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Facies Characterization and Genetic Implications of the Late Paleocene sandstone member of the Matanomadh Formation, Kutch, Western India

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ABSTRACT

In this paper, attempts have been made to decipher the depositional environment and provenance of the late Paleocene Sandstone member of the Matanomadh Formation (MF). Based on sedimentologic characteristics, the Matanomadh sandstone member broadly segregated into four lithofacies namely thickly-bedded sandstone, thinly-bedded sandstone, tangential cross-bedded sandstone exhibiting reactivation surfaces and tabular cross-bedded sandstone. The fining upward trend of the facies association shows shifting in energy condition of the depositional environment from upper flow regime in the lower part (thick and thin horizontal beds) to lower flow regime in the upper part (cross-beds) and depicts a fluvial depositional environment with utmost sedimentation within a confined channel. This is supported by the absence of muddy facies in the succession. MS dominantly contain quartz with minor proportions of feldspar and rock fragments; belong to quartzose arenite variety. Q-F-L and Qm-F-Lt plots suggest margin of the craton interior to transitional continental stable craton provenance. The dense mineral assemblages of these sandstones show sub-angular to sub-rounded grains of magnetite, tourmaline, monazite, rutile, kyanite, staurolite and hematite grains which might have been supplied chiefly from a basic igneous source supplemented with low- to medium-grade metamorphic rocks and sedimentary source. The cross-bedded sandstones of the Matanomadh Formation show unidirectional SW flow which suggests the source area lies in the NE direction of the depocentre. It is envisaged that the metamorphic rocks of the Aravalli Supergroup, basic igneous rocks of the Deccan Plateau and Mesozoic sedimentary rocks acted as a provenance for the clastic member of the Matanomadh Formation.

INTRODUCTION

Kutch basin is a pericratonic rift basin extended between latitudes 22°30' and 24°30' N and longitudes 68° and 72° E and evolved due to sequential rifting and repeated movements in relation with the northward drift of Indian plate after the breakup of the Gondwana land during Late Triassic-Early Jurassic period (Norton and Sclator, 1979; Koshal, 1984; Biswas, 1982; 1987). It is bounded by the Nagar-Parkar fault in the North, Radhanpur-Barmer arch in the east and North Kathiawar fault towards the south (Biswas, 1982). It has preserved almost a complete sequence from Triassic to Recent punctuated by several stratigraphic breaks between transgressive cycles. Matanomadh Formation represents the lowermost lithostratigraphic unit of the Tertiary sequence of Kutch and divided into a basal lateritic member and an upper clastic member (Saxena, 1975) where the latter is comprised of 4.6 meter thick succession of sandstones that are exposed around Matanomadh village (N 23^{0} 32'43"E 68^{0} 57'04") (Fig.1). The Matanomadh sandstone member disconformably overlies a variety of mudstones occurring in the basal part and is overlain by Eocene lignite-containing Nareda Formation (Biswas et al, 1992) in the western part of the study area. Provenance analysis includes all enquiries that would aid in reconstructing the lithospheric history of the Earth (Basu, 2003; Weltje and Eynatten, 2004) and can be performed with the help of detrital minerals, including dense minerals supported by paleocurrent analysis. An attempt has been made here to provide an insight on the depositional environment and plausible provenance of MS using light and dense minerals, rock fragments and paleocurrent analysis.

METHODOLOGY

Lithounits were identified in the field considering sedimentologic attributes such as lithology, texture and sedimentary structures and a detailed litholog was prepared. Pattern of the azimuthal data and angle of inclination were noted from the cross-beds for paleocurrent analysis. A total of twelve samples (three from each facies) were used in thin section preparation for petrographic analysis. Modal analysis was carried out with the help of Image Analysis Software. Dense minerals were separated from these samples by heavy liquid separation method using Bromoform heavy liquid (Sp. Gravity 2.89).

RESULTS

Results are presented in terms of types of lithounits, petrographic details of the sandstones, dense mineral compositions and paleocurrent analysis.

Lithounits

Lithounits were made primarily based on sedimentary structures coupled with particle size and petrographic details. A total of four lithounits were identified from bottom to top (Fig. 2) are as follows;

Thickly-bedded Sandstone facies is 0.5 m thick and characterized by brown colour, course to medium-sub-angular to sub-rounded grains and moderately sorted texture. It is texturally and compositionally moderately mature. Brown colour is due to the presence of ferruginous cement.

Thinly-bedded Sandstone facies has a total thickness of 0.3 m and is characterized by yellowish green colour, medium- to fine-grained, moderately to well sorted texture. These are stratified sandstones. The thickness of the individual beds varies from 1.3 to 1.6 cm. The beds are planar in outline with sharp upper and lower boundaries. The sub-rounded to rounded detritus of quartz, feldspar and rock fragments are bounded by both calcareous and ferruginous cements.

Tangential Cross-bedded Sandstone facies is 1.8 m thick and characterized by yellowish grey colour, three cosets of tangential cross stratification with absence of top set lamina and presence of reactivation surfaces within the foresets (Fig. 2B). The sandstone is texturally and compositionally moderately mature. It is dominated by quartz, feldspar and rock fragments with the occurrence of weathered feldspar in some thin sections. The quartz, feldspar and rock fragments are bounded by calcareous cement. The foresets of these cross beds are characterized by high angle of inclination ranging between 25-30°.

Tabular Cross-bedded Sandstone facies is nearly 2 meter thick brownish grey coloured sandstone exhibits atleast fourteen cosets of tabular cross stratification, each characterized by 20-25° inclined foresets. Each set of tabular cross stratification is 10cm to 15cm thick (Fig. 2C). Their lower and upper boundaries are sharp. It is texturally as well as compositionally mature. It is medium to fine grained with moderately well sorted texture. The quartz, feldspar, muscovite and rock fragments are bounded by calcareous as well as ferruginous cement with the dominance of former one.

Petrography

Sandstones of the study area can be grouped as moderately sorted quartzose arenite. Medium- to coarse-framework grains form the thickly- and thinly-bedded sandstones and tangential cross-bedded sandstones, and fine- to medium-framework grains form the tabular cross-bedded sandstone. In quartz (72-75%), monocrystalline quartz dominates over polycrystalline and non-undulatory quartz grains dominate over undulatory quartz (8%). Polycrystalline quartz show interlocking texture. Low amount of feldspar (~ 9%) is present in these sandstones, which are mainly microcline and plagioclase (Fig. 3B & C), including the weathered varieties (Fig. 3D). Rock fragments form a little proportion (1-2%) in the medium- to coarse-grained quartzose arenites. Cement is mainly calcareous in this variety of sandstones.

In the fine-to medium-grained quartzose arenite, framework grains are mainly sub-angular to sub-rounded (Fig. 4). Monocrystalline variety dominates over the polycrystalline in the 75-76% quartz grains (Fig. 4A). Mica is mainly muscovite in these sandstones (Fig. 4B, C, D). The rock-fragments of mica-schist and chert are observed in addition to few limestone fragments (Fig. 4C & D). Rock fragments form 7-8% in this type of quartzose arenite. Cementing material is mainly carbonate and iron-oxide. In some samples only carbonate cement is present, while in others, iron oxide coatings are present over the particles and cement is mainly carbonate. In those sandstones, which contain both the types of cement the carbonate cement looks earlier precipitated than ferruginous cement.

In Q-F-L diagram (after Dickinson et al., 1983), the composition of the three lower sandstone units occupy the position at the margin of the craton interior and transitional continental (Fig. 5) whereas the composition of the uppermost sandstone unit occupies the position between the craton interior and recycled orogen. Further, they occupy transitional continental and marginal quartzose recycled orogen field in the Qm-F-Lt diagram following Dickinson et al. (1983) (Table 2) (Fig. 6). This suggests small variation in tectonic setting at the source area. But composition of both types of sandstones suggests that they belong to quartzose arenite variety (after Okada, 1971).

Dense minerals

In these sandstones, both opaque and non-opaque dense mineral varieties occur where opaque variety dominates over non-opaque. In order of abundance, the dense minerals suite is comprised of magnetite (55-66%)> tourmaline (9-15%)> kyanite (6-11%)> rutile (6-12%)> monazite (6-10%)> staurolite (2-4%)> hematite (1-3%).

Magnetite shows angular to sub-angular nature of the grain corners. Tourmaline exhibits subangular to subrounded nature. Two varieties of tourmaline are identified; they are yellow to brown and blue tourmaline. Kyanite shows subhedral shape. Rutile reflects subhedral to euhedral shape. Monazite shows prismatic crystal outline with subhedral to euhedral shape. Staurolite forms 2-3% of the bulk dense minerals and contains numerous inclusions of quartz. Hematite ranges from 2-3% and shows angular to sub-angular nature of the grain corners (Fig.7).

Paleocurrents

Sediments dispersal pattern is controlled by the flow directions and hydrodynamics of the depositional medium. Mainly, the flow directions are determined on the basis of primary sedimentary structures. The cross-bedded sandstones of the MF show unidirectional southwesterly flow within a range of S40-60°W pattern (Fig. 8). The paleocurrent pattern for the uppermost tabular cross-bedded sandstone is slightly different and towards more westward direction than the underlying tangential cross-bedded sandstone. It may be due to the westward shift in the depositing channel during tabular sandstone deposition. It is dominated by S40-52°W for the tangential cross-bedded sandstone (Fig. 8A) and S50-60°W (Fig. 8B) for the tabular cross-bedded sandstone.

DISCUSSION

Depositional Environment

The depositional environment is deciphered based on lithounits association and sedimentary structures. The horizontally-stratified sandstones deposit in various depositional environments such as fluvial, estuarine, continental shelf and deep marine environments. Fluvial sandstones are characterized by horizontally stratified beds and cross-beds (Harms, 1982; Tunbridge, 1984) and are devoid of flaser and wavy beddings and tidal bundles, besides hummocky cross-stratification and graded beddings. Estuarine sandstones contain flaser and wavy bedding and tidal bundles (Singh and Singh, 1995; Singh 2013). Deep marine sandstones possess graded bedding, besides other sedimentary structures (Pettijohn, 1984; Nichols, 2009). Horizontally-stratified sandstone lithounits and plane bed conditions are the result of flash floods depositing under upper flow regime (Fr > 1.0) (Tunbridge, 1984). Thus, it can be interpreted that the thickly-bedded and thinly-bedded sandstone units deposited under the upper flow regime in a fluvial system. The planar cross-stratification suggests deposition during periods of low water level in channels. The two overlying cross-bedded sandstone units suggest their deposition by river flow in a laterally migrating channel (e.g. Allen 1965; Leeder 1973; Kirk 1983). Also, the planar cross-strata of low amplitude (10-15 cm thick) forms as a result of ripple migration during waning stage of flow (e. g. Singh et al. 2006).

Both tangential and tabular cross-beds are formed due to migration of two-dimensional straight crested ripples and dunes. These are formed under unidirectional laminar flow condition. The shift from tangential cross-beds in lower part to tabular cross-beds in upper part suggests shifting of energy condition from high to low which is coupled with the variation in bed thickness and grain size (e. g. Harms, 1982).The tangential-cross-bedded sandstone also exhibits reactivation surfaces. Reactivation surface results from unsteady flow velocities produced in the unidirectional flow system by migration of a faster moving mega ripple over a slower one, these surfaces have less inclinations of the cross stratifications and they are formed as erosion surfaces on foresets plane by ebb or flood currents in tidal environment or during the waning flow in fluvial environments (Allen, 1968). The tangential cross-bedded sandstone with reactivation surfaces likely deposited in a fluvial channel during the waning flow.

The fining upward trend of the lithounits shows shifting in energy condition of the depositional environment from upper flow regime in the lower part to lower flow regime in the upper part. The architecture of the lithounits also suggests that the entire sand body was deposited in a confined fluvial channel. This is also supported by the absence of muddy facies in the succession. The occurrence of weathered feldspar suggests that the climatic condition was unfavorable for the preservation of feldspar in the depositional basin. This may be because of the warm and humid climate during the Paleocene in and around western India.

Provenance

Provenance for the MS is discussed based on the light minerals, rock fragments and dense minerals. The occurrence of quartz having monocrystalline non-undulatory nature generally points towards sources such as volcanic and hypabasal igneous rock, fine-grained schists, phyllite and slates, and pre-existing sedimentary rocks (e.g. Blatt et. al. 1980). The polycrystalline quartz with interlocking texture is derived from a metamorphic rock, most likely quartzite. Chert in these rocks would have been derived from sedimentary rocks. Plagioclase variety of feldspar might have derived from a basaltic source. The limestone fragments suggest their derivation from a sedimentary source. The metamorphic rocks of the Nagar Parkar hills exposed in the NW and the Aravalli hills exposed in the NE must have acted as the chief sources for the MS. Deccan Trap forms the basement of the MF in the Kutch region. In the Kutch region, Deccan trap is the outpouring of tholeiitic basaltic lava that overlies the Mesozoic sedimentary rocks of marine and fluvio-lacustrine origin (Merh, 1995). This must have contributed part of the sediments to the MS.

Kutch Basin is an east-west oriented pericratonic rift basin at the westernmost periphery of the Indian craton. The Kutch Rift evolved within the Mid-Proterozoic Aravalli-Delhi fold belt by reactivation of pre-existing faults along NE-SW trend of Delhi fold belt that swings to E-W in Kutch region (Biswas, 2005).Thus, these faults mainly controlled the basinal configuration during Late Triassic/Early Jurassic and the uplifted blocks of the faults containing Mesozoic sequences were weathered and eroded before depositing in the grabens over Deccan basalt and Mesozoic succession during Paleocene epoch. Most of the quartzose sands are derived from stable craton having low relief and high proportion of lithic fragment suggests upliftment at the source area (Dickinson et al., 1983). The craton interior field in the Q-F-L diagram, and craton interior to transitional continental field in the Qm-F-Lt plot occupied by the lower three sandstone units suggest a stable craton that had supplied sediments to the depositional basin, while marginal recycled orogen field occupied by the uppermost sandstone unit in the Q-F-L diagram and marginal craton interior field in the Qm-F-Lt diagram suggest that the sediments were derived from an uplifted block that was largely composed of sedimentary and meta-sedimentary rocks

Considering that a part of the dense minerals was altered during diagenesis (e. g. Garzanti and Ando, 2007), the abundance of magnetite among the dense minerals in the studied sandstones suggests that they were derived from a basic igneous rock such as Deccan basalt. Brown tourmaline indicates low rank metamorphic source, while blue tourmaline indicates a pegmatitic source (Pettijohn, 1984).The dominance of the brownish tourmaline in the Matanomadh sandstones suggests its derivation from low-grade metamorphic rocks. The occurrence of kyanite in larger proportion and staurolite in smaller proportion suggest that they were contributed from a low- to medium-grade metamorphic source. Rounded grains of rutile, tourmaline and monazite in the studied sandstones are likely derived either from an acid igneous rock or from reworking of the sediments (Pettijohn et al., 1987). Thus, the Precambrian metamorphic rocks of the basement might have acted as the source along with Deccan basalt and Mesozoic sedimentary rocks during the sedimentation of the MS. Unidirectional paleocurrent pattern due to domination of the current in the SW direction suggests that provenance was in the NE direction and most likely the Precambrian Aravalli Supergroup.

CONCLUSIONS

The lithounits association shows a fining- upward trend and suggests shifting in energy condition of the depositional sequence from upper flow regime in the lower part to lower flow regime in the upper part. Based on present study a fluvial depositional environment for the Matanomadh sandstone member is suggested. Petrographic study of the sandstone shows abundance of sub-angular to sub-rounded monocrystalline non-undulatory quartz in association with feldspar and lithic-fragments that classifies them as quartzose arenite types. The Q-F-L and Qm-F-Lt plots suggest that the sandstones represent craton interior for the three lower sandstone facies and at the margin of the craton interior for the uppermost sandstone facies. Abundance of opaque variety of dense mineral (e.g. magnetite) over the non-opaque tourmaline, kyanite, rutile, monazite and staurolite is observed in these sandstones. The paleocurrents are unidirectional and dominated by the SW directed currents. Petrography and dense minerals study along with paleocurrents study suggest that the provenance was dominated by low- to medium-grade metamorphic rocks of the basement (Nagar Parkar and/ or Aravalli metamorphic rocks), volcanic rocks of basaltic composition such as Deccan Trap and older Mesozoic successions exposed in the northeast of the depositional basin.

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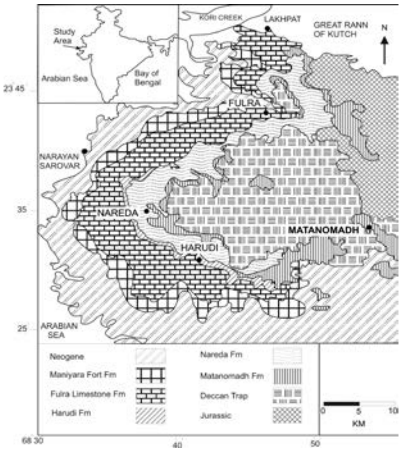
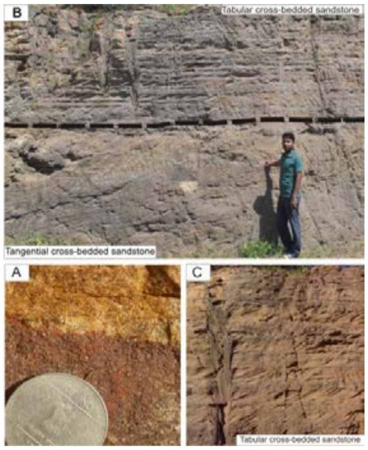




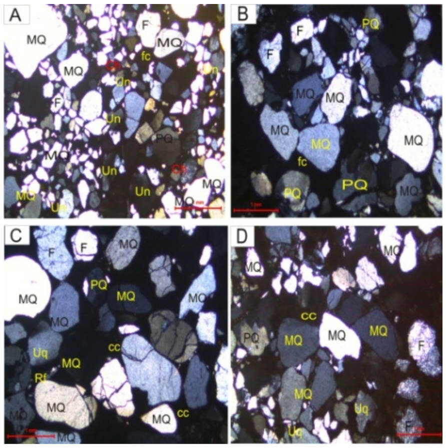
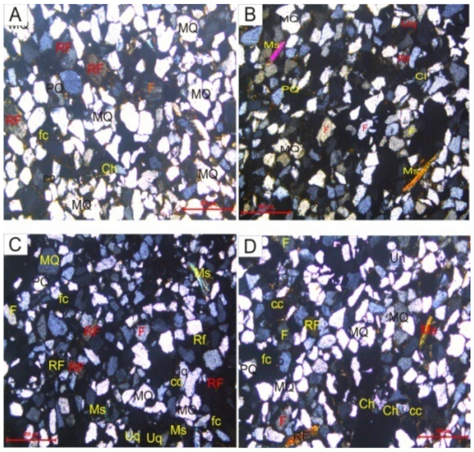
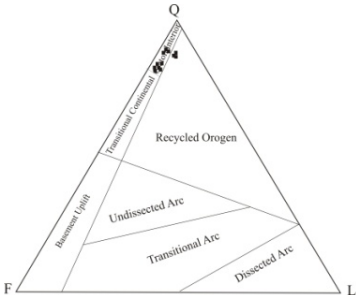


Fig. 1

Fig. 2

Fig. 3





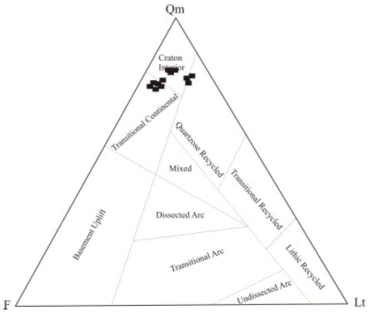


Fig.4

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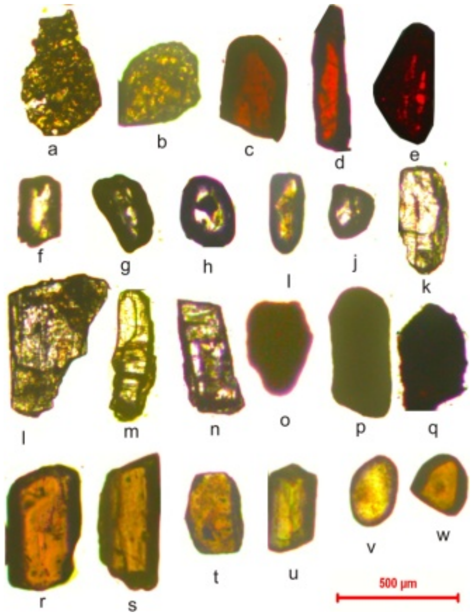

Fig. 7

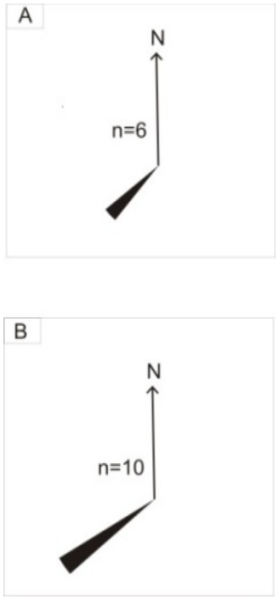

Fig.8