Geochronological studies of Archaean metapelites from Eastern Dharwar Craton, Southern India

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Abstract* — *Isotopic age data is an important tool being utilized by the earth scientists to address timing and duration of accretionary processes, reworking, metamorphism and rate of continental growth. The main objective of this paper is to present new isotopic age data on metapelites from different localities viz., Pavagada, Bidaloti, Bandihalli and Duntur areas in the Eastern Dharwar Craton (EDC) in order to deduce the timing of metamorphism and age of the provenance.

Keywords* — *Metapelites, Eastern Dharwar Craton, Isotopic age, Metamorphism, Provenance.

I. INTRODUCTION

The cordierite bearing metapelites were first reported by *Jayaram (1912)* in Karnataka and then by *Rama Rao (1926)*. Subsequently, *Radhakrishna (1954)* reported the occurrence of these rocks from a number of localities in the vicinity of Closepet granite. *Rama Rao (1962)* who noted the peculiarities of these rocks in Bidaloti, Bandihalli, Sakarsanahalli and Kodamballi areas, and realizing their importance assigned them a separate status. Accordingly he gave these rocks and associated lithounits of the above localities a 'series' status and termed them as Bidaloti, Bandite, Sakarsanite, and Kodamite series respectively. Subsequently *Radhakrishna (1954),* categorically stated that cordierite bearing metapelites have formed as a product of "basic front" activity during the intrusion of Closepet granite (2600 m. y). *Swaminath and Ramakrishnan (1981),* on the other hand, considered these as ancient supracrustals older than Peninsular gneiss and designated them as "Sargur type".

Previous study on cordierite bearing assemblages in Satnur area (*Radhakrishna, 1954; Devaraju and Sadashivaiah , 1969; Suryanarayana, 1960; Harris and Jayaram, 1982; Mahabaleswar et al 1995; Jayananda et al., 2008a*) in southern Karnataka, proved that the cordierite bearing rocks are restricted to transition granulite facies terrain (not found in the heart of charnockite terrain further south (in B.R Hills)). However, cordierite bearing rocks have also been reported from true granulite facies terrain, e.g., in Tiruvannamalai locality of North Arcot district and Thirunelveli district of Tamilnadu and parts of Southern Kerala. These areas are now considered as part of Khondalite belt (*Chacko et al, 1987 and Hansen et al., 1987*).

With reference to the sediments of the high-grade region, only the metapelites and BIF's have been studied to some extent. While the metapelites of Sargur area have been considered as products of a bimodal provenance dominated by acid igneous rocks (*Janardhan et al., 1990*), the metapelites of Eastern Dharwar craton have been considered as products of intense weathering of a heterogenous source (*Mahabaleswar et al., 1995a*). Both these studies are silent about the environment deposition of the sediments. As these metapelites contain mineral assemblages suitable for estimating the P-T conditions of metamorphism, an attempt has been made by *Harris and Jayaram (1982)* and they obtained 690 – 730^0 C and 4.5 – 5.0 kb. However the timing of metamorphism is not established, which is crucial, since the provenance age for these metapelites is 3.1 to 3.5 Ga (*Nutman et al., 1992; Taylor et al., 1988*) and the widespread metamorphic event recorded in the Eastern Dharwar craton is 2.5 Ga (granulite facies). Would they represent a metamorphic event prior to 2.5 Ga?

The cordierite bearing metapelites in the EDC occur in areas, which are affected by upper amphibolite facies to marginal granulite facies metamorphism. However, the timing of metamorphism, which led to the formation of cordierite-anthophyllite assemblages in these metapelites, remains uncertain. Further, the levels of Closepet granite intrusion from N-S and the related metamorphism of continental crust to a certain extent can be resolved by studying the cordierite bearing assemblages.

In this context we have studied metapelites from different localities (Pavagada, Bidaloti, Bandihalli and Duntur) of the EDC and comparing their geochronological data to understand the deformation history, age of the provenance and timing of metamorphism.

II. GEOLOGICAL SETTINGS

The Eastern Dharwar Craton comprises a younger (2.7 – 2.56 Ga) TTG basement with minor old (>3.0 Ga) TTG and interlayered supracrustal rocks remnants as enclaves, few thin lengthened (2.7Ga) greenstones belts and most abundant *2.56-2.5*2 Ga N-S trending Calc-alkaline plutons (*Krogstad et al., 1991; Peucat et al., 1993; Nutman et al., 1996; Jayananda et al., 2000; Chardon et al., 2002; Moyen et al., 2003*). The most interesting of these composite plutons is 400 km long Closepet granite (*Chardon et al., 2008, Jayananda et al., 2008*). Minor sporadic bands of high grade supracrustal rocks (metapelites - Calc silicates – quartzites – amphibolite - BIF) found along the western and eastern margin of the Closepet granite. The high grade supracrustal rocks occur along the eastern margin of the Closepet confined to SW-NE trending dextral shear zones where as the supracrustals in the western margin are confined to NW-SE trending sinistral shear zones and are well exposed around Pavagada, Bidaloti, Bandihalli and Duntur areas (*Fig. 1)*. Out of these supracrustal rocks we are mainly focussed on metapelites for the current study. The Pavagada area is situated in the eastern margin of the Closepet granite (*Fig. 1)*. The studied metapelites found as NE trending bouldary exposures, with large porphyroblasts of sillimanites with relict blades of kyanites. These metapelites are weakly migmatized and injected by tiny granitic veins. Migmatization and injection of granite veins are contemporaneous as melt accumulation can be observed along shear bands. Thin film of melt found around sillimanite/Kyanite porphyroblasts indicates development sillimanite/kyanite prior to migmatization. Bidaloti area is situated in the eastern margin of the Closepet granite. The studied metapelites occur as bouldary exposures and show N 5-10^0 E trending foliation. They are dark grey coloured and show weak migmatization, where melt accumulation as thin veins along shear bands can be observed. These metapelites are injected by Closepet granite veins. The Bandihalli area is situated on the western margin of the Closepet granite. The metapelites of the area are represented by cordierite-anthophyllite-garnet-biotite schist, and biotite-quartz-schist. These are widely exposed in the southern portions of the area and are sporadic in the northern portions. The striking feature of the metapelites is that most of the minerals are well developed and also shows migmatitic character. The Duntur area forms the southern end of the Closepet granite (*Fig. 1)*. The metapelites of this area occurs as small thin bands, bouldary outcrop, are grey to bluish grey with pink tints, medium to coarse grained nature with a compositional banding.

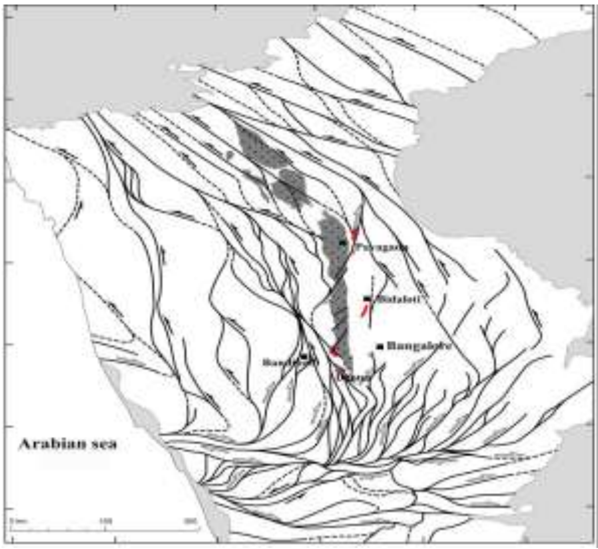

Fig. 1. Map showing studied areas along the boundary of the Closepet granite (after Chardon et al 2008).

III. GEOCHRONOLOGY

Geochronology is the science for age dating of rocks, minerals, fossils and sediments with wide applications in the earth sciences including isotope ratio measurements using accurate and precise mass spectrometric techniques. In the present study monazites from metapelites of Pavagada, Bidaloti, Bandihalli, Duntur area and zircon from metapelites of Pavagada area have been analyzed using EPMA technique at National Museum, Tokyo, Japan. EPMA technique has been successfully applied to obtain precise ages of protoliths and metamorphic processes (*Montel et al. 1996; Bindu et al. 1998; Braun et al. 1998; Biju-Shekar et al. 2002; Santhosh et al. 2003*).

Further in addition Sm-Nd garnet-whole rock age data for the metasediments (metapelites and calc silicate rocks) has been carried out at JAMSTEC, Tokyo, Japan.

We also performed Rb-Sr and Sm-Nd isotope analysis for representative whole rock samples of metapelites by using TIMS at IIT, Roorkee.

IV. ANALYTICAL TECHNIQUES

EPMA dating of monazite at National Museum, Tokyo, Japan:

The theoretical concepts of EPMA dating technique followed in this study and the equations for age computations are described in detail in *Suzuki & Adachi (1991, 1992), Montel et al. (1996) and Santosh et al. (2003).*

CHIME chemical analyses of monazite and zircon were made using an electron microprobe (JEOL JXA-

8800) at the National Science Museum, Tokyo, Japan. Sample preparation, usage of internal age standards, operating conditions and analytical techniques procedures were followed as mentioned in detail in the paper *Santhosh et al. (2005, 2006).*

Mineral-whole rock Sm-Nd Geochronology using TIMS, at IFREE, JAMSTEC, Japan.

Garnet, cordierite, orthopyroxene and a whole rock fragments were separated using the procedure of *Nakano (2002).* The Sm-Nd isotopes measurements were done using TIMS (TRITON TI®, Thermo Fisher Scientific Co., Germany) at IFREE, JAMSTEC, Japan.

Sm and Nd from garnet, cordierite, orthopyroxene and whole rock powder were extracted using the procedure of *Kagami et al. (1982, 1989).* The dissolution of garnet follows the techniques of *Hamamoto et al. (1999) and Krogh (1973).* The ^{149}Sm-^{150}Nd mixed spikes were added for isotope measurements. The $^{143}Nd/^{144}Nd$ ratios were corrected to 0.512116 for standard JNdi (Geological Society of Japan standard), which corresponds to 0.511858 of La Jolla (*Tanaka et al.1997*). Age calculations and isochrons were computed using the computer program of *Kawano (1994)* based on the equation of York (1966), with the following decay constant: $\lambda(^{147}Sm)=6.54 \times 10^{-12}\ yr^{-1}$ (*Lugmair and Marti 1978*).

The isotope compositions of garnet, cordierite, orthopyroxene and whole rock fragments were prepared for the geochronological studies. In our analyzed garnet sample, quartz only occurs as dominant inclusion and utmost care was taken during handpicking of garnets. The most contaminating materials (opaque phases) in the matrix of garnet samples were separated by using bar magnet followed by handpicking.

The Sm, Nd and isotopic ratios of the whole rock and separated minerals are presented in Table. I.

Table. I. Sm and Nd concentrations, isotopic ratios of whole rock and separated minerals.

Area	**Rock type**	**Sample No.**	**Fraction**	**Nd (ppm)**	**Sm (ppm)**	**Sm/Nd**	**$^{147}Sm/^{144}Nd$**	**1sd(%)**	**$^{143}Nd/^{144}Nd$**	**1sd(%)**	**2SE**
Pavagada	Metapelite	P-2	Garnet	55.698868	12.905596	0.231703	0.139995954	0.92	0.511563	0.001500	0.000011
		P-2	Cordierite	1.8234783	0.6094174	0.334206	0.201979908	0.92	0.512639	0.001500	0.000013
		P-2	Orthopyroxene	7.0525274	1.87358	0.2656608	0.160524601	0.92	0.511860	0.001500	0.0000008
		P-2	Whole rock	23.728745	6.4941285	0.2736819	0.165375566	0.92	0.511968	0.001500	0.0000008
Bidaloti	Calc-Silicate rock	BID-8	Garnet	4.7494559	11.397909	2.3998348	1.457297917	0.92	0.532936	0.001500	0.000012
		BID-8	Whole rock	8.3519239	3.600656	0.431117	0.260594721	0.92	0.513387	0.001500	0.000010
Bandihalli	Metapelite	BHA-16	Garnet	12.375801	3.0356297	0.2452875	0.148202949	0.92	0.511540	0.001500	0.000011
		BHA-16	Whole rock	40.224315	8.1861756	0.2035131	0.12295103	0.92	0.511134	0.001500	0.000011
Bandihalli	Calc-Silicate rock	BHA-21	Garnet	1.806846	3.3137453	1.8339943	1.112299707	0.92	0.527609	0.001500	0.000018
		BHA-21	Whole rock	2.219875	0.823298	0.3708759	0.224179172	0.92	0.513350	0.001500	0.000015
	Standard	Jndi-1-1							0.512091		0.0000007
	Standard	Jndi-1-2							0.512088		0.0000009
	Standard	JB-1a							0.512745		0.0000008

Whole rock Rb-Sr and Sm-Nd isotopic analysis using TIMS at IIT, Roorkee.

The whole rock Rb-Sr, Sm-Nd isotopic measurements were done using TIMS at IIT, Roorkee. The sample weighing and dissolution, spiking and centrifuging, ion exchange chromatography, filament welding and degassing, sample loading and mass spectroscopic analysis were done using the procedure mentioned in the paper Mahesha (2018).

The whole rock Rb-Sr and Sm-Nd isotope analysis data of studied metapelites is presented in Table. II and Table. III. T_{DM} Nd model ages of the studied metapelites are presented in table IV.

Table. II. Rb-Sr isotopic data of studied metapelites.

Area	**Sample ID**	**Rb ppm**	**Sr ppm**	**$^{87}Rb/^{86}Sr$**	**Error in X**	**$^{87}Sr/^{86}Sr$**	**Error in Y**	**Lambda L*t**	**Exp(Lt)-1**	**($^{87}Rb/^{86}Sr$)*(Exp(Lt)-1)**	**($^{87}Sr/^{86}Sr)_i$**
Pavagada	P-01	37.309	159.192	0.6805		0.743468	0.000080	0.042600	0.043520	0.029616	0.713852
Pavagada	P-10	53.637	130.923	1.1918		0.761666	0.000060	0.042600	0.043520	0.051868	0.709798
Pavagada	P-11	17.608	182.996	0.2798		0.758391	0.000020	0.042600	0.043520	0.012177	0.746214
Pavagada	P-15	39.081	4.610	2.4912		0.826993	0.000060	0.042600	0.043520	0.108418	0.718575
Pavagada	P-16	43.851	125.868	1.0117		0.746692	0.000060	0.042600	0.043520	0.044030	0.702662
Pavagada	P-18	28.404	85.997	0.9601		0.760999	0.000010	0.042600	0.043520	0.041784	0.719215
Bidaloti	BID-02	23.185	3.350	21.1806		1.668478	0.000030	0.042600	0.043520	0.921788	0.746690
Bandihalli	BHA-01	14.738	121.427	0.3517		0.720577	0.000010	0.042600	0.043520	0.015306	0.705271
Bandihalli	BHA-07	17.807	3.487	15.7054		1.436985	0.000030	0.042600	0.043520	0.683505	0.753480
Duntur	KOD-5	54.421	73.493	2.1640		0.804485	0.000076	0.042600	0.043520	0.094178	0.710307

Table. III. Sm-Nd isotopic data of studied metapelites.

Area	**Sl. No**	**Sm ppm**	**Nd ppm**	**Sm /Nd**	**(147Sm/144Nd)p**	**(143Nd/144Nd)p**	**lambda (L)**	**t (yr)**	**L.t**	**e^L.t**	**(e^L.t - 1)**	**(147Sm/144Nd)p *(e^L.t - 1)**	**(143Nd/144Nd)t**	**Ep. Nd (T=0)**	**Ep. Nd T=3.0Ga**
	Cho. Avg.				0.1967	0.512638	6.54E-12	3000000000	0.01962	1.019813737	0.019813737	0.003897362	0.508741	0	0.0
Pavagada	P-01	3.01	14.31	0.2103	0.1272	0.51109	6.54E-12	3000000000	0.01962	1.019813737	0.019813737	0.002520307	0.508570	-30.19675	-3.4
Pavagada	NAG-01b	3.54	17.27	0.2050	0.1239	0.511079	6.54E-12	3000000000	0.01962	1.019813737	0.019813737	0.002454922	0.508624	-30.41132	-2.3
Bidaloti	BID-05	1.72	6.46	0.2663	0.1614	0.511724	6.54E-12	3000000000	0.01962	1.019813737	0.019813737	0.003197937	0.508526	-17.82935	-4.2
Bandihalli	BHA-07	4.54	21.14	0.2148	0.1299	0.511206	6.54E-12	3000000000	0.01962	1.019813737	0.019813737	0.002573804	0.508632	-27.93394	-2.1
Duntur	D-01	5.95	28.12	0.2116	0.128	0.511151	6.54E-12	3000000000	0.01962	1.019813737	0.019813737	0.002536158	0.508615	-29.00682	-2.5

Table. IV. T_{DM} Nd model ages of studied metapelites.

Area	Sample ID	Nd ppm	Sm ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	Error Y	T_{DM} Ga
Pavagada	P-01	14.31	3.01	0.1272	0.51109	0.000002	3.56
	NAG-01b	17.27	3.54	0.1239	0.511079	0.000007	3.45
Bidaloti	BID-09	11.71	2.35	0.1213	0.510773	0.000005	3.6
Bandihalli	BHA-07	21.14	4.54	0.1299	0.511206	0.000007	3.47
Duntur	D-01	28.12	5.95	0.128	0.511151	0.000001	3.49

Several studied metapelites samples show anomalous $^{87}Rb/^{86}Sr$ values and initial $^{87}Sr/^{86}Sr$ values probably due to alteration of Rb/Sr ratios during metamorphism. Once Rb/Sr ratios were altered results in the anamolous values in $^{87}Rb/^{86}Sr$ ratios and consequently these values do not provide any precise information on provenance, but reflect Rb mobility during metamorphism or contemporaneous magmatic accretion.

Compared to Rb-Sr isotope system, Sm-Nd isotope system is more robust as Nd is less mobile. Thus Sm-Nd system can be used to evaluate the history of provenance. Several samples show anomalous Nd model ages probably due to anomalous Sm/Nd ratios developed due to the growth of minerals like garnet during metamorphism.

V. RESULT AND CONCLUSION

The outcomes of isotopic data of the studied metapelites and clac-silicate rocks from different localities viz., Pavagada, Bidaloti, Bandihalli and Duntur were discussed in the following paragraphs.
Pavagada area: Electron microprobe dating of detrital zircons in metapelites from Pavagada area (multipeak Gauss Fitting of weighted histogram for zircon ages) indicate ages as old as 3505±494Ma (Fig. 2) for provenance, whilst monazite indicate two distinct thermal events at 3161±74Ma and 2518±23 Ma (Fig. 3). Further the garnet bearing metapelites gives a Sm-Nd garnet whole rock isochron age of 2639±190 Ma (Fig. 4). Whole rock Sm-Nd data gives negative εNd values -2.3 to -3.4 at 3.0 Ga (Table. III) with T_{DM} Nd modal ages ranging from 3.45 to 3.56 Ga (Table. IV). Depleted mantle model (εNd value at 3.0 Ga) indicates that the provenance of Pavagada has extended crustal history prior to 3.0Ga, possibly sources differentiated from depleted mantel during 3.5-3.6 Ga.

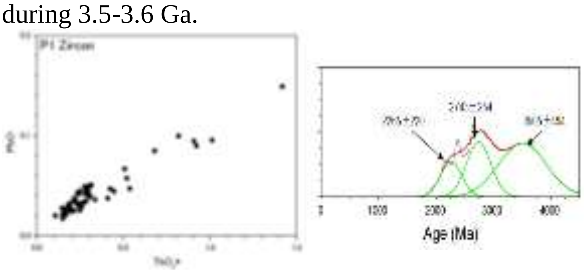

Fig. 2. Multipeak Gauss fitting of weighted histogram for Zircon ages of metapelite from Pavagada area.

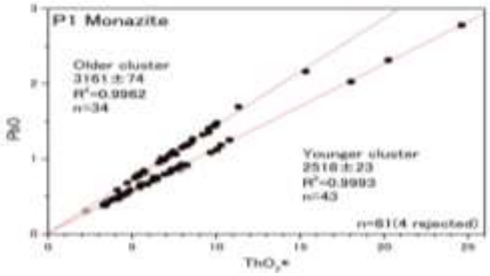

Fig. 3. Monazite age of Pavagada area metapelite.

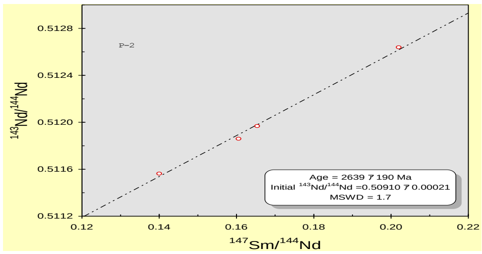

Fig. 4. Sm-Nd garnet-whole rock isochron of Pavagada area metapelite.

Bidaloti area: The Monazites generally anhedral and are found in the matrix of metapelite and yield an age of 2550±33Ma (Fig. 5). These ages are older than Closepet granite emplacement age. The Sm-Nd garnet whole rock isochron ages of Calc-silicate rocks define an age of 2478±55Ma (Fig. 6). Whole rock Sm-Nd data gives negative εNd value of -4.2 at 3.0 Ga (Table. III) with T_{DM} Nd modal age of 3.60 Ga (Table. IV). Depleted mantle model (εNd value at 3.0 Ga) indicates that the provenance of Bidaloti metapelite has extended crustal history prior to 3.0 Ga, possibly sources differentiated from depleted mantle during 3.5-3.6 Ga.

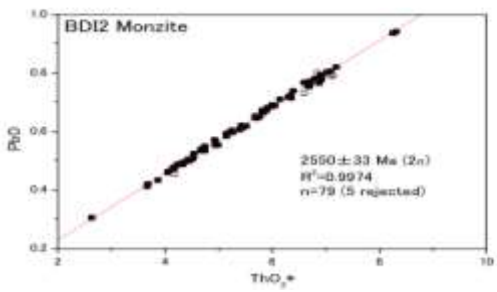

Fig. 5. Monazite age of Bidaloti area metapelite.

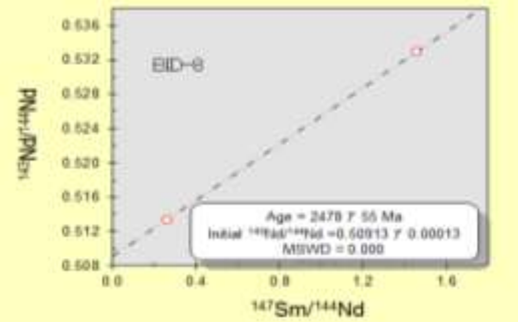

Fig. 6. Sm-Nd garnet-whole rock isochron age of Bidaloti area Calc-silicate rock.

Bandihalli area: Anhedral monazite found in the matrix of metapelites indicates an age of 2549±36Ma (Fig. 7), which is older than Closepet granite emplacement age, while Sm-Nd garnet-whole rock isochron indicate an age of 2439±360Ma (Fig. 8). Sm-Nd garnet whole rock isochron of Calc-silicates also indicate an age of 2435±56Ma (Fig. 9) which corresponds to a cooling stage. Whole rock Sm-Nd data gives negative εNd value of -2.1 at 3.0 Ga (Table. III) with T_{DM} Nd modal age of 3.47 Ga (Table. IV). Depleted mantle model (εNd value at 3.0 Ga) indicates that the provenance of Bandihalli metapelite has shorter crustal history prior to 3.0Ga, possibly sources differentiated from depleted mantle during 3.3-3.4 Ga.

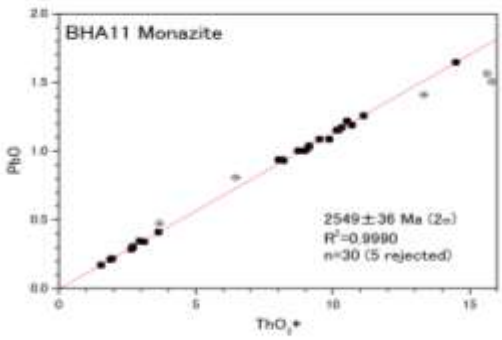

Fig. 7. Monazite age of metapelite (Pavagada area).

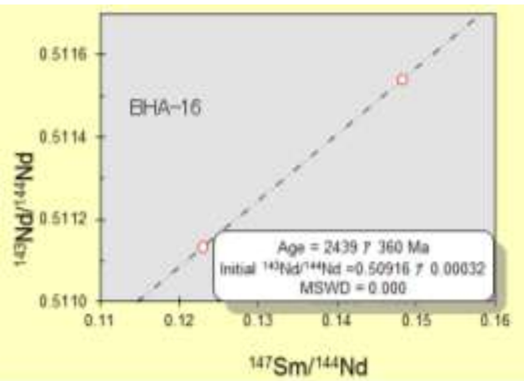

Fig. 8. Sm-Nd garnet-whole rock isochron of Bandihalli area metapelite.

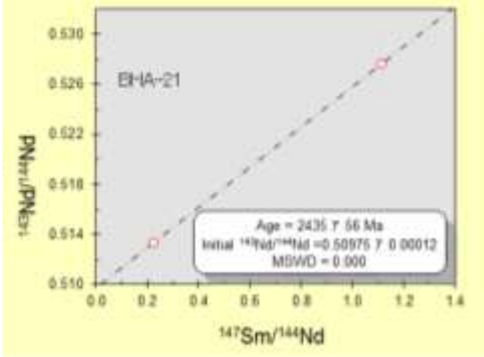

Fig. 9. Sm-Nd garnet-whole rock isochron age of Bandihalli area Calc-silicate rock.

Duntur area:
Electron microprobe dating of anhedral monazite found in the matrix of metapelite indicates an age of 2571±37 Ma (Fig. 10), which is older than Closepet granite emplacement age. Whole rock Sm-Nd data gives negative εNd value of -2.5 at 3.0 Ga (Table. III) with T_{DM} Nd modal age of 3.49 Ga (Table. IV). Depleted mantle model (εNd value at 3.0 Ga) indicates that the provenance of Duntur metapelite has shorter crustal history prior to 3.0Ga, possibly sources differentiated from depleted mantel during 3.3-3.4 Ga.

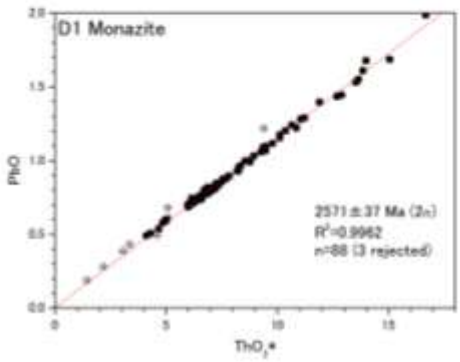

Fig. 10. Monazite age of Duntur area metapelite.

Conclusions

1. There is a record of older age population of 3.16Ga in the monazite of Pavagada metapelites may correspond to either ~ 3.1Ga thermal event or detrital monazite from TTG in the EDC.
2. The monazites of Bidaloti, Bandihalli and Duntur area do not documented the older ages and the ages given by them are 2.57-2.55 Ga. Since these ages are older than the Closepet granite emplacement age, they may correspond to cooling or exhumation of metapelites from deeper crustal levels.
3. Electron microprobe dating of detrital zircons in metapelites from Pavagada area (multipeak Gauss Fitting of weighted histogram for zircon ages) indicate ages as old as 3505±494Ma for the provenance.
4. The negative εNd values at 3.0 Ga with TDM Nd model ages ranging from 3.4 to 3.6 Ga obtained for the studied metapelites of Eastern Dharwar

Craton are in contrast to the earlier view that the EDC is formed mainly in late Archaean (Chadwick et al., 2000).

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