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Chapter 7

Petrology and Mineral Chemistry of Picrite Sill from Peddakudala-Velpula Area, in Southwestern Part of the Proterozoic Cuddapah Basin, Andhra Pradesh, India

V.V. Sessa Sai

Introduction

Mafic-ultramafic magmatism constitutes an integral part of evolution of Dharwar craton, having taken place repeatedly at various stages of its development (Srivastava et al., 2008; Ernst and Srivastava, 2008; Jayananda et al., 2008 and Srivastava and Ahmed, 2009). Basaltic sills and lava flows (~ 1.88 Ga) are commonly intercalated with sediments in the lower part of the sedimentary sequence in the intra-cratonic, mid-Proterozoic Cuddapah basin of southern India (Chatterjee and Bhatthcharji, 2001). The Proterozoic Cuddapah basin of Peninsular India covering an area of around 44,000 km² in the state of Andhra Pradesh, is one of the well known Proterozoic sedimentary basins in the world (Nagaraja Rao and Ramalingaswamy, 1976). Contemporaneous with the sedimentation, Cuddapah basin has witnessed number of phases of igneous activity during the course of its evolution Six phases of igneous activity are recorded in Cuddapah basin (Nagaraja Rao et al., 1987). Sub-aerial eruption of basic lava flows after the deposition of Vempalli Formation marks the first phase of igneous activity within the basin. The volcanic activity represented by fine grained basic rocks and tuffs within the Tadpatri Formation represents the second phase of igneous activity and intrusion of sills of picritic and doleritic composition into the Vempalle and Tadpatri succession marks the third phase of igneous activity. 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 (riebeckite syenites of Giddalur-Racherla-Idamakallu-Dhupadu and Chelima Lamproite) 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 the northeastern fringes of the Cuddapah basin. However, later work (Sessa Sai, 2005) revealed that the Nakerikallu and Ipuru granitoids are traversed by dolerite dykes. A number of NNW-SSE to NW-SE trending sills of picrite,

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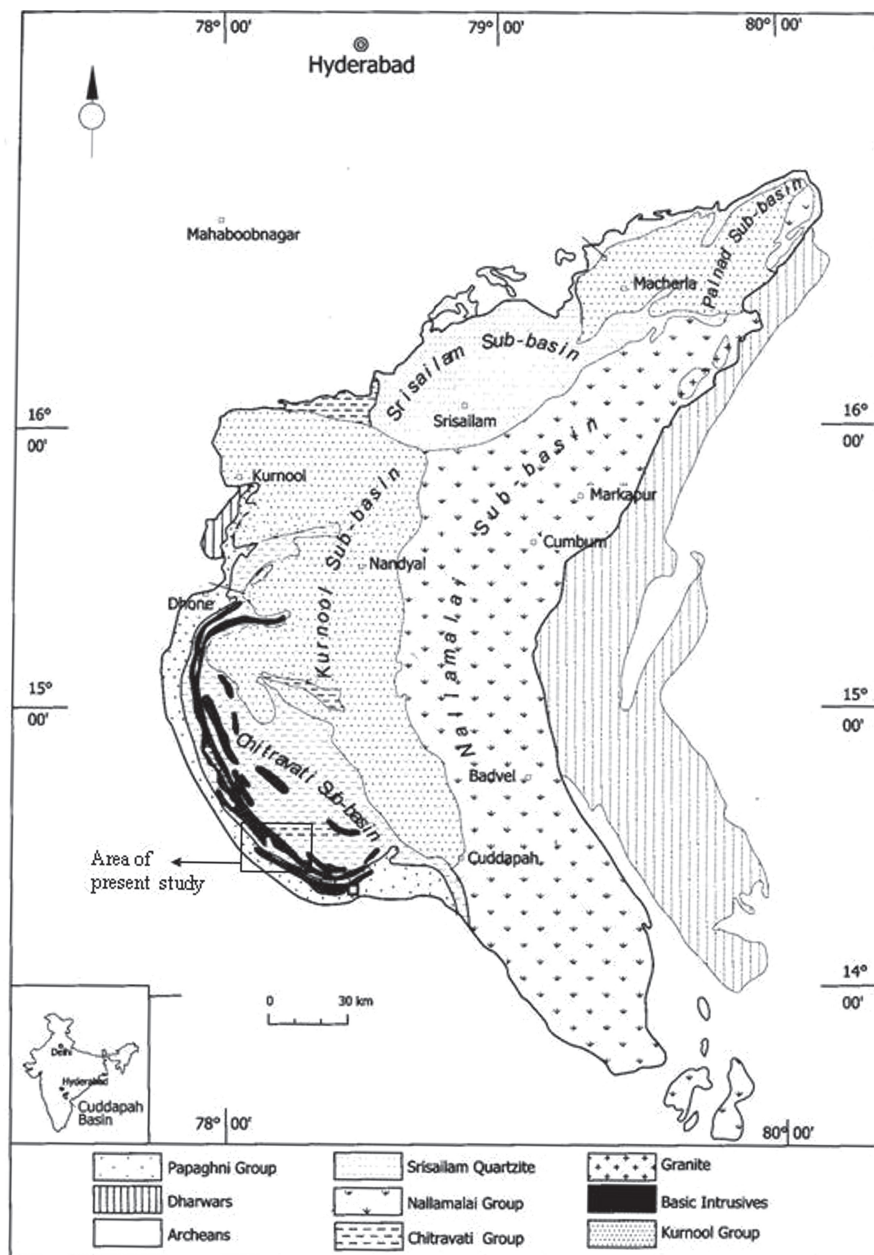


Fig. 7.1 Geological map of Cuddapah basin showing the spatial distribution of igneous rocks (after Nagaraja Rao et al., GSI 1987). *Inset map* showing the position of Cuddapah basin in India

dolerite and olivine gabbro compositions are emplaced parallel to the south western margin of Cuddapah basin (Fig. 7.1). The present paper pertains to petrology and mineral chemistry of a major NW-SE trending picrite body in southwestern part of Cuddapah basin.

Igneous Activity in Tadpatri Formation in Pulivendla-Muddanuru Section

A number of mafic-ultramafic sills exhibiting sharp contact with the shales and dolomite of Tadpatri Formation are noticed to around Pulivendla, Dondlavagu, Tonduru-Mallela section and Velupucherla area in south western part of Cuddapah basin. A NNW-SSE to NW SE trending composite sill made of two components i.e. picrite and dolerite has emplaced the shales and dolomites of Tadpatri Formation and is exposed over a stretch of 12 km from Peddakudala in northwest to Velpula in southeast. Field relationship indicates that dolerite cuts the picrite sill (Sesha Sai, 2006). Dolerite is medium grained, mesocratic, and massive showing spheroidal weathering and petrographically composed of laths of plagioclase, subhedral augite (altered at places to amphibole), accessory ilmenite and pyrite. Development of

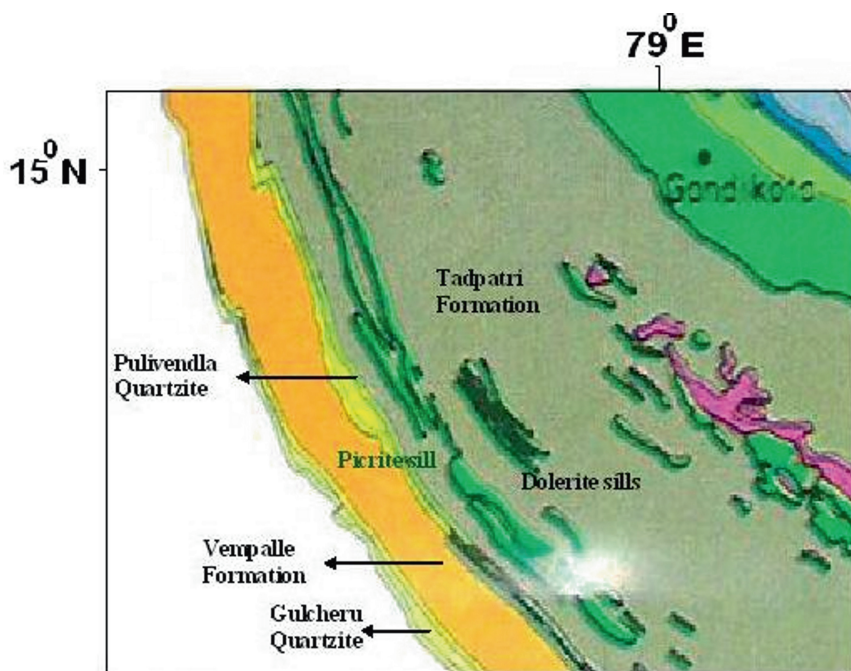


Fig. 7.2 Geological map of South western part of Cuddapah basin showing disposition of basic flows over Vempalle Formation and picrite and dolerite sills in Tadpatri formation (after, GSI, 1981)

sub-ophitic and ophitic textures is common in dolerites. To north of Peddakudala picrite is noticed as minor patches within the mesocratic dolerite. Towards south east the picrite becomes prominent and near Velpula it attains maximum thickness and represents the cumulus phase. On surface, picrite is melanocratic shows typical pitted weathering and vary in width from 15 to 20 m near Peddakudala to more than 100 m near Velpula. In the middle part of Tadpatri Formation as noticed in Tonduru-Mallela-Muddanuru section three major igneous rocks are noticed viz. dolerite sills, felsic tuffs and gabbro sills (porphyritic at places). These sills are emplaced along NW-SE striking and northeasterly dipping (12°) reddish ferruginous sub-arkosic quartz arenites and greyish green splintery shales interbedded with felsic tuffs and limestone bands. An olivine gabbro is noticed traversing the tuff and quartzite is noticed to west of Velupucherla in upper part of Tadpatri Formation. The mafic-ultramafic sills of Tadpatri Formation are emplaced parallel to the south western margin of Cuddapah basin (Fig. 7.2).

Petrology and Mineral Chemistry of Picrite Sill

Petrographic studies indicate that the picrite shows cumulus texture and is modally composed of olivine ($\sim 38\%$), clinopyroxene ($\sim 25\%$), plagioclase ($\sim 20\%$), phlogopite ($\sim 8\%$) orthopyroxene ($\sim 5\%$), while magnetite, ilmenite and chrome-spinel form the accessory opaques. Plagioclase showing lamellar twinning occur as relatively large subhedral laths (average width 0.5 mm and average length 1.5 mm), while olivine occur as equant grains that are perfectly euhedral at places. Olivine and plagioclase represent the cumulus phase, while phlogopite is noticed as randomly oriented flakes. Co-precipitation of cumulus plagioclase and olivine resulted in development of conspicuous poikilitic texture in the rock, wherein euhedral to subhedral grains of olivine chadacrysts are enclosed in the host plagioclase okiocrysts

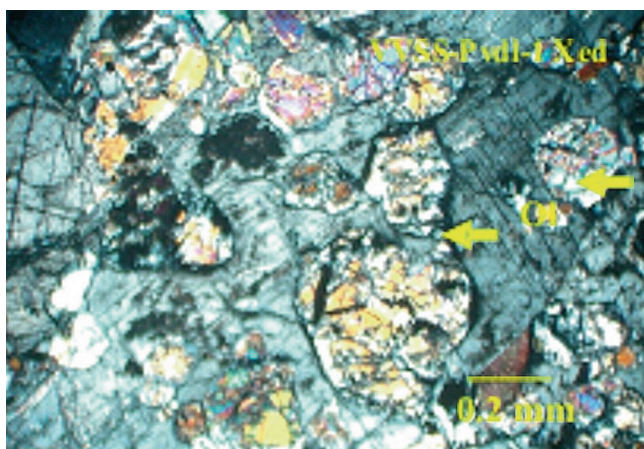


Fig. 7.3 Poikilitic texture in picrite; *olivine grains* (Ol) enclosed in plagioclase

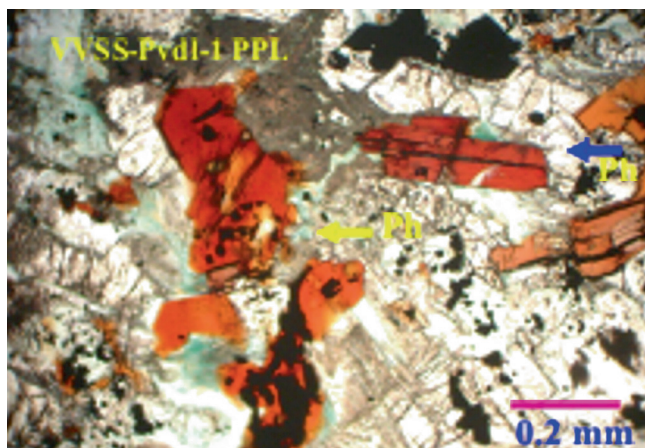


Fig. 7.4 Phlogopite (Ph) showing typical pleochroism in shades of orangish red colours

(Fig. 7.3). Phlogopite is pleochroic in shades of orangish red colours (Fig. 7.4) and most of the phlogopite flakes range in length from 0.3 to 0.4 mm. At places it is noticed that phlogopite partially transects olivine. Exsolution lamellae of orthopyroxene are noticed in clinopyroxene, while ilmenite lamellae are commonly noticed along the cleavage planes in phlogopite. Olivine is altered to serpentine along the cracks (Figs. 7.5 and 7.6).

EPMA analyses were carried out at Central Petrological Laboratory, GSI, Kolkata by CAMECA Sx 100. Analyses conditions: Accelerating voltage: 15 kV, current: 12 nA. Beam size: 1 μ . All natural standards have been used except for Mn and Ti for which synthetic standards have been used. Mineral chemistry studies carried out with the aid of EPMA (Table 7.1) indicate that olivine is forsterite (with 0.14% NiO), orthopyroxene is enstatite and plagioclase is labradorite in composition. Orthopyroxene (Cr_2O_3 – 0.38% and NiO – 0.10%) and phlogopite (Cr_2O_3 – 0.89% and NiO – 0.12%) analysed significant chromium

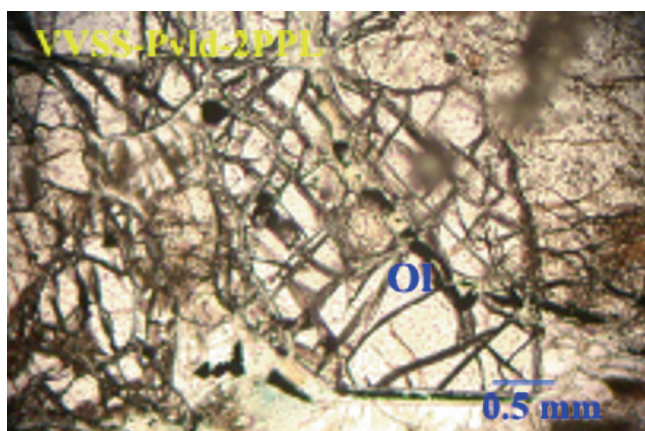


Fig. 7.5 Euhedral olivine (Ol) altered to serpentine along cracks

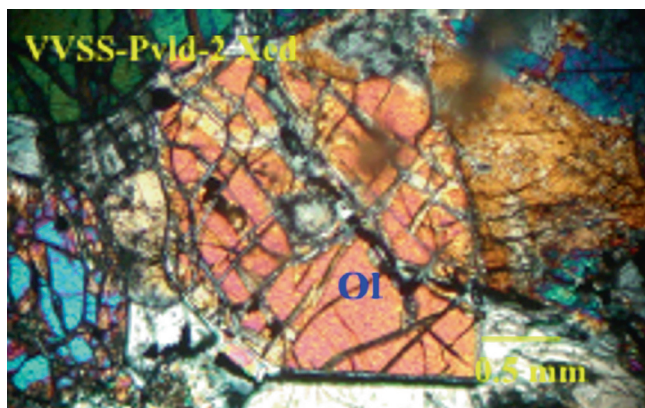


Fig. 7.6 Same as Fig. 7.5 under crossed nicols

Table 7.1 Mineral chemistry of the mineral phases in Picrite from Peddakudala-Velpula area in south western part of Cuddapah basin, Andhra Pradesh

Oxide (%)	Olivine	Opx	Phlogopite	Cpx	Plagioclase	Magnetite
SiO ₂	38.65	55.55	39.00	55.73	49.4	0.00
TiO ₂	0.00	0.38	2.61	0.39	0.00	5.64
Al ₂ O ₃	0.01	1.01	13.91	2.60	31.3	5.58
MnO	0.00	0.27	0.01	0.41	0.00	0.32
MgO	40.15	29.45	20.73	19.60	0.10	2.43
FeO	20.62	10.76	8.22	7.55	0.88	56.93
CaO	0.13	1.95	0.01	11.23	14.72	0.00
K ₂ O	0.00	0.00	6.94	0.01	0.17	0.01
Na ₂ O	0.00	0.06	1.26	0.75	3.20	0.04
Cr ₂ O ₃	0.00	0.38	0.89	0.00	0.00	23.13
NiO	0.14	0.10	0.12	0.11	0.00	0.19
Total	99.95	99.99	93.71	98.40	99.64	94.27
Cations						
Si	0.998	1.958	5.678	2.022	9.092	0.000
Al	0.000	0.042	2.386	0.111	6.784	2.158
Ti	0.000	0.010	0.285	0.011	0.000	1.393
Fe	0.445	0.362	1.001	0.229	0.132	15.628
Mn	0.005	0.008	0.001	0.013	0.000	0.089
Mg	1.546	1.539	4.449	1.060	0.027	1.190
Ca	0.004	0.074	0.001	0.437	2.879	0.002
K	0.000	0.000	1.290	0.001	0.040	0.006
Na	0.000	0.004	0.356	0.053	1.142	0.025
Cr	0.000	0.007	0.103	0.000	0.000	6.003
Ni	0.003	0.002	0.014	0.003	0.000	0.050
Species	Forestrite	Enstatite	Phlogopite	Augite	Labradorite	Magnetite

and nickel contents along with magnetite ($\text{Cr}_2\text{O}_3 - 23.13\%$ and $\text{NiO} - 0.19\%$) and chrome-spinel ($\text{Cr}_2\text{O}_3 - 36.61$ and $\text{NiO} - 0.19\%$). The notable Cr_2O_3 and NiO contents in silicate and oxides phases analysed in picrite is also substantiated by trace elements analyses of picrite carried out by ICP-MS where in Cr value ranging from 2,157 to 2,162 ppm, Ni values ranging from 981 to 982 ppm were recorded along with Co values ranging from 130 ppm to 134 ppm and V values ranging from 151 to 153 ppm (Sesha Sai, 1994).

Trace and REE Geochemistry: Trace element analyses of the cumulus picrite indicate Cr content of 2,157–2,898 ppm and Ni contents of 919–982 ppm (Table 7.2). Forestrite which is the most abundant mineral with $\sim 38\%$ by mode and with 0.14% NiO has controlled the Ni partitioning while, enstatite (0.38% Cr_2O_3),

Table 7.2 Trace element and rare earth element analyses of Picrite sill in Tadpatri formation from Peddakudala-Pulivendla-Velpula area in south western part of Cuddapah basin

Element	Sesha Sai (1994)		Anand et al. (2003)	
	Velpula-Pulivendla area, SW part of Cuddapah basin		Pulivendla area, SW part of Cuddapah basin	
Ba	41	42	97	106
Co	130	134	106.3	108.2
Cr	2,157	2,162	2,857	2,898
Cu	62	63	48.9	59.5
Nb	1.5	1.8	1.77	2.37
Ni	981	982	919	919
Rb	9.6	12	14.3	19.2
Sc	29	30	22.8	28.3
Sr	48	49	66.4	67.9
V	151	153	117	137
Y	8.6	10.6	8.47	10.63
Zr	25	27	32.8	44
La	2.69	2.71	6.40	7.93
Ce	4.56	4.60	15.4	19.1
Pr	1.28	1.31	1.4	1.8
Nd	2.04	2.14	5.83	6.91
Sm	0.63	0.83	1.3	1.53
Eu	0.14	0.13	0.42	0.53
Gd	0.36	0.39	1.64	2.07
Tb	–	–	0.27	0.32
Dy	0.76	0.78	1.75	2.08
Ho	–	–	0.36	0.44
Er	0.94	0.96	1.06	1.37
Tm	–	–	0.17	0.18
Yb	0.26	0.47	1.11	1.22
Lu	0.15	0.17	0.16	0.17
Rb/Sr	0.2	0.24	0.21	0.28
Zr/Y	2.90	2.54	3.8724	4.1392
Sm/Yb	2.42	1.76	1.17	1.25
La/Sm	4.26	3.26	4.92	5.18
Sm/Nd	0.30	0.38	0.22	0.22

magnetite (23.13% Cr_2O_3) and chrome-spinel (Cr_2O_3 – 36.61%) controlled the partitioning of Cr. Relatively enriched HFSE contents i.e. Zr (25–44 ppm) and Y (8.6–10.63 ppm), Zr/Y ratios from 2.54 to 4.13, La/Sm ratios (3.26–5.18) and Sm/Yb ratios (1.17–2.42) indicate a Mg rich primary mantle source. Rb/Sr ratios (0.21–0.28) and relatively Sm/Nd ratios (0.22–0.38) however indicate partial crustal contamination. Relatively dense picritic magmas may be trapped at or near the base of the crust where they become contaminated with lower crustal wall rocks and differentiate to form layered sills with gabbroic upper parts and olivine + pyroxene cumulate lower parts (Arndt and Goldstein, 1989).

Discussions

Paleo-Proterozoic dyke swarms of $1,769.1 \pm 2.5$ Ma are reported in North China craton (Halls et al., 2002), Fennoscandia and Greenland (Raimo Lahtinen et al., 2008), Sao Francisco craton, Brazil (Wilson Teixeira and Mario Cesar Heredia Figueiredo, 1991), North Atlantic and Baltic cratons (Bridgwater et al., 1995), Uruguay (Maurizio Mazzucchelli et al., 1995), Proterozoic sedimentary strata in the Baraga Basin in northern Michigan (Xin Ding et al., 2010) and wide spread Precambrian mafic-ultramafic magmatism has been recorded in Yilgarn and Pilbara cratons, Hamersley Basin, and Sylvania Inlier of Australia (Aus. Geo News, 2009). Paleoproterozoic Large Igneous Province has been identified in the southern Bastar craton and nearby Cuddapah basin from the adjacent Dharwar craton, India and this record of ~ 1.9 Ga mafic/ultramafic magmatism associated with concomitant intracontinental rifting and basin development preserved along much of the south-eastern margin of the south Indian shield is a widespread geologic phenomenon on Earth (French et al., 2008). The ultramafic picrite sill and the associated NW-SE to NNW-SSE trending dolerite sills and olivine gabbro bodies occurring in Tadpatri Formation in Peddakudala-Pulivendla-Velpula section and Tonduru-Mallela-Velupucherla section in SW part of Cuddapah basin indicate the surface expression and corroborate with the observation made during the geophysical studies by Tewari and Rao (1987), who indicated the presence of a high density igneous body beneath the SW part of Cuddapah basin. A positive gravity anomaly at the center of the concentric sills indicates a large lopolithic cupola that probably originated through mantle upwelling during the early part of the basin's history (Chatterjee and Bhattacharji, 2001). ^{40}Ar – ^{39}Ar laser fusion determination on the phlogopite mica from the mafic-ultramafic sill complex of Tadpatri Formation, constrain an age of initial phase of extrusion in the basin at 1.9 Ga (Anand et al., 2003). Lineament reactivation in NW-SE direction in response to mantle perturbation intensified middle Proterozoic times leading to emplacement of several cross cutting dykes in SW part of Cuddapah basin (Chatterjee and Bhattacharji, 2001). Mantle derived xenoliths of garnet-lherzolite composition were reported from this picrite body (Das Gupta, 1986). Basalt-eclogite transformation or olivine spinel transformation are the source of the basic magma emplaced in lower Cuddapahs (Bhattacharji and Singh, 1984) and these processes involve thermal boundary layer of the mantle.

Conclusions

Emplacement of the forestrite rich picrite sill along the NW-SE to NNW-SSE trending deep seated fractures within the lower Cuddapah Tadpatri sediments indicates a major phase of mantle derived Early Proterozoic magmatism contemporaneous with sedimentation within the stable intracratonic Cuddapah basin in southern Peninsular India. Conspicuous poikilitic relationship between cumulus plagioclase and olivine in picrite indicate co-precipitation of both the phases. Supercooling results in early, precumulus crystallisation of metastable, non-equilibrium plagioclase, followed by co-precipitation of cumulus plagioclase and olivine (Tegner and Wilson, 1994). Forward modeling of trace and major elements and inverse modeling of REE suggest that the primary melts that gave rise to emplacement of mafic-ultramafic sill Complex in Tadpatri Formation was generated due to partial melting of Iherzolite mantle source (Anand et al., 2003). Paleo-Proterozoic mafic-ultramafic magmatism in and around the southwestern margin of Cuddapah basin reflects the tectono-magmatic processes that have played a significant role in evolution of the Cuddapah basin and the adjacent granite-greenstone terrain to its west. Available Rb–Sr age of $1,817 \pm 24$ Ma (Bhasker Rao et al., 1995) and ^{40}Ar – ^{39}Ar laser fusion age of 1.9 Ga for the phlogopite mica from mafic-ultramafic sill complex of Tadpatri Formation (Anand et al., 2003), indicate that the deposition of sedimentary strata in the lower part of Cuddapah Super Group has commenced during Paleo-Proterozoic times.

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