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Facies and Sedimentary Structures of the Kerur Formation, Badami Group, South India: Implications for Depositional environment

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ABSTRACT

Facies architecture and sedimentary structures, followed by petrographic characteristics of the rocks of the Kerur Formation of the Badami Group of Kaladgi-Badami basin exposed in the Deshnur area near Belgaum, in South India is discussed in the present paper to understand their depositional environment. The Kerur Formation at Deshnur comprises of conglomerate, gritty sandstone- quartz arenite and shale. In the type area at Badami, it comprises of Kendur conglomerate, 90m thick sequence of arenite called "the temple arenite and the Halageri shale. In the western part, at Deshnur, near Belgaum, Kerur Formation show rhythmic variation in conglomerate and gritty sandstone followed by medium to fine grained arenite and intercalated thin shale beds suggesting fluctuating-fluvial, beach facies and shallow water depositional condition. Features of fluvial sedimentation such as pebble beds; shallow water sedimentary features such as symmetrical ripple marks, cross bedding; beach facies like dune lamination and Aeolian dunes; and shallow marine facies such as intercalation of shale with sandy facies are observed. Features such as pebbles size, rounding, along with current bedding structures within the gritty layers between the pebble beds suggest fluvial discharge to an open sea. The thicker, gentler landward-cross strata, thinner, steeper seaward cross-strata in the herringbone cross stratification in the overlying arenite indicate the tidal modulation during their deposition. In thin section, the grit show well rounded while the quartz arenite show moderately rounded to well rounded, medium grained, texturally and compositionally matured characters suggesting sorting by winnowing action of waves, implying coastal environment of deposition. The facies Architecture, sedimentary structure like tidalites indicative of interaction of tides and current (including changes in their speed and direction) suggest tidal modulation of depositional environment. Well rounded, moderately assorted, vein quartz rich pebbles in alternate sandy- pebbly layers along with arkosic nature of the grits indicate periodic flashy floods dominated the surface hydrodynamics of transport during the early phase of sedimentation.

KEYWORDS: *Meso-Neoproterozoic, Kerur Formation, Badami Group, Depositional environment, Facies analysis.*

INTRODUCTION

Understanding of the depositional environment and distinction between shallow-marine and fluvial deposits of ancient sedimentary records is challenging (Fedo and Cooper,1990; McCormick and Grotzinger, 1993; Bose and Chakraborty, 1994; Collinson, 1996; Eriksson et al., 1998; Bose et al., 2012), especially in the absence of fossil records like stromatolites, characteristic of depositional environment (Serebryakov, 1976) for texturally mature, tabular quartzite bodies (Long, 1978; Bose and Chakraborty, 1994; Martin et al., 2000; Bose et al., 2012). Attempts are being made to explore facies architecture integrated with sedimentological evidence, stratigraphy, and their comparison with modern examples to understand the depositional; environment (Harris and Eriksson, 1990; Fedo and Cooper, 1990; McCormick and Grotzinger, 1993; Chakraborty et al., 2009). Facies analysis of the sedimentary records has been found to be a potential tool to unravel their depositional environment and transportation history. Facies analysis is based on the regional geology, outcrop studies such as change in composition and texture and sedimentary structure. Borehole log seismic data of the basin architecture and configuration are also widely adopted.

Studies based on small scale features of sedimentary rocks and the processes involved in their development is based on the Walther's Law that, the facies occurring in vertical contacts with each other are the product of spatially neighboring environment. This explains the lateral migration of sedimentary environment in geological time scale (c.f. Blatt et al, 1980). The facies concept was developed due to non-availability of outcrops over a large area and access to the abundant sub-surface geophysical data (electrical and seismic data). This concept was later extended to large packets of seismic facies, bounded by unconformities traced across passive continental margin with very large sediment thickness (Mitchum et al., 1977a). Later, this facies concept was fitted into the models of sequence stratigraphy for large scale geological interpretation.

However, ancient sedimentary records are invariably deformed, metamorphosed, and undergone deep weathering. Hence, a well-preserved un-metamorphosed, un-deformed, unambiguous outcrop pattern is critical in this endeavor. Kaladgi-Badami basin in South India is one of the well-preserved, least-deformed siliciclastic sedimentary sequences. Many studies have been focused such as on Lithostratigraphy of the Kaladgi and Badami Groups (Vishvanathaiah, 1977), Sedimentological investigation (George 1999), the provenance, (c.f Ramachandran et al., 2016), Paleocurrent, Deformation, Petrographic and Geochemical studies (Devli and Mahender, 2018; Verlekar and Kotha, 2020), sedimentary cover and its relation with the basement–in the Kaladgi Basin (Mukherjee, et al., 2016). However, studies based on facies analysis, in particular Kerur Formation of the Badami Group are scarce. The depositional environment of the Badami Group has been inferred to be of shallow marine (Sathyanarayan, 1994) while equivalent Kerur Formation in Deshnur, Belagaum is inferred to be fluvial deposit (Atomic Mineral division report).These contradictory inferences of depositional environment suggest need for comprehensive study of sedimentary facies and sedimentary structures. In the present paper, attempt is made to describe the facies (lithofacies) and sedimentary structures identified in the study area and interpret the depositional environments of the siliciclastic rock record of the Kerur Formation.

METHODOLOGY

The paper, based on the field observed sedimentary structures, facies association and facies change, palaeocurrents inferred from the sedimentary structures at selected out crops, followed by petrographic studies.

Geological Setting:

The Kaladgi basin covering an area of ~8300 km^2 in parts of northern Karnataka and southern Maharastra in south India extends for about 500 km in east west and unconformably overlie the Archaean Peninsular Gneissic Complex (Fig.1). To the north and west, it is covered by the late Cretaceous Deccan basalts, to the south it is bounded by Dharwar schists and gneisses and to the east and northeast by Biligi granites and to the Southeast by the Gajendragarh granite. In the Bilgi area (Fig. 2), the Kaladgi sediments unconformably overlie the undeformed pink and grey granitoids which are mapped as part of the Neoarchaean Closepet Granite by the Geological Survey of India (geological quadrangle map 47P, 1997). Quartz-sericite schist, quartz-chlorite schist and banded iron formation of the Chitradurga Group of the Dharwar Super Group is exposed over a small area below the Kaladgi about 3.5km south of Bisnal (Fig. 2). In the easternmost part, near Almatti, pink and grey anatectic Closepet Granites underlie the Kaladgi sediments. All along the northern margin, the unconformity contact between the Kaladgi sediments and basement rocks, wherever exposed, is clearly erosional and sharp, and generally marked by conglomerate or pebbly sandstone.

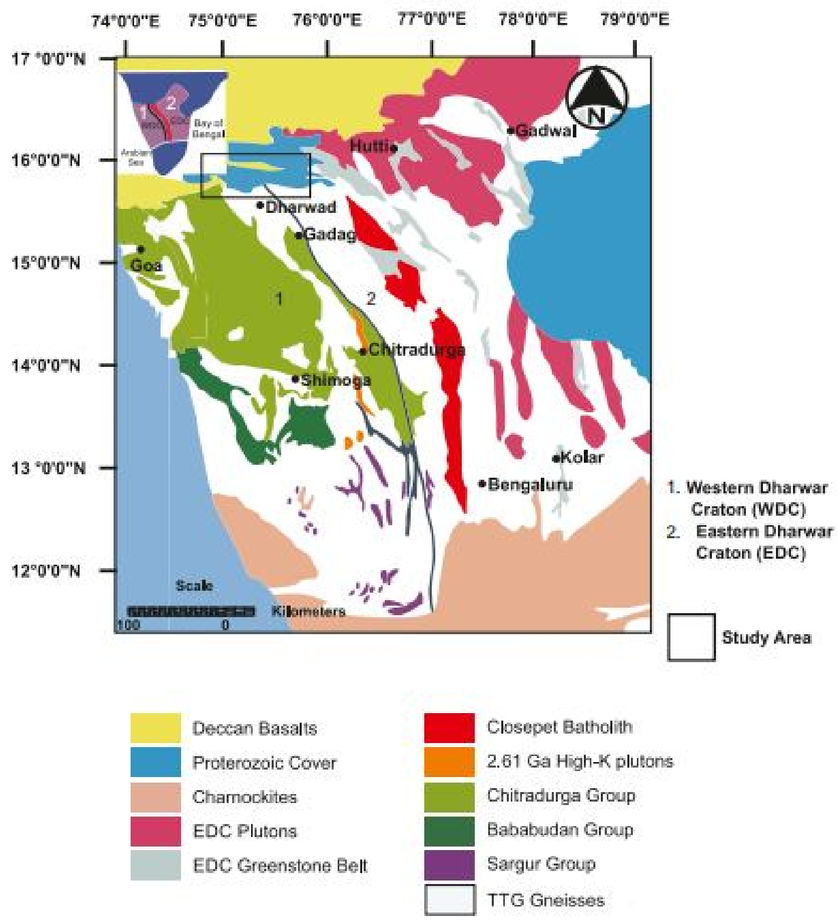

Figure 1: Geological map of Karnataka and location of the Proterozoic basin studied.

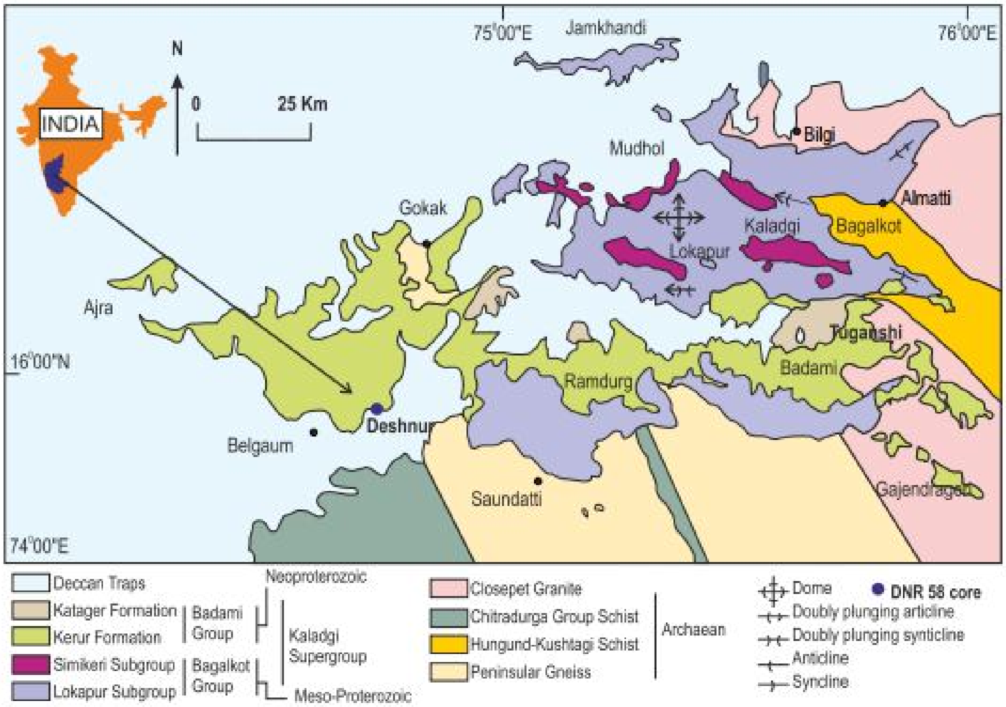

Figure 2: Geological map of the Kaladgi Badami basin and the Study area (after Jayaprakash et al., 1987)

The Kaladgi Supergroup consists of an older Bagalkot Group and a younger the Badami Group (Table 1, after Jayaprakash et al., 1987). The Bagalkot Group is further subdivided into lower Lokapur Subgroup and upper Simikeri Subgroup (Table 1). The Salgundi Conglomerate and Saundatti Quartzite which unconformably overlie the grey granites, show east-west trend with a low dip of 5° to 10° towards South.

The Badami Group consists of two formations: the lower, Kerur Formation and the upper Katageri Formation (Jayaprakash et al., 1987). The Kerur Formation commences with the Kendur conglomerate followed by ~90 m sequence of arenite, well exposed at Badami and called "the Temple arenite", and Halageri shale which shows limited exposure and thickness of <4m in the northern margin of the Kaladgi basin. This unit is well recognized around Halageri and Belikhindi where they underlie the Belikindi arenite (Table 1). They are bottle green to greenish yellow in color, friable, silty shale. The Belikhindi arenite has a sharp contact with the Halageri Shale Member. In the Deshnur area, near Belagavi, the Kerur Formation unconformably overlies the Archaean schistose rocks while in the east it overlies the Biligi granite. Overlying Katageri Formation is divided into two members: the Halkurki Shale, and the Konkankoppa Limestone. The Konkankoppa limestone is flaggy and medium bedded, bottle green, cream, buff, and pale gray in color with frequent shale partings, and fine color banding. The Limestone shows a gradational contact with the Halkurki shale.

Based on geochronological studies, Padmakumari et al., (1998), Balesh Kumar et al. (1998) inferred that the Bagalkot Group was deposited around 1800 ± 100Ma. Their Late Palaeoproterozoic age is also inferred from the stromatolitic studies (Sharma et al., 1998). The trace fossil occurrences in the Badami Group indicated its Neoproterozoic age (Kulkarni and Borkar, 1997). Recently, Wabo et al. (2021) based on their palaeomagnetic studies and comparison of palaeopoleposition with that of Harohalli dykes inferred age of 1100Ma for the Badami Group sedimentation.

Table 1: General Stratigraphy of the Kaladgi- Badami basin (after Jayaprakash et al., 1987)

	Groups	Sub Groups	Formation	Member	Thickness in m
	BADAMI GROUP		Katageri Formation	Konkanakoppa limestone	85
				Halkurki Shale	67
			Kerur Formation	Belikhindi Arenite	30
				Halageri Shale	3
				Cave Temple Arenite	89
				Kendur Conglomerate	3
	Angular Unconformity				
KALADGI SUPER GROUP	BAGALKOT GROUP	SIMIKERE SUB GROUP	Hosakatti Formation	Mallapur Intrusive	7
				Dadanhatti Argillite	695
			Aralikatti Formation	Lakshnhatti Dolerite	67
				Kerkalmatti Hematite schist	42
				Niralkeri chert breccias	39
			Kundargi Formation	Govinakoppa Argillite	80
				Muchkundi Quartzite	182
				Bevinmatti Conglomerate	15
		Disconormity			
		LOKAPUR SUBGROUP	Tadalli Formation	Argillite	58
			Muddapur Formation	Bomanbudni Dolomite	402
				Petlur Limestone	121
				Jalikatti Argillite	43
			Yendlgeri Formation	Nagnur Dolomite	93
				Chikshelikeri Limestone	
				Hebbal Argillite	166
			Yargatti Formation	Chitrabhanukot Dolomite	218
				Muttalgeri Argillite	502
				MahakutChert Breccia	133
			Ramdurg Formation	Manoli Argillite	61
				Saundatti quartzite	383
				Salgundi Conglomerate	31
		Unconformity			
			Granite, gneiss and Metasediments		

Study area: Badami Group (Jayaprakash et al., 1987) comprises of an undisturbed sequence of sandstone and shale exposed in the northern margin of the basin between Badami on the east and Gokak, Deshnur on the west. The sequence unconformably overlies Archaean granitoids and schists. It commences with the Kendur conglomerate which grades into the Cave Temple Arenites in the Badami on the east and, Sogal on the west where it is well exposed, and forms thick bedded ~1.5m vertical scarps (Fig 3a), at other places it occurs as small mounds (Fig 3b). In Deshnur area, the conglomerate unconformably overlies the Archaean schistose rocks and consists of thin pebbly units (Fig, 3c). They grade to alternate gritty sandstone (Fig 3d) and gritty layers show poorly developed current bedding structures (Fig.3e). Conglomerate grades to grit and thick sequence of arenite with local interbedding of thin layer of shale (Fig. 3f). In turn arenite is succeeded by thin <4 m flaggy, grey, with fine color banding shale.

Figure 3: Field photos showing

a) Vertical scarp of the sandstone at Sogal showing thick bedded nearly horizontal sandstone (lat 158603N; Long 748603E)

b) Sandstone forming small mound and flat topped hills near Belagavi(lat 15.982222N; Long 74. 50583333E).

c) Archaean Proterozoic boundary separated by erosional unconformity at Deshnur (Lat 15. 90277778N, Long 74. 590555556E).

d) Alternate pebbly gritty sandstone of the Basal Conglomerate at Deshnur(Lat 15.9033333, Long 74.55750000E).

e) Poorly developed current bedding structure with-in gritty layers of the Conglomerate(Lat 15.85944444N, Long 74.97472222E)

f) Fine grained sandstone with thin argillaceous/shale unit near Belagavi Poona High way road cutting.

Sedimentary facies: In general, five sedimentary facies can be recognized in the Kerur Formation of Deshnur area viz the matrix-supported pebbly conglomerate interbedded with massive coarse arkosic gritty sandstone, occasionally with current bedding structure (F1); thick horizontally bedded parallel laminated to plane-cross stratified/current bedded, well-sorted arenitic sandstones with occasional thin pebble/gravel beds (F2), Fine grained horizontal laminated with thin intercalated muddy sandstone(F3), fine grained sandstone with rhythmic interstratified thin shale unit (F4), flaggy, grey, with fine banded shale (F5).

The conglomerate commonly lack internal structure with very coarse chaotically oriented clasts (Fig 4a). The clasts of the conglomerate are predominantly of white vein quartz, black and grey chert and jasper components. Clasts are mostly angular to sub-angular to subrounded with large variations in their size. Roundness varies widely from angular especially BIFs (Fig 4b), to very well-rounded clasts (of white quartz). The matrix contains dominantly quartzose sands.

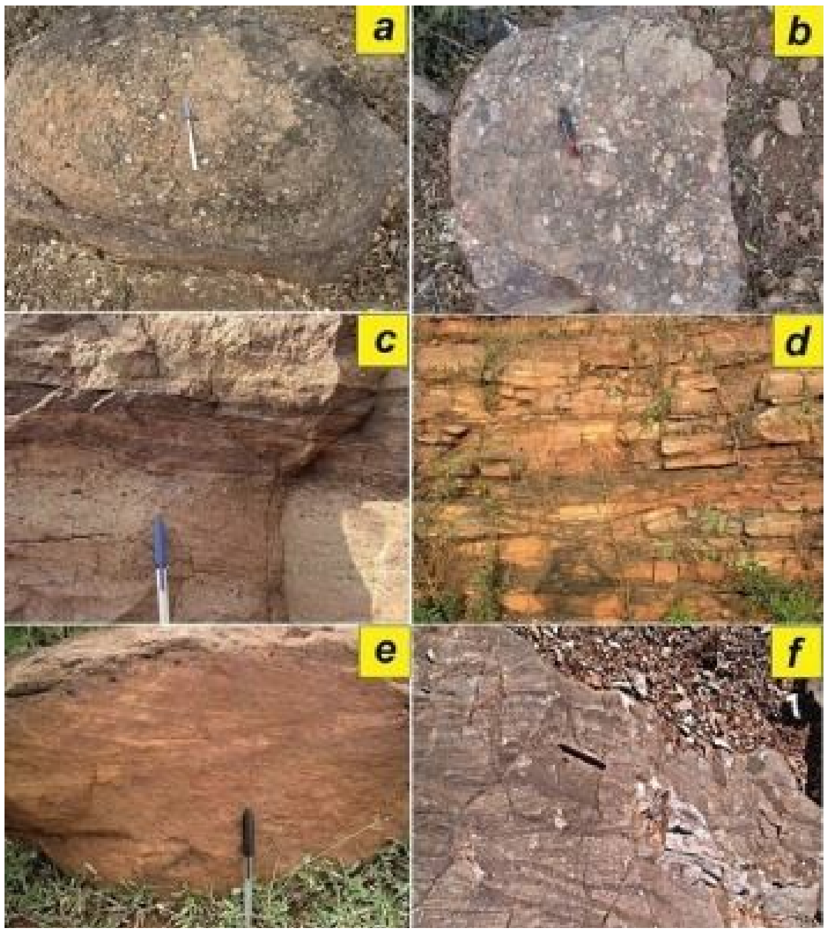

Figure 4:

- **a) Matrix supported conglomerate at the Base of Kerur Formation showing well rounded, gravels to pebbles sized vein quartz at Deshnur(Lat 15. 9033333N; Long 74.55944444E)**
- **b) Polymictic conglomerate showing rounded vein quartz alongwith angular jasper and BIF fragments at Deshnur(Lat 15 .85472222N; Long 74.97638889E).**
- **c) Horizontal lamination in sandstone of Kerur Formation at Gokak(Lat 16. 18877499 N. Long 74. 78704494E)**
- **d) Horizontal fine lamination with local undulation in sandstone at Gokak (16.17453N, Long. 74. 80086 E)**
- **e) Trough cross bedding in the gritty sandstone of Deshnur of Kerur Formation(15. 90277778N, Long 74 .55750000E)**
- **f) Cross bedding structures in sandstone of the Kerur Formation (Lat 15. 9160297N,75.299957E)**

Sedimentary structures: The rocks show planar tabular, with horizontal laminations both in the Gokak, Gudchi, Deshnur exposures (Fig 4c). Beds show fine grained fine laminated with local undulations 4d). At places arenite shows trough cross bedding with axis sloping towards South to Southwest (Fig.4e). Cross-bedding structures range in height from 10 to 35 cm, with a lateral extent varying from 1 to 3m is common in the Deshnur sandstone (Fig. 4f). Well-developed herringbone cross-stratification is found at places (Fig.5a). They are thicker, gentler towards northeast (we infer landward-cross strata) and thinner, steeper towards Southward (we infer–seaward). Thick and thin laminae in alternation, which are characteristic of tidal deposits, are common in the Gudchi and Gokak river beds (Fig.5b). Tidal channels and tidalite like structures are commonin the study area (Fig.5c and d) similar to modern coastal environment (Fig.5e).

Figure 5:

a) Herringbone crosses stratification in the sandstone at Deshnur (Lat 15. 8833333N, 75.3000E)

b) Thick and thin lamination with cross bedding in the sandstone of Kerur Formation ((Lat 15.8833333N, Long 75. 3000E)

c) Tidal channels (shown in arrow mark) in sandstone of KerurFormation (Roadside cutting Saundatti- Ramdurga Road (Lat 15. 88647392N; 75. 29812779E)

d) Tidalite structures in sandstone of Kerur Formation (Roadsite cutting Saundatti-Ramdurga Road Lat 15. 88647392 N; long. 75. 29812779E)

e) Tidalite developed in modern tidal channels in the Manjuguni beach near Ankola (Lat 14.61416667N; Long 74. 42166667 E)

f) Symmetrical ripples in the medium grained sandstone of Kerur Formation. Near Navilteerrth Dam Lat 15.8300000; Long 75.11666667) Hammer pointing S20° W

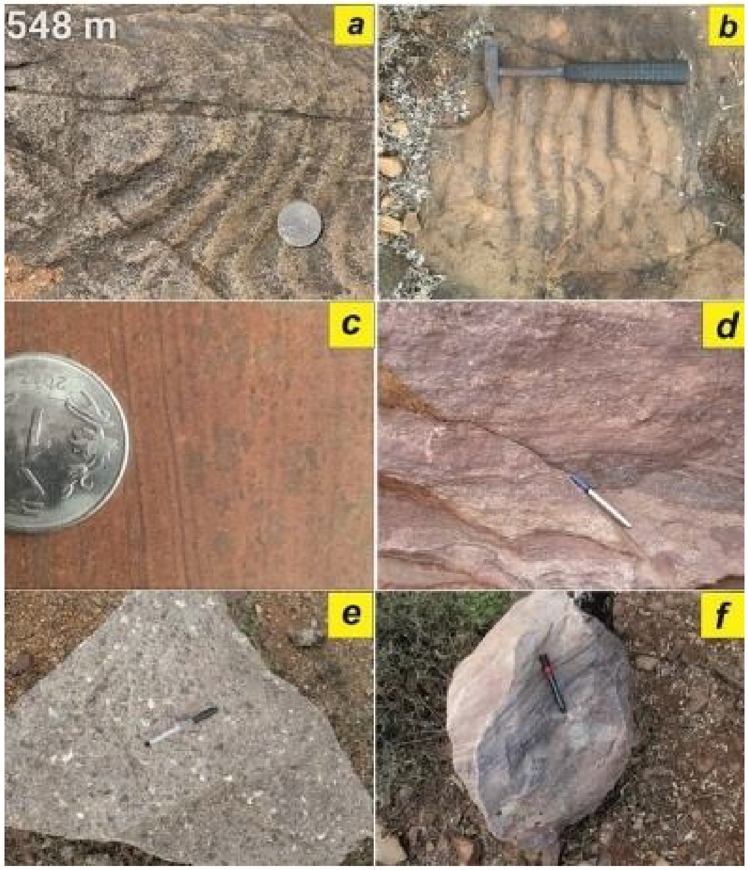

Figure 6:

a) **Tunning fork like ripples in the medium grained sandstone of Kerur Formation (Lat. 15.92250000N, Long 74.65166667E).**
b) **Assymmetrical aeolin ripple structure in the medium grained sandstone of Kerur Formation (hammer pointing S20-25^{o} E)(Lat. 15. 82993639N; Long 75. 11466705E)**
c) **Alternate dark and light layering in the sandstone near Gokak (16.17453N, Long. 74. 80086 E**
d) **Poorly developed trough cross bedding in the gritty layers (Lat 15.90500000, Long 75.300000E).**
e) **Sandstone showing moderately to well rounded vein quartz, chert and BIF in the basal unit at Deshnur.**
f) **Arenite showing alternate bands of dark and light colour (Lat 15.9225000; Long 74.6516667E)**

Nearly symmetric, low amplitude (up to 0.5 cm) and straight to sinuous crested ripples often with tuning fork-like bifurcation on bedding plane (Fig. 5f, and Fig. 6a), with orthogonal south to southeast and southwest are common. In ~30 m distance from the symmetrical ripples, and~1m above with respect to the symmetrical ripples, asymmetrical ripples display characteristics of dune environment with gentle windward side and relatively steep leeward with orthogonal NE are common in the lower part of the Kerur Formation (Fig. 6b). Medium-grained, well sorted sandstone with subrounded to rounded grains, and characteristic heavy mineral concentration with forest planes defined by alternate dark and light coloured minerals (Fig. 6c) and poorly developed trough cross laminations (Fig. 6d) are observed in Gokak and Gudchi area.

Petrography: Conglomerate show rounded to subangular pebbles ranging in diameter from a cm to 10 cm consisting mostly of vein-quartz, cherts, jasper and fragments of BIFs (Fig. 6e). Gradation from pebbly to grity is often sharp. Near the contact of the Kerur Formation, the conglomerates become more quartz rich; pebble size decreases and become well rounded. Overlying sandstone unit, especially in its upper section shows intercalation of thin shale beds.Sandstone often display dark and light layers (Fig. 6f)

Under microscope, the basal unit sandstone within the conglomerate is gritty, and exhibit typical arkosic composition with quartz and feldspar as the main framework constituents (Fig. 7a). The framework grains in the gritty sandstone show large range of size from 0.2 to 6 mm. The grains are subangular to well rounded (Fig. 7b). Detrital quartz occur both as mono and poly-crystalline grains and quartzite clasts (Fig. 7c). Both strained and unstrained quartz grains are present. Feldspars are mainly microcline with subordinate orthoclase and plagioclase. Both fresh and variably altered feldspars (kaolinized and sericitized) occur in the same sample. Some of the microcline grains show micrographic growths. Few larger fresh grains of plagioclase and microcline displaying different types of twinning and nearly euhedral are commonly observed. There is no distinct difference in grain size between quartz and feldspar grains. Secondary enlargement / overgrowth are common, partly producing euhedral rhombic or angular outlines giving false impression of original detrital grain boundary. Rock fragments in the grits include rounded hematite clasts, sericitic quartzite / schist, quartzite, and cherty BIF and rare granite clasts. The matrix consists mainly of sericite and ferruginous clay forming less than 10% of the rock. Authigenic silica and less commonly, iron oxide form the main cementing material.

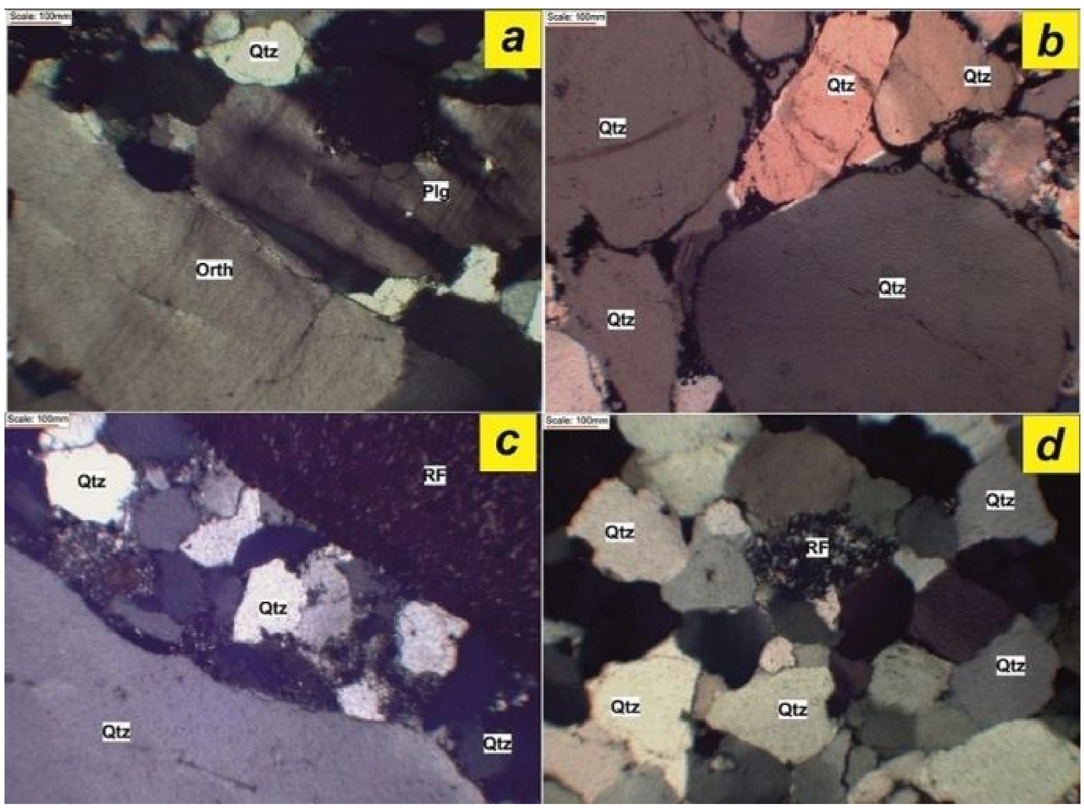

Figure 7:

a) Microphoto of the Grit showing arkosic composition consisting of moderately Rounded quartz, orthoclase and plagioclase. Note either feldspar is larger or similar in size as that of the quartz. Abbreviations: Orth-Orthoclase; Plg-Plagioclase; Qtz-Quartz

b) Microphoto of grits showing large well rounded quartz grains of varying size.

c) Microphoto showing polycrystalline quartz.

d) Microphoto of quartz arenite (Sogal area) showing moderately rounded mature arenite dominantly consisting of quartz and rock fragments are cherts.

The overlying sandstone is medium to coarse grained and more mature than the basal gritty sandstone Fig. 7d). The sandstone consists of sub angular to subrounded grains of quartz and feldspar with variable amount of sericite and clayey matrix. Some of the grains are also angular or rounded. The abundance of quartz over feldspar, apparent roundness and sorting is higher in the sandstone than that of the basal gritty sandstone. Most of the quartz grains are monocrystalline; a few are polycrystalline. Occasionally biotite grains are included within the larger quartz clasts. Rock fragments are mostly cherty. Zircon, tourmaline, monazite, form the minor detrital constituents. Some of the microcline clasts are fresh and rounded indicating their detrital nature.

Quartz is the dominant mineral range between 61 to 74% and polycrystalline quartz 4 to 13% (Table 2). The monocrystalline and polycrystalline grains have straight to strongly-undulose extinction. However, the polycrystalline quartz has curved to sutured intra-grain boundaries. The ratio monocrystalline to polycrystalline quartz grain is higher. Feldspar constitutes 7 to 15% of the detrital grains of the sand bodies. Microcline dominates with the characteristic grid twinning. Most of the feldspar grains were extensively altered. Cherty fragments constitute 2- 4 %. Siltstone, igneousand metamorphic rock fragments are rare. Matrix ranges between 6 to 9% of the detrital fraction, and more common in very fine to fine sandstone samples. Cement constitutes a significant proportion of silica, and iron oxide constitutes minor proportion of the matrix. In modal classification (after Dickinsonet al., 1983) the rocks can be classified as quartz-arenite (Fig. 8).

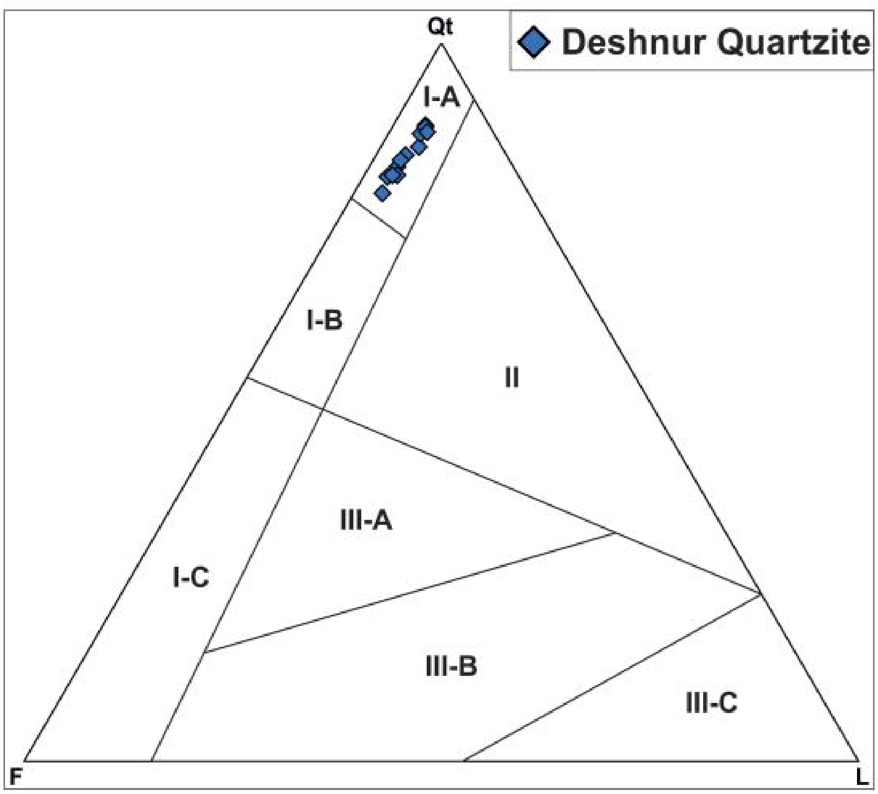

Figure 8: Q-F-L modal classification of the sandstone of the Kerur Formation, Badami Group plot for the sandstone (after Dickinson, 1983). (I-A Craton Interior, I-B Transitional Continental, I-C Basement uplift, II- Quartzose, IIIA; Dissected, III-B Transitional, III-C Undissected).

Table 2: Petrographic mode of the quartzite of the study area

In Percentage	V 26	V509 /2	DN/ 1	GOK 1A	Gok 1B	YARG 2	YAR-Gog	KR 1	KR 2	BD M	KR 3	KR 5
Qtz	73.5	69.5	70	70	71	69	74.5	70	61.5	65	4	66
Poly Q	7	9	7.4	6	7.2	11	4	7	13	13	11	7.5
Micr	4.7	6	9	9	5.5	5	5	8.2	10.5	9	9	11
Orth	1.3	1.5	2	2	1.8	1	1	2.3	1.8	2	2	2
Plag	2	1.5	2	2.5	2.5	1	1	0.5	2.1	1	2	2
R	3.5	4	3	3.5	3.5	3.5	4	3	2.5	3	3	3
mat	7	8	6	6.5	7.5	8.5	9	8.5	7.5	6	6	7.5
Oth	1	0.5	0.6	0.5	1	1	1.5	0.5	1	1	1	1

DISCUSSION

Depositional environment and Palaeogeography: Sedimentary structures are the manifestation of the process involved in their deposition, hence widely used to infer their depositional environment. Well rounded, vein quartz rich pebbles in alternate sandy-pebbly layers of arkosic grits indicate that periodic flashy floods dominated the surface hydrodynamics of transport during the deposition of the basal units. Unsorted, un-oriented pebbly beds with gradation to gritty with poorly developed current bedding structures in the lower part of the Kerur Formation indicates fluvial to a shallow-marine intertidal deposition (F1) while the sedimentary structures like current bedding, cross bedding, herringbone structure and ripple marks in the sandstone in the up section (F2) suggest beach and coastal aeolian sediments. Transition from marginal (fluvial - intertidal-beach) conglomerate to shallow marine to beach facies deposition of the arenite to the shale up section indicates deposition during overall relative sea level increase and marine transgression. The appearance of shale above the beach-aeolian association reflects the progressive deepening upwards nature of the basin.

Well rounded pebbles in alternate sandy- pebbly layers along with textural maturity indicate surface condition of absence of land plants where periodic flashy floods dominated the surface hydrodynamics of transport resulting in rounded pebbles.

A secular variation from basal conglomerate to arenite, arenite–shale intercalation to shale in the up-section is indicated by facies arrangement and sedimentary structures. Laterally persistent sets of plane laminated, medium grade sandstone (F2) suggests their deposition under high energy condition of upper flow regime (Miall, 1988). Occasional gravels within parallel laminated well-sorted sand facies (F-3) is believed to be deposited in a reflective to dissipative shoreline morphology. Horizontally, bedded and planar low-angled cross-stratified sandstones reflect the traction current (Reineck and Singh, 1986; Bridge and Best, 1988) in upper flow regime (Eriksson, 1979; Fedo and Cooper, 1990), commonly observed in transitional type beaches (Hedge et al., 2021). Predominance of medium to fine sands, with mud drapes in the arenite up-sequence suggests a gradually changing to low energy, gentle foreshore (F3), while fine grained sandstone with rhythmic shale intercalation suggest rhythmic shallowing to deepening (F4). The flaggy shale (F5) suggests shallow marine deposition.

High degree of sorting action (F2 and F3, F4) suggests a possible mainland foreshore (beach) depositional setting where action of wave and current activities of sea is dominant (Singh, 1980). Shallow water swash and backwash current in foreshore (beach environment) at a very gentle slope is responsible for such characteristic sorting in individual lamina.

Cross bedding data and ripple marks studied on few outcrops from Deshnur, Gokak areas indicate dominant palaeocurrent direction toward south to SSW and few SE implying reversal in the direction of current, commonly observed in modern coastal environment also (c.f. Hegde et al., 2009). Medium-grained, cross-bedded sandstone facies suggest its tidal facies. The sedimentary structures associated with the large-scale cross-bedding are typical (although not individually diagnostic) of tidal action (Eriksson and Simpson, 2004). Characteristic features of a tidal deposit include: widespread herringbone cross-stratification and broadly periodic rise and fall of current strength, compatible with tidal current (see De Boer et al., 1989; Mazumder, 2004). Undulatory lower boundaries associated with successive four-set bundles coupled with thick-thin alternation of the cross-stratification, clearly indicate that the facies represents a tidal channel deposit (Tirsgaard, 1993; Eriksson and Simpson, 1998, 2004, 2012; Mazumder, 2004, 2005; Longhitano et al., 2012). Very fine-grained rippled sandstone facies characterized by thinly bedded, very fine sandstone with thickness up to 4cm without any significant vertical change in grain-size with tuning fork like features are common in modern beach environments (Fig. 9a). Presence of straight to sinuous crested near-symmetric ripples with tuning fork-like bifurcation clearly indicate that this facies (F2) formed in a wave influenced, low energy tidal flat environment (Tirsgaard, 1993; Johnson and Baldwin, 1996; Eriksson et al., 1998, Longhitano et al., 2012).

Cross beddings in modern coastal environment are developed in estuarine to shallow marine and tidal channels (Fig.9b). Presence of cross and trough cross bedding in Deshnur area therefore implies such a transitional estuarine to shallow marine deposition. Beach facies association at Gokak with sub-rounded to rounded grains and characteristic heavy mineral layering (Fig.9b) directly overlies the shallow marine medium-grained, well sorted gritty sandstone. The foreset planes in the arenite are defined by alternate dark and light coloured layers. The relatively well sorted nature of this sandstone, in combination with the sub-rounded to rounded nature of the grains, indicate repeated reworking by water current or air, either in a shallow marine, or near coastal setting (Eriksson, 1979, Kocurek, 1996; Eriksson et al., 1998). The characteristic parallel heavy mineral layering is also very common in modern and ancient beach deposits (Allen, 1984; Mazumder, 2000).

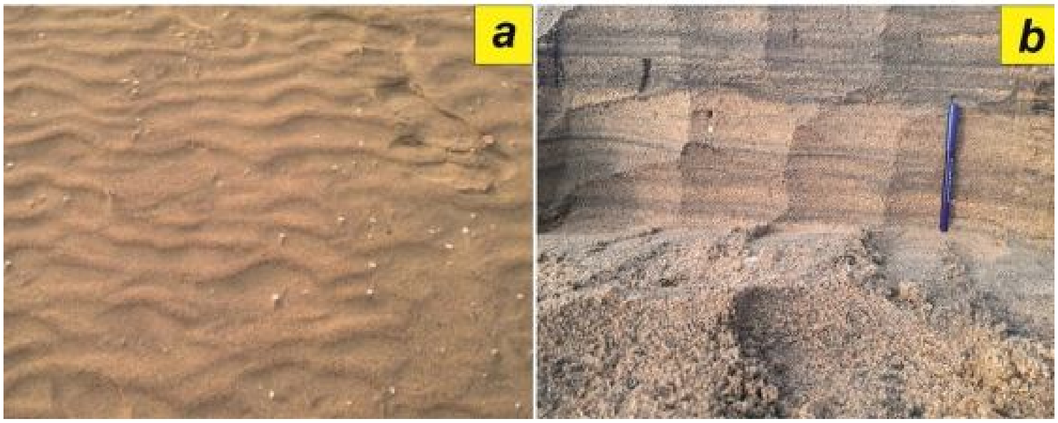

Figure 9:
a) Sinous crested, tuning fork like ripples in modern dune sands at Honnavar.
b) Alternate dark and light coloured minerals and cross bedding in the modern beach At Devbagh, Karwar

Presence of low amplitude ripples are typical of aeolian deposition (cf. Kocurek, 1991, 1996; Grotzinger et al., 2005), are also common in modern beach environment and their association with medium-grained well sorted sandstone with heavy mineral layering corroborate their generation in a coastal environment (Eriksson et al., 1998, 2013). Similar sedimentary structures are observed along the Karnataka coast. Coupled with abundant fresh and altered microclines and granitic pebbles in the conglomerate followed by beach facies environment of the arenite imply some of the feldspar and granitic fragments may have been derived from the local source, implying the coast was rocky and made up of granitic rocks.

Similar sedimentary environment of transition from marine to fluvial in the Paleoproterozoic sequence of Turee Creek Group, Western Australia were observed by Mazumder et al. (2015), and Tirsgaard, (1993) from the Lyell Land Group (Eleonore Bay Supergroup), northeast Greenland. Similar facies architecture was also observed in the basal Lower Cambrian Wood Canyon Formation of southern Marble Mountains, California (Fedo and Cooper, 1990). Hence, such studies not only helps to understand evolution of the depositional environment in the basin but also helpful for basin correlation and global understanding the Precambrian marine transgression history.

CONCLUSIONS

From the foregoing account it can be inferred that

- Sedimentary facies from fluvial –estuarine to shallow-marine beach facies to shallow marine sedimentation in the Mesoproterozoic Kerur Formation of the Badami Group, South India indicate marine transgression.
- Rhythmic intercalation of shale-sandstone sequence of the Kerur Formation suggests rhythmic deepening and shallowing of the depositional environment.
- The sandstone is texturally and mineralogical sub-mature to mature, and indicates a relatively short distance of transportation.
- Similar facies architecture partially or complete are globally widespread and helps to reconstruct global marine transgression and regression and their correlation.

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