JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.83, June 2014, pp.657-664

Provenance of the Late Paleocene Sandstones of the Jaisalmer Basin, Western India

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Abstract: Provenance of the late Paleocene sandstone of the Jaisalmer basin has been determined by petrographic and heavy minerals analysis supported by paleocurrent study. Petrography of the quartzose-arenite sandstone reveals an abundance of sub-angular to sub-rounded monocrystalline non-undulatory quartz and some amount of feldspar and rock fragments. The rock fragments are dominated by argillites (slate, phyllite) and limestone. The heavy minerals suite of these sandstones comprises of angular to sub-angular grains of magnetite, zircon, tourmaline, kyanite and staurolite. The paleocurrent analysis indicates bipolar paleocurrent pattern with the dominance of NW flow suggesting that the provenance was in the SE direction of the depositional basin. Q-F-L and Qm-F-Lt diagrams suggest for a provenance at the margin of the craton interior and transitional continental. It is envisaged that the basic igneous rocks of the Deccan basalt, low- to medium-grade metamorphic rocks of the Aravalli belt and Jurassic limestones present in the vicinity are the source rocks for the late Paleocene sandstones of the Jaisalmer basin.

Keywords: Provenance, Paleocene, Petrography, Paleocurrent, Jaisalmer Basin, Western India.

INTRODUCTION

Provenance analysis serves to reconstruct the pre-depositional history of a sediment or sedimentary rock. In its broadest sense, provenance analysis would aid in reconstructing the lithospheric history of the Earth (Basu, 2003; Weltje and Eynatten, 2004). Provenance study includes the distance and direction of transport, size and setting of the source region, climate and relief in the source area and the specific types of source rocks (Pettijohn et al., 1987). Provenance studies can be performed with the help of detrital minerals, including heavy minerals and geochemistry supported by paleocurrent analysis. Established provenance models of sedimentary rocks have commonly taken into account the mineralogical and/or chemical composition of sandstones and shales (Dickinson, 1970; Basu, 1976; Ingersoll and Suczek, 1979; Dickinson and Suczek, 1979, Dickinson et al., 1983; Vande Kamp and Leake 1995, Singh, 1996, 2013; Singh et al., 2000, 2004; Srivastava and Pandey, 2011; Jalal and Ghosh, 2012).

Paleogene succession exposed in the Jaisalmer area is crescent shapes (Fig.1). The general strike of the Paleogene succession is NW-SE and dipping northerly with dip angles 6°-8°. The limestone exposures form an escarpment in the southern part and plateau like geomorphology in the north that extends for kilometers which is a consequence of dip slope with low angles. The Paleogene successions of the Jaisalmer basin are mostly studied for micropaleontology, stratigraphy, tectonic set-up and possibility of petroleum occurrences (e. g. Oldham, 1886; Rahman, 1963; Sigal et al. 1971; Rao, 1972; Dasgupta, 1975; Singh, 1976, 1984, 2007; Kumar et al. 2007; Pandey and Bhadu, 2010). Detailed sedimentologic and provenance studies have not been yet attempted in this succession of the Jaisalmer basin. The present study is an attempt to determine provenance of the late Paleocene sandstones of the Jaisalmer basin, western India, using detrital modes and paleocurrent data sets.

GEOLOGICAL SET-UP

The Jaisalmer basin is differentiated into four geotectonic blocks from north to south. The Kishangarh sub-basin is a part of northwesterly homoclinally gentle dipping shelf with NE-SW strike. The Jaisalmer-Mari high shows upwarping of the basement affecting overlying sediments. The high is a gravity high feature located along the shoulder zone of Kanoi fault and is attributed to upthrusting and wrench faulting (Singh, 2007). Further, the Shahgarh

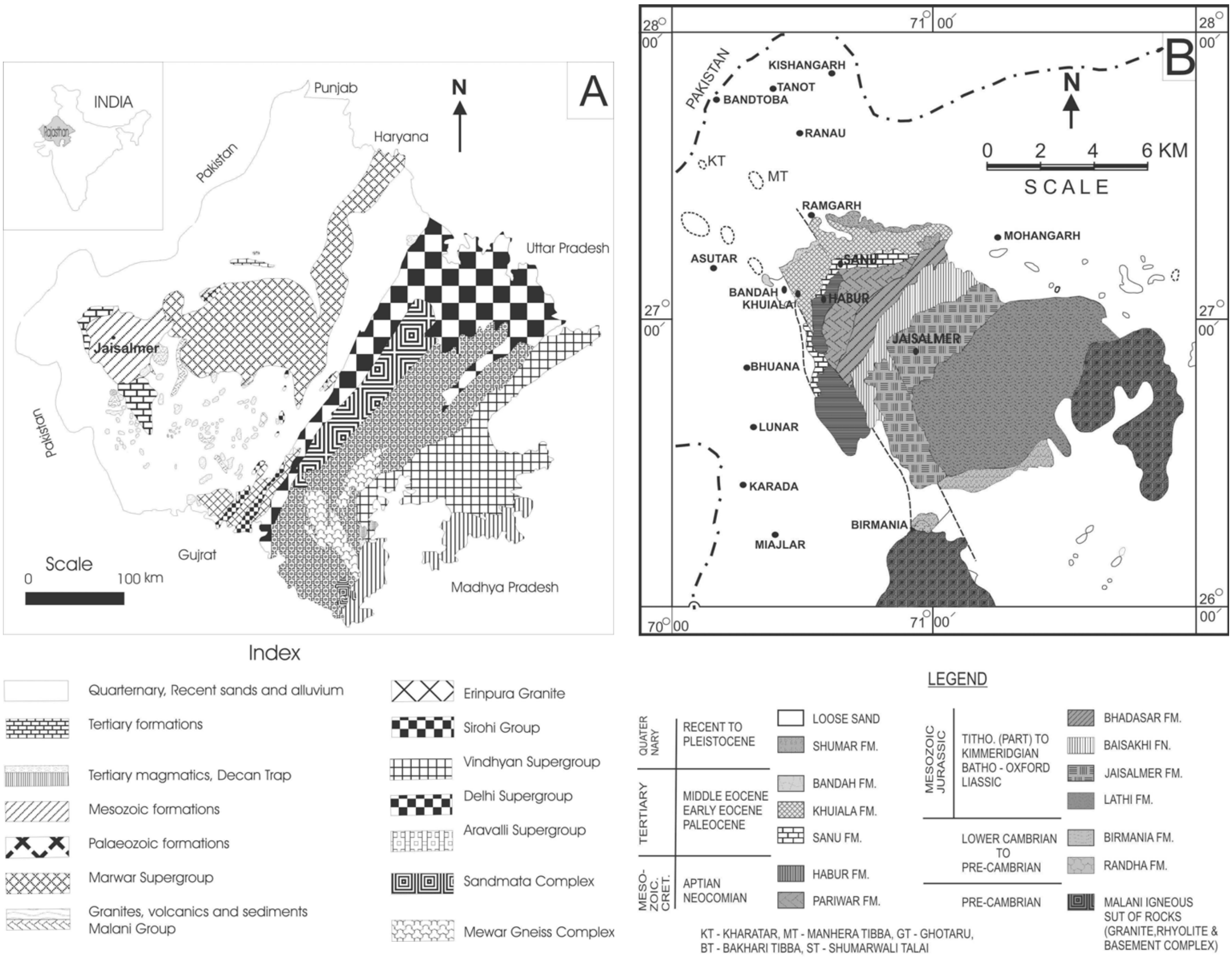

Fig.1. (A) Geological map of Rajasthan showing the distribution of exposures of the various formations (after Roy and Jakhar, 2002). **(B)** Geological map of the Jaisalmer area (after Singh, 2007). Note the Tertiary formations in the northern side of the map.

sub-basin is deepest depression and is less distributed having NNW-SSE trending faults, while structurally simpler Miajlar sub-basin is located in southern extreme of the basin (Singh, 2007).

Aravalli Supergroup forms the basement of the Jaisalmer basin containing Jurassic and Paleogene sequences. The Aravalli-Delhi mountain belt in Rajasthan, are made of Proterozoic volcano-sedimentary rocks (Sharma, 2009). The Aravalli Supergroup has been divided into three sectors such as Bhilwara sector, consisting of amphibolite facies schists, gneisses and migmatites in the northeast, Udaipur sector, consisting of greenschist, conglomerate, quartzite, carbonate and metapelite and the southern sector consisting of metapelite, mafic/ultramafic rocks and minor carbonates that are low-grade in the northern part and high-grade in the southern and eastern part (Mohanty and Naha, 1986).

The Paleogene succession of the Jaisalmer basin rests over the Jurassic succession that occurs in the southern part as basal beds. The uppermost Jurassic limestone (Habur Limestone) is unconformably overlain by a meter thick calcrete that represents an unconformity. The Cenozoic succession begins with late Paleocene cross-bedded, thin-bedded and laminated sandstones (Fig. 2) of Sanu Formation (sensu Singh, 2007). The overlying Eocene Khuiala Formation is comprised of shale and nodular/ chalky fossiliferous and pink limestones (Fig. 2). A major hiatus ranging from upper Cretaceous to lower Paleocene resulted due to a major uplift of the belt (Rahman, 1963) that caused considerable erosion of the Cretaceous sediments.

METHODOLOGY

Individual facies were demarcated in the field and

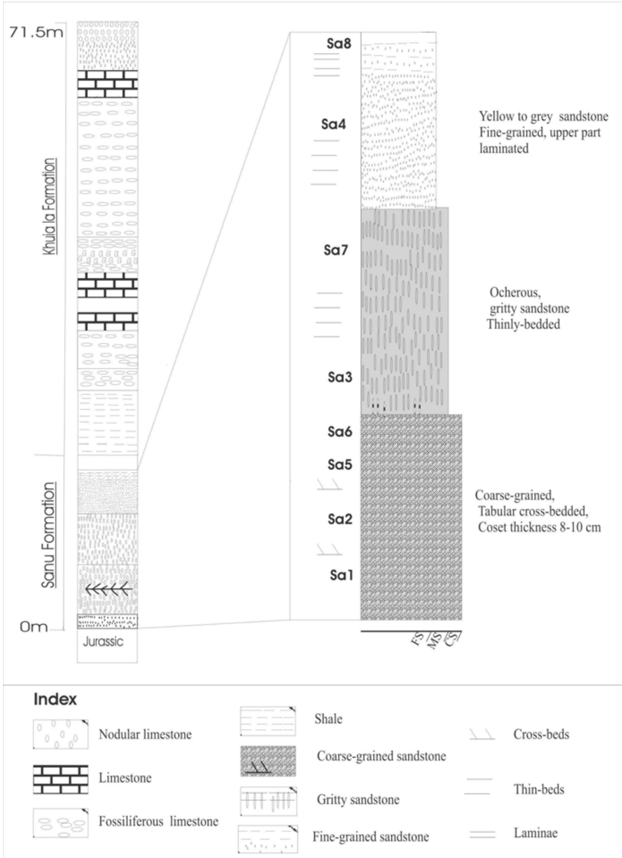

Fig.2. Lithocolumn displaying vertical organization of different lithofacies in the Paleogene succession of the Jaisalmer basin, including late Paleocene sandstones.

litholog was prepared. Unaltered samples of the late Paleocene sandstones were collected from exposed sections. A total number of 8 samples were used in thin section preparation for petrographic study. Modal analysis was carried out with the help of Image Analysis software. Heavy minerals were separated from the sandstones using heavy liquids. The sandstone was disaggregated by gently grinding it and the disaggregated fraction was sieved to obtain a size range of 0.0125-0.088 mm. The sieved fraction was poured in the heavy liquid (bromoform)-containing separating funnel. The liquid was stirred with a glass rod for proper mixing. Heavy minerals were allowed to settle at the bottom for nearly 20 minutes and subsequently, they were collected on a filter paper and dried at room temperature and later, washed with acetone to remove coatings. The heavy minerals were then mounted on glass slides with canada balsam.

RESULTS

Petrography

Sandstones are hard, and grey to yellow in colour, and often has ochral appearance due to concentration of iron minerals. The grains are coarse to fine, sub-angular to sub-rounded and moderately to well sorted.

Quartz is the most abundant component of the sandstones and constitutes 72%-76%. Mono-crystalline quartz (62%-66%) dominates over polycrystalline (7-13%) and non-undulatory quartz grains (44%-56%) dominate over undulatory quartz (10%-19%) (Table, 1; Fig. 3). Poly-crystalline quartz grains show interlocking texture. Small amount of feldspar (4%-5%) is present, mainly plagioclase. The rock-fragments of slate, phyllite and limestone are observed (Fig. 3). Cementing material is mainly carbonate and iron-oxide. In some samples only carbonate cement is present, and in others, iron oxide coatings are present over the particles (Fig. 3). In those sandstones, which contain both the types of cement the carbonate cement seems to have precipitated early.

The sandstones possess an average composition of Q-74%, F-4%, RF-3%, CT-19% (Table 1). The sandstone composition suggests that they belong to quartz-arenite variety (after Okada, 1971). In Q-F-L diagram (after

Table 1. Modal composition of the Late Paleocene sandstones of the Jaisalmer basin

Constituents (in percent)	Sa-1	Sa-2	Sa-3	Sa-4	Sa-5	Sa-6	Sa-7	Sa-8
Quartz	74.00	75.00	72.00	73.00	73.00	76.00	75.00	73.00
Polycrystalline Quartz	8.00	13.00	8.00	10.00	7.00	11.00	10 .00	11 .00
Monocrystalline Quartz	66.00	62.00	64.00	63.00	66.00	65.00	65.00	62.00
Undulatory Quartz	10.00	11.00	15.00	19.00	13.00	11.00	16.00	10.00
Non-Undulatory Quartz	56.00	51.00	49.00	44.00	53.00	54.00	49.00	52.00
Feldspar	4.00	4.00	4.00	4.00	4.00	5.00	3.00	5.00
Rock Fragments (m)	1.00	2.00	2.00	2.00	2.00	1.00	2.00	1.00
Rock Fragments (s)		2.00	1.00	1.00	1.00	2.00	1.00	2.00
Rock Fragments (i)								
Carbonate Cement	21.00	11.00	5.00	–	20.00	11.00	14.00	1.00
Ferruginous Cement	–	5.00	16.00	20.00	–	4.00	5.00	17.00
Total	100	99.00	100	100	100	99.00	100	99.00

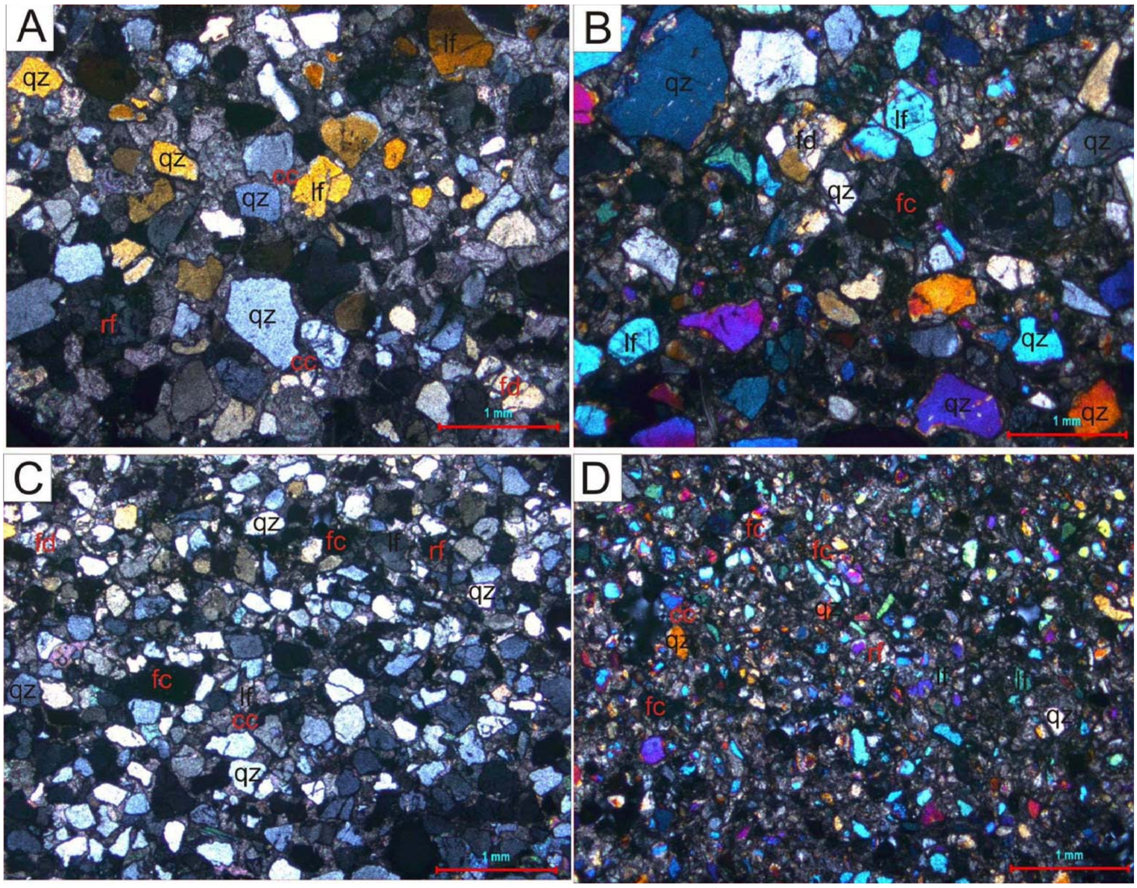

Fig.3. Photomicrographs of sandstone A. coarse to medium grained dominantly possessing monocrystalline quartz (qz), feldspar (fd) and limestone (lf) and phyllite/slate rock fragment (rf) cemented with calcite cement (cc). B. medium-grained sandstone dominantly containing monocrystaline quartz and feldspar cemented by a ferruginous cement (fc). C. medium-grained sandstone containing quartz, feldspar and metamorphic rock fragments. D. fine-grained sandstone dominantly containing monocrystalline quartz and subordinate feldspar and rock fragments.

Dickinson et al., 1983), these sandstones plot on the margin of the craton interior and transitional continental (Fig. 4) and in Qm-F-Lt diagram they plot in the transitional continental field (Fig. 5).

Heavy Minerals

Heavy minerals are commonly angular to sub-angular in shape and some of them are euhedral. Both opaque and non-opaque varieties occur in these sandstones where opaque variety dominates over non-opaque. In order of abundance, they are magnetite> tourmaline> kyanite> staurolite> zircon (Table 2).

Angular to sub-angular, magnetite grains with black colour and high relief (Fig. 6) ranges from 52%-55%. Tourmaline percentage varies from 14%-16% (Table 2). It is angular to sub-angular in shape and shows pleochroism, high refractive index, imperfect cleavage, high birefringence and parallel extinction. It contains numerous inclusions.

Table 2. Distribution of heavy minerals in the Late Paleocene sandstones of the Jaisalmer basin

Constituents (in percent)	Sa-1	Sa-2	Sa-3	Sa-4	Sa-5	Sa-6	Sa-7	Sa-8
Magnetite	52.00	55.00	53.00	53.00	54.00	54.00	53.00	53.00
Tourmaline	16.00	15.00	15.00	15.00	16.00	14.00	15.00	15.00
Kyanite	13.00	13.00	13.00	12.00	13.00	13.00	13.00	13.00
Staurolite	14.00	11.00	13.00	14.00	12.00	12.00	12.00	13.00
Zircon	4.00	5.00	6.00	5.00	5.00	5.00	4.00	5.00
Total	**99.00**	**99.00**	**100.00**	**99.00**	**100.00**	**98.00**	**97.00**	**99.00**

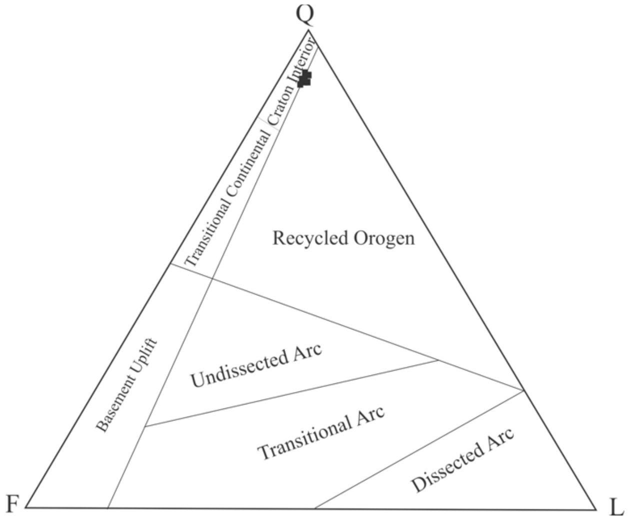

Fig.4. Q-F-L diagram of the late Paleocene sandstones of the Jaisalmer basin (after Dickinson et al., 1983).

Two varieties of tourmaline are identified. They are yellow to brown (Fig. 6) and blue coloured.

Kyanite constitues about 13% of the heavy mineral population (Table 2). It is identified by colourless to light blue colour, anhedral shape, non-pleochroic nature, high refractive index, with two sets of cleavages oblique to one another, presence of inclusions, low to moderate birefringence and oblique extinction (Fig. 6).

Staurolite forms 11%-14% of the heavy mineral population. It is yellowish in colour, anhedral in shape, pleochroic with high refactive index, imperfect cleavage, low birefringence and parallel extinction. It contains numerous inclusions of quartz (Fig. 6).

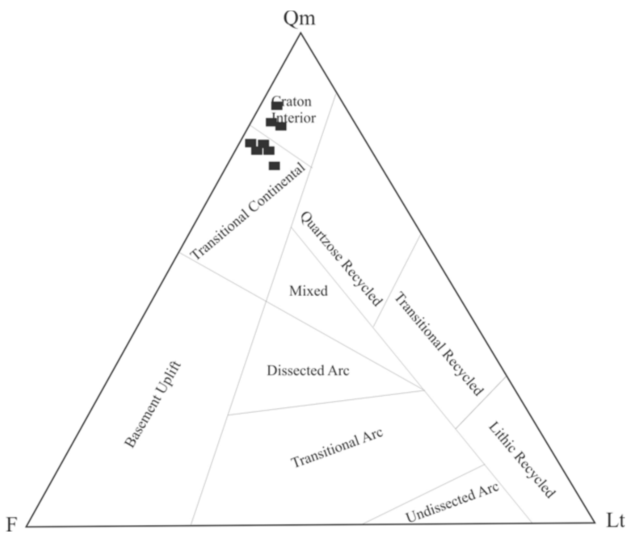

Fig.5. Qm-F-Lt diagram of the late Paleocene sandstones of the Jaisalmer basin (after Dickinson et al., 1983).

Zircon occurs within a range of 4%-6% (Table 2). It is prismatic and angular to sub-angular in shape (euhedral). It is non-pleochroic to feebly pleochroic, exhibits zoning, has very high refractive index, cleavage is absent and contains inclusions (Fig. 6). It is also characterized by high birefringence and parallel extinction.

Palaeocurrents

Sediments dispersal pattern is controlled by the flow directions and hydrodynamics of the depositional medium. Primary sedimentary structures commonly indicate the flow directions in sedimentary successions (Shelly, 1980; Pettijohn, 1984). Fore-sets of the cross-beds are directed towards the flow in the cross-bedded sandstones. The fore-sets data collected from the cross-beds in the Sanu Formation shows bipolar paleocurrent pattern with current directions towards WNW and ENE dominated by the WNW direction (Fig. 7).

DISCUSSION

The sandstone of late Paleocene Sanu Formation of Jaisalmer basin shows abundance (74%) of sub-angular to sub-rounded monocrystalline and non-undulatory quartz. The occurrence of quartz having monocrystalline non-undulatory character generally points towards sources such as fine-grained schists, phyllite and slates; volcanic and hypabasal igneous rock and pre-existing sedimentary rocks (e.g. Blatt et al., 1980). The polycrystalline quartz grains with interlocking texture are derivatives of metamorphic rock, most commonly quartzite. Plagioclase might have been derived from a basaltic source region. The slate and phyllite rock fragments belonging to rank-2 of Garzanti and Vezzoli (2003) suggest their derivation from a low to medium grade metamorphic rock. The limestone rock fragments suggest a sedimentary source. Further, the angular and sub-angular grain shapes of the framework grains as well as the heavy minerals suggest that the provenance was in the vicinity of the depositional basin. Most quartzose sands are derived from stable craton interiors having low relief and lithic fragments are locally introduced in few cases (Dickinson et al., 1983). The craton interior field occupied by these sandstones in Q-F-L diagram, and craton interior and transitional continental field in Qm-F-Lt plot suggest that stable craton supplied sediments to the depositional basin and lithic fragments were contributed locally.

The abundance of magnetite among the heavy minerals in the studied sandstones suggests that they were derived from a basic igneous or its metamorphic equivalent. As the Deccan basalts and the mafic and ultramafic rocks are

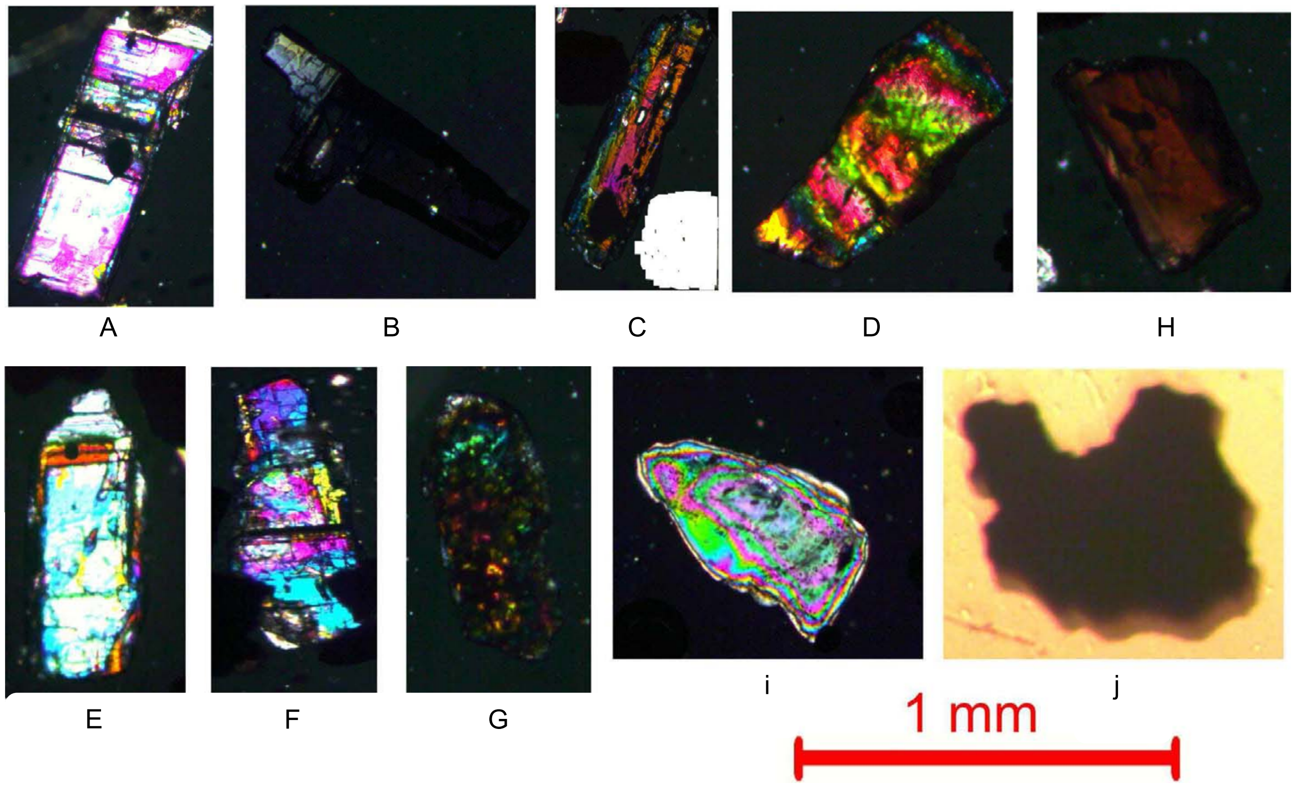

Fig.6. Heavy minerals. a, b, c, d, e, f = Kyanite; g = Staurolite; h= Tourmalin i = Zircon; j = Magnetite.

present in the nearby Aravalli Supergroup, it can be interpreted that the Deccan basalt or the Aravalli Supergroup was the main source for the magnetite. However, a part of magnetite was dissolved and precipitated as ferruginous cement during diagenesis. Brownish tourmaline indicates low grade metamorphic source whereas blue tourmaline indicates pegmatite source (Pettijohn, 1984). The dominance of the former in the Sanu sandstones suggests its derivation from low-grade metamorphic rocks. The occurrence of both staurolite and kyanite suggests that they were derived from a low to medium grade metamorphic source. Euhedral zircon in the sandstones might have derived from an acid igneous rock.

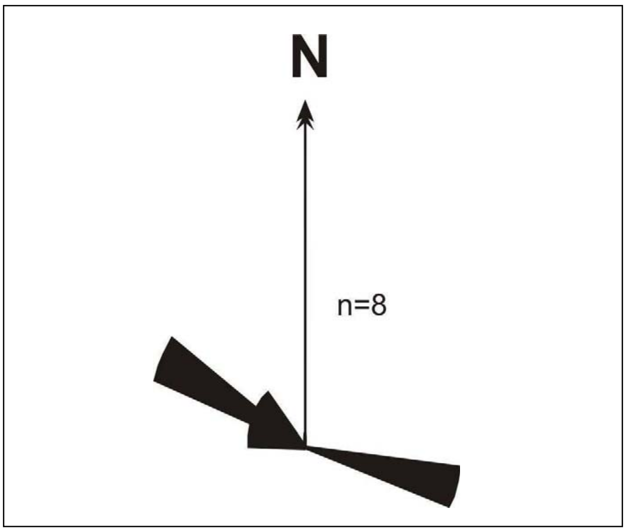

Fig.7. Rose diagram prepared from the tabular cross-bed data. Note bipolar paleocurrent pattern.

Bipolar paleocurrent pattern is observed in the depositional basins that are influenced by tides (Shelly, 1980). The cross-bedded, thin-bedded and laminated sandstones were most likely deposited either in estuaries or tidal flats. The estuaries are either river-dominated or tide- and wave-dominated or ocean-dominated (Dalrymple et al., 1992). The gritty nature of the sandstone associated with cross-beds suggests that it was formed under the influence of river current domination. Thus, it is presumed that the NW directed flow was a result of the river current and NE dominated flow was a result of advancing tides. The domination of the NW paleocurrent direction in the cross-bedded sandstone suggests that the main provenance was in the SE direction of the depositional basin.

Most likely, the metapelite and mafic/ultramafic rocks of the southern sector of the Aravalli belt contributed the detrital sediments to the depositional basin during late Paleocene. However, the magnetite might have been supplied from the basic rocks either from the mafic/ultramafic rocks

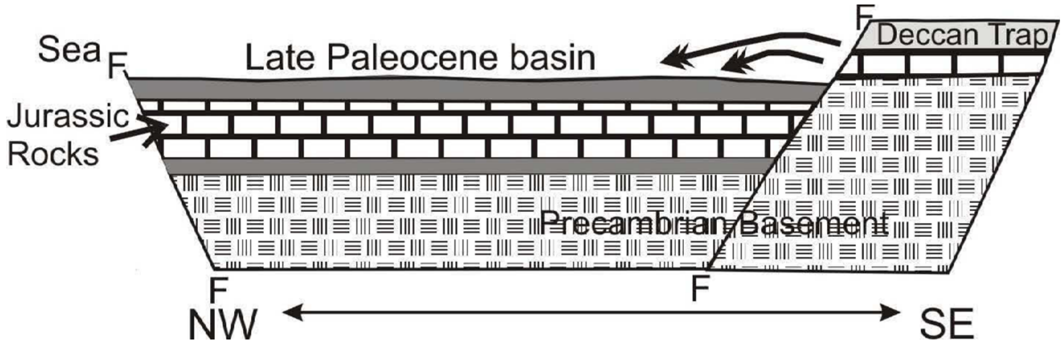

Fig.8. Cartoon exhibiting broad composition of the provenance for the late Paleocene sandstones of the Jaisalmer basin.

of the Aravalli belt or Deccan basalt present in the vicinity (Fig. 8). The limestone fragments further suggest that the underlying Jurassic carbonate rocks also contributed as a source for the Paleogene sequences of the Jaisalmer basin (Fig. 8). The occurrence of unstable rock fragments such as limestone suggests that the climate was unfavourable for weathering. The Jaisalmer basin is a pericratonic basin and is located on the northwestern slope of the Indian platform (Singh, 2006). The structural trends in the Jaisalmer basin are mainly NNW-SSE or NW-SE corresponding to the general trend of the Dharwar craton (Singh, 2007). Besides, a subsidiary NE-SW trend corresponding to the Aravalli ranges also exists. Thus, these mainly controlled the basinal configuration during Paleocene and the uplifted blocks of Proterozoic and Mesozoic sequences were weathered and eroded before being deposited in the Paleocene grabens (Fig. 8).

CONCLUSIONS

Petrographic study of the sandstone shows dominance of sub-angular to sub-rounded monocrystalline non-undulatory quartz in association with feldspar and rock-fragments. The Q-F-L and Qm-F-Lt plots suggest that the sandstones represent craton interior of a pericratonic basin. The heavy minerals study shows the abundance of magnetite over tourmaline, kyanite, staurolite, and zircon. The paleocurrents are dominated by the NW directed currents. All these suggest that the provenance was dominated by low to medium grade metamorphic and volcanic rocks of the Aravalli Supergroup, Jurassic succession and the Deccan basalts which were denuded during late Paleocene.

Acknowledgements: Authors are grateful to the authorities of Banaras Hindu University for providing working facilities. Reviewers are thanked for helpful suggestions.

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(Received: 10 September 2012; Revised form accepted: 25 March 2013)