Carpathian Journal of Earth and Environmental Sciences, February 2017, Vol. 12, No. 1, p. 269 - 282

# DEPOSITIONAL SYSTEM OF AN OPEN COAST TIDALFLAT - AN EXAMPLE FROM PALEOPROTEROZOIC VEMPALLE FORMATION, CUDDAPAH BASIN, INDIA

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**Abstract:** The sedimentological study in the Paleoproterozoic Vempalle Formation of the Cuddapah Basin, in and around Gandi, (14°20'2.51"N, 78°28'52.96"E), Vempalle town (14°21'27.74"N, 78°28'16.46"E; 14°21'28.86"N, 78°27'46.63"E) and Nandemandalam village (14°24'33.84"N, 78°31'39.22"E) reveals three major facies associations viz. supratidal facies association consisting of cross-bedded gritty quartzite facies, heterolithic facies and laminate facies; intertidal facies association consisting of red shale, lime-mudstone, ooliticgrainstone, and domalstromatolite facies whereas deeper intertidal environments are locally dominated by columnar stromatolite, massive dolomite and intraformational carbonate conglomerate and subtidal facies association consisting of conical stromatolite facies. Facies association and associated syn-sedimentary deformation structures, stromatolite morphology and microfabric clearly demonstrate that the Vempalle Formation in the study area was deposited in an open coast tidalflat having mixed influence of waves and tides, the storm dominated depositional processes marked by accretionary deposition of HCS and the scarce influence of tides in depositing sand.

**Keywords:** Facies, Tidalflat, Palaeoproterozoic, Vempalle, Stromatolites

## 1. INTRODUCTION

The Paleoproterozoic Vempalle Formation, an essentially carbonate succession overlying the basal siliciclastic Gulcheru Formation in the southwestern part of Cuddapah Basin, Dharwarcraton, Southern India records the preservation of rocks in an extensional set up during development of a low gradient ramp where supratidal to deep subtidal environment prevails (Chakrabarti et al., 2014). This paper is a detailed description of the carbonate rocks of the Vempalle Formation in and around Gandi (14°20'2.51"N, 78°28'52.96"E), Vempalle (14°21'27.74"N, 78°28'16.46"E; 14°21'28.86"N, 78°27'46.63"E) and Nandemandalam(14°24'33.84"N, 78°31'39.22"E) area. Our purposesareto outline and interpret spatial and temporal distribution of facies in order to understand the development of a carbonate platform in a tectonically active paleoproterozoic setting and also its relationship to other Proterozoic platforms.

## 2. GEOLOGICAL SETTING

### 2.1. Geologic setting of the Cuddapah Basin

The distinctly crescent-shaped Cuddapah Basin of Southern India preserves nearly 12 km of sedimentary and volcanic strata that are assigned to the Cuddapah Supergroup and the unconformably overlying Kurnool Group (Nagaraja Rao et al., 1987; Fig. 1). These strata rest unconformable on basement rocks of the Dharwarcraton.

The origin of the Cuddapah Basin is uncertain, with basin development generally believed to reflect a series of thermal upwarping, rifting, and crustal thinning events (Nagaraja Rao et al., 1987; Mohanty, 2011; Saha & Tripathy, 2012a,b), although a foreland basin scenario has also been suggested (Singh & Mishra, 2002).

A combination of deep seismic profiling (Kaila et al., 1987), seismic tomography (Gupta et al., 2003), and gravity analysis (Singh & Mishra, 2002) indicates that the majority of Cuddapah strata in the western basin overlies thick, continental

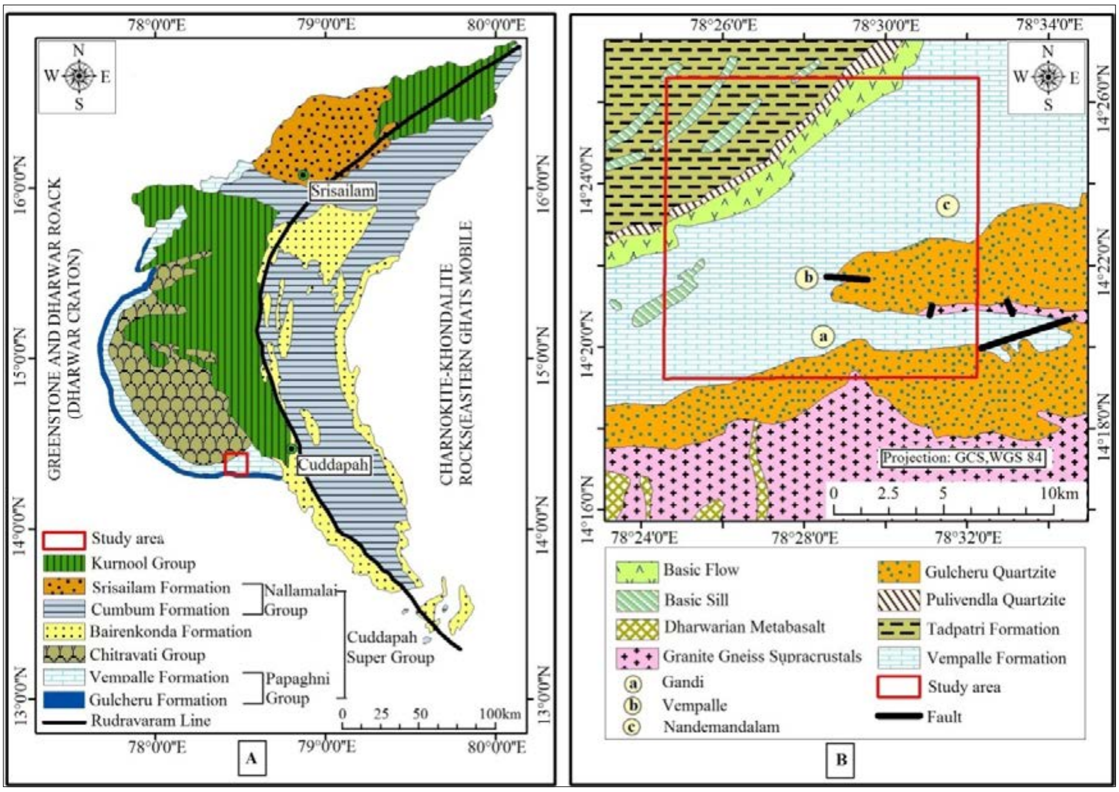


Figure 1. Geological map of the study area. (A) Generalized geological map of the Cuddapah basin, India (after GSI, 1981). (B) Detail of the southernmost Papaghni sub-basin showing location of the measured sections investigated in this study (modified after Zachariah et al., 1999).

crust that contains a number of steep basement faults. Strata in the western basin (Papaghni, Srisailam, and Kurnool sub-basins) remain unmetamorphosed and relatively undeformed (Meijerink et al., 1984). The original structure in the eastern part of the basin (Nallamalai and Palnad sub-basins) is obscured by deformation and metamorphism within the Nallamalai Fold Belt (Saha & Chakraborty, 2003), which is associated with the uplift of lower crustal rocks during development of the Cambrian Eastern Ghats Mobile Belt (Biswal et al., 2007).

### 2.2. Regional stratigraphy of the Cuddapah Basin

Strata comprise the Cuddapah Supergroup and the unconformably overlying Kurnool Group. The Cuddapah Supergroup consists, in turn, of the Papaghni, Chitravati and Nallamalai groups, each separated by regional unconformities (Table 1). Each of these groups is composed, broadly, of a fining-upward succession from quartzite at the base to shale at the top, and is interpreted to represent a shallow-marine shelf that underwent periodic transgressive and regressive events (Chakrabarti & Shome, 2007, 2010, 2011; Chakrabarti et al., 2009; Saha & Tripathy, 2012a,b; Saha et al., 2013) associated with a combination of tectonic reorganization and eustatic sea level changes (Patranabis-Deb et al., 2012).

Table 1.Stratigraphy of the Cuddapah basin (Saha & Tripathy 2012a and 2012b).

| Super group | Group | Formation | Thickness (m) |
|---|---|---|---|
| | Kurnool Group | Nandyal Shale | 50–100 |
| | | Koilkuntala Limestone | 15–50 |
| | | Paniam Quartzite | 10–35 |
| | | Auk Shale | 10–35 |
| | | Narji Limestone | 100–200 |
| | | Banganapalle Quartzite | 10–57 |
| | | Unconfomity | |
| CuddapahSupergroup | | Srisailam Quartzite | >620 |
| | Nallamalai Group | Cumbum Formation | >2000 |
| | | Bairenkonda Quartzite | 1500 |
| | | Unconfomity | |
| | Chitravati Group | Gandikota Quartzite | 1200 |
| | | Tadpatri Formation | 4600 |
| | | Pulivendla Quartzite | 1–75 |
| | | Unconfomity | |
| | Papaghni Group | Vempalle Formation | 1500 |
| | | Gulcheru Quartzite | 28–250 |

Whereas the relatively undeformed Papaghni and Chitravati groups, exposed in the western part of the basin, were deposited during successive thermal upwarping and rifting events, the highly-deformed Nallamalai Group exposed in the eastern part of the basin likely represents development of active convergence along the eastern margin of the basin (Mishra, 2011). The Kurnool Group likely records resumption of an extensional regime via reactivation of basement normal faults in the western part. Within this context, the Vempalle Formation of the lowermost Papaghni Group, reaching 1500 m in thickness, represents the only regional carbonate deposition within the Cuddapah Supergroup. The Vempalle Formation conformably overlies basal siliciclastic strata of the Gulcheru Formation and is associated with a number of basic volcanic flows in its upper reaches (Murthy et al., 1987). The Vempalle Formation is then overlain with possible unconformity by coarse-grained siliciclastic strata of the basal Chitarvati Group. The Vempalle Formation contains stromatolitic dolomite and dolomitic shale, with subordinate sandstone, and was deposited on a carbonate ramp (Dhana Raju et al., 1993).

### 2.3. Geochronological constraints on stratigraphic development

Ages reported from Vempalle Formation, are from mineralized and non-mineralized dolomite, as c. 1900-2000 Ma by Pb-Pb method (Rai et al.,2015), 1841 ± 71 Ma by K-Ar method(Murthy et al., 1987) and 1756 ± 29 Ma by Pb-Pb method (Zachariah et al., 1999). More recently, the age of the Pulivendla sills has been reanalyzed by $^{40}Ar$–$^{39}Ar$ laser fusion techniques on phlogopite, providing an improved age of 1899 ± 20 Ma (Anand et al., 2003). This older age is in good agreement with a recent high-precision U–Pb (baddeleyite) age of 1885 ± 4 Ma obtained on a similar mafic sill in the Chitarvati Group (French et al., 2008). These ages constrain the Vempalle Formation to have been deposited between approximately 2.1 Ga and 1.9 Ga or within the late Paleoproterozoic (Orosirian period).

## 3. STRATIGRAPHY AND FACIES OF VEMPALLE FORMATION

### 3.1. Study area

The Vempalle Formation is well exposed in the southwestern sector of the Cuddapah Basin. Three sections were chosen for sedimentological investigation: the first one exposed on the northern and southern banks of the Papaghni river, beside the Rayachoti–Vempalle Highway, 5 km from the town of Vempalle, near Gandi temple (14°20'2.51"N, 78°28'52.96"E), in and around Kummarampalle and Chintalamadugupalle village; one exposed beside Vempalle town, on northern and southern banks of the river, near V. Swamy temple and around Jr. Vasavi College (14°21'27.74"N, 78°28'16.46"E; 14°21'28.86"N, 78°27'46.63"E) and a third exposed beside Vempalle–Kadapa Highway, 8 km from the town of Vempalle, in and around Nandemandalam village (14°24'33.84"N, 78°31'39.22"E). A representative litholog has been constructed based on sedimentological and stratigraphic information gathered from these sections (Fig. 2).

### 3.2. Facies associations within the Vempalle Formation

In the course of sedimentological studies on the Vempalle Formation in the study areas between Gandi, Vempalle and Nandemandalam, three stratigraphic sections are measured and described together with the sedimentary facies analysis, resulting in the recognition of three depositional facies associations. In order of increasing water depth they are: tidal flat, intertidal and subtidal environments. Depositional facies are composed of 11 lithofacies representing environments that are defined on the basis of grain types, sedimentary structures and vertical facies relationships. Faciesinclude (1) Cross bedded gritty quartzite facies, (2) Heterolithicfacies, (3) Red shale facies, (4) Limemudstone/ Dolomudstone facies, (5) Massive dolomite facies, (6) Laminite facies, (7) Intraformational conglomerate facies, (8) Columnar stromatolite facies, (9) Domalstromatolite facies, (10) Conical stromatolite facies, (11) Ooliticgrainstone facies (Table 2, Fig. 3).

The facies preserved in the Vempalle Formation are interpreted as corresponding to a low-gradient, carbonate ramp that inherited its depositional gradient from the shallow antecedent topography of the Gulcherusiliciclastic shelf (Chakrabarti et al., 2014).

## 4. DISCUSSIONS

The facies association represents a tidal-flat depositional environment prevailing during Vempalle time. The depositional processes here are divided between tide and wave action. Tides are responsible for the deposition of most of the clastic and non-clastic mud in slack water conditions, although this fact does not exclude the possibility that a portion of mudstone could have been deposited after the storms in a calm water condition.

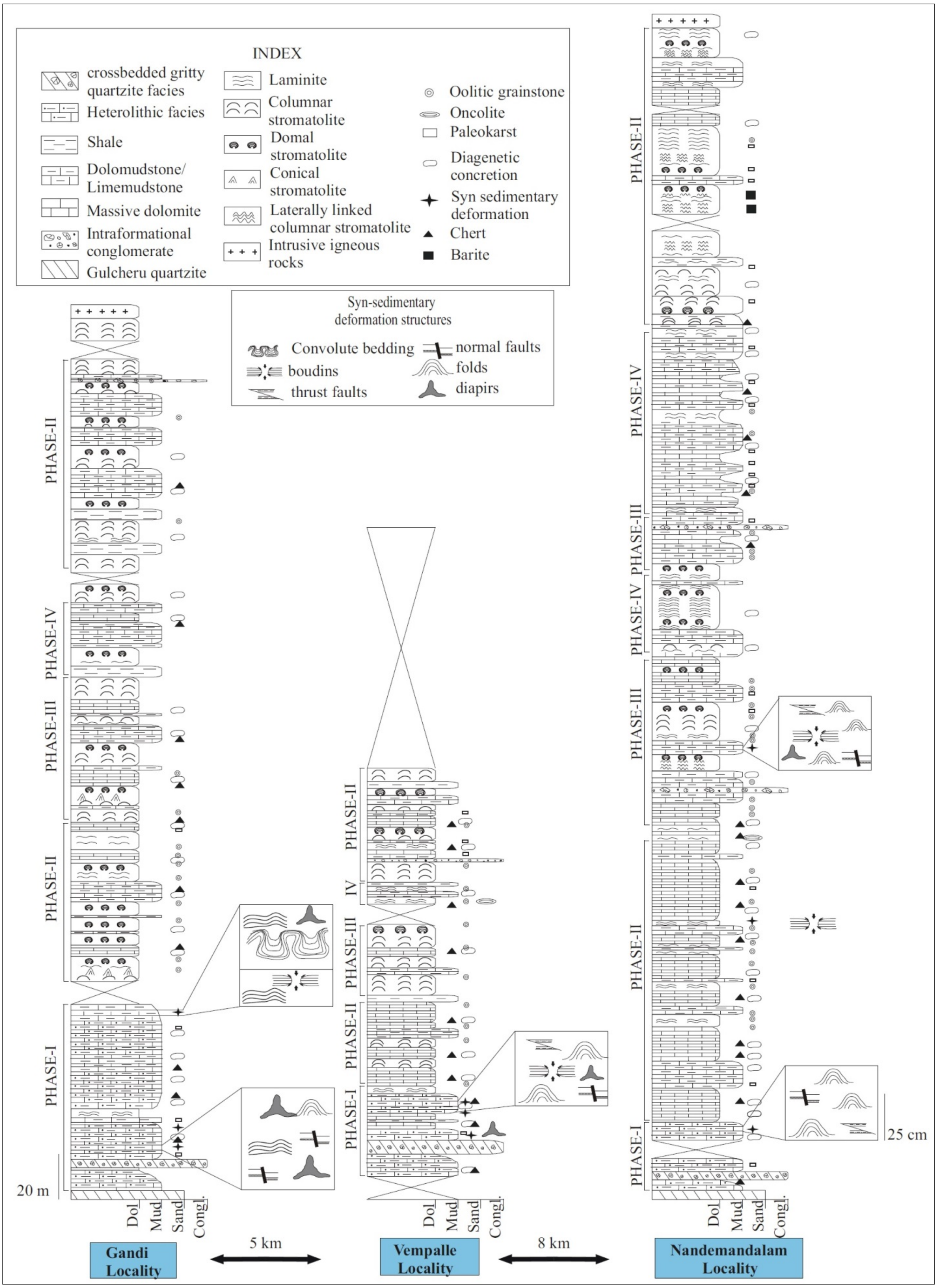


Figure 2. Lithologs showing measured stratigraphic sections of the Vempalle Formation.

Table 2. Summarized table of the several facies types recognized in the Vempalle Formation, Cuddapah basin.

| Facies association | Constituent facies | Lateral trend | Sedimentary features | Interpretation |
|---|---|---|---|---|
| 1. Supratidal | Cross bedded gritty quartzite facies | Laterally continuous | White to greyish-brown, trough cross bedding (Photo 3) with paleo flow to the SSE to SE and SW, thin beds (2-15 cm) of shale/mudstone with mudcracks (Fig. 3)are occasionally found interbedded with quartzite/sandstone, also marked by poorly sorted, matrix supported conglomeratic quartzite beds (Photo. 2). | Generated by small sand dunes, wave-influenced; pebble sized conglomerate represents probably a transgressive lag deposit, which accumulated with a rising base level during the landward migration of coastline (cf. Krapež et al., 2015; Basilici et al., 2012). |
| | Heterolithicfacies | Laterally continuous | Interbedding of terrigenous siltstone, cherty mudstone, calc-arenite and dolomitic siltstone (Photo 4) contains SSDS (illustrated in Table 3), cross-stratification,syneresis cracks, paleokarstic surfaces (Photo 5) and karstic breccia (Photo 6). | Storm dominated shallow marine environment, periodically exposed(Aitken, 1981; Turner et al., 1997), SSDS produced due to earthquake tremor, an episodic increase of carbonate deposition followed by decrease in siliciclastic flux caused by climatic changes may have been responsible for developing these siltstone-carbonate alternations (cf., Donovan, 1980; Trewin, 1986). |
| | Laminitefacies | Laterally continuous | Thinly (mm thick) interbedded units, wrinkled, rolled,ptygmatic folded and faulted(Photo 11)laminae indicate compaction effect,sometimes exhibit typical mushroom shaped (Photo 12) and cauliflower or rossete type (Photo 13), sometimes form laterally linked, low-relief (2–10 cm) stromatolites associated with ministromatolites (Photo 14).Large oncolite coated grains associated with laminated dolomite (Photo 15). | Subjected to high energy wave agents, deformed laminites experienced slight deformation from either tectonic activity/seismic activity or loading (Elmore 1983). Presence of oncoliticcoated grains within this facies indicate that this facies subjected to high energy wave agents. Laminae (cm scale) to thin laminae (mm scale) represents landward thinning of storm and tidal generated sediment sheets and is the result of seaward progradation of supratidal flats over intertidal flats (Hardie & Shinn, 1996). |
| 2. Intertidal | Red shale facies | Laterally continuous | Red coloured, dm to m thick shale, mudcracks are common which curls upward, and raindrop imprints (0.5-2 cm in diameter)found (Photo 7). | Shallow, quiet water environment, mudcracks indicate exposure in arid supratidalsabkha settings (Shinn, 1983). |
| | Limemudstone facies | Laterally continuous | Massive to laminated, 20 cm to 1 m thick beds, syneresis cracks (Photo 8) present may be straight, curved, sinusoidal, sigmoidal or jagged, diagenetic concretions present commonly. | Quiet, poorly oxygenated waters below storm wave base. These are mainly formed due to subaqueous shrinkage whereby salinity changes caused deflocculation of clay (Pratt, 1998). |
| | Ooliticgrainstonefacies | Laterally continuous | Fine- to coarse-grained, well-sorted, tabular or lensoidaloolitic grainstone beds, wavy microbial laminae and small-scale cross-lamination present (Photo 24). Beds are 5- 60 cm thick. Individual ooid range from 0.01 to 0.1 mm in diameter. | Ooids are deposited in shoreface settings of ramps (Flügel, 2004). This microfacies suggests high energy environments such as oolitic shoals and beaches (Wilson, 1975; Flügel, 2004). |
| | Massive dolomite facies | Laterally continuous | Light to tan grey in colour, at few places dark grey in colour, diagenetic concretions (Photo 9) present commonly, interbedded with dolomudstone, common reddish brown stylolites (Photo 10). | Restricted, shallow subtidal environment (LaMaskin & Elrick et al., 1997). |

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| | | | | |
|---|---|---|---|---|
| | Intraformatio-nal conglomerate facies | Laterally continuous | Matrix supported, very poorly sorted and composed of rounded to sub-rounded, tabular clasts, ranging from 0.5 mm to 4 mm diameter sized clasts within a dolomicrite matrix (Photo 16, 17); clast composed of dolomite, mudstone. | Debris flow (Dasgupta et al., 2005), high energy storm events (Chakrabarti et al., 2014). |
| | Columnar stromatolitefacies | Laterally continuous | Columns generally are10 - 60 cm long and 3-10 cm wide and may be solitary (Photo 18) or branching, at places show inclination (5° - 8°) (Photo 19). Lamina is steeply convex to parabolic, having moderate to high relief, and circular to sub circular in plan. Stratabound barite mineralization is occurring in stromatoliticbioherms which are laterally linked hemispheroid with small diameter (less than 5 cm) and low relief (less than 10 cm) and in crinkly laminite with common stylolite (Photo.20). | Intertidal environments under high energy condition, inclination of columns may represent the dominance of unidirectional waves or currents (Hoffman, 1967). Laterally linked stromatolites found here as a result of the fluctuation in water level and energy levels in the medium. |
| | Domalstromatolitefacies | Laterally continuous | Forming laterally linked or isolated mounds with generally low relief (< 1 m). Domes are hemispherical (Photo.21)to slightly elongate, associated with ooliticgrainstone facies and laminate facies | Intertidal environments under episodic agitation (Beukes, 1987; Altermann & Herbig, 1991; Sami & James, 1994; Whalen et al., 2002; Jiang et al., 2003). Higher synoptic reliefs of stromatolites indicate that it had enough space to grow in quiet water setting. |
| 3. Subtidal | Conical stromatolitefacies | Locally restricted | Observed average height of 10 cm and width of 4 cm, with 10 centimetres of synoptic relief. Steeply dipping (Photo 22) (>70°) with narrow, acute apexes (Photo 23). | Quiet water environment, below wave base, restricted to deepest water environment that are characterized by low current energy (Kah et al., 2009). Basically columnar stromatolites have been described in intertidal environment (Logan et al., 1974) while the group conicalstromatolites have been assigned as a deeper subtidalstromatolite. In this sense, the close association of conical stromatolite with columnar and domalstromatolite of the Vempalle formation suggests intertidal shallow marine conditions during its sedimentation, with some gently marine ingressions pointed out by the conical stromatolite growing. |

Table 3. Summarized table of the several syn-sedimentary deformation structures(SSDS) recognized in the Vempalle Formation, Cuddapah basin.

| Lithofacies | Deformation types | Deformation features | Description | Interpretation |
|---|---|---|---|---|
| Heterolithicfacies | Ductile deformation features | Boudins or Pinch and swell structure | Boudins separated by pinched zones of dolosiltite, rounded ends, 1-4 cm in height and 10-25 cm in lateral extent. | "Loop bedding" in dololutitelaminae are initiated by back and forth motion which disrupts softer layers hosted in slightly stiffer thinly bedded laminae by hydroplastically deforming them into interconnected loops or chain. |
| Heterolithicfacies | Ductile deformation features | Diapirs | Dark silicified carbonates intruding vertically upward or downward into the overlying or underlying light grey dolomite, 2-25 cm height and 40 cm width. | Dipiric structures are produced due to earthquake tremor which helps to compress unconsolidated sediments and subsequent upward intrusion of the plastic material through the zone of relative weakness in the already consolidated overlying layer (Montenat et al., 2007; Su D. & Su A et al., 2012). |
| Heterolithicfacies | Ductile deformation features | Convolute bedding | Laterally folded laminae, open synforms and narrow antiforms limited by upper and lower normal layers, width of synforms ranges 20-25 cm and height 24-30 cm. | Localized expulsion of pore water from a liquefied bed and foundering of overlying sediments forming troughs are considered to be the cause of such convolute bedding (Allen, 1977). |
| Both Heterolithic and Laminitefacies | Ductile deformation features | Folds | Simple, open harmonic to tight isoclinals, disharmonic folds of mm to cm scale, undeformed base (Photo 25). | Recurrence of folded layer points to the disturbance occurring in discrete events several times. Folds are the product of drastic reduction of shear strength produced by earthquake shaking (Owen, 1987). |
| Both Heterolithic and Laminitefacies | Brittle deformation features | Intrastratal faults and downsagging structures | Normal, reverse or thrust fault with displacements from mm to cm scale, small scale faults define fault bounded semi-graben like structures. | The intrastratal faults are likely to be formed by extension under brittle to semi-brittle deformation, most likely triggered by seismic activity. Movements along faults, developed in pairs with opposite sense, are likely to be responsible for such graben like features. |
| Heterolithicfacies | Brittle deformation features | Synsedimentarybreccias | Angular, non-sorted (1mm-few cm) carbonate intraclasts derived from the fragmentation of laminite layer | These breccias are likely formed by extension and brittle to semi-brittle deformation, most likely triggered by seismic activity ( Su D. & Su A et al., 2012). |
| Heterolithicfacies | Brittle deformation features | Vein arrays and dykelets | Microspar filled dykelets, a few mm to a cm wide. | Vein arrays and dykelets are likely to be formed by short wavelength shear waves which segregates the finer particles (ElTaki& Pratt et al., 2012) |
| Heterolithicfacies | Brittle deformation features | Cracks | Cracks about 2-20 mm wide, few cm long and vary from ragged lenses to lines which may be straight, curved, sinusoidal, sigmoidal or jagged. | Cracks are formed as instantaneous intrastratal shrinkage and dewatering, usually accompanied by liquefaction and injection of interbedded silts in all directions during ground shaking by synsedimentary earthquake (Pratt, 1998) due to association of other synsedimentary earthquake induced SSDS. |
| Heterolithicfacies | Brittle-Ductile deformation features | Brittle-Ductile features | Folds are associated with small scale faults and fractures. | Asymmetric structures are formed under ductile-brittle deformational phase. |

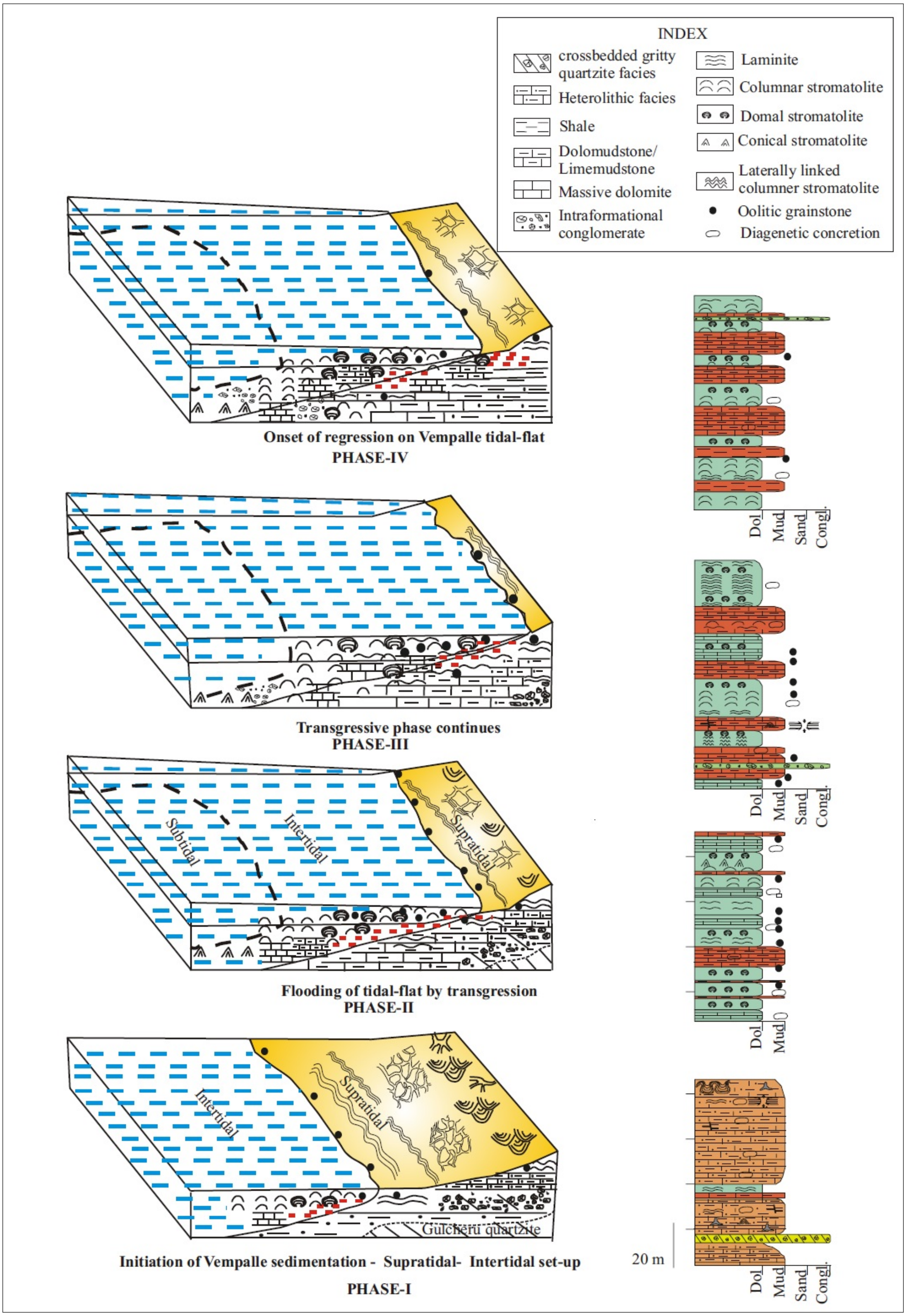


Figure 3. Paleoenvironmental reconstruction of the late Paleoproterozoic Vempalle Formation carbonate ramp showing the transgression- regression event and distribution of facies.

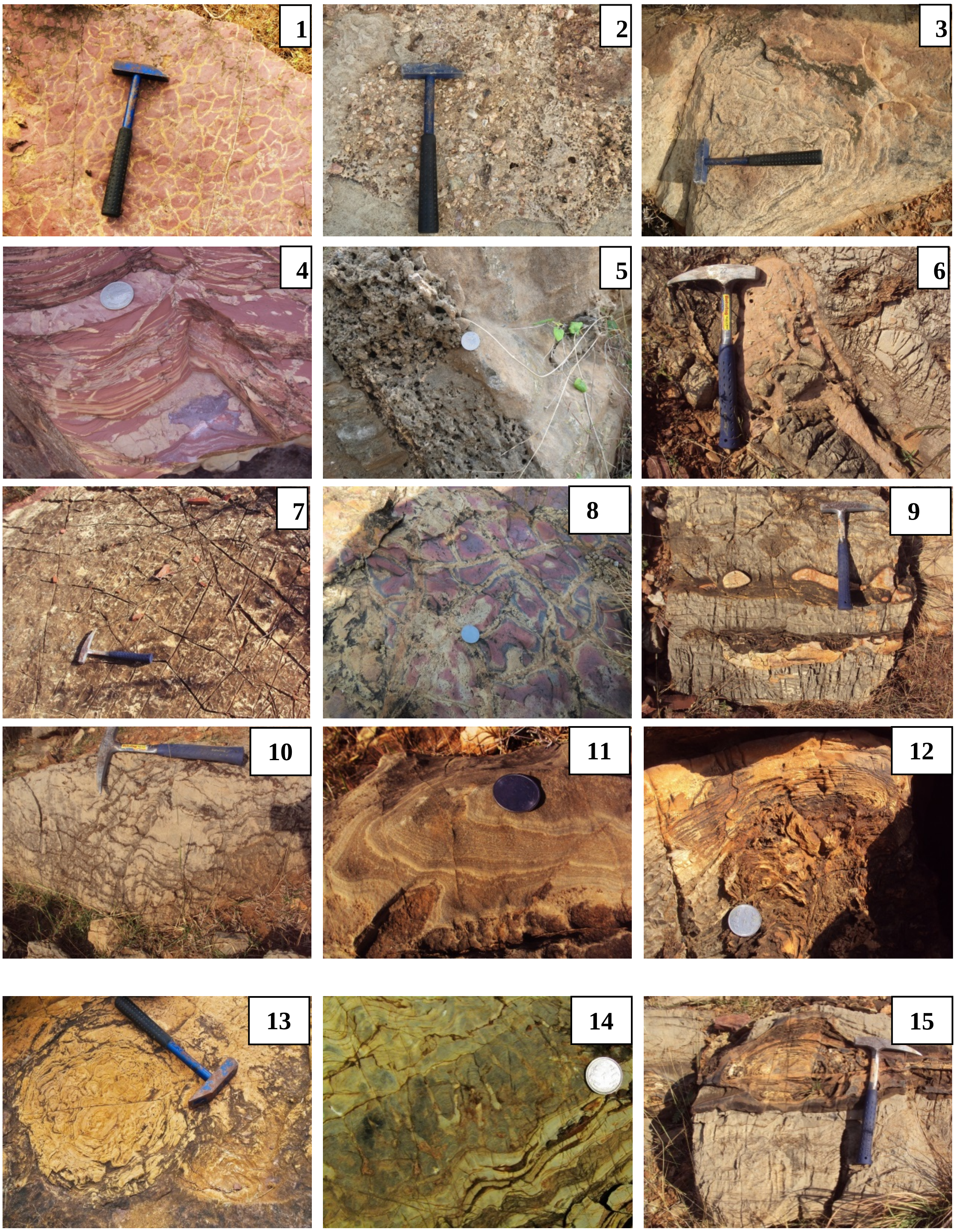


Figure 4. Photo 1. Mudcracks on red shale. 2. Basal conglomerate in gritty quartzite.3. Trough cross-bedded gritty quartzite. 4. Alternation of red siltstone and yellowish grey dolostone. 5. Paleokarstic surface. 6. Karsticbreccias. 7. Rain drop imprints. 8. Syneresis crackson lime mudstone. 9. Diagenetic concretions in massive dolomite. 10. Stylolites. 11. Folded laminite layers with small scale faults. 12. Folded laminiteexhibiting mushroom shaped geometry. 13. Deformed laminaeshow a typical cauliflower or rossete type geometry. 14. Ministromatolitesassociated with laminites. 15. Large oncolite coated grains associated with laminated dolomite. Scale: - Length of hammer- 31.8 cm. Coin diameter-2.1 cm.

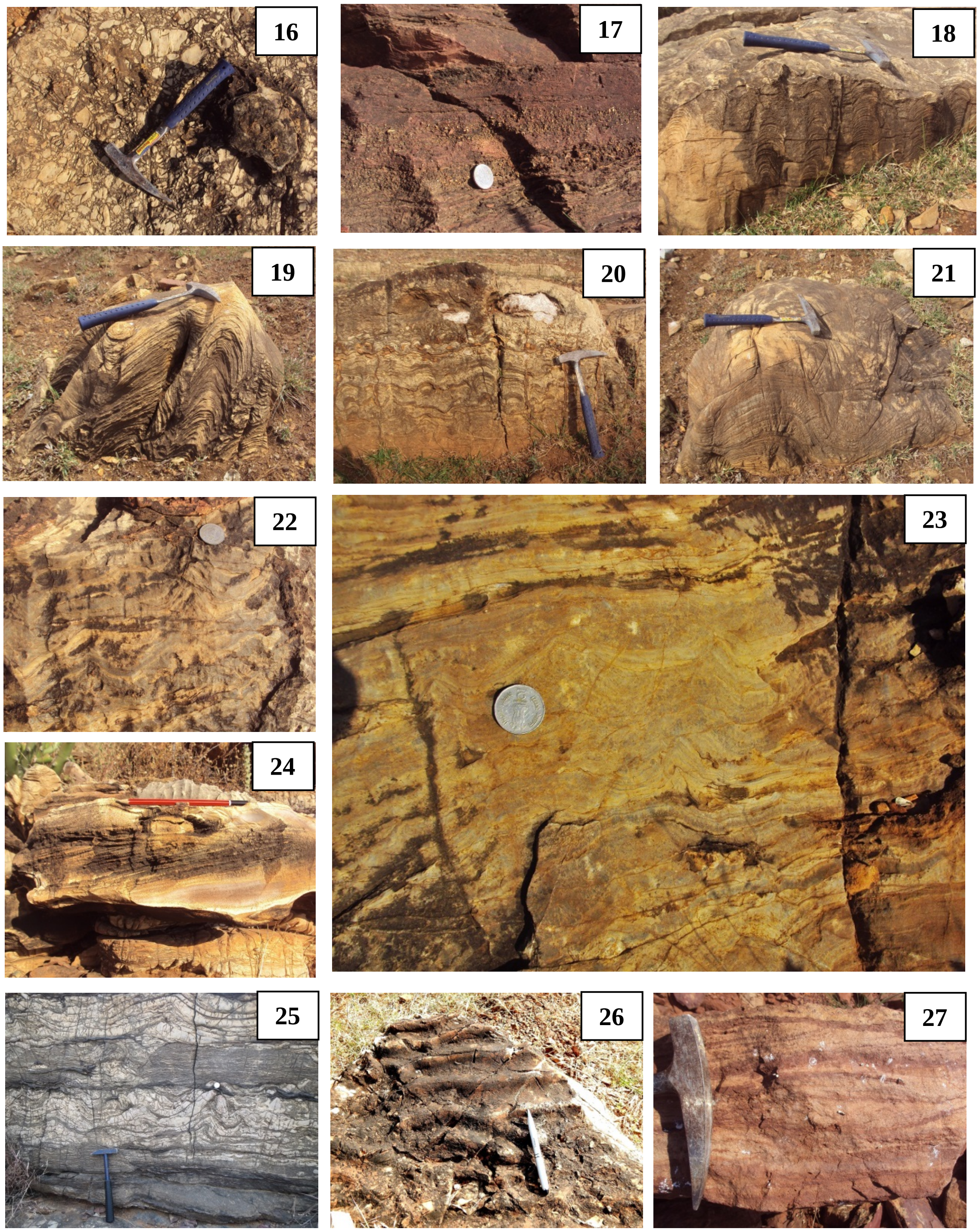


Figure 5. Photo 16, 17. Intraformational conglomerate.18. Columnar stromatolite (unbranched) with definite wall structure. 19. Columnar stromatolite with acute apex showing inclination. 20. Barite mineralization associated with laterally linked hemispheroid stromatolite. 21. Domalstromatolite. 22. Conical stromatolite associated with columnar ones. 23. Laterally linked conical stromatolites. 24. Crossbedding within ooliticgrainstone. 25. Deformed beds sandwitched between undeformed units. 26. Symmetric wave ripple (bifurcated) structure. 27. Hummocky cross stratification with reactivation surface. Scale: - Length of hammer- 31.8 cm, Coin diameter-2.1 cm, Length of pencil-12 cm, Length of pen- 10 cm.

Part of the sandstone beds are deposited by tides but there are some evidences which show that they are generated by oscillatory flows such as wave ripples (Photo 26), alone or combined with unidirectional flows. The anisotropic hummocky cross stratified sandstone (Photo, 27) represents sporadic events of high intensity storm condition that affected the more proximal and sheltered areas of the coast.

The three facies associations indicates hybrid depositional conditions controlled by waves and tides and show features that evidence periodic subaerial exposition, allowing an interpretation of deposition within a generic intertidal paleo-environment. The mudstone beds with subaerial exposure features do not represent prolonged emersion phases because they preserve delicate structures, such as subaerial desiccation cracks, rain drop imprints. If these beds have been subjected to prolonged phases of emersion representing stratigraphic unconformities, they would be characterized by pedogenic structures, horizons of paleosoles, nodules or concretions, continental deposits and/or erosional surfaces; these characteristics are not preserved. Thus, this system cannot be attributed strictly to a beach-shoreface or a purely tidal flat depositional model and it may instead of identified as a system intermediate between a beach-shoreface and a tidal flat setting (Dashtgard et al., 2009; Basilici et al., 2012).

The cross bedded gritty sandstone facies may not be formed in a classical tidal flat setting because most of the sandstone strata are deposited by oscillatory flow and typical sedimentary bodies formed in tidal bars or tidal channels are never observed. Tidal effects are relatively dominant only in facies association 1 which most resembles the tidal flat environment, although deposits produced by wave actions are noticed.

Carbonate/clastic mudstone deposits are distributed throughout the three facies association but with very variable thickness, distribution and lateral continuity. Mudstone deposition in an intertidal flat is due to settling during the slack water phase of tide and /or after storm events. In tidally influenced settings, the amount of mudstone in the sediments increases landwards because the tidal currents decrease in this direction due to frictional dissipation at the sea bed (Bird, 2008). The distribution in the thickness of mudstone beds may be considered proportional to the paleo-coast proximity.

The horizontal distribution of three facies association, based on the distribution and genetic interpretation of facies, permitted the reconstruction of supratidal-intertidal depositional model with a mixed wave-tidal influence. The more distal portion of this intertidal area was dominated by storm activity, which deposited accretionary deposition of HCS. Low orbital velocity wave have little influence on depositional processes, and tide effects are almost insignificant. Landwards, the storm influence is reduced and replaced by the action of low energy waves and tides. The tidal effects are manifested with the deposition of cross bedded gritty sandstone and mudstone blankets.

In the more coastal portion (associated with facies association 2 and 3) tidal action divided the influence into sedimentation of low orbital velocity waves. Presence of columnar and domalstromatolites and presence of inclined stromatolites testify to the effects of waves and sporadic storms. The depositional system represents by the Vempalle Formation is comparable with the depositional system of open coast tidal flats described of the coasts of Yellow sea (Yang et al., 2005, 2006, 2008). This depositional environment provide the mixed influence of waves and tides, the storm dominated depositional processes and the scarce influence of the tides in the depositing sand and their importance in the depositing mudstone.

## 5. CONCLUSIONS

The Palaeoproterozoic Vempalle Formation of the Cuddapah basin in and around Gandi, Vempalle and Nandemandalam area consists essentially of three facies associations representing tidal flat, intertidal and subtidal environments. The shallowest of these facies associations includes cross-bedded gritty quartzite facies, heterolithic facies and laminate facies which represent supratidal environments. Shallow intertidal environments are locally dominated by red shale, lime-mudstone, ooliticgrainstone, and domalstromatolite facies whereas deeper intertidal environments are locally dominated by columnar stromatolite, massive dolomite and intraformational carbonate conglomerate. Conical stromatolitefacies then represent subtidal deposition.

Syn-sedimentary deformation is common and although soft-sediment deformed beds could be due to sediment loading, there are sets of bed-specific soft-sediment deformation structures that are better related to syn-sedimentary earthquake shock which is not unexpected in a rift basin.

The horizontal distribution of three facies association, based on the distribution and genetic interpretation of facies, permitted the reconstruction of supratidal-intertidal depositional model with a mixed wave-tidal influence. The more distal portion of this intertidal area was dominated by storm activity, which deposited accretionary deposition of HCS.

The facies association and associated stromatolite morphology and microfabrics clearly demonstrate that the Vempalle Formation in the study area is deposited in an open coast tidal-flat depositional environment. This depositional environment provide the mixed influence of waves and tides, the storm dominated depositional processes and the scarce influence of the tides in the depositing sand and their importance in the depositing mudstone.


### Acknowledgments

Financial assistance provided by UGC is gratefully acknowledged by the author. The first author is alsograteful to Late Dr. P.K. Dasgupta, Emeritus Professor of Geology, University of Calcutta for introducing him to the Cuddapah Basin and sharing his experience and insights about the rock types. This contribution has greatly benefited from reviews by the anonymous Journal reviewers.


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Received at: 12. 01. 2015
Revised at: 01. 10. 2016
Accepted for publication at: 16. 11. 2016
Publised online at: 22. 11. 2016