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Facies Architecture and Sedimentary Structures in the drill cores of Uranium Bearing Sediments of Banganapalle Formation of Palnad Sub-basin, Guntur District, Andhra Pradesh

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Abstract

The Banganapalle Formation, the lowest member of the Neoproterozoic Kurnool Group of rocks, resting over the Lower Proterozoic basement granitoids, has been identified as the host rock for uranium in Koppunuru area in the western part of Palnad sub-basin. Limited outcrops and sub horizontal dip of the Banganapalle Formation constrains the study of the sedimentological aspects but the drill cores of exploratory boreholes drilled for uranium exploration in Koppunuru and adjoining areas provide the sole access to study the structural and textural attributes of the different sub-lithounits of Banganapalle Formation in this area. Sedimentary structures recorded in the five distinct comparable lithofacies of Banganapalle Formation reported earlier viz., basal conglomerate facies, quartzite-shale intercalated facies, and two quartz arenite facies separated by a grey shale facies, were analysed. This study suggests deposition of the Banganapalle Formation sediments in Palnad Sub-basin commenced in fluvial, alluvial fan setting and culminated in a marginal marine (inter- to supra-tidal flat) environment.

Keywords: *Banganapalle Formation, Kurnool Group, Palnad sub-basin, drill core, Facies, sedimentary structures.*

Introduction

The sedimentation of the Neoproterozoic Kurnool Group of rocks, is evidenced in two homotaxial sub-basins i.e. Kurnool in the west and Palnad in the northeastern part of Proterozoic intracratonic Cuddapah basin (Nagaraja Rao et al., 1987; Saha and Chakraborty, 2003; Ramakrishnan and Vaidyanadhan, 2008). The Banganapalle Formation, of Kurnool Group has been reported as potential target for unconformity-related uranium mineralization considering favourable time and space domains (Sinha et al., 1995, 1996). Intensive exploration efforts by Atomic Minerals Directorate for Exploration and Research (AMD) has brought the Palnad sub-basin into prominence after the discovery of a number of uranium occurrences in Banganapalle sediments and adjoining basement granites in the northern and western parts of the sub-basin (Jeyagopal et al., 1996; Roy et al., 2000; Singh et al., 2002; Nageswara Rao et al., 2005; Gupta et al., 2016). Sub-surface exploration activities have established a sizeable uranium deposit in Koppunuru–Chenchu Colony area where two sub-horizontal lodes of mineralization occur in the upper quartz arenite unit and one lode in the basal grit/conglomerate unit of Banganapalle Formation which at places transgresses below the unconformity in the basement granitoids (Verma et al., 2011). The Banganapalle Formation is thus, temporally and spatially regarded as a potential host for Proterozoic unconformity-related uranium mineralization (Jeyagopal et al., 2011; Ramesh Babu et al., 2012).

Recent integrated studies on facies association and architectural element analysis of Banganapalle Formation in Kurnool basin have given a detailed insight of sedimentology and have led to the identification of fourteen facies types, grouped under four different facies associations, which record Palaeoenvironmental settings ranging between mid-alluvial fan to distal fluvial plain (Barkat et al., 2020). In Palnad sub-basin, five distinct comparable lithounits of Banganapalle Formation viz., basal conglomerate unit, quartzite-shale intercalated unit, and two quartz arenite units separated by a grey shale unit, were reported earlier (Gupta et al., 2010). In the present work, examination of drill core samples and down-hole lithological examination on course of exploratory drilling for uranium in Koppunuru area has provided exclusive access to study the structural/textural attributes of different sub-lithounits of Banganapalle Formation, as outcrops are scanty and dips of the Banganapalle Formation are sub horizontal. The scope of the present work is henceforth confined to documentation of the sedimentary facies and sedimentary structures in the drill cores of different lithounits of Banganapalle Formation from Koppunuru and adjoining areas and infer their depositional environments.

Geological Setup

The Neoproterozoic Kurnool Group of rocks were deposited in two homotaxial sub-basins i.e. Kurnool in the west and Palnad in the northeastern part of Palaeo- to Meso-Proterozoic intracratonic Cuddapah basin which rest unconformably over the Archaean to Palaeoproterozoic peninsular gneisses with younger intrusive granitoids and mafic rocks (Nagaraja Rao et al., 1987; GSI, 1981, 2001, Chakraborti and Saha, 2006, Ramakrishnan and Vaidyanadhan, 2008). Cuddapah sediments predominantly consist of arenaceous and argillaceous rocks with subordinate calcareous units whereas the Kurnool sediments are dominated by calcareous rocks with minor arenaceous and argillaceous strata. In the Palnad sub-basin, spread over an aerial extent of ~ 3,400 sq km, Kurnool sediments unconformably overlie the older Cuddapah sediments in the eastern part whereas older granitoids form basement in the north and west of the basin. The Kurnool succession begins with Banganapalle Formation, followed by Narji, Auk shale, Paniam, Koilkuntla and the uppermost Nandyal Formation (Nagaraja Rao et al., 1987; Ramakrishnan and Vaidyanadhan, 2008) (Table-1). Sedimentological and geochemical aspects of the Banganapalle Formation were studied by various workers with special reference to incidence of diamond and uranium and shallow marine depositional environment with provenance comprising of granites in the north and west while older Cuddapah sediments in the south and east is envisaged (Vijayam and Reddy, 1976; Sivaji and Rao, 1989; Lakshminarayana et al., 1999; Gupta et al., 2010, 2012).

The study area falls in the westernmost part of the Palnad sub-basin. Palaeoproterozoic biotite granite exposed as an inlier, indicate basement highs (Fig. 1). Basement granites are also exposed to the south of the study area along the up-thrown block of WNW–ESE trending post Kurnool fault (Kandlagunta Fault). This fault is further offset by younger N–S trending faults. The basement granitoids are highly fractured and are profusely traversed by dolerite dykes and quartz veins. These granites are unconformably overlain by sub-horizontal beds of Palnad sediments. The overall thickness of the Palnad sediments varies from 10m to 140m and dips are gentle (3-7^0). In the area around Koppunuru –Chenchu colony, five different lithofacies of Banganapalle Formation viz., basal conglomerate (LF-1), quartzite–shale intercalated unit (LF-2), lower quartz arenite (LF-3), dark grey shale dominated, siltstone intercalated unit (LF-4) and upper quartz arenite (LF-5) were identified from the borehole cores and study of borehole lithologs (Gupta et al., 2010). The overlying Narji Formation comprises of massive limestone and calcareous shale. The limonitised, yellowish Auk shale marks a gradational contact between the calcareous Narji Formation and the arenaceous Paniam Quartzite. The Paniam Quartzites occur as discontinuous ridges to the west of Koppunuru. The gentle dip of the Banganapalle sediments conceal the exposure of its lower lithounits and the exposed surface sections comprise only the upper quartz arenite (LF-5) which is monotonously extensive and conformably overlain by the Narji Limestone. This quartz arenite facies is characterized by light grey to white, medium grained, well sorted and uniformly rounded to sub rounded quartz clasts.

Table 1: Generalised lithostratigraphic succession of Cuddapah basin (modified after Ramakrishnan and Vaidyanadhan, 2008)

Super Gr / Group/ Sub Group		Formation	Thickness (m)
Kurnool Group	Kundair Sub-Group	Paniam Quartzite	10-35
	--------- Paraconformity----------		
	Jamma-lamadgu Sub-Group	Auk (Owk) Shale	10-15
		Narji Limestone	100 -200
		Banganapalle Quartzite	10 – 170*
--------- Unconformity----------			
Cuddapah Super Group	Srisailam Quartzite		300
--------- Unconformity----------			
Archean/ Dharwars	Intrusive Granite, Gneisses / Greenstones		

*Modified after Banerjee et al., 2012.

Facies and Sedimentary structures

Scope of studying the sedimentary facies assemblages across different sections to charecterise the facies architecture and infer the depositional environment is restricted owing to sub horizontal dips and hence the absence of exposed straigraphic lithocolumn lithocolumn” or “lithocolumn of the Banganapalle Formation. Hence, the depth-wise, down-hole drill core samples of ~52 mm diameter are the exclusive window available for study of the structural and textural attributes of the sub-lithounits of Banganapalle Formation. Since, the size of the drill cores cannot accommodate the lateral continuity of the bedform features viz., planar/trough cross-beds,

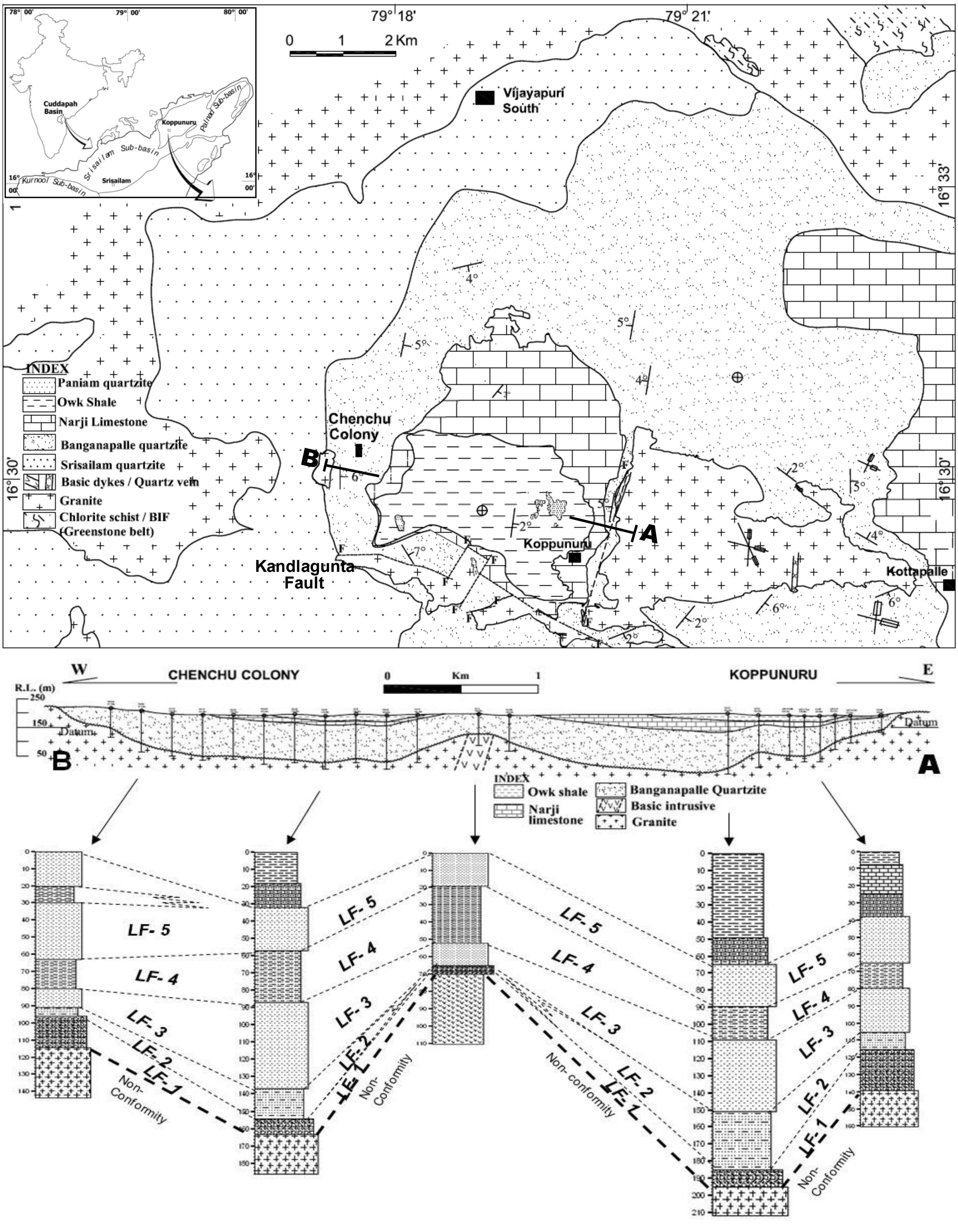

Fig.1 Geological map of the study area showing correlation of lithounits of Banganapalle Formation based on examination of of drill cores (after Gupta et al., 2010).

ripples and channel geometry, the inferences on the sedimentation patterns and depositional environments are drawn solely based on the small scale sedimentary structures preserved in the cores and textural attributes limited to megascopic and microscopic observations in borehole core samples. However, observations recorded in the study area are compared with the architectural elements and facies associations of the Banganapalle Formation reported in the Kurnool Basin (Barkat et al., 2020).

Basal conglomerate (LF-1):

The basal unit of Banganapalle Formation is represented by a <1m to 38m thick polymictic conglomerate, with unsorted grit to pebble size clasts of granite, shale, quartzite, vein quartz and dolerite (Fig. 2a). This unit is deposited over basement granite along a visibly sharp non-conformity contact (Fig. 2b). Matrix is mainly composed of sericite and chlorite with minor pyrite as interstitial matrix, intergranular fracture fillings and as segregation along pebble margins (Fig. 2c). Petromineralogical studies have confirmed the presence of carbonaceous matter and colloform pyrite in matrix at places (Latha et al., 2009, 2011; Shobhita et al., 2014). Nature of different clasts suggests their derivation from nearby granitoids traversed by quartz reef/basic dykes, and Upper Cuddapah sediments. The maximum thickness of this unit is seen along the slopes of the basement lows developed in proximity to the granite inliers (Fig. 1). The slopes of the basement highs have favourable conditions for alluvial-fan type sedimentation. Fining upward, planer, normal graded bedding observed at places along the non-conformity marks a flash flood like rapid depositional event (Fig. 2d).

This unit has been correlated to the similar conglomerate facies reported at the base of Banganapalle Formation in Kurnool Basin (Barkat et al., 2020). The comparable facies codes following the standard definitions (Miall, 1985) are- Gmm (clast-/matrix-supported, poorly sorted, ungraded, massive cobble-pebble conglomerate comprising of angular, pebble to cobble size clasts of quartzite, vein quartz and basic rock in crudely stratified sandy matrix), Gm (lenticular, clast-supported, massive conglomerate with boulder, cobbly clasts with intraclast voids filled by coarse granular sandstone) and Gsm (conglomerate-normal graded granular sandstone couplet).

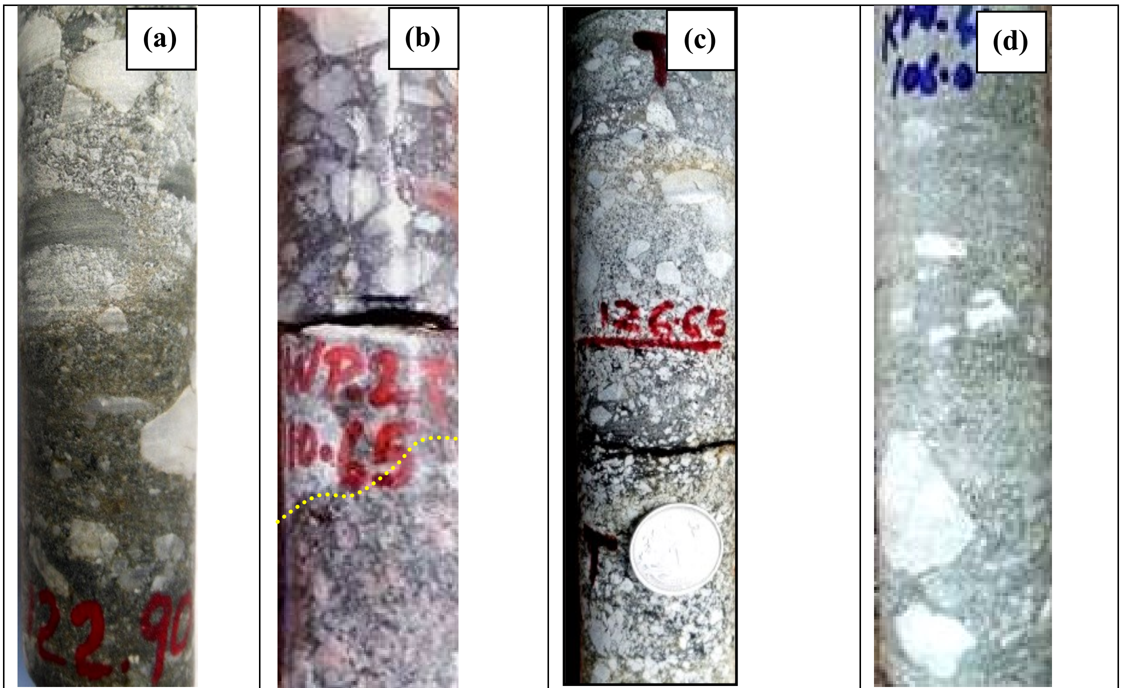

Fig. 2. Lithounit -1 (Basal Conglomerate):
a) Polymictic nature with subrounded to sub angular mixed clasts of shale, quartzite and vein quartz (KPU-438: 122.90m)
b) Sharp non-conformity contact between basement granite and LF-1 (DWP/21: 110.65m)
c) Unsorted clasts in matrix dominated by sericite and chlorite matrix (KPU-422: 126.65m)
d) Fining upward, planer, graded bedding (KPU-444:106.00m) in LF-1

Quartzite-shale intercalation (LF-2)

This lithounit was deposited immediately above the basal conglomerate unit in the deeper parts of the basin. It is apparent from the borehole lithologs that quartzite–shale intercalated sequence is not developed in those parts where the overall thickness of the Banganapalle sediment column is below 25–30m. LF–2 is marked by rhythmic repetition of arenaceous (predominantly orthoquartzites) and argillaceous layers (grey to dark grey shales). Grey shale occurs as planner laminae with varying thickness from 2-3mm to 2cm and occasionally shows discontinuous/lenticular nature at places (Fig. 3a). Small scale cross stratification in the form of planar cross bedding is exhibited at places and the thickness of cross beds varies from 4 to 10cm (Fig. 3b). However, information on direction of current can't be derived since the directional drilling is not being carried out in this area to generate oriented borehole core. Presence of carbonaceous matter and pyrite specks/disseminations/lumps are common in this unit (Fig. 3c&d). Because of competency contrast between the arenaceous and argillaceous layers and occasional rapid sedimentation, soft-sedimentary deformation structures like convolute lamination, load and slump fault/fold structures are more prominent in LF–2 (Fig. 4a-d).

Convolute structures occur in the form of intrastratal crumpling and contortions of laminae (Fig. 4a). Folded laminae in this structure form upright cusps with broad U-shaped troughs and sharp crests. At places these contorted laminae form discrete lobes giving rise to load convolutions. The generally agreed mechanism for formation of convolute beddings is differential liquefaction and rapid internal readjustment of sediments as is evident from the confinement of convolutions within a single bed (Lowe, 1976; Nichols, 2009). Load structures occur as slight bulges and knobby bodies, a common feature observed in channels of muddy intertidal flats where arenaceous layers are deposited over argillaceous layers (Fig. 4b). At places, isolated lenticular arenaceous loads are also observed. These arenaceous load structures show contorted lamination. The contortion of lamination is more in the central part as compared to the periphery of the load structure. Such deformations generally occur before the deposition of overlying strata as evidenced by the presence of planar, non-contorted overlying beds.

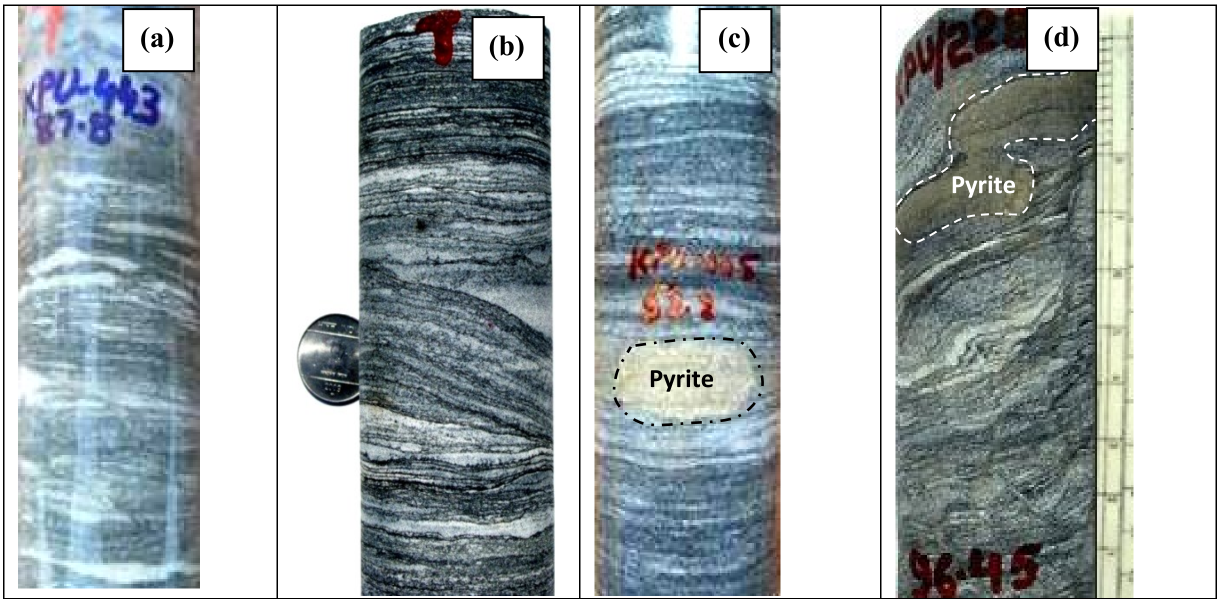

Fig. 3. Lithounit-2 (Quartzite-shale intercalation):
a) Lenticular and wavy bedding / laminae in LF-2 (KPU-443: 87.80m)
b) Cross bedding in LF-2 indicating change in current direction and intensity (KPU-310: 122.90m)
c) Rhythmic sequence of quartzite-shale planer laminae with sub-rounded pyrite lump (KPU-445: 92.20m)
d) Deformed wavy laminations with pyrite lump in LF-2 (KPU-228: 96.45m)

Small scale deformation structures, attributed to slumping are most commonly observed within the intercalated units. Such deformation zones are usually bounded by undisturbed beds and observed as offset of intercalated laminae along curvilinear fault planes (Fig. 4c), minor slippage of localized intercalated beddings along the inclined to sub-vertical planes (Fig. 4d) and hinge section of slump fold (Fig. 4e). Such rhythmic sand – shale sequence with synsedimentary deformation structures in this unit and its stratigraphic disposition over the basal conglomerate indicates regular changes in generation and transport of sediments and a transgressive change from alluvial fan to inter-tidal flat environmental conditions of deposition.

Lower and Upper quartz arenite (LF-3 & LF-5)

The lower quartz arenite (LF-3) and upper quartz arenite (LF-5) lithounit are mineralogically and texturally mature and similar in nature. They are light grey in colour, medium to fine grained and saccharoidal in nature. Occasional grey shale lenses are also observed in these units (Fig. 5a). Previous works on petromineralogical characterization have shown that these arenites are composed of moderate to well sorted, sub-rounded framework clasts (~90% of the rock by volume), which is dominated by quartz (~97%) with minor glauconite, chert and traces of carbonaceous matter. The quartz is mainly monocrystalline in nature with a few grains of polycrystalline quartz. The well indurated framework clasts are bounded by silica cement and matrix (Gupta et al., 2010).

The thickness of LF-5 unit varies from 10m to 26.50m and is recorded in all boreholes while LF–3 attains maximum thickness up to 45m and overly the quartzite–shale intercalated sequence in the deeper parts. LF–5 is also exposed on surface and exhibit blanket type nature due to near horizontal beds of vast expense. These arenites also exhibit various alteration features such as ferrugination, silicification, chloritization and kaolinization leading to formation of clay minerals viz., illite and kaolinite. Cross stratification observed at places suggests change in current direction and intensity (Fig. 5b). Numerous isolated mud streaks/lenses with streaks of pyrite are seen forming simple flaser beddings in these sand dominated units. The presence of flaser bedding also indicates the depositional environment more favourable

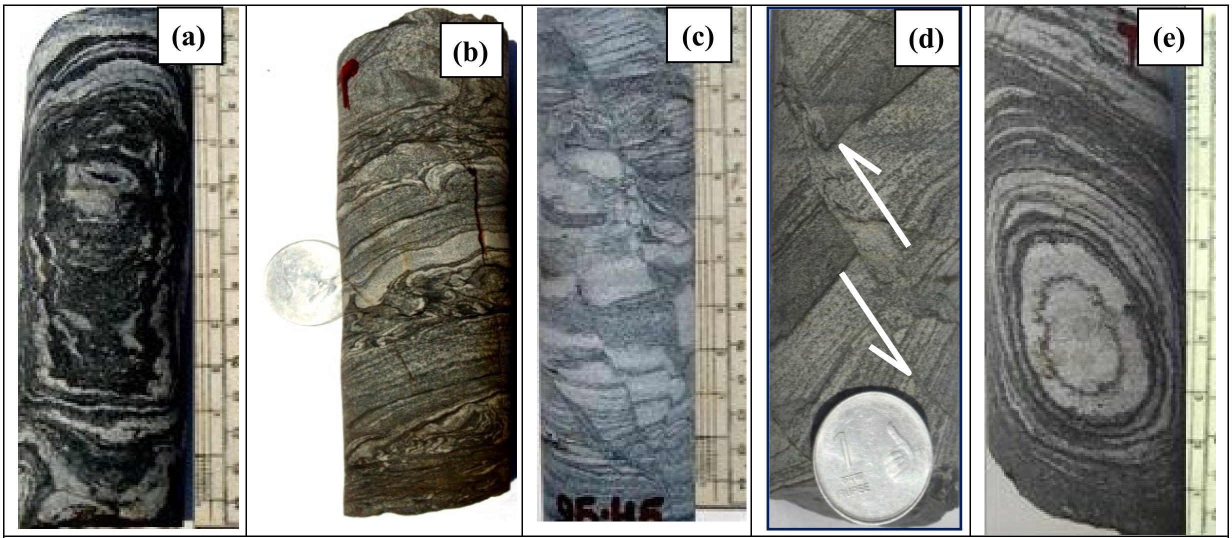

Fig. 4. Soft-sedimentary deformational structures in Lithounit -2:
a) Convolute Lamination with broad U-shaped troughs and sharp crests (KPU-227: 158.30m)
b) Lode Convolution structure; contorted laminae forms discrete lobes (KPU-271: 132.20m)
c) Offset of laminae along sub-parallel vertical slip planes in LF-2 (KPU-302: 95.45m)
d) Offset of laminae along oblique slip planes in LF-2 (KPU-310: 117.20m)
e) Hinge section of slump fold (KPU-232: 122.10m)

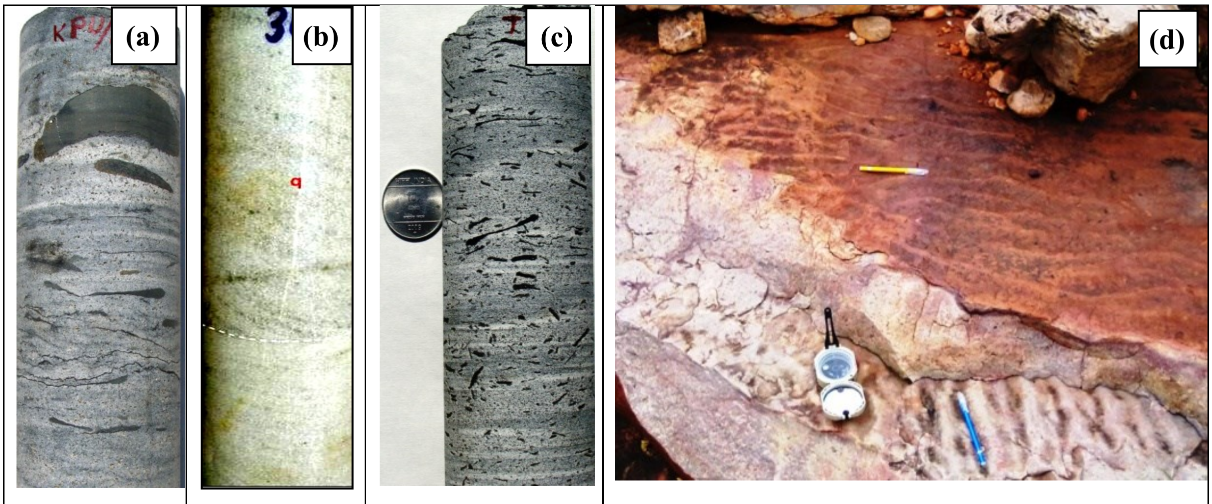

Fig. 5. Lower and upper quartz arenite, Lithounits -3 and 5:
a) Isolated mud lenses in LF-5 (KPU-229: 64.30m)
b) Cross stratification in LF-5 (DWI-28: 31.75m)
c) Flaser bedding with numerous mud streaks in arenaceous LF-3 (KPU-226: 127.20m)
d) Outcrop showing bi-directional, symmetrical ripples developed on the top of LF-5 (Dwarakapuri-Kottapalle area, southwest of Koppunuru).

environment more favourable for preservation of sands as compared to mud (Fig. 5c). Further, bi-directional symmetrical ripples recorded in outcrops of upper arenite unit suggest two different paleocurrent directions and points to dual provenance for the Banganapalle sediments. Geochemical studies on major element distribution patterns, alteration indices and discriminant function plots of these the different lithounits of Banganapalle Formation in the same area also suggest that Banganapalle Formation is mainly derived from two different sources i.e., basement granitoids and quartzose Cuddapah sediments in a passive margin setup (Gupta et al., 2012).

Shale-siltstone intercalation (LF-4)

This dominantly argillaceous unit (dark grey shale–siltstone intercalation) is sandwiched between the upper and lower arenite units (LF- 3 and 5). The thickness of LF–4 ranges from 3m to 46m, and show thinning of the beds close to the basement granite inliers. Megascopically, this unit is characterized by higher argillaceous component as compared to LF–2. Shales are dark grey in colour, sub horizontally laminated and show fine intercalations of siltstone (Fig. 6). This unit is marked by the abundance of sulphides (mainly pyrite) occurring as fine disseminations, big nodules, thin stringers and veinlets. Sulphur isotope studies have indicated biogenic origin of these pyrites (Jeyagopal et al., 2008). Presence of glauconite with trashes of carbonaceous matter indicate mildly alkaline and reducing environment of deposition. Planer laminations, lenticular beddings and sand lenses embedded in argillaceous layers showing synsedimentary deformation structures are quite apparent in LF–4.

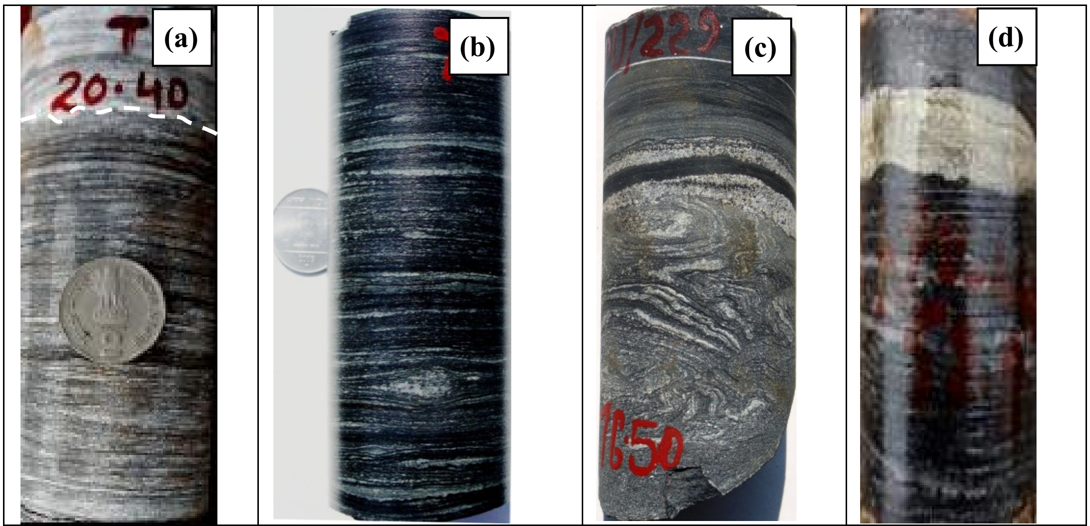

Fig. 6. Lithounit -4:

a) Planer laminated shale along gradational contact of LF- 4 and 5 (KPU-420: 20.40m)
b) Planer laminations and lenticular beddings in the form of sand lenses in argillaceous layers (KPU-229: 38.30m)
c) Syn-sedimentary deformations in LF-4 (KPU-229: 46.50m)
d) Dark grey shale with pyrite along bedding plane (KPU-444c: 52.10m)

Discussion

The basal conglomerate unit marks the non-conformity contact between the basement granite and the overlying Banganapalle Formation. Presence of carbonaceous matter and colloform pyrite are indicators of a reducing environment. The unsorted nature of the clasts and intragranular fractures also indicates high degree of porosity and permeability in this unit. The ungraded, angular, pebble to cobble size clasts of quartzite, vein quartz and basic rock in crudely stratified sandy matrix which points to their derivation from nearby granitoids traversed by quartz reef/basic dykes, and possibly, upper Cuddapah sediments. This is indicative of sub aerial rapidly freezed non-cohesive hyper-concentrated flow (Sohn et al., 1999; Saula et al., 2002). The gradual fining upward, conglomerate-granular sandstone, normal graded bedding suggests a transformed cohesive flow. Overall, this facies marks a flash flood like rapid depositional event in an alluvial-fan type setting. The conglomerate is better preserved at places which were apex portions of fan (along the slopes) and could not be traced with similar thickness everywhere, as the thickness tapered as a conical wedge at the toe portions of the fan.

The overlying quartzite-shale intercalatory unit is marked by synsedimentary deformation structures like convolute beddings, load structures, lenticular and wavy beddings and slump structures. The rhythmic repetition of arenaceous and argillaceous layers indicates regular changes in generation and transport of sediments in inter-tidal flat environment where sand layers get deposited in periods of flood and ebb current activity while the argillaceous/mud layers represent quiescent sedimentation phase. The planar cross beds are indicative of change in current direction and their intensity and suggest shallow water depositional environment. The disposition of this lithounit over the basal conglomerate indicate regular changes in generation and transport of the sediments and a transgressive change from alluvial fan to inter-tidal flat depositional environment.

The soft sedimentary deformation structures common in LF- 4 and LF-2 indicate submergence of the basin contemporaneous to the sedimentation. This is evidenced by the presence of deformed zones sandwiched between undisturbed beds. Convolute laminations commonly develop due to the deposition of sediments on sloping surfaces (Leeder, 1999; Collinson et al., 2006). Differential liquefaction and rapid internal readjustment of sediments are the accepted mechanism for formation of convolute beddings. In this study, it is evident from the confinement of convolutions within a single bed which indicates deposition of sediments under inter-tidal flats environment where sediments get compacted due to the expulsion of water during sub-aerial exposure at low tides. The development of load structures is attributed to the differential deposition and sinking of sandy bodies in underlying muddy layer in the channels of muddy inter-tidal flats. Development of the slump structures observed in the drill core are attributed to the mechanism of down slope movement of sediments under gravity due to elevated pore fluid pressure (Tucker, 2003; Collinson et al., 2006). Slump folds indicate compressive regime in the downslope position and the slippage along folded limbs are generally caused by synsedimentary basinal tectonics. Slump structures observed in the study area indicate their deposition under inter-tidal flat tectono-sedimentary environment, particularly restricted to the over steepened segments. Formation of lenticular beddings in LF-4 is attributed to the fluctuating flows i.e., calm periods with a few short and strong currents allow incomplete sand ripple formation, which in turn is completely covered by argillaceous material. These are generally indicative of low energy depositional environments suitable for preservation of mud vis-à-vis low supply of the sand in the system. In contrast, flaser beddings in the arenaceous lithounits (LF-3&5) indicate strong current environment where both sand and mud were subjected alternatively to the periods of high current activity followed by intermittent short periods of quiescence.

High degree of mineralogical and textural maturity of arenites in LF-3 and LF-5 signify high current activity and deposition under high energy settings in shallow marine conditions. In contrast, the argillaceous facies LF-4 and LF-2 indicate deposition during standstill phase. Bi-directional symmetrical ripples in outcrops of upper arenite unit indicate that the Banganapalle sediments were derived from the basement granitoids exposed to the north and upper Cuddapah sediments to its west.

Banganapalle Formation in western part of Palnad sub-basin has shown immense potential of uranium mineralisation (130-5,500ppm U_3O_8; Jeyagopal et al., 1996) and intensive exploratory drilling by AMD has resulted in delineation of substantial uranium deposit in Koppunuru-Chenchu colony area, Guntur district, Andhra Pradesh. In this sector, comparable uranium mineralization has been intercepted in the upper quartz arenite facies and in the basal conglomerate facies occasionally transgressing to basement granitoids (Verma et al., 2011). Hydrothermally induced, fracture-controlled and epigenetic uranium mineralisation is postulated for this uranium mineralisation which was accentuated due to the presence of porous and permeable medium viz., quartz arenite and conglomerate facies which allowed free flow of mineralised solutions and the presence of suitable reductants like sulphides and carbonaceous matter favoured the precipitation and fixation of uranium mostly along the fractures, fine veins, intergranular cavities, intragranular fractures (Gupta et al., 2010, 2012; Jeyagopal et al., 2011). Various alteration features such as ferrugination, silicification, chloritization and kaolinisation substantiate hydrothermal activity in the system (Thomas et al., 2014).

Conclusions

Based on observations of the disposition of the five distinct comparable facies of Banganapalle Formation, their lateral and depth continuity, sedimentary structures and textural attributes, it can be concluded that deposition of these sediments commenced in fluvial, alluvial fan setting and culminated in a marginal marine (inter to supra-tidal flat) environment. The transitional relationship of upper quartz arenite of Banganapalle Formation and overlying calcareous Narji Formation suggests shift from intertidal to supratidal regime where the detrital material became scarce and chemical milieu became suitable for carbonate precipitates. The porous and permeable lithounits viz., quartz arenite and conglomerate with available reductants in the form of sulphides and carbonaceous matter are the best suited loci for uranium mineralization.

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