartz grain triple junction (QTJ), Long Contact (LC), Concavo-Convex Contact (CC), (d) Ferruginous cement, (e) Matrix, (f) Volcanic Rock Fragment.

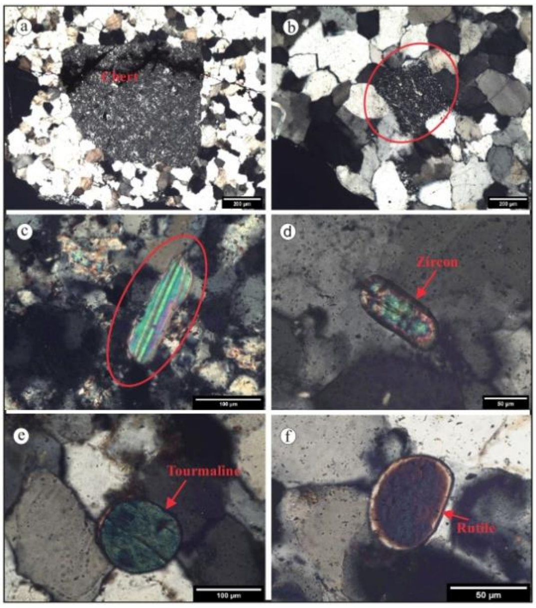

Fig. 6: Photomicrographs of Jiran Sandstones, (a) Chert, (b) Metamorphic Rock Fragment, (c) Sparkling color of muscovite flake between quartz grains, (d) Rounded zoned zircon grain, (e) Rounded greenish tourmaline, (f) Rounded rutile.

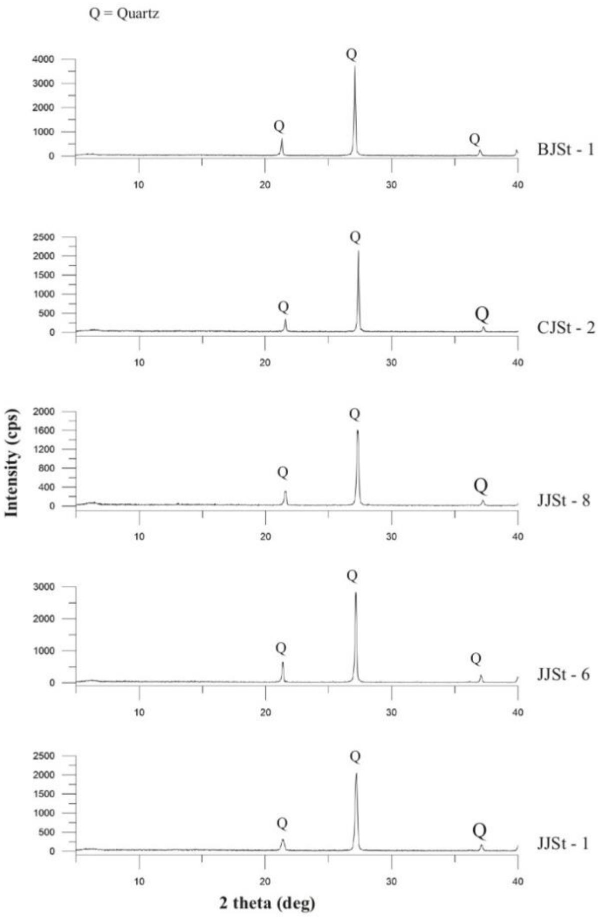

Fig. 7: X-ray diffraction pattern of Jiran Sandstone shows peaks of Quartz (Q).

DISCUSSION

Provenance and Palaeoclimatic conditions

Various petrographic techniques, such as the study of polycrystallinity and undulosity of quartz grain (Basu et al., 1975; Young, 1976), types of feldspar (Pittman, 1970), and type of heavy minerals (Morton, 1985) have been used to establish the provenance of Jiran Sandstone. Due to the ultra-deficiency of feldspars and rock fragments in the samples, provenance was mainly determined by quartz type and the examination of heavy minerals. In the sandstone sample, dominant medium to strong undulose monocrystalline quartz grains indicates a metamorphic origin, whereas mildly undulose to non-undulose quartz grains indicate a plutonic origin (Basu, 1975; Potter, 1978a). According to Basu et al. (1975), Diamond diagrams of polycrystalline quartz vs. non-undulatory and undulatory monocrystalline quartz reveal a dominant metamorphic with plutonic origin (Fig. 8).The heavy minerals observed, mostly zircon, tourmaline, and rutile, indicate an alkaline plutonic rock source (Preston et al., 2002; Wanas and Abdel-Maguid, 2006), with some quantity of garnet suggesting a metamorphic source rock (Morton, 1985; Morton et al., 1992), and moderately rounded to rounded zircon grains indicating reworked sedimentary sources (Chaudhuri et al., 2018). Zircon and opaque mineral inclusions in certain monocrystalline quartz grains suggest plutonic origin (Krynine,1940). As a result of the availability of heavy mineral types, the Jiran Sandstone is originated from metamorphic, igneous, and sedimentary rock sources.

The variation in the framework mineralogy or compositional maturity of sandstone is influenced by the climate. Climate is thought to be the most important element influencing maturity (Young et al., 1976; Suttner et al., 1981; Franzinelli and Potter, 1983; Ghosh and Kumar, 2000). The lack of feldspar and rock fragments suggests that source rocks were subjected to extensive weathering over a long period in a warm, humid climate (Pettijohn et al., 1987; Amireh, 1991) and also indicating that sandstones were originated from low relief interior part of the craton (Burnett and Quirk, 2001; Patra et al., 2014). Jiran Sandstone is plotted in a metamorphic source with a humid climatic field in the QFR ternary diagram (Suttner et al., 1981) (Fig. 4b). In warm and humid climatic conditions, feldspar and other unstable components are destroyed during weathering of igneous and metamorphic source rock. Phyllite rock fragments indicate low to medium metamorphic rocks in the source, whereas shale and chert fragments indicate derivation from the sedimentary source rock. Shale and phyllite are unstable rock fragments that are usually disintegrated in humid climates; hence their retention implies a very slow source material transportation rate and/or a low subsidence rate in a passive tectonic setting. NE-SE paleocurrent data shows provenance lies in NW to SW direction (Prasad, 1984). Paleocurrent of Vindhyans of Rajasthan suggests Palaeoproterozoic Delhi-Aravali Supergroup including Berach granite rocks are the most probable source of this sandstone.

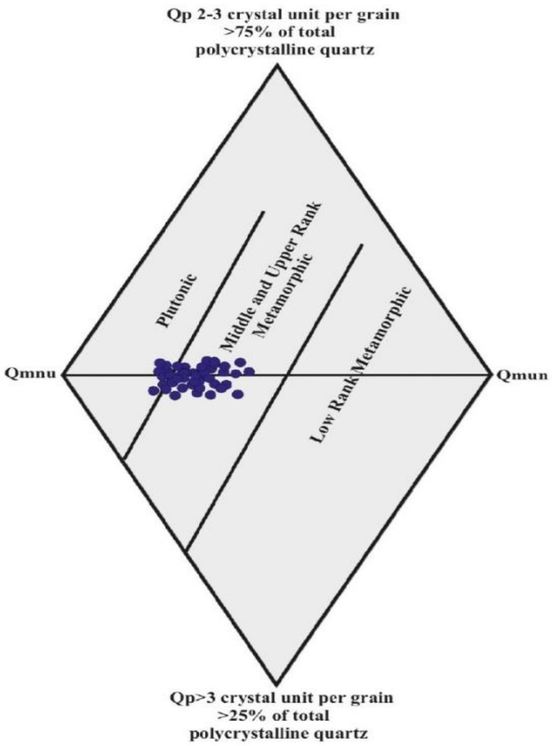

Fig. 8: Diamond diagram plot of Jiran Sandstone, a plot between polycrystalline quartz vs. non-undulatory and undulatory monocrystalline quartz. Qmnu: Low undulosity monocrystalline quartz grains; Qmun; High undulosity monocrystalline quartz grains; Qp 2-3: Coarse-grained polycrystalline quartz grains; Qp>3: Fine-grained polycrystalline quartz grain. Jiran Sandstone is compared with the provenance field, after Basu et al. (1975).

Tectonic setting

The principal premise behind the provenance analysis of sandstone is to consider that different tectonic setting contains characteristic of the rock type which, when eroded, produce sandstone with specific composition (Dickinson, 1985). The framework mineralogy is used to establish the tectonic setting of sandstone (Crook, 1974), characterised sandstone composition based on primary provenance types such as craton interior, basement uplifts, recycled orogens, and magmatic arcs (Dickinson and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985; Verma and Shukla, 2015). Detrital components displayed on QFR ternary diagram with significant provenance types such as craton interior, basement uplift, recycled orogeny, and magmatic arc are used to define the tectonic setting of Jiran Sandstone (Dickinson and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985). The data from the modal analysis of the Jiran Sandstone plotted in the ternary Qt-F-L and Qm-F-Lt diagrams (Dickinson et al., 1983), the examined samples fall in the craton interior and partially in recycled orogenic fields (Fig. 4c and 4d), illustrates that the Jiran sandstones are mainly mature sandstone originate from craton and medium to high rank metamorphosed supra crustal rock release quartzose debris of continental affiliation into the basin with supplemented by recycled sediment which associate with passive marginal basin.

CONCLUSIONS

The petrographic study reveals that the Proterozoic Jiran sandstone in the south-east Rajasthan is mainly quartzarenite, predominantly comprised of quartz, ultra-scarcity of feldspar, and rock fragments with various types of cementing materials are mainly silica and iron. Fine to medium detrital grains of sandstone are showing moderately to moderately well sorted, sub-angular to sub-ounded nature.

The presence of dominant long and concavo-convex contact between quartz grains, quartz overgrowth, and quartz triple junction suggests that Jiran sandstones has suffered mechanical compaction due to the pressure of overlying strata.

Petrographic attributes, mainly framework mineralogy-quartz type and heavy minerals suggest the Jiran sandstones are originated from medium to high-rank metamorphic, plutonic, and recycles sedimentary sources. Qt-F-L and Qm-F-Lt ternary diagrams suggest these sandstones were derived mainly from craton interior with comparatively low contribution from quartzose recycled orogeny.

Palaeocurrents of the sandstones supported the Precambrian basement rock of the pre-Aravalli and Berach granite as the most probable source of this sandstone.

According to the XRD analysis, the sandstone samples show almost identical minerals wirh mostly quartz peaks.

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