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Petrographic Study of the Meso-Neo Proterozoic Kaimur Sandstone, Vindhyan Supergroup, Chittorgarh, southeastern Rajasthan, India: Implication for Provenance, Tectonic Setting and Paleoclimate

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Abstract: Proterozoic Kaimur Sandstone succession rests unconformably on calcium carbonate-rich succession of the Khorip Group (Lower Vindhyan) in and around Chittorgarh, southeastern part of Rajasthan. The Kaimur Group consists multicoloured, medium -to fine-grained, thick beds of sandstones with thin beds of sandy shale and flagstone, display of various primary sedimentary structures such as current bedding, ripple marks and mud cracks. Kaimur quartz arenite composed of varieties of quartz with rare feldspar, mica, rock fragments, and heavy minerals. The X-ray diffraction (XRD) data has shown that quartz is more abundant with little iron oxide mineral. The provenance, tectonic setting and paleoclimatic of the Kaimur Sandstone is evaluated using integrated petrographic studies. Analysis reveals detrital derivation from granitic and metamorphic Precambrian basement source rocks of a craton interior setting with a minor quartzose recycled sedimentary rock. Intense weathering in warm and humid climate indicated lack of feldspar and rock fragments. Paleocurrent indicate flow from NW and SW.

Keywords: Kaimur Sandstone, Petrography, X-ray diffraction, Provenance, Tectonic setting, Southeastern Rajasthan.

INTRODUCTION

Mineralogical composition of siliciclastic rocks is influenced by various parameters including provenance, tectonic setting, weathering condition, sediment transport processes and depositional environment (Armstrong-Altrin, 2015, Dickinson, 1988; Johnsson and Basu, 1993; Boggs, 2006; Critelli, 2018). Siliciclastic rock provenance studies usually aim to disclose composition and geological evolution of sediment source area and to constrain the tectonic setting of the depositional basin (Verma and Armstrong-Altrin, 2013&2016; Dickinson, 1985). Quantitative mineralogical evolution of quartz, feldspar, rock fragments and undulosity in detrital quartz of sandstone are useful for investigating classification, Tectonic setting,

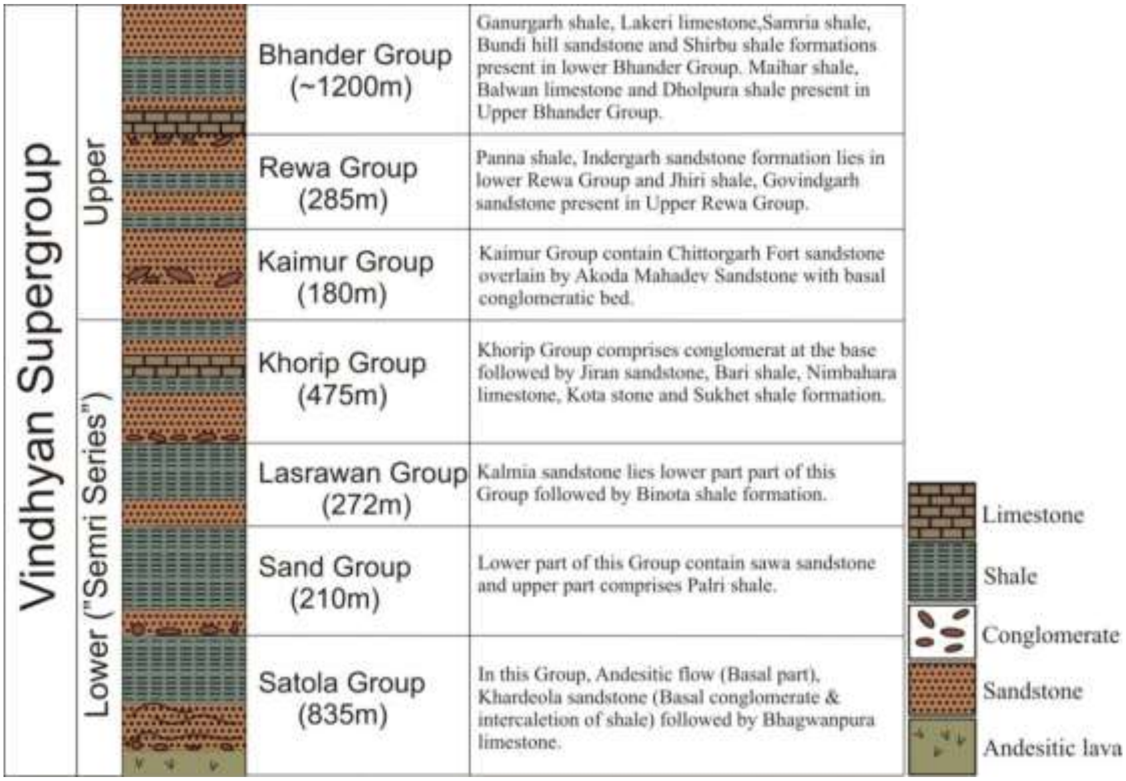

Fig. 1: Generalized lithostratigraphy and correlation of Rajasthan and Son valley columnar section, Vindhyan Supergroup, modified after Malone et al. (2008) and Khan (2013).

provenance and paleoclimatic condition of Kaimur Sandstone. Frequency of different type of quartz grain used to deduce the type of source rock (Basu et al., 1975; Tortosa et al., 1991), tectonic setting of sandstone reveal by using framework mineralogical composition (Crook, 1974; Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985) and type of sandstone categorized by Folk (1980) classification scheme. Paleoclimatic condition during weathering of the source rock is explained by using Suttner et al. (1981) model.

From the sedimentological point of view, the Kaimur Sandstone of southeastern Rajasthan is less explored than Son Valley. In the present work, two analytical techniques used to determine the mineralogical composition of sandstone have been considered: (i) Petrography (optical analysis of thin sections); (ii) X-ray diffraction (XRD). The main objectives of this study are to evaluate source area composition, tectonic setting and to infer paleoclimatic conditions during deposition of the Kaimur Sandstones of southeastern Rajasthan.

GEOLOGICAL SETTING OF THE STUDY AREA

1999; Prasad, 1984; Malone et al., 2008). Unconformity was identified between the Semri and succeeding groups (Soni et al., 1987).

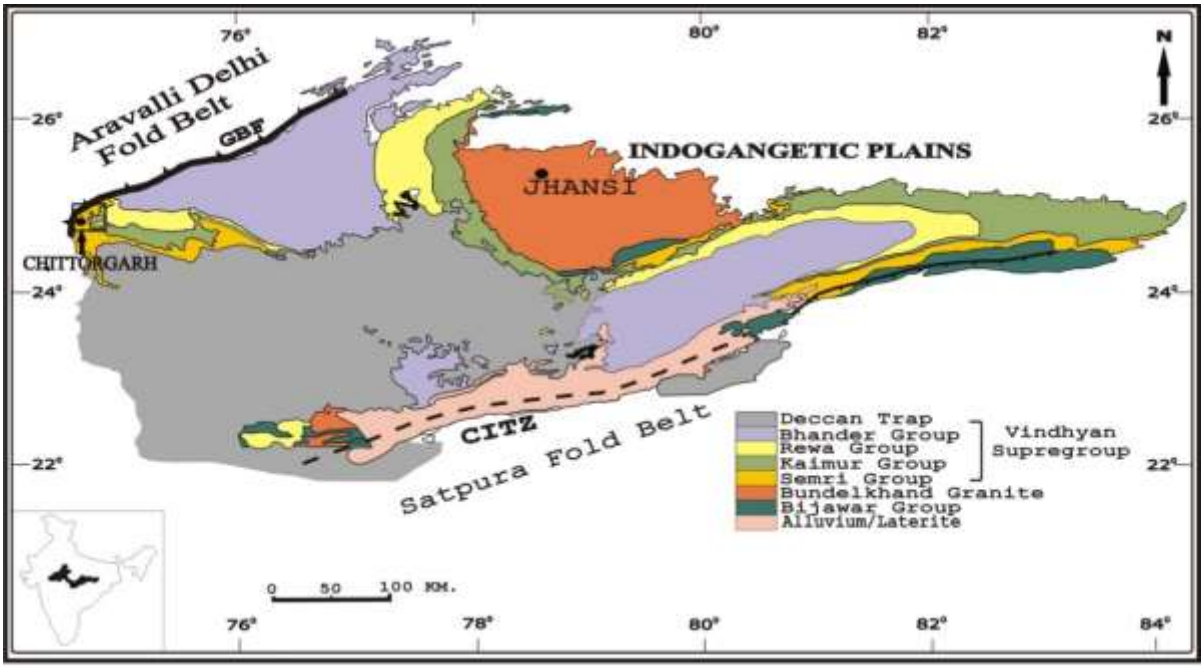

Fig. 2: Geological map of the Vindhyan Basin, Modified after Prasad and Rao (2006).

The 4500 m thick Vindhyan Supergroup is subdivided into two major successions on the basis of their distinct tectonic setting. The Lower Vindhyan developed in an intracratonic rift basin (Bose et al., 1997) and Upper Vindhyan in an intracratonic sag basin (Sarkar et al., 2002). Carbonate controlling Lower Vindhyan sedimentary succession composed by Satola, Sand, Lasrawan and Khorip Groups in ascending stratigraphic order of Rajasthan can be correlated with Semri Group of Lower Vindhyan in Son Valley (Fig. 1). The siliciclastic controlling Upper Vindhyan succession subdivided further into the Kaimur, Rewa and Bhander Groups (Chaudhari et al.,

In Rajasthan, Vindhyan basin in NW side bounded by the Delhi-Aravali orogenic belt and to the SE by the Satpura orogenic belt. Aravali and Satpura mobile belt are tectonic in nature show inherent disturbances feature characterized by existence of major zone of displacement specified as Great Boundary Fault Zone (GBFZ) in the west and Central Indian Tectonic Zone in the south (Fig. 2). The SSW boundary is concealed below Deccan continental flood basalt and the southern continuation by Indo-Gangetic alluvial plain. Great Boundary Fault is a NE and SW trending

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 L= Total lithic fragments	Qm= Monocrystalline quartz F= Total feldspar Lt= Total lithic fragments+ Polycrystalline quartz

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

major lineament which separating the Aravali-Delhi orogeny from the Vindhyan basin (Khan, 2013). The Achaean Berach granite and Palaeoproterozoic Delhi-Aravali Supergroup both are the basement of Vindhyan Supergroup (Raza et al., 2012).

The Kaimur Group of Rajasthan consists predominantly of quartzitic sandstone successions and it is broadly subdivided into two formations such as Chittorgarh Fort sandstone Formation overlain by Akoda Mahadev sandstone Formation. Chittorgarh Fort sandstone is generally showing pinkish white or dirty white in colour, fine to medium grain quartzitic sandstone with variable thickness of bedding (0.2 to 1.5m) having primary sedimentary structures mainly current bedding, herringbone cross-bedding, ripple marks and mud cracks. Akoda Mahadev sandstone formation contain Badanpur conglomerate in the basal portion and intercalation of silty shale present in the upper portion (Prasad, 1984). Kaimur formation occurs as small isolated ridges and hillocks in the vicinity of Chittorgarh but extensively, forming parallel ridges trending North-south, farther east. It is underlain by laminated to splintery Sukhet shale with variable sharp to intercalated contact and sandstone which crop out farther away in northeastern part of study area

SAMPLING AND ANALYTICAL TECHNIQUE

Petrographic analysis

Thirty four unweathered sandstone samples were taken from relatively less disturbed part of the Kaimur Sandstone outcrop with variation of lithofacies. The thin sections were prepared and examined under optical microscope. K-feldspar was identified mainly by staining of thin section by sodium cobaltinitrite solution (Carver, 1971). Modal analysis was performed using point-counting technique for evaluating quantitative mineralogical aspect of sandstone. About 300-350 framework grains were counted per thin section using Gazzi Dickinson point-counting technique (Ingersoll et al., 1984).

The parameters used in this study are provided in Table 1 and the relative proportion of quartz, feldspar and rock fragment are summarized in Table 2. Data are plotted on the diagrams proposed by Folk (1980), Basu et al. (1975), Tortosa (1991), Dickinson et al. (1985) and Suttner et al. (1981), to determine type of sandstone, source rock composition, tectonic setting and paleoclimatic condition.

Sample	**QFR**			**QtFL**			**QmFLt**		
	Q	F	R	Qt	F	L	Qm	F	Lt
KFST-1	99.44	0.00	0.56	100.00	0.00	0.00	93.60	0.00	6.40
KFST-2	100.00	0.00	0.00	100.00	0.00	0.00	94.06	0.00	5.94
KFST-3	98.87	0.00	1.13	98.87	0.00	1.13	93.68	0.00	6.32
KFST-4	99.52	0.28	0.20	99.72	0.28	0.00	93.05	0.28	6.67
KFST-5	98.59	0.00	1.41	98.59	0.00	1.41	95.04	0.00	4.96
KFST-6	98.62	0.00	1.38	99.74	0.00	0.26	92.90	0.00	7.10
KFST-7	100.00	0.00	0.00	100.00	0.00	0.00	92.67	0.00	7.33
KFST-8	96.49	0.46	3.05	96.98	0.46	2.56	86.00	0.47	13.53
KFST-9	100.00	0.00	0.00	100.00	0.00	0.00	93.22	0.00	6.78
KFST-10	97.51	0.00	2.49	98.06	0.00	1.94	89.18	0.00	10.82
KFST-11	98.79	0.00	1.21	98.79	0.00	1.21	94.42	0.00	5.58
KFST-12	98.44	0.00	1.56	99.20	0.00	0.80	94.17	0.00	5.83
KFST-13	100.00	0.00	0.00	100.00	0.00	0.00	93.12	0.00	6.88
KFST-14	98.25	0.48	1.27	98.88	0.48	0.64	88.51	0.48	11.01
KFST-15	98.65	0.00	1.35	98.65	0.00	1.35	89.55	0.00	10.45
KFST-16	98.51	0.00	1.49	98.51	0.00	1.49	95.17	0.00	4.83
KFST-17	100.00	0.00	0.00	100.00	0.00	0.00	90.12	0.00	9.88
KFST-18	99.52	0.00	0.48	100.00	0.00	0.00	94.54	0.00	5.46
KFST-19	98.81	0.30	0.89	99.70	0.30	0.00	91.03	0.30	8.66
KFST-20	97.26	0.00	2.74	98.06	0.00	1.94	93.58	0.00	6.42
KFST-21	100.00	0.00	0.00	100.00	0.00	0.00	93.00	0.00	7.00
KFST-22	99.79	0.00	0.21	100.00	0.00	0.00	94.57	0.00	5.43
KFST-23	98.38	0.00	1.62	98.38	0.00	1.62	91.00	0.00	9.00
KFST-24	100.00	0.00	0.00	100.00	0.00	0.00	94.04	0.00	5.96
KFST-25	100.00	0.00	0.00	100.00	0.00	0.00	94.88	0.00	5.12
KFST-26	99.04	0.00	0.96	99.40	0.00	0.60	92.80	0.00	7.20
KFST-27	99.20	0.00	0.80	100.00	0.00	0.00	95.22	0.00	4.78

KFST-28	100.00	0.00	0.00	100.00	0.00	0.00	91.89	0.00	8.11
KFST-29	99.30	0.00	0.70	100.00	0.00	0.00	91.85	0.00	8.15
KFST-30	99.62	0.38	0.00	99.62	0.38	0.00	93.46	0.38	6.16
KFST-31	98.79	0.00	1.21	99.42	0.00	0.58	90.37	0.00	9.63
KFST-32	98.82	0.00	1.18	100.00	0.00	0.00	89.34	0.00	10.66
KFST-33	99.28	0.00	0.72	100.00	0.00	0.00	89.94	0.00	10.06
KFST-34	99.54	0.00	0.46	99.54	0.00	0.46	91.80	0.00	8.20

Table 2: Recalculated percentage of detrital grain modes of Kaimur Sandstone of Chittorgarh, Rajasthan

X-ray diffraction analysis

Bulk powder samples of Kaimur Sandstones have been quantitatively analyzed by X-ray diffractometer (Rigaku Ultima IV, CIF Jamia Millia Islamia, New Delhi) for their mineral composition. The samples have scanned in 2θ

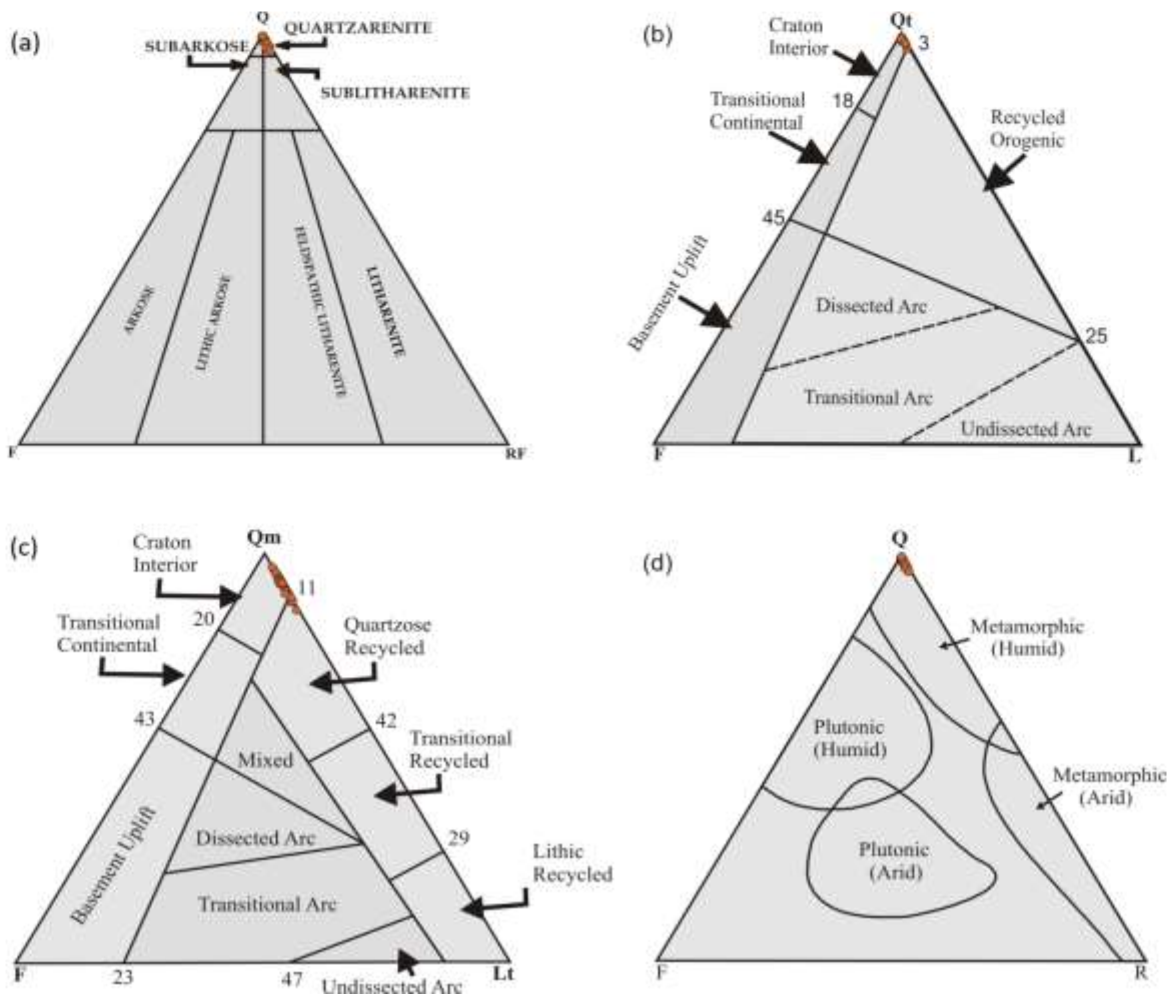

Fig. 3: Ternary plots of Kaimur Sandstone. QFRF diagram, after Folk (1980), QtFL & QmFLt diagram, after Dickinson (1985) and QFR diagrams, after Suttner et al. (1981).

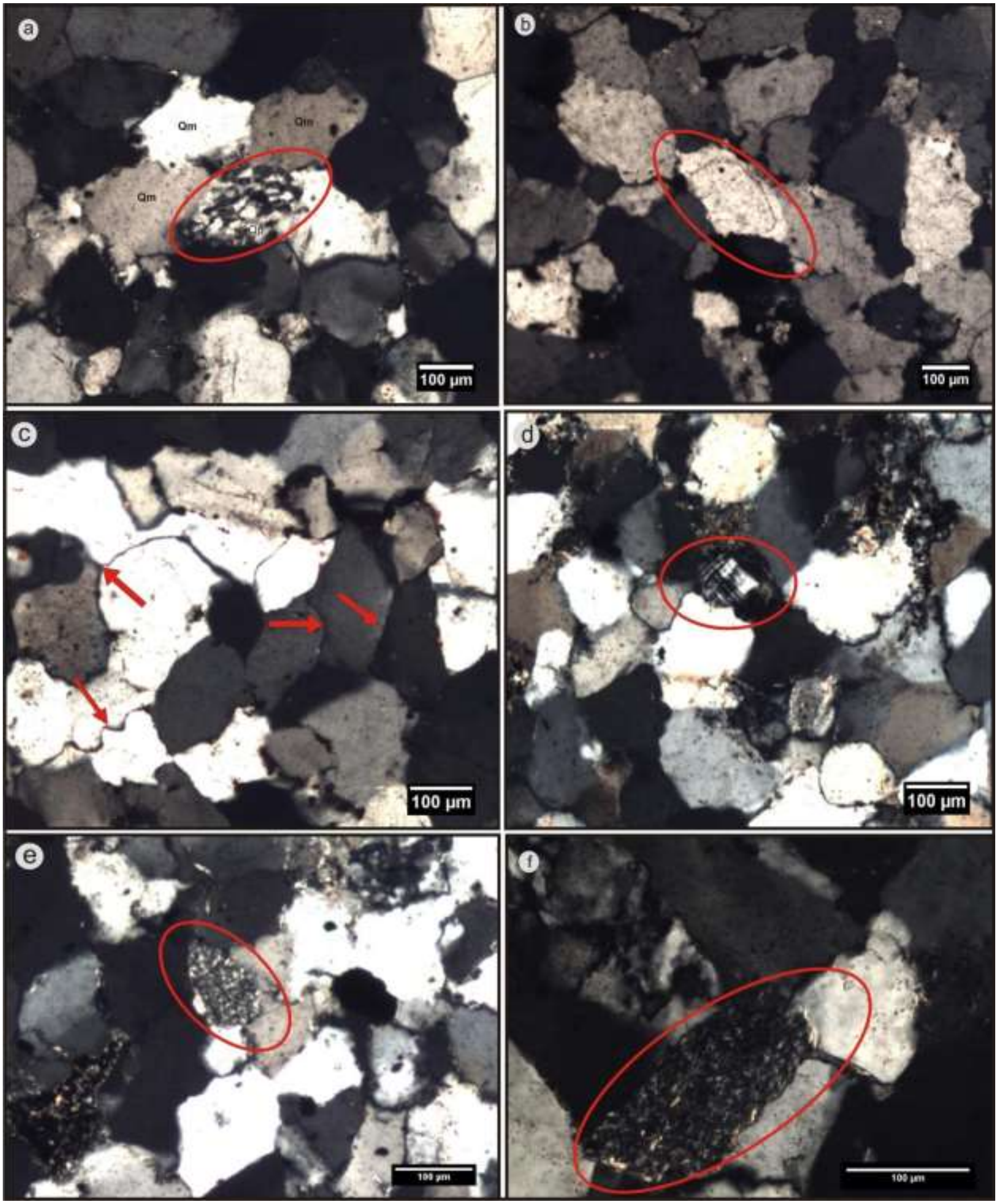

Fig. 4: Photomicrographs of Kaimur Sandstones (a) Medium size polycrystalline quartz grain, (b) Grain of quartz with silica overgrowth, (c) An arrow shows grain contacts and quartz triple junction, (d) Microcline grain, (e) Detrital subrounded chert, (f) Shale fragment.

range of 10°-80° with X-rays using Cu (λ=1.540598) target source for crystalline phase identification. Obtained "Intensity vs. 2 theta" data plotted by origin pro 9 software and minerals peaks identified by using PANalytical HighScore Plus software.

RESULTS

Sandstone petrography and x-ray diffraction

Kaimur Sandstone is showing medium- to fine-grained with subangular to subrounded that are moderately to moderately well sorted. Mineralogically, the detrital grain of the sandstone sample is mainly dominated by quartz (98.75%) with scarcity of feldspar (0.03%), lithic fragments (0.5%), mica (0.5%) and heavy minerals (0.2%) are also present in minor amount. In QFRF triangular diagram, all the sandstone samples data are showing tight clustering in quartzarenite field (Fig. 3a) indicating Sandstone is mainly quartzarenite with small variation in its mineralogy.

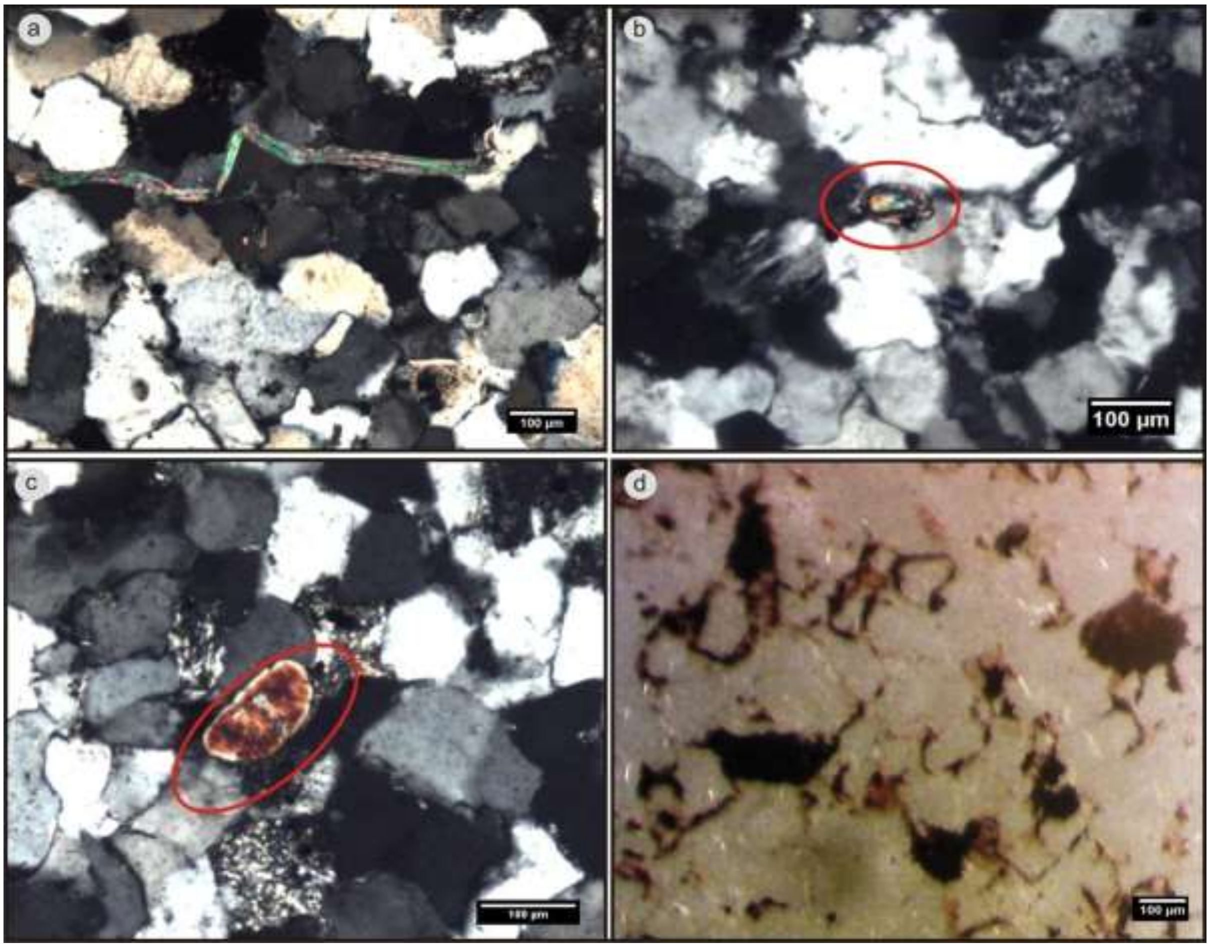

Fig. 5: (a) Sparkling colour of bended muscovite flake between quartz grains, (b) Rounded zoned zircon grain, (c) Rounded brown tourmaline, (d) black colour iron cement present between quartz grains.

Both undulose and non undulose quartz occur in Kaimur Sandstone, dominant quartz

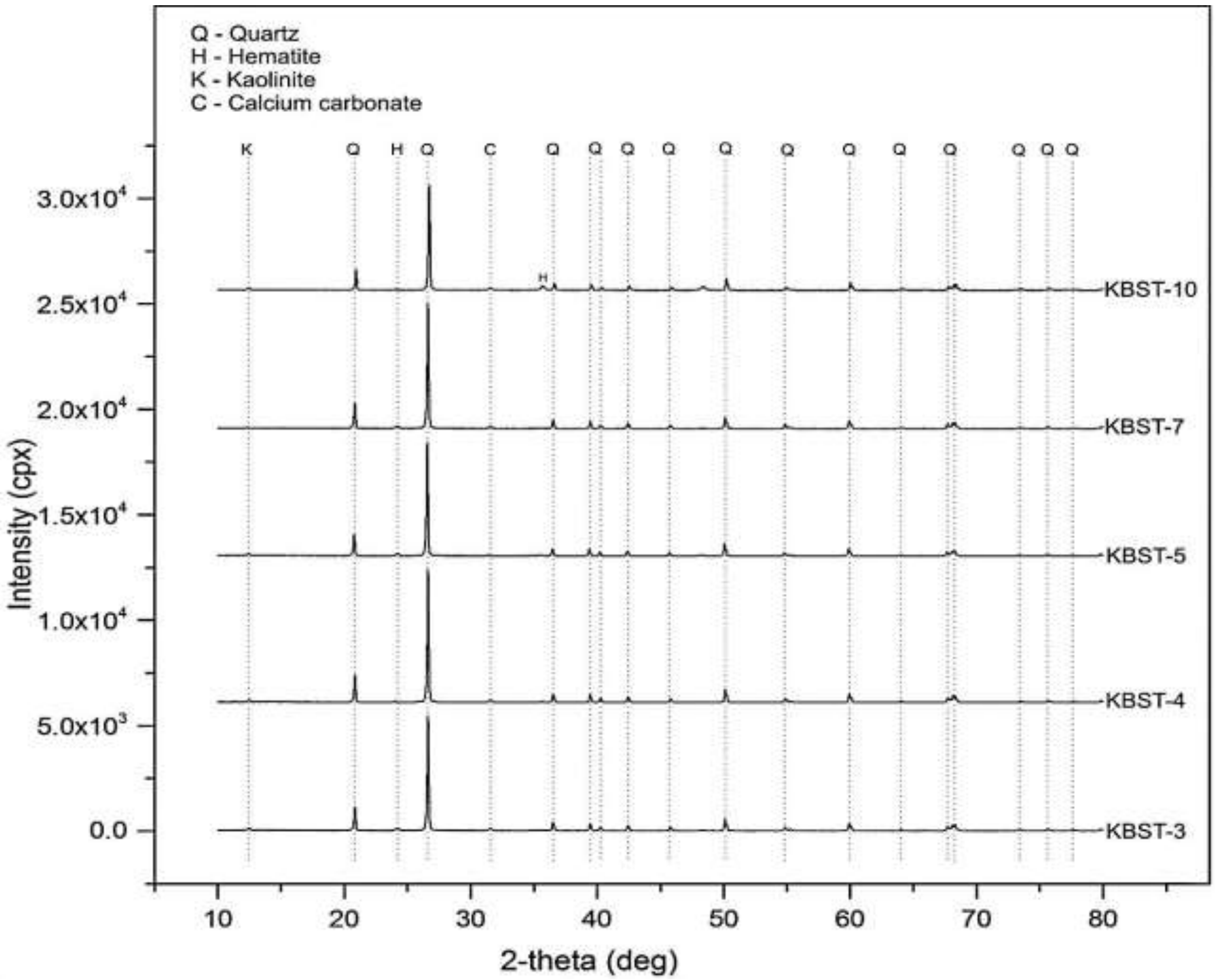

Fig. 6: X-ray diffraction pattern of Kaimur Sandstone shows peaks of Quartz, Hematite, Kaolinite, Calcium carbonate.

grains is monocrystalline quartz (Qm) with low polycrystalline quartz (Qp) grains (Fig. 4a). Silica overgrowth (Fig. 4b), quartz triple junction and dominant long and concavo-convex contact are common (Fig. 4c). Detrital feldspar grains present as microcline and plagioclase varieties, microcline (Fig. 4d) is dominant over plagioclase feldspar. Rock fragments are very rare in thin section and identified rock fragments are mainly chert (Fig. 4e), shale (Fig. 4f) and phyllite. Subrounded chert is more dominant than other rock fragments. Bended sparkling colour of muscovite (Fig. 5a) and heavy minerals mainly zircon (Fig. 5b), tourmaline (Fig. 5c) and rutile present in sandstone. The framework grains are bunded together by both cement and matrix. The matrix is mainly clay minerals with some of fine detrital constituents formed as results of framework grain alteration and precipitation, as well as the other matrix minerals being recrystallized. Silica and iron oxide (Fig. 5d) is the main cementing material of framework grains of Kaimur Sandstone.

Mineralogical studies of Kaimur Sandstone using bulk X-ray diffraction spectrum analysis (Fig. 6) revealed that high intensity and dominant quartz (Q) with minor iron oxide (H) peaks and very rare calcite (C) peak. Clay minerals, mainly Kaolinite (K) shows minor peak, so Kaolinite probably exist as pore-filling aggregates. The XRD study indicates that the Kaimur Sandstone mainly consist of quartz, with little iron oxide and very rare calcium carbonate, so silica and hematite are the main binding material of framework quartz grains.

DISCUSSIONS

Source rock and paleoclimate evaluation

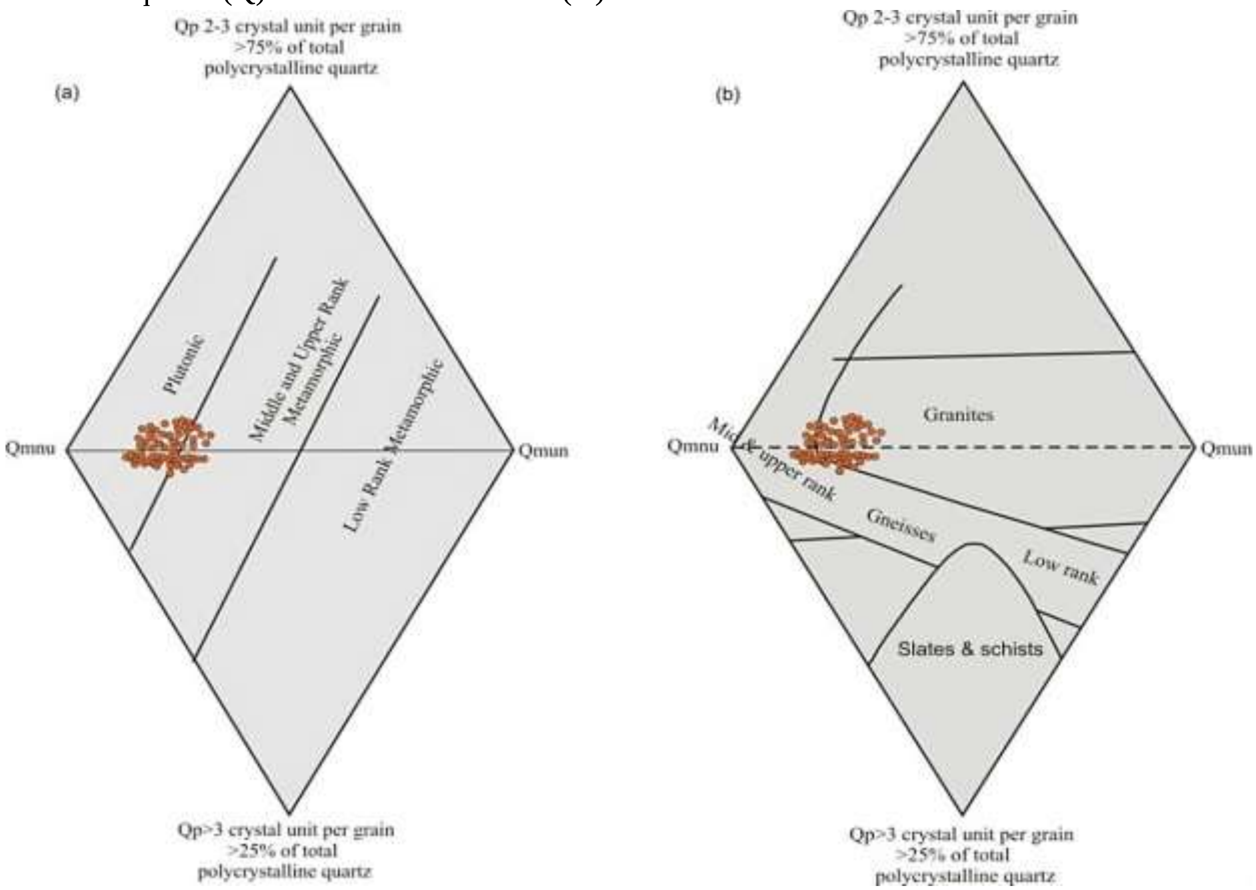

Fig. 7: Diamond diagram plot of Kaimur Sandstone, plot between polycrystalline quartz vs. non-undulatory and undulatory monocrystalline quartz. Qmnu: Low undulosity monocrystalline quartz grains; Qmun; High undulosity polycrystalline quartz grains; Qp 2-3: Coarse-grained polycrystalline quartz grains; Qp>3: Fine-grained polycrystalline quartz grain. Kaimur Sandstone is compared with provenance field, after Basu et al. (1975) and Tortosa et al. (1991).

Provenance of Kaimur Sandstone can be determined by various petrographic methods such as undulosity and polycrystallinity of the quartz grains (Basu et al., 1975), feldspar type (Pittman, 1970) and assemblage of heavy minerals (Morton, 1985). Source rock of this sandstone is mainly established by type of quartz and investigation of heavy minerals because feldspar and rock fragments is very rare in the sandstone samples. In sandstone sample dominant medium to strong undulose monocrystalline quartz grain suggest metamorphic origin with slightly undulose to non undulose quartz grain suggest plutonic source (Basu, 1975; Potter, 1978a). According to Basu et al. (1975) and Tortosa et al. (1991), polycrystalline quartz vs. non-undulatory and undulatory monocrystalline quartz plotted in diamond diagrams suggesting a gneissic-plutonic provenance (Fig. 7a & b).

The heavy minerals identified are mainly zircon, tourmaline and rutile suggest alkaline plutonic rock source (Wanas and Abdel-Maguid, 2006) with minor amount of garnet indicate metamorphic source rock (Morton, 1985; Morton et al., 1992) and moderately rounded to rounded zircon grain suggest reworked sedimentary sources (Sharma and Chutia, 2013). Mineral inclusions of zircon and opaques seen in some monocrystalline quartz grain indicate plutonic origin quartz (Krynine, 1940). Therefore, the presence of heavy mineral varieties suggested that the Kaimur Sandstone is derived from igneous, metamorphic and sedimentary rock sources.

The scarcity of feldspar and rock fragments suggest source rocks experienced long period of intensive weathering in a warm humid climate (Pettijohn et al., 1987; Amireh, 1991) and also suggesting that sandstones were derived from low relief cratonic interior (Burnett and Quirk, 2001). In QFR ternary diagram (Suttner et al., 1981), Kaimur Sandstone of the Chittorgarh area plot in metamorphic source with humid climate field (Fig. 3d). Igneous and metamorphic source rock was weathered under relatively warm and humid climatic condition which destroyed feldspar and other unstable component. Presence of shale and chert fragments suggests derivation from sedimentary source rock and phyllite rock fragments indicate low to medium metamorphic rocks in the source area. Shale and phyllite are unstable rock fragments which mostly destroyed in humid climate, so rare preservation of this lithics indicates very slow transportation rate of source material and/or low subsidence rate of passive tectonic setting.

NE-SE paleocurrent data analyzed from cross-bedded sandstones suggested provenance lies in NW to SW direction (Prasad, 1984), so Palaeoproterozoic Delhi-Aravali Supergroup including Berach granite rocks are the most probable source of this sandstone.

Tectonic Setting

Tectonic setting of sandstone is first determined by using the framework mineralogy (Crook, 1974), defined sandstone composition with major provenance type such as craton interior, basement uplifts, recycled orogens, magmatic arcs (Dickinson and Suczek, 1979; Dickinson et al., 1983).

Tectonic setting of Kaimur Sandstone determine by using detrital components plotted on QFL ternary diagram that having major provenance type such as craton interior, basement uplift, recycled orogeny and magmatic arc (Dickinson and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985). Modal analysis data of sandstone were plotted on QtFL and QmFLt ternary diagrams of Dickinson (1985), shows that sandstone fall mainly in craton interior field and partially in recycled orogenic field (Fig. 3b & 3c). In QtFL ternary diagram, all samples are clustered near quartz pole indicating that sandstone is commonly mature, which originate from stable cratonic source. Mature sandstone derived from relatively low-lying granitoid and gneissic rocks, supplemented by recycled sand from associated platform or passive margin basin.

Conclusions

Based on petrographic data of Precambrian Kaimur Sandstone of Chittorgarh area in Southeastern Rajasthan is chiefly medium- to fine-grained and moderately to moderately well sorted quartzarenite, having quartz predominantly with scarcity of feldspar and rock fragments. The cementing materials are mainly silica, iron oxide and clay.

Quartz overgrowth, bended mica laths and grain contacts (concavo-convex, suture and long) suggested rock has undergone mechanical compaction due to overburden pressure.

Detrital components of sandstone were derived from craton interior and quartzose recycled orogen rocks that were deposited along former passive continental margins. Metamorphic and igneous rocks of stable craton were the most important source rocks for the Kaimur Sandstone. This interpretation is supported by the northwesterly and southwesterly provenance from Paleocurrent data, so rocks the Delhi-Aravali Supergroup including Berach granite are the most probable source of this sandstone.

The XRD study shows that the sandstone samples have nearly same minerals, Kaimur Sandstone is composed of quartz with minor amount of iron oxide and rare calcite.

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