

# Petrofacies and tectonic setup of Kaimur Group of rocks, Son Valley, India

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## ABSTRACT

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The paper embodies results of petrofacies and detrital mineralogical aspects of Scarp and Dhandraul sandstones of Upper Kaimur Group, Son Valley. These sandstones are medium to coarse grained and moderately to well sorted. The constituent mineral grains are subangular to subrounded. These sandstones consisting of various types of quartz, rock fragments, mica, feldspar and heavy minerals. The plots of petrofacies in Qt–F–L, Qm–F–Lt, Qp–Lv–Ls and Qm–P–K ternary diagrams reveal that these sandstones belong to the continental block, recycled orogen, rifted continental margin tectonic regime and maturity and stability of the source region. These sandstones were derived from Palaeoproterozoic and Mesoproterozoic granite, granodiorite, gneiss and metasedimentary rocks of Mahakoshal Group and Chotanagpur granite–gneiss. The sediment composition extensively modified during weathering warm humid climate at the surface area and weathering during transport before burial thereby providing mineralogical maturity to the Upper Kaimur Sandstone.

**Key–words**—Petrofacies, Tectonic setup, Vindhyan Supergroup, Kaimur Group, Son Valley.

## भारत में सोन घाटी की शैलों के कैमूर समूह का शैलसंलक्षणी एवं विवर्तनिक विन्यास

एम. अदनान कासिम एवं ए.एच.एम. अहमद

### सारांश

यह शोध-पत्र ऊपरी कैमूर समूह, सोन घाटी के स्कार्प एवं धनद्रौल बलुआपत्थरों के शैलसंलक्षणी व अपरदी खनिज विज्ञान संबंधी पहलुओं के परिणामों को साकार करता है। ये बलुआपत्थर मध्यम से मोटे दानेदार तथा मध्यम रूप से भली-भाँति छटे हुए हैं। अंतर्वस्तु खनिज दाने उपकोणित से उपगोलित हैं। ये बलुआपत्थर क्वार्ट्ज, शैल खंडज, माइका, फेल्सपार एवं भारी खनिजों के विविध प्रकार से युक्त हैं। Qt–F–L, Qm–F–Lt, Qp–Lv–Ls एवं Qm–P–K त्रिअंगी आलेखों में शैलसंलक्षणी की सारिणी उद्घाटित करती है कि बलुआपत्थर महाद्वीपीय खण्ड, पुनः चकित पर्वतजन, अनुपाट महाद्वीपीय उपांत विवर्तनिक प्रवृत्ति एवं परिपक्वन तथा स्रोत क्षेत्र की स्थिरता के हैं। ये बलुआपत्थर पुराप्राग्जीव एवं मध्यप्राग्जीव ग्रेनाइट, ग्रनोडायोराइट, नाइस तथा महाकौशल समूह व छोटा नागपुर ग्रेनाइट–नाइस के मेटाअवसादी शैलों से व्युत्पन्न थे। पृष्ठीय क्षेत्र पर अपक्षय कोण आर्द्र जलवायु के दौरान अवसाद संघटन गहन रूप से परिवर्तित हो गया तथा शवाधान पूर्व परिवहन के दौरान अपक्षय परिणामतः ऊपरी कैमूर बलुआपत्थर में खनिज विज्ञान संबंधी परिपक्वता प्रदान कर रही है।

**सूचक शब्द**—शैलसंलक्षणी, विवर्तनिक विन्यास, विंध्य महासमूह, कैमूर समूह, सोन घाटी।

## INTRODUCTION

**M**INERALOGICAL composition of terrigenous sedimentary rocks is the product of several variables such as provenance, weathering conditions, transport, diagenesis, climate and tectonism (Johnsson & Basu, 1993).

Weathering and depositional reworking are highly effective modifying agents of detrital composition on cratons or in passive continental margins as a result of low rates of erosion and sedimentation. The chances of distribution of labile detrital constituents are increased due to long residence time in the soil horizon or at the sediment/water interface of

shallow marine environments (Suttner *et al.*, 1981). In some cases, total dissolution of grains of feldspar, rock fragments and heavy minerals by corrosive meteoric or subsurface waters severely modify original sand composition and provide diagenetic quartzarenites (McBride, 1985). All these processes which modify the original sand composition make the sandstone highly quartzose and sandstones to the extent that the signature of the source rocks and tectonic setting are entirely marked resulting in anomalous sandstone. A lot of works on sandstone petrofacies and plate tectonic setting has been carried out in the last four decades (Dickinson & Suczek, 1979; Dickinson, 1985; Cox & Lowe, 1995b; Ahmad & Bhat, 2006; Pandita & Bhat, 1995; Pandita *et al.*, 2014). Regional scale sandstone petrofacies of different ages have been found to be helpful in interpreting geotectonic evaluation (Dickinson *et al.*, 1983; Schwab, 1991; Graham *et al.*, 1993; Cox & Lowe, 1995a, b). However the correlation between tectonic setting and sandstone petrofacies may not always be valid due to modification of its composition by different processes. Some knowledge about the tectonic evaluation of the potential provenance helps in elucidating the tectono–provenance of a petrofacies association (Graham *et al.* 1993; Cox & Lowe, 1995a). Hence, a critical analysis of

the various factors is required to the correct identification of petrofacies and their ‘generic’ tectono–provenance in the light of contemporary regional tectonic setup. This paper attempts to study petrofacies and tectono–provenance of Kaimur Group Sandstone of Son Valley.

## GEOLOGICAL SETTING

The Vindhyan Basin overlies the stable Bundelkhand Craton of Archaean–Early Proterozoic age (Roy, 1988; Chakraborty & Bhattacharyya 1996; Bose *et al.*, 2001; Acharyya, 2003). This basin is the repository of the thickest Proterozoic succession in India. An unmetamorphosed sequence of Upper Proterozoic sedimentary rocks about 4.5 km in thickness occupies the northern fringe of Peninsular India. These sedimentary rocks surround the batholithic Bundelkhand granite and are known in Indian stratigraphy as the Vindhyan Supergroup which is subdivided in to the Semri Group (Lower Vindhyan) is dominantly comprised of limestone with subordinate amounts of shale and sandstones, whereas the other (Upper Vindhyan) Groups of dominantly argillaceous and arenaceous with minor limestone (Table 1).

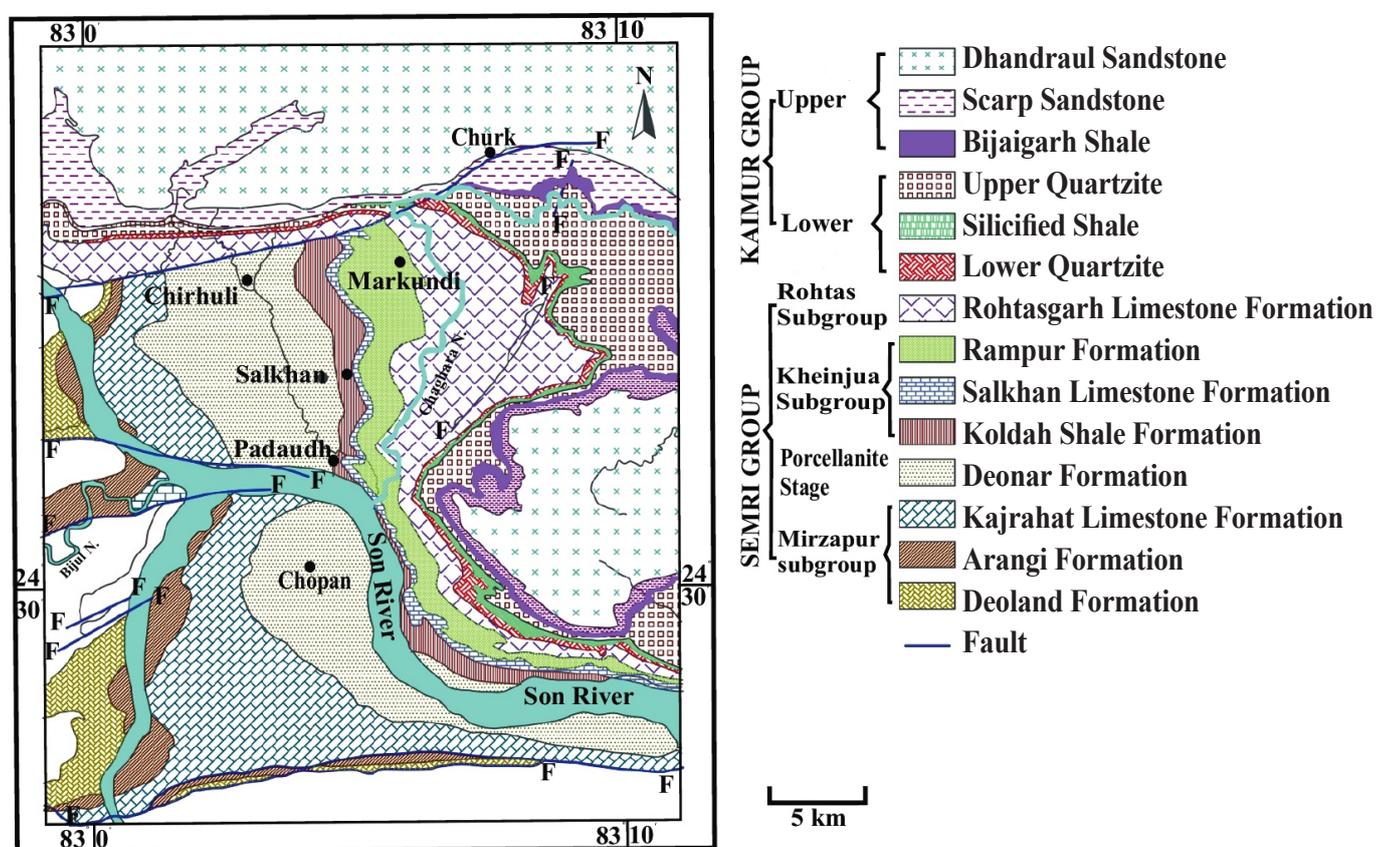


Fig. 1—Detailed geological map of the Vindhyan Basin in Son Valley (modified after Auden, 1933; Sastry & Moitra, 1984).

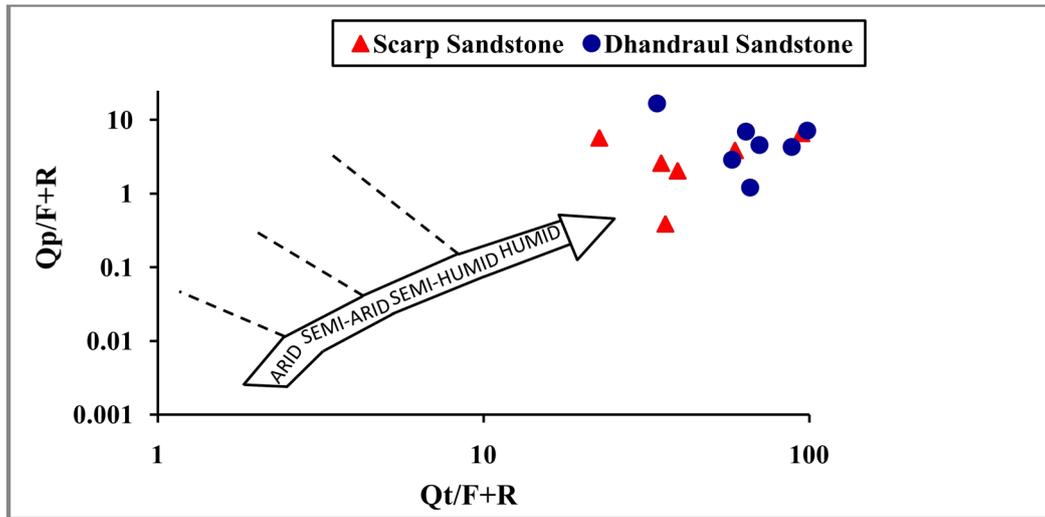
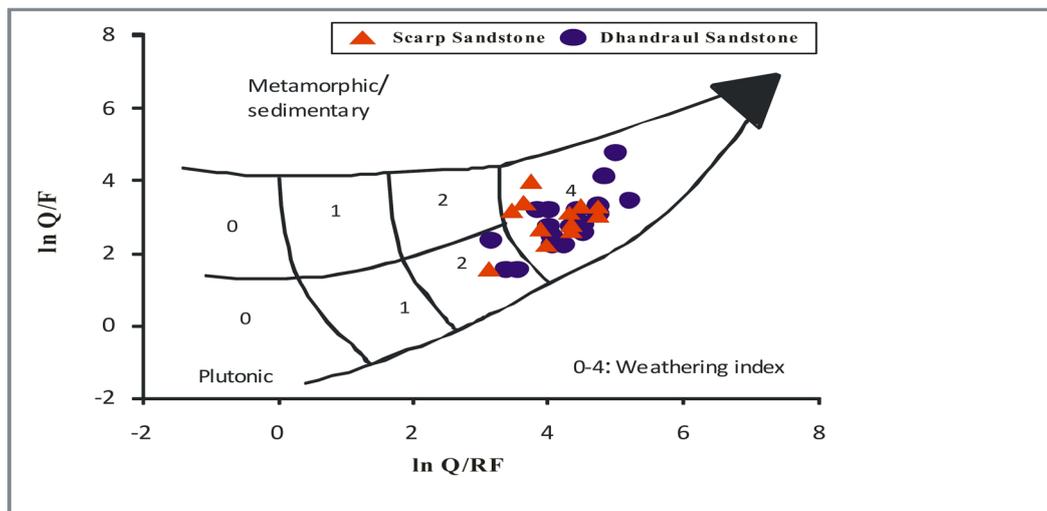


Fig. 2A—Bivariant log/log plot for Kaimur Group of sandstones in Son Valley, according to Suttner and Dutta (1986).



Semi-quantitative weathering index		Physiography (relief)		
		High (Mountain)	Moderate (Hill)	Low (Plains)
	(Semi) Arid and Mediterranean 0	0	0	0
Climate (Precipitation)	Temperate subhumid 1	0	1	2
	Tropical humid 2	0	2	4

Fig. 2B—Log ratio plot after Weltje *et al.* (1998). Q=Quartz, F=Feldspar, RF=Rock fragments. Fields 1–4 refer to the semi-quantitative weathering indices declined on the basis of relief and climate as indicated in the table (respectively).

The Kaimur Group measuring at upto 400 m in thickness (Sastry & Moitra, 1984) lies unconformable over tilted, deformed and eroded Rohtas limestone of Semri Group (Misra, 1969) along the Son River Valley. The rocks of the Kaimur Group are largely of fluvial origin (Auden, 1933; Bhattacharyya *et al.*, 1986; Morad *et al.*, 1991; Bhattacharyya & Morad, 1993; Bose *et al.*, 2001; Mishra & Sen, 2008a, b), whereas some workers have interpreted their depositional environment varying from beach to barrier bar or shoal to tidal flat and lagoon (Misra, 1969; Banerjee, 1974; Singh, 1980).

The Kaimur Group comprises unmetamorphosed gently dipping, sub horizontal beds of sandstone and shales (Fig. 1). It is broadly divided into three formations—Bijaigarh Shale (bottom most), Scarp Sandstone (middle) and Dhandraul Sandstone (topmost) (Auden, 1933; Prakash & Dalela, 1982). Bijaigarh Shale is dominantly sandy to clayey in nature. Scarp Sandstone is pinkish red, olive green to grey and even black coloured, medium grained sandstone. Dhandraul Sandstone overlying the Scarp Sandstone is dirty white to white coloured, medium to coarse grained sandstone. The present study was carried out around Markundi Ghat and Churk, Son Valley in Sonbhadra District.

## METHODOLOGY

Fifty samples of medium to coarse grained sandstones from the Upper Kaimur Group were collected from Markundi Ghat and Churk for petrological study. About 300 grains were counted per thin section using the Gazzi–Dickinson Point Counting Method. The modal data from these sandstones are given in Table 2. The source rock composition, provenance, tectonic setting and palaeoclimate of the Upper Kaimur Sandstone were deduced using the modal analysis data. The modal data were plotted in the diagrams suggested by Basu *et al.* (1975), Dickinson *et al.* (1983), Dickinson (1985) and Suttner and Dutta (1986). Folk's (1980) classification was used for characterizing the sandstones.

## PETROFACIES

The sandstones are hard, compact and colour varies from whitish brown to flesh red. The mean size value ranges from 0.85 to 2.99 phi. The sandstones are medium to coarse grained and moderate to moderately well sorted. The sorting value ranges from 0.40 to 0.85 (well to moderately sorted). Majority of the constituent sand grains are subangular to sub rounded.

These Scarp and Dhandraul sandstones consist of various types of quartz including common quartz, recrystallized metamorphic quartz and stretched metamorphic quartz. Volume-wise, different quartz types comprise about 97.64% in Scarp Sandstone and 97.57% in Dhandraul Sandstone of the sandstone composition out of which 90.88% in Scarp Sandstone and 91.49% in Dhandraul Sandstone are represented by monocrystalline quartz and 6.77% in Scarp Sandstone and 5.08% in Dhandraul Sandstone by polycrystalline quartz grains (Table 2). The monocrystalline variety is mostly nonundulatory and contains inclusion of tourmaline, zircon, mica and rutile. In polycrystalline quartz intercrystalline boundaries are either sharp and straight or highly curved. Some of these grains possess deformed elongate crystal units along which tiny nonundulatory quartz crystals are aligned. A few of the polycrystalline quartz grains are equidimensional having 120° interfacial angles (Pl. 1.1). Feldspar is rarely present both in Scarp and Dhandraul sandstones with average modal composition of 0.16 to 0.12%. The feldspars are mainly of microcline and plagioclase (Pl. 1.2). Mostly chert, siltstone, phyllite and schist are found as rock fragments in these sandstones (Pl. 1.3). In addition to the above described framework, a suite of heavy minerals including opaques are reported from these sandstones. We observed three varieties of opaque minerals including limonite (yellowish brown), hematite (reddish brown) and magnetite (silver black). These mineral grains are angular to subrounded. Other heavy minerals observed are tourmaline, zircon, biotite, rutile and garnet (Pl. 1.4, 5). The other detrital constituent is mica (muscovite) (Pl. 1.6). As per Folk's (1980)

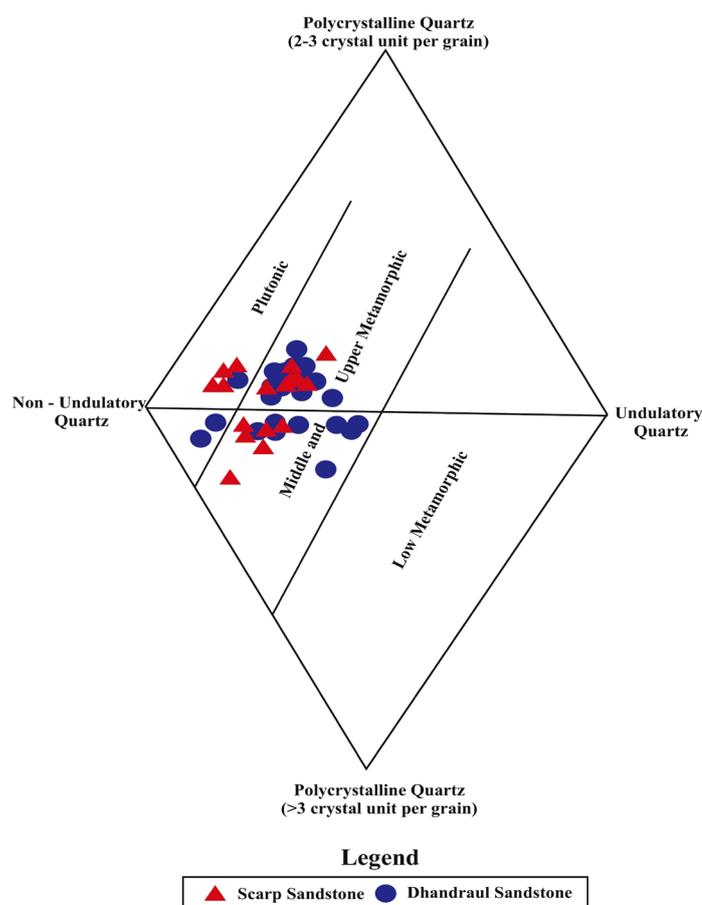


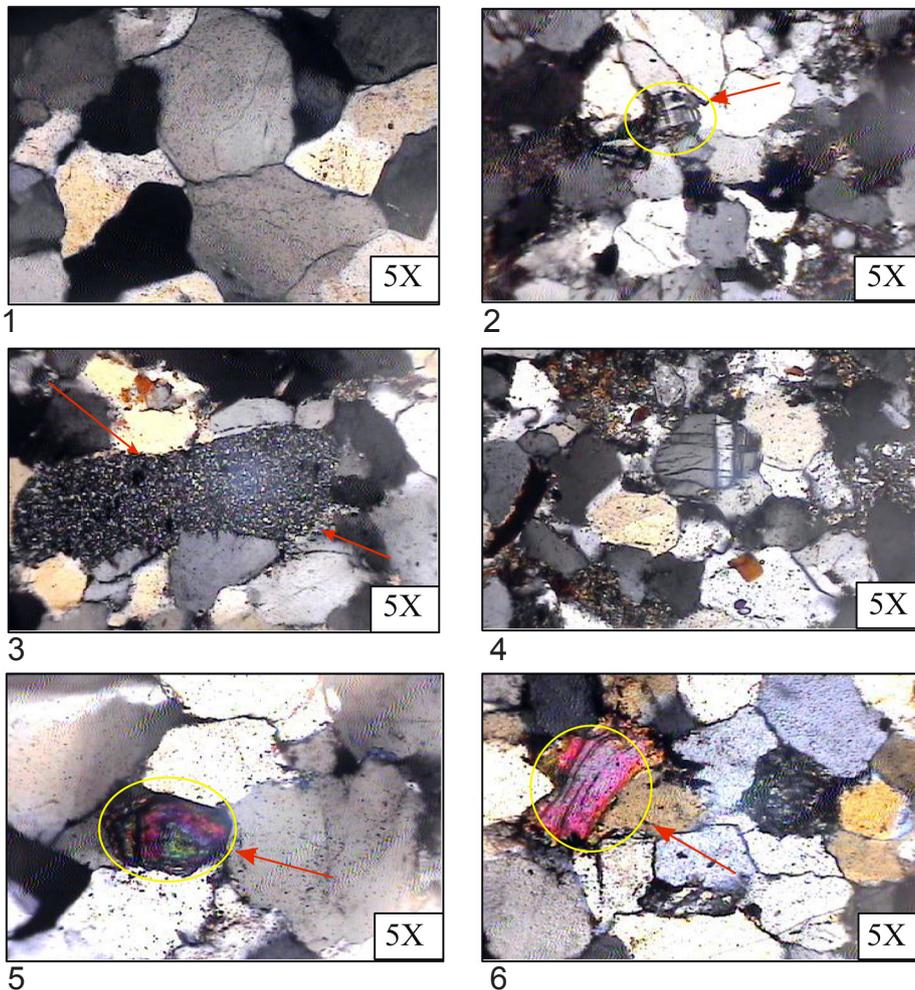
Fig. 3—Diamond diagram of Kaimur Group of sandstone (after Basu *et al.*, 1975).

classification, the sandstones of Upper Kaimur Group are mainly quartzarenites and sublitharenite.

**PROVENANCE**

Detrital quartz grains in sedimentary rocks are often used as indicator of provenance. In the present case, monocrystalline quartz grains (average 90.88% and 91.49% in relation to F plus L) showing strong undulatory extinction and polycrystalline quartz grains (average 89.77% in Scarp Sandstone and 89.94% in Dhandraul Sandstone in relation to L plus Ls) are suggestive of metamorphic source rocks. The index of mineralogical maturity of sandstone is reflected in the relative proportion of quartz to feldspar plus rock fragments. Many comparative studies of sand populations have reflected that a unique

combination of extreme climate, relief, transportation and rate of sedimentation are necessary for highly matured, first cycle quartz sand (quartzarenites). However, this imprint of climate, although preserved for the first 75 km of transportation in high gradient stream, is rapidly destroyed as soon as a high energy marine environment (beach) is reached (Suttner *et al.*, 1981). Bivariant log plot of the polycrystalline quartz to feldspar plus rock fragments (Suttner & Dutta, 1986) has been used for interpreting the palaeoclimate of Scarp and Dhandraul sandstones. This diagram indicates a humid climate for the region (Fig. 2A). The mineralogical data plotted on Weltje *et al.*, (1998) diagram fall in the field number 2 and 4 which point to the sedimentation a low relief tropical humid climate (Fig. 2 B). In the present study, the percentage of quartz with small amount of rock fragments and absence of feldspar in



**PLATE 1**  
Microphotographs showing

- |    |                         |    |                   |
|----|-------------------------|----|-------------------|
| 1. | Monocrystalline quartz. | 4. | Tourmaline grain. |
| 2. | Microcline grains.      | 5. | Zircon grain.     |
| 3. | Chert grain.            | 6. | Muscovite flake.  |

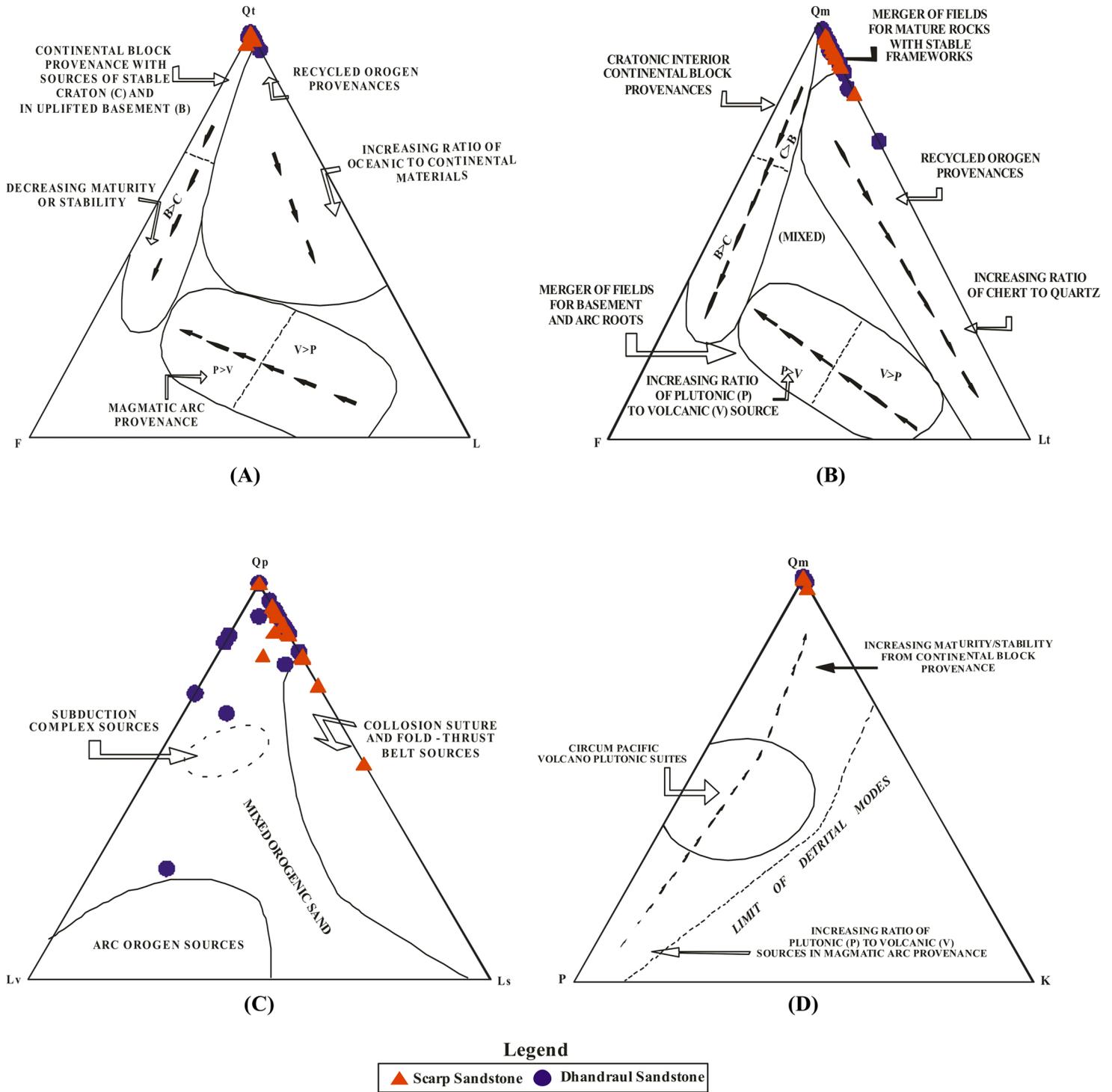


Fig. 4 (A)–(D)—Plots of Kaimur Group Sandstone in Son Valley, according to Dickinson, (1985).

sediments is dependent not only on the source rock and climate but also to some extent on the degree of crustal stability (Dickinson & Suczek, 1979).

The formations of mature quartzose sands, such as those of the Kaimur Sandstone, have been ascribed to multicyclic reworking on cratons by several workers. However recent work has shown conclusively that quartzose sand is also being produced as first cycle sediment from deeply weathered granite and gneissic bed rock exposed in tropical low lands of the modern Amazon Basin (Franzinelli & Potter, 1983). The development of first cycle quartz rich sand requires low relief for prolonged weathering. This is demonstrated by quartz-poor nature of both fluvial and littoral Holocene sands derived from drainage basins in tropical highlands with high relief (Ruxton, 1970). Thus, even where the climate potential for intense weathering exists, quartz rich sands can not be produced unless the relief is low. A low relief must have marked the continental block provenance prior to rifting, from where the Kaimur Sandstone was derived.

The quartz-type data are plotted on the provenance discrimination diagram of Basu *et al.*, (1975) in Fig. 3. The data plot in the plutonic and middle to high rank metamorphic fields with almost equal contribution from each other. This plot yields consistent result that indicates a source area containing largely of plutonic and upper metamorphic rocks, which represent the exposed roots of magmatic cores or older crystalline basement in the area (Dickinson & Suczek, 1979).

The above observation suggests that the sediments of the Kaimur Group have been derived from a variety of source rocks. The abundant opaque mineral grains including magnetite, hematite and limonite, suggest derivation of the sediments from the metamorphic and igneous rocks. The suite of heavy minerals including biotite, tourmaline and zircon indicates an acid igneous source for these sandstones. Presence of small amount of alkali feldspar indicates their source as plutonic and metamorphic rocks (Trevena & Nash, 1981). Presence of garnet reflects a metamorphic source. Well rounded grain of rutile and zircon, is indicative of reworked source for these sandstones.

Palaeocurrent pattern of the Vindhyan succession in the Son Valley indicates that the sediments derived from Palaeoproterozoic and Mesoproterozoic granite, granodiorite and gneiss of the Mahakoshal Group and Chotanagpur granite-gneiss (Ghose & Mukherjee, 2000; Singh, 2001) dominantly contributed to the sediments of the Kaimur Group later than Satpura Orogeny in an intracratonic type of tectonic setting.

### TECTONIC SETUP

The use of quantitative detrital modes, calculated from point counts of thin section, to infer sandstone provenance is now well established (Dickinson, 1985). The detrital modes of sandstone primarily reflect the different tectonic

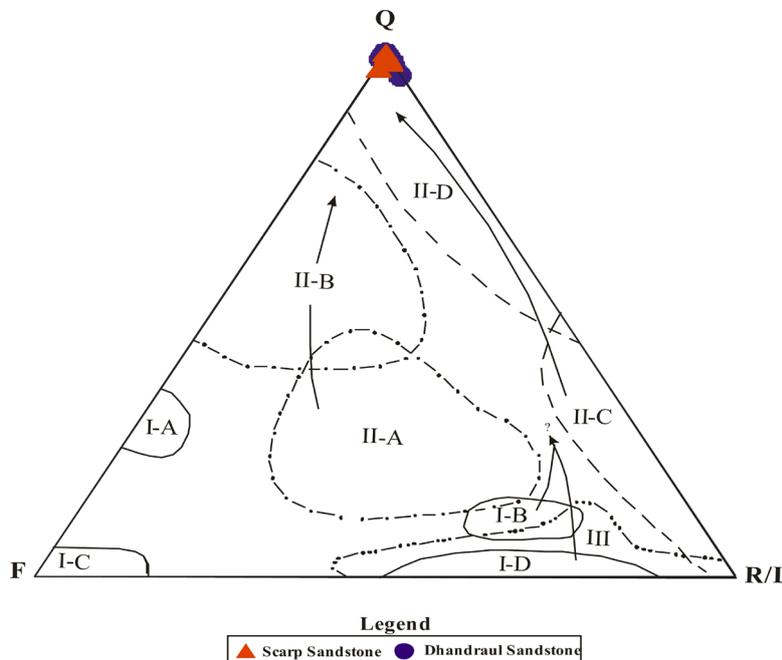


Fig. 5—Postulated idealized evolution model of Kaimur Group of sandstones with emphasis on source rocks and climate. Expected petrofacies composition from ideal provenances with different climate and their relationship with primary source rocks by Alam (2002). The modal modified after Cox and Lowe (1995b). Fields—IA, IB, IC, ID are of granite, rhyolite, gabbro, and andesite-basalt respectively after McBirney (1983), IIA, IIB, IIC and IID are first cycle of Holocene fluvial sands from granite (arid climate), granite (humid climate), metamorphic (arid climate) and metamorphic (humid climate) respectively after Suttner *et al.*, (1981). III represents sediments from magmatic arcs after Marsaglia and Ingersoll (1992).

Table 1—Stratigraphy of Vindhyan Supergroup showing details of Upper Kaimur Group (after Prakash &amp; Dalela, 1982) with special reference to lithology and structure.

Group	Formation	Lithology	Structures	
Upper Vindhyan	Upper Kaimur	Dhandraul Sandstone (120 m)	Dominantly arenaceous (medium to coarse grained) texturally coarsening upward sequence, milky white and compact	Large scale cross bedding, through bedding ripple marks, tabular and lenticular beds
		Scarp Sandstone (150 m)	Medium grained multi-colored sandstone (pink to grey) sublitharenite, micaceous siltstone and sandstone	Cross bedding, fault gouge and breccia, water seepages, seepages, drag fold, ripple marks, clay galls
		Bijaigarh Shale (25 m)	Heterogeneous lithology, reddish brown to buff colour shale ranging from siltstone to mudstone Carbonaceous shales	Wavy laminations, Wavy pyritiferous laminae, microbial mats, mud cracks, ripple and wrinkle marks, flute casts, rain prints, adhesion marks
	Lower Kaimur	Markundi Sandstone	Lower Kaimur formations are omitted by Markundi-Jamwal fault (Prakash & Dalela, 1982)	
		Ghurma Shale		
		Sasaram Sandstone		
..... Faulted/Normal contact .....				
Lower Vindhyan/ Semri Group (760-3055 m)				

setting of the provenance but various other factors which effect sandstone composition are relief, climate, transport mechanism, depositional environment and diagenetic changes. Kaimur Group Sandstone were identified and recalculated to 100 percent as the sum of Qt, Qm, Qp, P, K, Lv and Ls (Table 3). The sandstones do not contain intrabasinal grains (Zuffa, 1980).

In order to understand the tectonic setting of the Kaimur Group Sandstone, the petrofacies were plotted in standard triangular diagrams Qt-F-L, Qm-F-Lt, Qp-Lv-Ls and Qm-P-K plot. In Qt-F-L diagram the sample data plot in the continental block provenance with source on the stable craton because most of the points fall near the Qt pole (Fig. 4A). On the Qm-F-Lt plot, the data fall in continental block basement uplift provenance with almost equal contribution from recycled orogen provenance (Fig. 4B). The Qp-Lv-Ls plot, which is based on rock fragment population from a petrographic source, gives a more resolved picture about the tectonic elements. The studied samples fall in the rifted continental margin provenance (Fig. 4C). The Qm-P-K plot of the data shows that all the data sediment contribution is from the continental block basement and suggests stability of the source area (Fig. 4D). The petrofacies analysis of the

Kaimur Group Sandstones suggests their source as stable craton.

The Vindhyan Basin was formed largely through rift controlled subsidence under extensional regime and locally by downward flexuring of the basement near tectonic margins (Ravi Shankar, 1993). The original basin possibly extended beyond the existing tectonic boundaries to the south and west. The sediments of the extended basin are no longer exposed / preserved due to subsequent widespread thrusting and erosion with a few exceptions like occurrence of basal Vindhyan rocks of Jungle outlier in the Mahakoshal (Bijawar) belt of Son Valley. Observation on tectonics of Son Valley supports the condition of possible extension of Vindhyan Basin on the Satpura-Bijawar basement beyond the existing boundary in the south (Ravi Shankar, 1993). In accordance with Dickinson (1985) scheme, the detrital modes of the Vindhyan Basin covers a large part of the northern Indian Shield and rest on a wide variety of basement rocks including the Banded Gneissic Complex in the northern part and the Bijawar Group, the Chotanagpur granite-gneiss (CGG) and the Mahakoshal Group in central and western part of India. The palaeocurrent directions for the Vindhyan sediments are mostly northerly and northwesterly (Bose *et al.*, 2001).

Table 2—Range and average of mineralogical composition of sandstones of Kaimur Group, Son Valley.

	Monocrystalline quartz	Polycrystalline quartz		Feldspar		Mica		Chert	Rock fragments	Heavy minerals
		Recrystallized metamorphic quartz	Stretched metamorphic quartz	Plagioclase	Microcline	Muscovite	Biotite			
<b>Dhandraul Sandstone</b>										
<b>Range</b>	83.02-97.46	0.00-4.17	0.87-13.27	0.00-0.39	0.00-1.06	0.00-10.46	0.00-0.87	0.00-1.47	0.00-2.77	0.00-1.11
<b>Average</b>	91.49	1.2	4.88	0.02	0.1	1.37	0.07	0.32	0.36	0.19
<b>Scarp Sandstone</b>										
<b>Range</b>	82.22-96.71	0.00-2.80	1.35-17.04	0.00-0.35	0.00-1.93	0.00-2.64	0.00-0.61	0.00-1.70	0.00-0.62	0.00-0.54
<b>Average</b>	90.88	0.6	6.16	0.03	0.13	0.08	1.26	0.72	0.05	0.09

Table 3—Percentage of framework mode of sandstones of Kaimur Group, Son Valley.

**Qt=Total quartz, F= Total feldspar, L= Total lithic fragments, Qm= Monocrystalline quartz, Lt= Total lithic grains, Qp= Polycrystalline quartz, Lv= Volcanic lithic grains, Ls= Sedimentary lithic grains, P= Plagioclase, K= Orthoclase and microcline**

	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
<b>Dhandraul Sandstone</b>												
<b>Range</b>	98.20-100.00	0.00-1.07	0.00-4.23	71.43-98.23	0.00-1.07	1.77-28.57	72.22-100.00	0.00-56.00	0.00-17.20	99.13-100.00	0.00-0.47	0.00-1.26
<b>Average</b>	99.04	0.12	0.84	92.2	0.12	7.67	89.86	5.67	4.47	99.86	0.03	0.11
<b>Scarp Sandstone</b>												
<b>Range</b>	97.15-100.00	0.00-2.32	0.00-1.50	82.84-96.71	0.00-0.00	3.29-17.16	54.55-100.00	0.00-8.20	0.00-45.45	97.44-100.00	0.00-0.39	0.00-2.17
<b>Average</b>	99.06	0.16	0.78	92.34	0.00	7.66	87.74	0.61	11.65	99.82	0.04	0.14

The main source for craton derived quartzose sands are low lying granitic and gneissic exposures, supplemented by recycling of associated flat lying platform sediments. It has been mentioned that the source rocks of Kaimur Sandstone exposed in the north and northwest, consisted of Chotanagpur granite–gneiss (CGG), Bijawar Group and Banded Gneissic Complex. The sandstone petrofacies and heavy minerals suites of Kaimur Group Sandstone indicate multiple rock sources for these sandstones, which are not reflected in the triangular plots. The apparent reason for this could be diagenetic alteration and weathering of unstable framework grains, which increased the population of quartz grain relative to the original detrital composition.

The present petrofacies might have been resulted through mixing of detritus from granite–gneiss basement uplift on the one hand, and from metasedimentary rocks of a recycled orogen on the other. The sediment composition was extensively modified during weathering, transport and sedimentation. The quartz rich detritus were shed into the Son Valley rift. The relief of the provenance was low and the erosion processes were not strong enough to remove the cover rocks from the basement. The evolutionary trends of the Kaimur petrofacies suggest two evolutionary lineages (Fig. 5). The present petrofacies evolved through mixing of detritus from granite–gneiss, granodiorite basement and metasedimentary rocks. The sediments composition was extensively modified during weathering under warm, humid climate at the source area and by weathering during transport action and sedimentation.

### CONCLUSIONS

1. The plots of detrital modes of Kaimur Group Sandstone on Qt–F–L and Qm–F–Lt diagrams suggest stable continental block and recycled orogen provenance fields, which has been recognized as the Mahakoshal Group of rocks and Chotanagpur granite–gneiss. The sediments were deposited in rifted basin condition as is evidenced by plot on Qp–Lv–Ls diagram. The Qm–P–K diagram suggests the maturity and stability of the source area.
2. The sediment composition was extensively modified during weathering under humid climate at the source area and during transport and sedimentation. The maturity of the studied petrofacies is mainly due to the recycling of the sediment which was derived from thick supracrustals typical of quiescent shield areas adjacent to the passive margin Son Valley.
3. The sandstones consist of various types of quartz, with minor amounts of feldspar, rock fragments and heavy minerals. Since the palaeocurrent direction was northerly and northwesterly, the provenance is suggested to be the Chotanagpur granite–gneiss and Mahakoshal Group of rocks.

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