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Geochronology of the Polycyclic Granulite Terrain of The Eastern Ghats Mobile Belt: An Overview

Saurabh Singh, Rajeev Kumar Pandey✉, Divya Prakash and Chandra Kant Singh

Department of Geology, Banaras Hindu University, Varanasi-221005
✉rajeev21pandey@gmail.com

Abstract: **The Eastern Ghats Mobile Belt is dominantly characterized by the granulite facies of high-grade metamorphic rocks lying along the eastern coast of the Indian subcontinent. These polycyclic high-grade rocks include several blocks bounded by faults in the northern margin and a prominent shear zone towards the western margin. Recent imputes made in the EGMB proclaim various smaller domains characterized by their distinct tectono-metamorphic evolutions. However, the correlation made between the various metamorphic and tectonic events with respect to their geochronologic ages still lack solid results. As such, we contemplate to impart an overview based on the observations made from the available isotopic data of the Eastern Ghats Mobile Belt.**

Index Terms: **Eastern Ghats Mobile Belt, Geochronology, Granulites, High-grade Rocks, Tectonic events.**

I. INTRODUCTION

The globally dispersed mobile belts provide a strong evidence of the ever-changing configuration of the continents corresponding to the drifting and suturing of the various land masses since ancient geological times (Condie, 2005). The Eastern Ghats Mobile Belt (EGMB) is one such mobile terrain that has attracted workers from across the world for its unusual assemblages and anomaly in their isotopic ages on both local and regional scale. These anomalies in the isotopic ages of the different provinces and localities of EGMB may be attributed to the various thermal and tectonic events that have occurred in the geologic past of the Earth's history.

The Eastern Ghats, being typical example of a mobile belt from India (fig. 1), comprises high grade metamorphic rocks of granulite facies striking NE-SW over its major part. This trend of the strike changes slowly to N-S towards the southern margin. At the northern margin the strike trend shifts from ESE-WNW to almost E-W trend (Mukhopadhyay and Basak, 2009). The polycyclic tectonic and metamorphic events have taken place in the geological history of the EGMB ranging in age from as early as Palaeoproterozoic (Rickers et al., 2001) to the beginning of the Palaeozoic Era (Simmat and Raith, 2008). Occurrences of the fragments of Archaean crust have also been suggested by Grew and Manton (1986).

Extensive study of the EGMB has been done on the petrological and geochronological aspects since last two to three decades that has set the background for understanding the mechanisms involved in the tectono-metamorphic evolution of the EGMB, though few limitations still prevail. Hence this communication renders an overview of the present state of knowledge on the EGMB.

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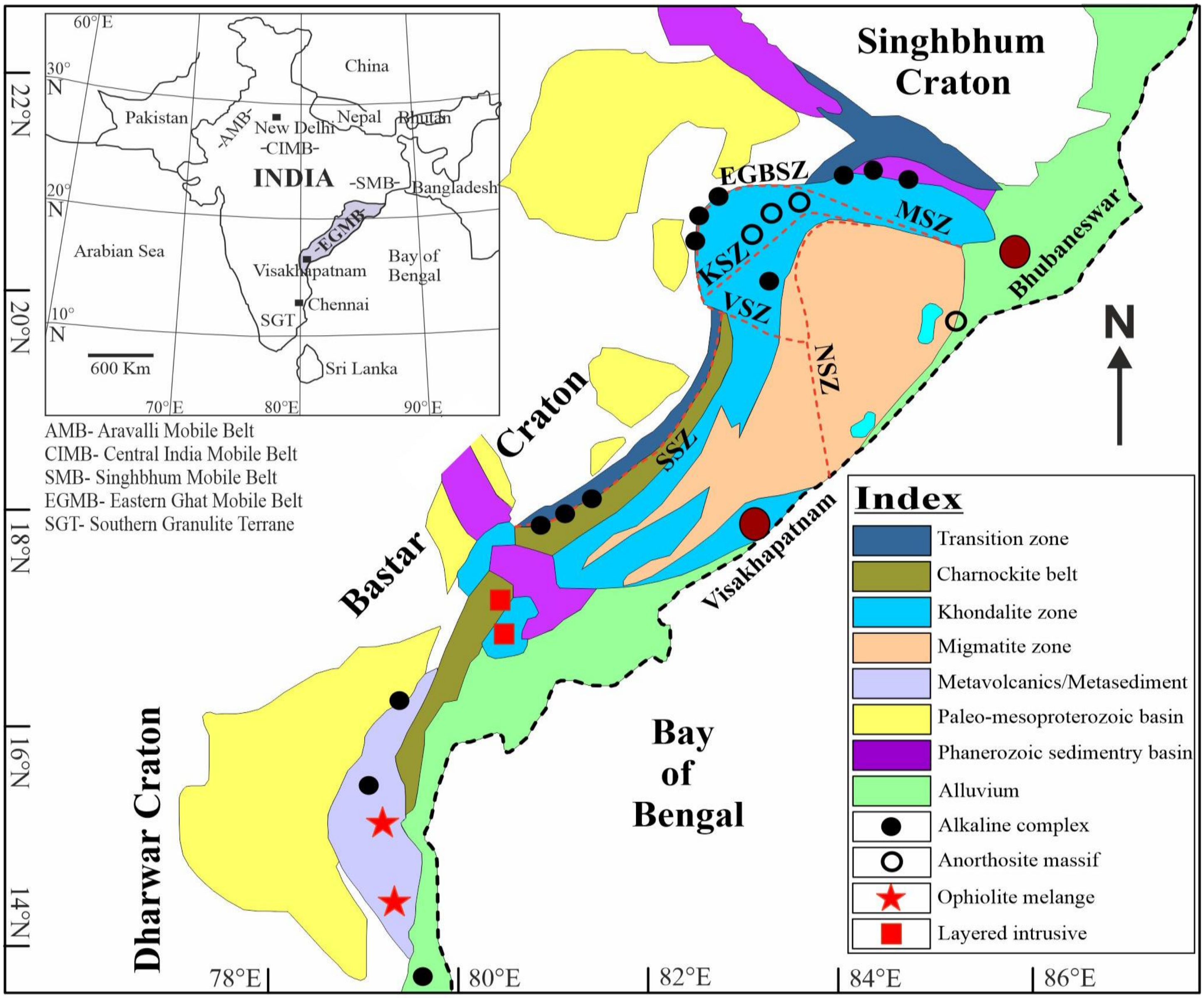

Fig. 1. Regional map of the Eastern Ghats Mobile Belt showing broad lithological associations and major shear zones after Ramakrishnan et al. (1998) and Chetty and Murthy (1994). Abbreviations used are MSZ – Mahanadi Shear Zone, VSZ – Vamshadhara Shear Zone, NSZ – Nagavalli Shear Zone, SSZ – Sileru Shear Zone, KSZ – Koraput-Sonepur Shear Zone, and EGBSZ – Eastern Ghats Boundary Shear Zone.

II. Metamorphic Facies and P-T Estimates

The metamorphic terrain of the EGMB consists of both low grade and high grade of rock assemblages. The Nellore - Khammam schist belt in the southern portion of the EGMB is dominated by the low-grade rocks of green schist facies like phyllite, quartzite, chlorite schist, meta-volcanics (Vasudevan & Rao, 1975). Some occurrences of rocks of the amphibolite facies are also found near Khammam area. These facies, the greenschist facies and the amphibolite facies, are separated by a fault of oligomictic conglomerate (Vasudevan and Rao, 1975) showing a sharp-break in the grade of metamorphism at the basal part of the younging greenschist facies.

The northern portion of the EGMB is mainly characterized by the high-grade rocks of granulitic terrain. These granulite facies of rocks are comprised of mainly the charnockite formation, khondalite formation and the migmatized rocks at places (Murthy et al., 1971). The charnockite present along with the associated enderbites and mafic granulite record in them garnet-pyroxene-plagioclase-quartz assemblages representing high temperature and high pressure at various localities (Mohan et al., 1997). Further the estimated P-T condition also shows Isothermal Decompression (ITD) path and Isobaric Cooling (IBC) trajectory from the recorded mineral assemblages (Mohan, 1995). The high Mg-Al granulites of these terrain records orthopyroxene – sillimanite – sapphirine – kornerupine assemblage (Dasgupta, 1995), insisting the temperature to be in between 800-850°C and pressure ranging from 6-10 kbar. In some parts of Mg-Al rich granulites from the EGMB, the peak P-T constraints estimated using conventional geothermobarometers corresponds to the Ultra High Temperature (temperature in excess of 950°C and pressure above 9 kbar) metamorphism (Lal et al., 1987; Prakash et al., 2017c).

III. Structural Framework

The EGMB, strategically occupies a major portion on the eastern coast of the Indian sub-continent, is a curvilinear mobile belt having width of about 60 km and length of more than 700 km. The greenschist and amphibolite facies rocks in the southern part of EGMB strikes NNW-SSE to NNE-SSW. Earlier workers Natarajan & Nanda (1981) and Sriramdas & Rao (1979) postulated that the granulitic terrains of Vishakhapatnam domain striking NE-SW and dipping towards SE had undergone at least two phases of deformation. The first generation of isoclinal fold (F1) identified plunges NE and is overturned in the northern part of Visakhapatnam to NW. Sriramdas and Rao in 1979 also suggested that this fold (F1), due to the superimposition of cross-fold F2 along NW-SE, is overturned from NE-SW to E-W. Now the folds (F2) is hypothesized to result from the rotation of the fold axis due to the progressive simple shearing (Bhattacharya, 1989).

Since the polycyclic EGMB possesses imprints of multiple phases of deformation, the third episode of deformation is recorded as an upright open fold with roughly horizontal axis. The third generation of folding (F3) was recognized as the consequence of the migmatization process in the eastern portion of the EGMB (Bhattacharya, 1994). The last tectonic imprints resulting in fourth phase deformation was dominated by the shearing and fracturing of the rocks trending WNW and NNE (Sarkar et al., 1981). The parallel orientations of the layered lithology and the foliation trends is hence attributed to the isoclinal folding in the EGMB.

IV. Stratigraphy and Lithology

Preliminary workers including Blankford (1858) and King (1886) had extensively studied the stratigraphy of the eastern portion of the Indian subcontinent. At the onset of the 20th century, Walker (1902) gave a new term "Khondalite" for a gneissic rock containing garnet and sillimanite irrespective of the presence of graphite in it. Later in 1990, Holland also coined a term ‘charnockite’ for hypersthene-granite from a type locality in Chennai and charnockite series for differentiated igneous suite of hypersthene bearing rock. The event stratigraphy of the EGMB given after Ramakrishnan et al. (1998) and Ramakrishnan & Vaidyanadhan (2008) has been summarized in the table below.

Table-1: Stratigraphic succession of the of the Eastern Ghats mobile belt.

Age (Ma)	Events and Lithology
550–650	Exhumation and stabilisation (=Pan-African)
800–850	Emplacement of anorthosite massifs, some alkaline rocks (?), Younger granitoids and charnockites
950–1100	Main Eastern Ghats orogeny (= Grenville), Khondalite Group, Garnet-sillimanite-graphite gneiss (khondalite) with minor cordierite sapphirine-spinel gneiss (Mg-Al gneiss), Calc-silicate rocks and rare marbles Quartzite (garnet ± sillimanite)
~1500	Emplacement of alkaline rocks along the rift margins
1800–2600	Evolution of platform (Purana) basins like Cuddapah, Chhattisgarh, Indravati etc. Evolution of Nellore-Khammam schist belt in Dharwar craton
2600–2800	Charnockites and gneisses of the basement (WCZ)

On the basis of the dominant lithologies in the EGMB, Nanda & Pati (1989) and Ramakrishnan et al. (1998) gave on integrated map which is longitudinally divided into four zones from west to east which are as follows:

1. Western Charnockite Zone
2. Western Khondalite Zone
3. Central Migmatite Zone
4. Eastern Khondalite Zone

In the western part of the EGMB, the transition (shear zone) demarcates the boundary between the Bastar Craton and the EGMB (Narayanaswami, 1975). In 2001, Crowe et al. suggested a distinct transitional zone called the Kerajang Fault towards the northern boundary of the granulitic terrain of EGMB and separating it from the amphibolite facies rocks present in the shear zone, bringing the EGMB into juxtaposition with the Singhbhum Craton.

V. Geochronological Evolution

On the basis of the observations made in the field and the petrographic studies of the varying rock types in the EGMB, three major events of metamorphism and deformations have been recognized by several workers (Paul et al., 1990; Mezger & Cosca, 1999; Bose et al., 2021). The first metamorphic event (M1) marks the metamorphism of the pre-existing supracrustal rocks to high grade granulite facies of rocks which is further extended to an extent of ultra-high temperature metamorphism at places in the EGMB documented by the stable co-existence of sapphirine-spinel-quartz mineral assemblages. The second phase of the tectonometamorphic event (M2) was marked by the intrusions of voluminous enderbitic charnockites which also underwent the granulite facies of metamorphism on a regional scale and is a widely recognized tectonothermal event in the EGMB. The second event was succeeded by the vast granitic and anorthosite intrusions showing related deformational feature like tensional fissures along with the overprints of metamorphism in them.

The Godavari Rift in the southern portion of the EGMB divides it into two unequal parts of which the northern segment is dominated by the events that occurred around 1000 & 500 Ma, while the southern segment records a major tectonothermal event at about 1600 Ma (Mezger & Cosca, 1999).

Several workers in the past, has reported the major tectonothermal metamorphic event (M2) that led to the formation of significant portions of the granulitic terrain in the EGMB to have occurred around 950-1000 Ma (Grew & Manton, 1986; Mezger & Cosca, 1999; Bhattacharya et al., 2003; Das et al., 2011). This metamorphic event M2, in the northern portion of the EGMB, can be well co-related globally with the Grenvillian orogeny at 1000 Ma and is characterized by the steep decompression P-T path (Bose et al., 2000). Hence, the event M2 can be held responsible for the exhumation of the granulites at 950 – 1000 Ma. Further, the metamorphic event M2 in the EGMB is coeval with that of the tectonothermal history of the Rayner complex in the Eastern Antarctica and so it plays a vital role in the re-construction of the Gondwana assembly.

Mezger and Cosca (1999) reported U-Pb cooling ages for the minerals allanite and monazite to be 1600 Ma and 1672±4 Ma respectively, apparently documents the Pre-Grenvillian metamorphism of rocks to the granulite facies in the EGMB. Dharma Rao et al. (2012) have also reported 1634 ± 18 Ma event through Pb-Pb method from the Kondapalle in EGMB.

Older ages corresponding to 2300 to 3000 Ma have also been proposed by a few workers (Paul et al., 1990; Rickers et al., 2001; Bose et al., 2016 & 2021) suggesting that the orogenic belt of the EGMB also incorporates material from the Archaean times that has been reworked and admixed with the juvenile material of the Proterozoic ages, although further characterization of these older rocks has become important to obtain a clear picture of the events that encountered during the Archaean.

In recent years, several workers reported the last thermal event in the EGMB and co-related it with the Pan-African orogeny that occurred at around 500-550 Ma (Mezger & Cosca, 1999; Upadhyay et al., 2006a; Sarkar et al., 2014; Ravikant et al., 2019; Bose et al., 2021). The radiometric dating of the various events has been done by several workers from across the EGMB and is summarized in Table-2.

From the Geochronological study of the available data, it is evident that the various episodes of tectonothermal activities have influenced significantly in shaping the present structure of the EGMB, as such the modern and systematic isotopic study is of key importance and has to be competently pursued in detail from time to time.

The geochronology of the EGMB can be well correlated with that of the Southern Granulite Terrain (SGT) and the Eastern Dharwar craton as similar ages attributing to the reworking of the metapelites from Madurai section of the SGT have been reported during the Pan-African time which were accreted in the Paleoproterozoic period (Prakash et al., 2010; Brandt et al., 2014). And the Jagtiyal granulites from the Eastern Dharwar craton renders zircon ages having Th/U ratios between 0.16 - 0.73 with upper and lower intercepts at 2604 ± 27 Ma and 638 ± 65 Ma respectively (Prakash et al., 2017c) also falls in close correlation with the discussed geochronology of the EGMB which depicts the regional impact of the tectonic and thermal events in the peninsular portion of the Indian subcontinent.

Table-2: Radiometric dating of rocks of the granulite facies from across the Eastern Ghats Mobile Belt.

Sl. No.	Area	Method	Rock Type	Radiometric dates (Ma)	Author (References)
1	Visakhapatanam	Sm-Nd, Model age, Whole rock U-Pb date of Zircon& sphene U-Pb age in Zircon	Basic granulites, Charnockites, Zircon from apatite magnetite veins Charnockite-Zircon	2860, 2600 & 2350 516 ± 1 979	Paul et al., 1990 Mezger and Cosca, 1999 Grew & Manton, 1986
2	Anakapalle	U-Pb, lower intercept on Concordia	Zircon from Charnockites	979 & 500	Grew & Manton, 1986
3	Angul	U-Pb Concordia	Calc silicate rock-Titanite	504±20 to 935±25	Mezger & Cosca, 1999
4	Chilka Lake	Rb-Sr Whole Rock Pb-Pb Zircon	Xenoliths of Khondalite in anothosite Patchy Charnockite	1388 ± 22 943	Sarkar et al., 1981 Bhattacharya et al., 2002
5	Phulbani	U-Pb concordia-discordia plot	Zircon&Monazite from Charnockite	985 – 965	Paul et al., 1990
6	Godawari graben (South)	Sm-Nd model age	Orthogenesis Metasediments	2300 & 2500 2600 & 2800	Rickers et al., 2001
7	Panirangini	U-Pb Zircon SHRIMP II	Monazite grains from orthoyroxene and sapphirine porphyroblast	1700 – 900	Das et al., 2011
8	Paderu	$^{207}Pb/^{206}Pb$ Concordant U-Pb Upper intercept	Sapphirine granulite monazite	900 – 988 ± 18	Bhattacharya et al., 2003
9	Nellore	U-Pb Zircon	Ophiolite Emplacement	1330	Dharma Rao et al., 2011a

10	Khariar Alkaline complex	$^{207}Pb/^{206}Pb$ age of sphene SHRIMP U-Pb on Zircon	Nepheline syenite- Titanite Alkaline Igneous pluton	593 517	Upadhyay et al., 2006a Biswal et al., 2007
11	Pangidi Kondapalle Complex	$^{207}Pb/^{206}Pb$ Zircon	Anorthosites and Gabbronorites	1634 ± 18	Dharma Rao et al., 2012
12	Ongole Domain	Monazite U-Pb-Th U-Th-total Pb Mnz EPMA	Granite emplacement Charno-enderbites	1650 & 1550 510	Simmat & Raith (2008) Sarkar et al., 2014
13	Rengali province	Zircon U-Pb Zircon U-Pb Monazite	Granitoid Emplacement Khariar Alkaline complex Rengali paragenesis	2776 ± 24 1370 – 1320 2943 ± 35	Bose et al., 2016 Ranjan et al., 2018 Bose et al., 2021
14	Bolangir	Garnet Sm-Nd Zircon U-Pb	Granulites Monzodiorite	500 – 475 490 ± 3	Ravikant, 2019 Bose et al., 2021

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References

Bhattacharya, S. (1989). Ductile shear zone in Purulia, West Bengal. *Indian Journal of Geology*, 61(3), 172-178.

Bhattacharya, S., & Kar, R. (2002). High temperature dehydration melting and decompressive P-T path in a granulite complex from the Eastern Ghats, India. *Contrib Min Petrol*, 143, 175–191.

Bhattacharya, S., Kar, R., Teixeira, W., Basei, M. (2003). High-temperature crustal anatexis in a clockwise P-T Path: isotopic evidence from a granulite-granitoid suite in the Eastern Ghats Belt, India. *Journal of Geological Society of London*, 160(1), 39–46.

Bhattacharya, S., Sen, S.K., Acharyya, A., (1994). The structural setting of the Chilka Lake granulites–migmatite–anorthosite suite with emphasis on the time relation of charnockites. *Precambrian Research*, 66, 393–409.

Blankford, H. F. (1958). Pressure-temperature time path and a tectonic model for the evolution of granulites. *Journal of Geology*, 95, 617-632.

Bose, S., Das, K., Kimura, K., Hidaka, H., Dasgupta, A., Ghosh, G., Mukhopadhyay, J. (2016). Neoarchean tectonothermal imprints in the Rengali Province, eastern India and their implication on the growth of Singhbhum:

Bose, S., Ghosh, G., Kawaguchi, K., Das, K., Mondal, A. K., & Banerjee, A. (2021). Zircon and Monazite Geochronology from the Rengali-Eastern Ghats Province: Implications for the Tectonic Evolution of the Eastern Indian Terrane. *Precambrian Research*, 355, 106080.

Bose, S., Fukuoka, M., Sengupta, P., Dasgupta, S. (2000). Evolution of high Mg-Al granulites from Sunkarametta, Eastern Ghats, India: evidence for a lower crustal heating-cooling trajectory. *Journal of Metamorphic Geology*, 18, 223–240.

Brandt, S., Raith, M. M., Schenk, V., Sengupta, P., Srikantappa, C., & Gerdes, A. (2014). Crustal evolution of the Southern

DOI: 10.37398/JSR.2022.660104

Granulite Terrane, south India: New geochronological and geochemical data for felsic orthogneisses and granites. *Precambrian Research*, 246, 91-122.

Candie, K. C. (2005). High field strength element ratios in Archean Basalt: A window to evolving sources of mantle plumes? *Lithos*,79 (3-4) ,491-504

Chetty, T. R. K., & Murthy, D. S. N. (1994). Collision tectonics in the late Precambrian Eastern Ghats Mobile Belt: mesoscopic to satellite-scale structural observations. *Terra Nova*, *6*(1), 72-81.

Crowe, W. A., Cosca, M. A., & Harris, L. B. (2001). 40Ar/39Ar geochronology and Neoproterozoic tectonics along the northern margin of the Eastern Ghats belt, in north Orissa, India. *Precambrian Research.*, 108, 237–266.

Das, K., Bose, S., Karmakar, S., Dunkley, D. J., & Dasgupta, S. (2011). Multiple tectonometamorphic imprints in the lower crust: first evidence of ca. 950 Ma (zircon U-Pb SHRIMP) compressional reworking of UHT aluminous granulites from the Eastern Ghats Belt, India. *Geological Journal*, 46(2-3), 217-239.

Dasgupta, S., Sengupta, P., Ehl, J., Raith, M., & Bardhan, S. (1995). Reaction textures in a suite of spinel granulites from the Eastern Ghats Belt, India: evidence for polymetamorphism, a partial petrogenetic grid in the system KFMASH and the roles of ZnO and Fe2O3. *Journal of Petrology*, *36*(2), 435-461.

Dharma Rao, C.V., Santosh, M., Purohit, R., Wang, J., Jiang, X., & Kusky, T. (2011a). LA-ICP-MS U-Pb 2510 zircon age constraints on the Paleoproterozoic and Neoarchean history of the Sandmata Complex 2511 in Rajasthan within the NW Indian Plate. *J Asian Earth Sci*, 42, 286–305.

evidence from zircon U–Pb SHRIMP data. *Journal of Metamorphic Geology*, *34*(8), 743-764.

Grew, E. S., & Manton, W. I. (1986). A new correlation of sapphirine granulites in the Indo-Antarctic metamorphic terrain: Late Proterozoic dates from the Eastern Ghats province of India. *Precambrian Research*, *33*(1-3), 123-137.

Holland, T. H. (1990). The Charnockite series: A group of Archaean hypersthene rocks in Peninsular India. *Memoir Geological Survey of India*, 28(2).

King, W. (1886). Geological sketch of Vishakhapatnam district, Madras. *Rec. Geological Survey of India*, 19(3), 143-156.

Lal, R. K., Ackermand, D., & Upadhyay, H. (1987). PTX Relationships Deduced from Corona Textures in Sapphirine—Spinel—Quartz Assemblages from Paderu, Southern India. *Journal of Petrology*, *28*(6), 1139-1168.

Mezger, K., & Cosca, M. A. (1999). The thermal history of the Eastern Ghats Belt (India) as revealed by U-Pb and 40Ar/39Ar dating of metamorphic and magmatic minerals: implications for SWEAT correlation. *Precambrian Research*, 94, 251–271.

Mohan, A. (1995). Petrogenesis of Metamorphic Rocks. *Journal of Geological Society of India*, *45*(5), 618-619.

Mohan, A., Tripathi, P., & Motoyoshi, Y. (1997). Reaction history of sapphirine granulites and a decompressional PT path in a granulite complex from the Eastern Ghats. *Proceedings of the Indian Academy of Sciences-Earth and Planetary Sciences*, *106*(3), 115-129.

Mukhopadhyay, D., & Basak, K. (2009). The Eastern Ghats Belt: A polycyclic granulite terrain. *Journal of the Geological Society of India*, *73*(4), 489-518.

Murthy, M. V. N., Viswanathan, T. V., & Chowdhery, R. S. (1971). The Eastern Ghats Group, Rec. *Geol. Surv. Ind.*, 101, 15 – 42.

Nanda, J. K., & Pati, U. C., (1989). Field relation and petrochemistry of the Granulites and associated rocks in the Ganjam-Koraput sector of the Eastern Ghats Belts. *Ind. Mineral*, 43, 247-264.

Narayanaswami, S. (1975). Oroposal for charnockite-khondalite and Sargur-Nellore-Khamman-Bengpal-Deogarh-Pallahare-mahagiri rock groups-older than Dharwar type greenstone belts in the Peninsular Archaeans. *India. Mineral*, *16*, 16-25.

Natarajan, V., & Nanda, J. K. (1981). Large Scale Basin and Dome Structures in the High Grade Metamorphics, Near Visakhapatnam, South India. *Journal of Geological Society of India*, *22*(12), 584-592.

Paul, D. K., Barman, T. K. R., McNaughton, N. J., Fletcher, I. R., Pottes, P. J., Ramakrishnan, M., & Augustine, P. F. (1990). Archean-Proterozoic evolution of Indian Charnockites: Isotopic and geochemical evidence from granulites of Eastern Ghats Belt. *J. Geol.*, 98, 253–263.

Prakash, D. (2010). New SHRIMP U-Pb zircon ages of the metapelitic granulites from NW of Madurai, Southern India. *Journal of the Geological Society of India*, 76(4), 371-383.

Prakash, D., Singh, P. C., Tewari, S., Joshi, M., Frimmel, H. E., Hokada, T., & Rakotonandrasana, T. (2017c). Petrology, pseudosection modelling and U-Pb geochronology of silica-deficient Mg-Al granulites from the Jagtiyal section of Karimnagar granulite terrane, northeastern Dharwar Craton, India. *Precambrian Research*, *299*, 177-194.

Ramakrishnan M., Nanda, J.K., Augustine, P.F. (1998). Geological evolution of the Proterozoic Eastern Ghats mobile belt. *Geol Surv India Spl Publ*, 44, 1–21.

Ramakrishnan, M., Vaidyanadhan, R. (2008). Geology of India. *Geol Soc India Bangalore*, 1, 293-556.

Ranjan, S., Upadhyay, D., Abhinay, K., Pruseth, K.L., & Nanda, J.K. (2018). Zircon geochronology of deformed alkaline rocks along the Eastern Ghats Belt margin: India-Antarctica connection and the Enderbia continent. *Precambr. Res.*, 310, 407424.

Rao, C. D., Santosh, M., & Dong, Y. (2012). U–Pb zircon chronology of the Pangidi–Kondapalle layered intrusion, Eastern Ghats belt, India: constraints on Mesoproterozoic arc magmatism in a convergent margin setting. *Journal of Asian Earth Sciences*, 49, 362-375.

Ravikant, V. (2019). Cambrian garnet Sm-Nd isotopic ages from the polydeformed Bolangir anorthosite complex, Eastern Ghats Belt, India: Implications for intraplate orogeny coeval with Kuunga orogeny during Gondwana assembly. *J. Geol*., 127, 437456.

Rickers, K., Mezger, K., & Raith, M. M. (2001). Evolution of the continental crust in the Proterozoic Eastern Ghats Belt, India and new constraints for Rodinia reconstruction: implications from Sm–Nd, Rb–Sr and Pb–Pb isotopes. *Precambrian Research*, *112*(3-4), 183-210.

Sarkar, A., Bhanumathi, L., & Balasubrahmanyan, M.N. (1981). Petrology, geochemistry and geochronology of the Chilka Lake igneous complex, Orissa State, India. *Lithos*, *14*(2), 93-111.

Sarkar, T., Schenk, V., Appel, P., Berndt, J., Sengupta, P. (2014). Two-stage granulite formation in a Proterozoic magmatic arc (Ongole domain of the Eastern Ghats Belt, India): part 2. LA-ICP-MS zircon dating and texturally controlled in-situ monazite dating. *Precamb Res.*, *255*, 467-484.

Simmat, R., & Raith, M. M. (2008). U–Th–Pb monazite geochronometry of the Eastern Ghats Belt, India: timing and spatial disposition of poly-metamorphism. *Precambrian Research*, *162*(1-2), 16-39.

Sriramadas, A., & Rao, A. T. (1979). Charnockites of Visakhapatnam, Andhra Pradesh. *Journal of Geological Society of India*, *20*(10), 512-517.

Upadhyay, D., Raith, M.M., Mezger, K., Bhattacharya, A., & Kinny, P.D. (2006a). Mesoproterozoic rifting 3200 and Pan-African continental collision in SE India: evidence from the Khariar alkaline complex. *Contrib. Min. Petrol.*, 151, 434–456.

Vasudevan, D., & TM, R. (1975). The High-Grade Schistose Rocks of Nellore Schist Belt Andhra Pradesh and their Geological Evolution. *Geological Survey of India*, 16, 43-47.

Walker, T.L. (1902). Geology of Kalahandi State, Central Provinces. *Mem. Geol. Surv. India*, 33(3), 1–22.

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