JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.83, April 2014, pp.355-362

Pyroclastic Volcanism in Papaghni Sub-basin, Andhra Pradesh: Significant Paleoproterozoic Tectonomagmatic Event in SW Part of the Cuddapah Basin, Eastern Dharwar Craton

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Abstract: Detailed field and petrological studies in Vanambayi-Lingala-Lopatnutala section and old Kadiri Ghat-Pulivendela section in SW part of the Proterozoic Cuddapah basin of Eastern Dharwar craton brought to light the occurrence of hitherto unreported two significant phases of pyroclastic volcanic activity associated with the Vempalle Formation in Papaghni sub-basin. Occurrence of a significant pyroclastic agglomerate at the contact zone of Vempalle dolomite of Papaghni Group and Pulivendela quartzite of Chitravathi Group represents a significant event of the mafic phase of pyroclastic volcanic activity, while the finely laminated felsic tuff within the intercalated reddish siltstone, chert and dolomite sequence in the lower part of Vempalle Formation represents the felsic phase of pyroclastic activity. Studies indicate that the pyroclastic agglomerate zone in Vanambayi-Lingala-Lopatnutala section is a classical example of pyroclastic volcanism wherein the highly vesicular rock with rounded basalt clasts often exhibit embayed contact of welded nature with the matrix. The pyroclastic zone reported in the present paper particularly at the interface of Vempalle Formation and Pulivendela quartzite in Vanambayi-Lingala-Lopatnutala section represents a significant tectono-magmatic event of explosive volcanic activity that is contemporaneous with the culmination of the carbonate precipitation of Vempalle dolomite and marks the termination of sedimentation in Papaghni Group in southwestern part of Cuddapah basin during Paleoproterozoic times.

Keywords: Pyroclastic volcanic activity, Vempalle Formation, Proterozoic Cuddapah basin, Andhra Pradesh.

INTRODUCTION

Pyroclastic volcanic activity recorded in some of the Proterozoic basins around the world, provides critical information on the associated magmatic process during basin evolution and also throws light on the tectonic disposition of the sedimentary basin. Preservation of high-level volcanic rocks suggests that the zone never had an unusually thick crust and, therefore, is similar to some intra-arc depressions (Hildebrand and Bowring, 1984). Extensive volcanic activity is reported in the Archaean Warrawoona Group of Pilbara craton, wherein volcanoclastic breccia and dacitic lava is associated with tuffaceous rocks and chemically precipitated chert (DiMarco and Lowe, 1989). Eruption of pyroclastic volcanic activity was recorded in the Paleoproterozoic Flin Flon belt of Trans Hudson orogen of Canada (Ayres, 1991). Significant event of pyroclastic volcanic activity is recorded in the Campo Alegre and Castro Proterozoic basins of southern Brazil (Basei et al., 1998). The early Proterozoic Gunnison and Salida basins of Colorado recorded extensive 1750 Ma volcanic activity (Bickford and Boardman, 1984). The Proterozoic volcano-sedimentary succession in Dhanjori and Dalma Formations in Singhbhum craton records sedimentation and volcanism in rapidly changing tectonic scenario (Mazumder, 2005). The crescent shaped Cuddapah basin in Peninsular India occupies an area of 44500 sq.km. and hosts about 10 km thick pile of sedimentary strata and associated igneous rocks (Nagaraja Rao et.al., 1987). Six phases of igneous activity is recorded within the Cuddapah basin (Nagaraja Rao et.al., 1987; Chatterjee and Bhattcharji, 2001; Anand et.al., 2003, French, et.al. 2008). The present paper brings to light the hitherto unreported two significant phases of pyroclastic volcanic activity recorded in Vempalle Formation of Papaghni Group in the old Kadiri Ghat – Pulivendela section and Vanambayi-Lingala-Lopatuntala section in SW part of the Cuddapah basin.

GEOLOGICAL SETTING

The Cuddapah basin of the Eastern Dharwar craton

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(EDC) is bounded by Archaean greenstone belts and Peninsular Gneissic Complex to its west and south respectively, while 2.7 Ga Nellore schist belt (NSB) occurs to its east (Fig.1, Chetty, 1999). In the Cuddapah Super Group, the lithounits constituting the lower Papaghni and Chitravathi Groups are virtually undeformed and unmetamorphosed, while the rocks belonging to the upper Nallamalai Group are subjected to multiple phases of deformation. Contemporaneous with the sedimentation a number of phases of igneous activity was associated with the evolution of Cuddapah basin (Sesha Sai, 2010). Sub-aerial eruption of basic lava flows after the deposition of Vempalle Formation marks the first phase of igneous activity within the basin. The volcanic activity represented by fine grained basic rocks and tuff beds within the Tadpatri Formation represents the second phase of igneous activity. Intrusion of sills of picritic and doleritic composition into the Vempalle and Tadpatri succession marks the third phase of igneous activity. These phases of igneous activity are substantiated by the geophysical observation indicating presence of a high density igneous body beneath the SW part of Cuddapah basin (Tewari and Rao, 1987). The barium and iron oxide rich volcanic activity, which was contemporaneous with the Pullampet / Cumbum Formation, represents the fourth phase, while intrusion of basic dykes and alkaline rocks (alkali syenites at Racherla and Lamproite at Chelima, Chalapathi Rao et.al., 2012) into the rocks of Nallamalai Fold Belt represents the fifth phase of igneous activity. The sixth phase of igneous activity is represented by intrusion of granitic rocks into the Nallamalai Group in northeastern fringes of Cuddapah basin (Sen and Narasimha Rao, 1967; Nagaraja Rao et.al., 1987). However, later work revealed that the Nakerikallu and Ipuru granitoids in the northeastern fringes of the basin are traversed by dolerite dykes (Sesha Sai, 2005, 2006) and tuff beds were reported in the younger Neoproterozoic Kurnool Group (Saha and Tripathy, 2012).

GEOLOGY OF PAPAGHNI GROUP

Gulcheru quartzite, the oldest stratigraphic unit in the Cuddapah basin of Papaghni Group constitutes conglomerate and quartzite, while the Vempalle Formation is represented mainly by dolomite (stromatolitic at places) with intercalated siltstone and chert (Lakshminarayana et.al. 2001). Gulcheru quartzite exhibits vertical lithofacies

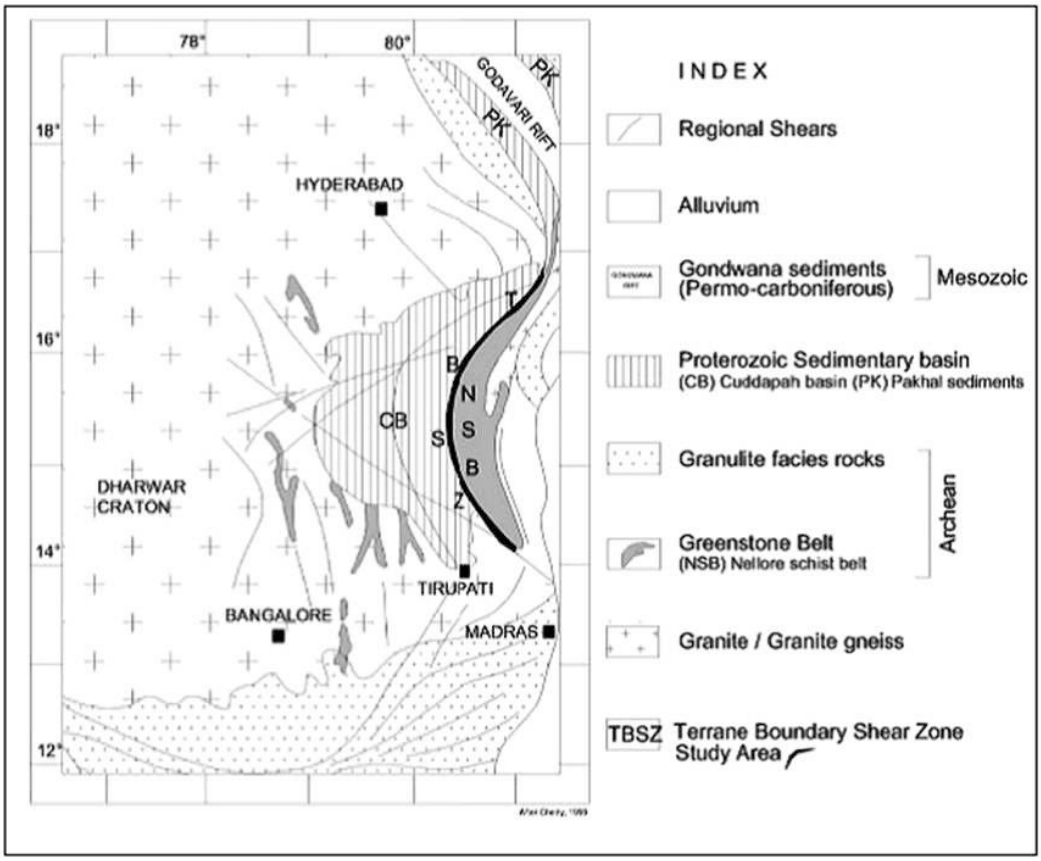

Fig.1. Geological map of Eastern Dharwar Craton showing the position of the Proterozoic Cuddapah basin (CB) (Chetty, 1999).

Table 1. Geological succession in old Kadiri Ghat section and Vanambayi-Lingala-Lopatnutala section of Proterozoic Cuddapah basin (Sesha Sai, 2006)

CHITRAVATHI GROUP	PULIVENDELA QUARTZITE	Reddish quartz arenite (medium to fine grained) Reddish sub lithic quartz arenite (coarse to medium grained) Polymict matrix supported conglomerate ——————— Unconformity ——————-	
PAPAGHNI GROUP	VEMPALLE FORMATION	Pyroclastic zone (Pyroclastic agglomerate characterised by mafic pyroclasts embebed in highly epidotised vesicular matrix) Dolomite (with intercalated chert) Basalt flows (highly vesicular on surface)	
		Predominantly Dolomite (serpentinised at places with development of steatite and chrysotile)	with basic sills
		Dolomite (stromatolitic at places) with intercalated chert (oolitic at places) and uranium mineralization	with basic dykes
		Intercalated sequence of fine grained reddish siltstone and dolomite	with felsic tuff
	GULCHERU FORMATION	Conformable contact with upper Vempalle dolomite Medium to fine grained reddish quartz arenite Coarse to medium grained reddish sublithic arenite Polymict matrix supported conglomerate	
		Archaean granite basement	

variation from basal rudaceous facies (matrix supported, polymict, extraformational conglomerate) that grades to an arenaceous facies mainly represented by coarse to medium grained reddish sub-lithic quartz arenite and medium to fine grained cross bedded reddish quartz arenite (Table 1). Vempalle dolomite conformably overlies the Gulcheru quartzite (King, 1872; Jhanwar, et.al., 1964). In Motnutalapalle-Lopatnutala section it is noticed that the lithounits of Vempalle Formation strike NW-SE with northeasterly dips of 10° to 12°. Intercalated sequence of dolomite finely laminated reddish siltstone and ferruginous quartz arenite bands are dominant in the lower part, while stromotitic dolomite (with chert) is dominant in the upper part of Vempalle Formation.

Petrographic studies of the ferruginous quartz arenite show the presence of sub-angular to sub-rounded grains of quartz (0.02 to 0.3 mm) embebbed in ferruginous material. It further reveals that the chert in Vempalle Formation (interbedded with dolomite) is cryptocrystalline. Occurrence of basic sills and vesicular flows associated with Vempalle Formation has been recorded much earlier (Murthy, 1964; Jhanwar, et.al., 1964; Sen and Narasimha Rao, 1967). Srikantia (1984) reported basic volcanic flows near Kupalapalle area, within the Papaghni sub-basin, while Sesha Sai (2008) reported the presence of chert and basic rock fragments within the vesicular basalt flows at the interface of Vempalle dolomite and Pulivendla conglomerate near Lingala in SW part of the Cuddapah basin.

PYROCLASTIC VOLCANIC ACTIVITY IN VEMPALLE FORMATION

Detailed field studies in old Kadiri Ghat Road-Pulivendela section and Lingala-Lopatnutala section in SW part of Cuddapah basin brought to light the occurrence of

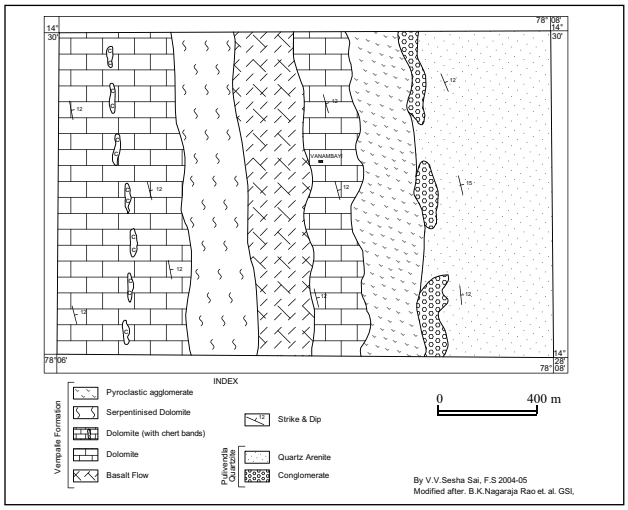

Fig.2. Geological Map of Vanambayi-Lingala-Lopatnutala section in Cuddapah basin, Andhra Pradesh.

hitherto unreported two significant phases of pyroclastic activity associated the Vempalle Formation. (i) Occurrence of finely laminated felsic tuff within the intercalated reddish siltstone and dolomite sequence exposed in the lower part of Vempalle Formation in Pulivendela-old Kadiri Road section and (ii) occurrence of a significant linear pyroclastic agglomerate in the uppermost part of the Vempalle dolomite; i.e. right at the contact zone of upper Vempalle dolomite of Papaghni Group and lower Pulivendela quartzite of Chitravathi Group (Fig.2). The present work involves field observations that are substantiated by detailed petrographic studies to ascertain the mineralogical and textural aspects and EPMA analyses for understanding the chemistry of minerals. EPMA analyses of samples from felsic tuff and basic pyroclastic zone were carried out using CEMECA Sx100 Electron Probe Micro Analyzer at the EPMA Laboratory, Geological Survey of India, Hyderabad. The operating conditions were 15 kV accelerating voltage, 1–2 micron beam diameter and 12 nA current.

FIELD AND PETROGRAPHY OF FELSIC TUFF

Felsic tuff occurs within the intercalated reddish siltstone and dolomite sequence and varies in thickness from 30 cm to 75 cm. It is finely laminated and yellowish in color (Fig. 3a) and underlies the siltstone interbedded with chert in the lower part of Vempalle Formation. Individual lamina vary in thickness from 0.2 m to 1 mm and this lithounit is traced along the strike length of more than 1 km. Weathered surface of the laminated tuff is about 1 to 2 mm thick with reddish brown surface colour. Petrographic studies under high magnification reveal that the rock exhibits the clast matrix texture characteristic of fine pyroclastic rocks and composed of quartz and feldspar as essential minerals, while fine flakes of brown biotite along with few opaque grains are noticed in minor amounts. Tuff size euhedral to sub-hedral clasts of quartz and twinned feldspar (0.07 mm 0.1 mm size) are embedded in extremely fine grained cryptocrystalline felsic matrix (< 0.05 mm size). Often embayed contact is noticed between the clast and matrix; characteristic textural feature of fine grained pyroclastic rocks (Fig.4). EPMA studies revealed that feldspar with SiO_2-63.33 to 63.89 %, Al_2O_3-17.54 to 17.59% and K_2O-15.18 to 16.43% is a K-feldspar and biotite with SiO_2-49.06%, Al_2O_3-23.05%, FeO-7.51% and K_2O-9.44% is annite (Table 2).

FIELD AND PETROGRAPHY OF PYROCLASTIC AGGLOMERATE ZONE

In Vanambayi-Lingala-Lopatnutala area in SW part of the Cuddapah basin, the contact zone of upper part of Vempalle dolomite of Papaghni Group and lower part Pulivendela quartzite of Chitravathi Group is marked by a thick horizon of pyroclastic rock. This pyroclastic zone trends NNW-SSE and has been traced discontinuously over a strike length of more than 10 km from east of Vempalle in SE to Lopatnutala-Lingala in NW. To the southwest of Lingala the zone has an exposed width of 300 m in Vanambayi section; representing a significant event of volcaniclastic activity. Field observations reveal that the pyroclastic zone comprises of rounded to sub-rounded lithoclasts of basalt (varying in dimension from 3 cm to 8.5 cm in diameter) that are embedded in fine grained highly vesicular basic matrix. Clasts of basalt often show embayed contact with the matrix. Significantly this pyroclastic agglomerate (Fig.4) as a whole is highly vesicular indicating

Table 2. EPMA analyses of mineral phases from pyroclastic rocks associated with Vempalle Formation in the Cuddapah basin

Oxide	CV/16	CV/17	CV/22	CV-12/7	CV-12/7	CV-12/72	CV-12/72
SiO_2	63.889	63.333	49.06	52.988	53.440	50.698	50.925
TiO_2	0.056	0.01	0.889	0.088	0.092	0.84	0.84
Al_2O_3	17.589	17.541	23.047	28.086	28.136	2.312	2.208
MnO	0.06	0.013	0.027	0.002	0.002	0.369	0.369
MgO	0.005	0.003	3.077	0.129	0.132	14.232	14.327
FeO	0.082	0.072	7.509	1.008	1.008	12.385	12.499
CaO	0.002	0.078	0.139	12.649	12.629	18.15	18.05
K_2O	16.43	15.185	9.436	0.192	0.189	0.02	0.02
Na_2O	0.301	0.89	0.711	4.324	4.174	0.238	0.256
ZnO	0.004	0.028	0.077	0.027	0.024	0.085	0.085
P_2O_5	0.025	0.033	0.017	0.025	0.025	0.008	0.008
Cr_2O_3	0.015	0.026	0.005	0.016	0.012	0.139	0.121
Total	98.406	97.041	94.341	99.533	99.935	99.381	99.683
Mineral	K-feldspar	K-feldspar	Biotite	Ca- plag	Ca- plag	augite	augite
Rock	Felsic tuff			Basalt clast from pyroclastic zone from Vanambayi-Lingala-Lopatnutala section			

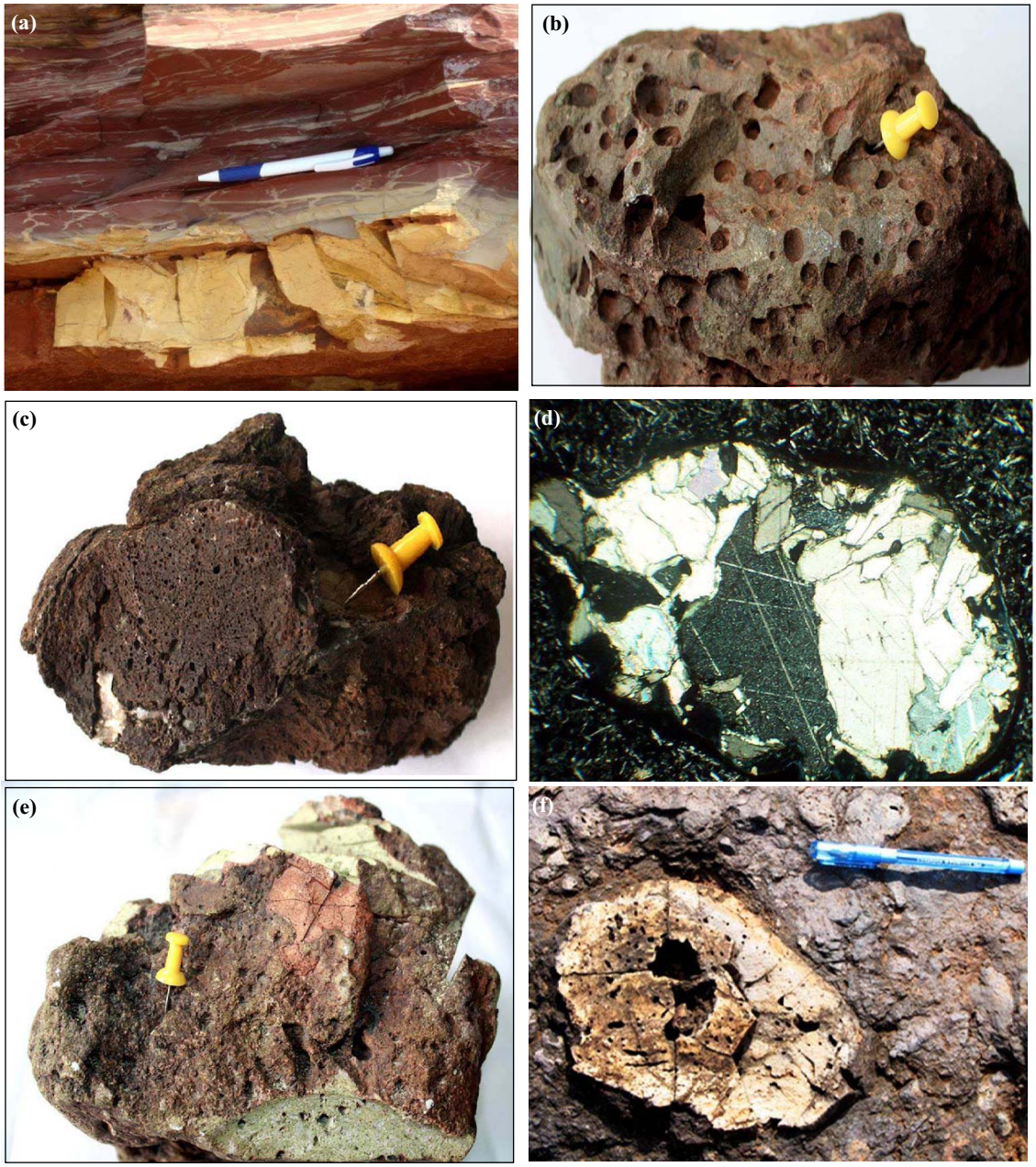

Fig. 3. (a) Felsic tuff (below the pen) underlying the siltstone. (**b**) Photograph showing highly vesicular nature of the pyroclastic rock on the surface. (**c)** Basalt pyroclast exhibiting welded contact with matrix. The pyroclast is vesicular and rounded in shape. (**d)** Photomicrograph showing calcite amygdules in basalt pyroclast. (**e)** Note the embayed contact of the pyroclast within highly epidotised matrix. Note the minute vesicles in epidotised matrix. (**f)** Field photograph showing sharp contact of basalt clast with adjoining matrix. Note the radial cracks and vesicles

eruption of volatile rich lava and the vesicles range in size from 0.1 to 0.3 mm in diameter (Fig. 3b). Often the basalt pyroclasts show vesicular nature and exhibit welded contact with surrounding matrix (Fig.3c). Petrographic studies reveal that the pyroclasts of basalt are essentially made of fine grained randomly oriented plagioclase laths (0.05 to 0.1 mm size) and clinopyroxene, while opaques are noticed as accessories. EPMA studies revealed that the plagioclase with SiO_2-52.99 to 53.44 %, Al_2O_3-28.08 to 28.14%, Na_2O-4.17 to 4.32% and CaO-23.63 to 13.65 %) is a labradorite and clinopyroxene with SiO_2-50.69 to 50.92 %, Al_2O_3 - 2.21 to 2.31 %, FeO-12.38 to 12.50% and MgO-14.23 to 14.32 % is a augite (Table 2). The vesicles are infilled by amygdules of calcite (Fig.3d) and notably the pyroclastic zone is affected by extensive epidotisation (Fig. 3e). Further it is noticed that some of the basalt fragments are not only

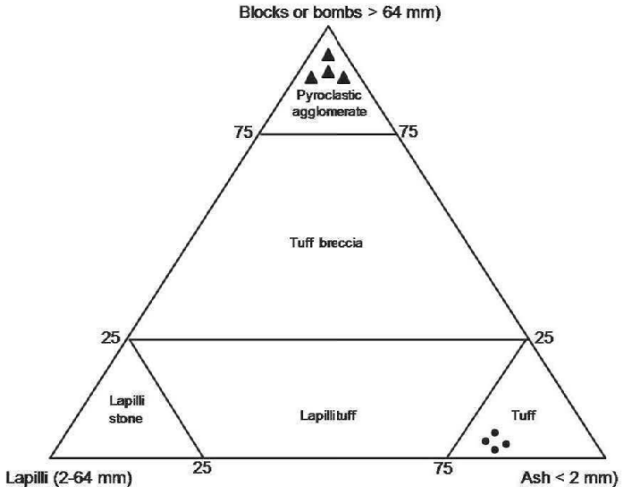

Fig.4. Position of mafic pyroclastic agglomerate (▲) of Vanambayi-Lingala-Lopatnutala section and felsic tuff (•) in triangular diagram for IUGS classification of pyroclastic rocks (Fischer, 1966)

vesicular but also exhibit radial cracks (Fig.3f) characteristic of pillowed basalts; implying that during the ascent of the violent pyroclastic material on to the surface it has fragmented the underlying pillow basalt flows that are embebed in the pyroclastic zone.

TECTONOMAGMATIC SIGNIFICANCE

Field studies indicate that the linear NNW-SSE mafic pyroclastic zone exposed in Vanambayi-Lingala-Lopatnutala section is disposed right at the contact of carbonate dominated Vempalle Formation of Papaghni Group and Pulivendela conglomerate of Chitravathi Group. Non-clastic sediments in the form of dolomite (stromtolitic at places) and interbedded chert deposited in shallow marine intertidal environment represent the Vempalle Formation lithounits, while a polymictic conglomerate unconformably overlies the Vempalle dolomite in Vanambayi-Lingala-Lopatnutala section in SW part of Cuddapah basin. The lensoidal Pulivendela polymict conglomerate consists predominantly of rounded clasts of chert (oolitic at places) derived from the underlying Vempalle Formation. The polymict conglomerate is overlaid by reddish sub-lithic arenite consisting of rounded grains of quartz, chert and chalcedony.

The mafic pyroclastic zone exposed in this section separates two critical sedimentary units deposited in contrasting sedimentary environments i.e. shallow marine intertidal (carbonate-chert) to fluvial-beach interface (rudaceous-aranaceous). Shallow-water, eruption-fed, mafic pyroclastic deposit was identified along a Paleoproterozoic coastline in the Kangerluluk volcano-sedimentary sequence, southeast Greenland (Mueller et.al. 2000). Similarly the eruption of mafic pyroclastic zone in Vanambayi-Lingala-Lopatnutala section corroborates with the facies transition accompanied by basin shallowing from carbonate platform to clastic originated rudaceous facies; indicating active tectonomagmatic processes characteristic of continental arc setting contemporaneous with the sedimentation in SW part of the Cuddapah basin during Paleoproterozoic times.

DISCUSSION

Recent work indicated that the Cuddapah basin was opened before 1900 Ma (Basu and Brickford, 2013). Presence of 1890 Ma magmatism in Bastar and Dharwar cratons is established (French et.al. 2008) and the Cuddapah Large Igneous Province has witnessed the event (Srivastava and Gautam, 2009). Mantle perturbation, magmatism and gravitational loading leading to isostatic subsidence are intimately woven together in the evolution of Cuddapah basin (Bhattacharji and Singh, 1984). Eruption of pyroclastic rocks in a very shallow marine to sub-aerial setting has been described in the Paleoproterozoic Flin Flon assemblage of Canada (Ayres, 1991), where pillow fragment breccias and mafic pyroclastic rocks of few metres to hundreds of metres thick zones is found. The outpour of basalt flows and emplacement of sills of varied compositions parallel to the NNW-SSE curvilinear SW margin of the basin implies a deep seated fracture zone that paved way to a significant event of Paleoproterozoic magmatism in the Cuddapah basin (Sesha Sai, 2010) and volcanic sequences in the form of flows (lavas) and pyroclastic zones within the Papaghni sub-basin represent a proximal facies with respect to source vents or linear fissures that are parallel to the basin margin in SW part of Cuddapah basin.

Episodic volcanism associated with the Vempalle Formation was perhaps sufficiently voluminous to congest local fluvial dispersal systems, resulting in the widespread accumulation of volcanic / volcaniclastic material, similar to what is seen at the interface of Vempalle Formation and Pulivendela quartzite in Lingala-Lopatnutala section.

CONCLUSION

The pyroclastic volcanic activity reported in the present work at the interface of Vempalle Formation and Pulivendela quartzite in Vanambayi-Lingala-Lopatnutala section in Cuddapah basin proves the presence of an active site of eruptive zone within the Papaghni sub-basin (earlier than

1.9 Ga; age of mafic-ultramafic sill dissecting Tadpatri Formation, Anand et al., 2003). Further, the linear pyroclastic zone not only signifies a relatively large scale explosive volcanic activity, but its disposition right at the contact of upper part of Vempalle dolomite of Papaghni Group and lower part of Pulivendla quartzite of Chitravathi Group indicate that this eruptive zone marks the culmination of carbonate facies deposition and termination of sedimentation in Papaghni Group during Paleoproterozoic times.

Acknowledgements: Dr.S.K.Wadhawan, Director General, Geological Survey of India, and Deputy Director General, GSI, Training Institute are thanked for according permission to publish the work. Dr.H.M.Ramachandra for invaluable guidance and Dr. N. Ramakrishna Reddy, Loyola College, Pulivendela, for co-operation at field, are profusely thanked. Dr.S. Bhattacharjee, GSI, Southern Region is thanked for EPMA analyses. Dr. Tarun C. Khanna and Dr.G.Samuel Sukumar are acknowledged for help in photography. The author wishes to deeply acknowledge the invaluable support rendered by his late parents Shri. V.S.Ramachandra Murthy and Smt.V.Bhramarambha to pursue research. Prof. Rajesh K. Srivastava, BHU, Varanasi, is thankfully acknowledged for inspiring discussions and suggestions.

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(Received: 6 November 2013; Revised form accepted:22 January 2014)