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Review Article

ZONATION OF THE EASTERN GHATS MOBILE BELT: A REVIEW

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Eastern Ghats Mobile Belt (EGMB), a poly-cyclic, high grade metamorphic terrane occurs along the eastern margin of Indian subcontinent, bounded by the three Archean cratons along suture zone which relates to Indo-Antarctica collision. Along the boundary, alkaline rocks are present linearly and are believed to be formed during the crustal thickening process. Anorthosite plutons are emplaced in entire EGMB during different episodes and are thought to be formed during the rift formation associated with crustal thinning process. The main lithologies of EGMB are Charnockite-Enderbites, Metapelites, Leptynites, Mafic Granulites and Calc-silicate Gneisses. The characteristic metamorphic assemblages of the belt were developed during different stages of deformational history along with the imprints of Ultra High Temperature metamorphism. As far as the classification of the EGMB is concerned, different classification schemes have been proposed by different workers such as Zonal classification, Domain classification, Terrane classification and Province classification. Each classification has its own merits and demerits these have been summarized and discussed in this paper.

Keywords: EGMB, Granulite, Charnockite, Leptynite, Khondalite, Province, Domain, Terrane

INTRODUCTION

The NE-SW trending ~900 km long Eastern Ghats Mobile Belt (EGMB) is a high grade poly-metamorphic terrain along the East Coast of India. The belt has an average width of 100 km. In northern part the width is >300 km whereas in southern part the width is <50 km (Figure 1). It is bounded by three Archean cratons namely to the north by Singhbhum Craton, to the west by Bastar Craton and to the southwest by Eastern Dharwar Craton. The narrow South margin is also in contact with Cuddapah Prtoterozoic Basin and Nellore Khammam Schist Belt. The EGMB is dissected by two Gondwana Rifts; i.e., Mahanadi Rift at the north and Godavari Rift at the south (Ramakrishnan and Vaidyanandhan, 2008; Sharma, 2008; and Sarkar and Gupta, 2012). The junction between the EGMB and the above said three Archean cratons of India are marked as suture zone which are presumably related to the Indo-Antarctica collision (Chetty and Murthy, 1994). The EGMB is considered to be a Proterozoic granulite belt that formed during Indo-Antarctic repeated collision event (Dobmier and Raith, 2003), though the available geo-chronological data indicate the EGMB has formed over a long time period.

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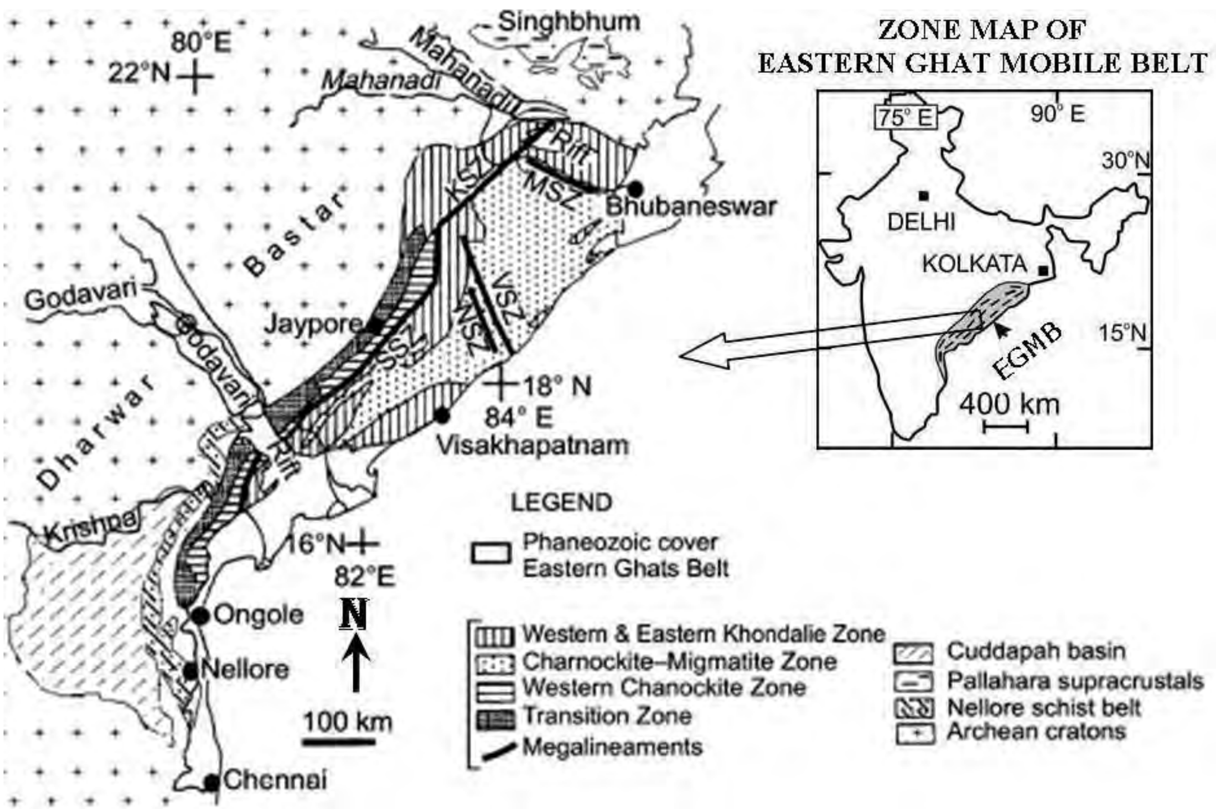
Figure 1: Generalized Lithological Map of EGMB (Ramakrishnan *et al.*, 1998) with Mega Lineaments (Chetty, 1995)
MSZ=Mahanadi Shear Zone; NSZ=Nagavalli Shear Zone; SSZ=Sileru Shear Zone; VSZ=Vamsadhara Shear Zone



GEOLOGICAL SETUP

The EGMB is a poly-cyclic granulite terrain thrusted over the Archean cratons of India where the general trend of the rocks are N-S to NE-SW. The different rock types of the EGMB can be grouped under Metapelites (Khondalites), Charnockites-Enderbite, Leptynites, Calc-granulites, Mafic Granulites, Anorthosites and Alkaline complex.

Metapelites: Metapelites are high aluminous meta-sedimentary gneissose rocks formed by high grade metamorphism (granulite facies) of pelitic assemblages. There are two distinct groups namely (1) Khondalite (garnet-sillimanite-perthite-quartz gneiss); and (2) Mg-Al granulite (spinel-cordierite-sillimanite-orthopyroxene-garnet$\pm$quartz). These rocks are generally associated with leptynites and charnockites. Mg-Al granulites usually occur as lenses within khondalites as well as xenoliths within charnockites and mafic granulites. At few places orthopyroxene and sapphirine have been reported which indicates towards UHT metamorphism. The depositional age of khondalites is 1.1 - 1.35 Ga. (Rickers *et al.*, 2001).

Charnockite-Enderbite: Charnockites (orthopyroxene-quartz-feldspar$\pm$garnet gneiss) are exposed in almost all parts of the EGMB. The composition of charnockites varies from charnockite to enderbite. Enderbites and mafic granulites are present as xenoliths within charnockites. Mafic rocks are considered as protolith of charnockites, as the petrogenetic studies indicate that the charnockitic melt is the product of partial melting of mafic rocks under granulite facies condition (Bhattacharya *et al.*, 2011). The charnockites are emplaced in Domain IA, IB and IV at 1.63-1.60 Ga, 3.4-2.7 Ga and 2.8-2.7 Ga respectively (Dasgupta *et al*., 2013). The different nature of charnockites and their emplacement ages indicate that the rock type are formed under two or more phases.

Leptynite: The leptynites are quartzo-felspathic gneisses with or without garnet and are free from orthopyroxene and sillimanite. The chief mineral assemblages are palgioclase-quartz-perthite+garnet. These rocks are mainly distributed in the Central Migmatites Zone and are closely associated with charnockites and metapelites. A characteristic feature of this zone is the extensive anatexis and migmatisation of all pre-existing rocks that leads towards formation of leptynites by partial melting.

Calc-Granulites: Calc-granulites are represented by the mineral assemblage wollastonite-scapolite-calcite-plagioclase-garnet-clinopyroxene and generally occur as bands and lenses within or in association with metapelites.

Mafic Granulites: Mafic granulites (Orthopyroxene-clinopyroxene-plagioclase-garnet) occur as bands and lenses within metapelites as well as in the form of xenoliths within charnockite-enderbite.

Anorthosites: Various massif anorthosite complexes of varying size occur in the EGMB. Several small bodies are also present along different Domain boundary. The emplacement age of anorthosites in Domain 1A is 1.17 Ga and in Domain II is 980 – 930 Ma (Dharma Rao *et al*., 2011). It is generally thought that these anorthosites are formed by plagioclase fractionation from high alumina basaltic melts during lithospheric thinning. The estimated temperature and pressure conditions of these anorthosites are 750^0 - 800^0 C at 6-7 kb pressure (Mukhopadhay and Basak, 2009).

Alkaline Rocks: The alkaline plutons are confined within the boundary between EGMB and adjacent cartons. The principal rocks are nepheline syenite, hornblende syenite, syenite and quartz syenite. The alkaline rocks are emplaced syn-tectonically during thrusting and shearing along western and northern contact zone of EGMB (Biswal *et al.,* 2007; Chetty, 2001) where as at southern contact zone of EGMB, the alkaline magmas are emplaced before the crustal reworking. The intrusion age of alkaline complex is nearly 1.5 – 1.2 Ga (Upadhyay and Raith, 2006). The alkaline magmas are generated by mantle melting in the presence of CO_2 fluid (Banarjee *et al.*, 2013). The linear chain of alkaline complexes mark the location of paleo-rift at the cratonic margin and these are deformed during the collisional event of EGMB with the cratons.

STRUCTURE

The boundary between the EGMB and the cratons is marked by shear zone and is termed as Transition Zone (Ramakrishnan *et al.*, 1998; Chetty, 1995). The contact of EGMB with the Bastar carton is gradational one where the eastern boundary is marked as Sileru Shear Zone (Chetty and Murthy, 1994) and the western boundary is marked as Terrane Boundary Shear Zone (Biswal *et a.l*, 2004). The rock types found within the marginal zones are mafic granulites, charnockites, dykes and alkaline plutons. The contact between EGMB and Singhbhum Craton is demarcated by Sukinda Thrust and are characterized by the presence of alkaline rocks. Mahanadi Shear Zone marks the southern boundary of the E-W striking shear systems of the EGMB (Chetty, 2001).

DEFORMATION AND METAMORPHISM

The rocks of the EGMB display superposed structures and overprinted mineral assemblages which indicate towards multiple episodes of metamorphism and deformation. According to Bhowmik (1997), there are five distinct episodes of deformation (see Table 1) and four phases of metamorphism (see Table 2) in EGMB. The post-tectonic metamorphism in EGMB is marked by the intrusion of anorthosites and alkaline rocks (Mishra, 2013). Both clockwise and anticlockwise P-T-t paths have been reported from different parts of the EGMB. Grenvillian and Pan-African Orogenies are the two most important orogenic processes that has been pretentious over a long geological time scale. The imprints of these orogenies are also envisaged in the EGMB.

CLASSIFICATION OF EGMB

Zonal Classification: The first systematic classification of EGMB was given by Ramakrishna *et al*. (1998) on the basis of the dominant rock types (i.e., leptynites, charnockites and khondalites) by expanding the division earlier proposed by Nanda and Pati (1989) and is known

Table 1: Details of Different Phases of Deformation in EGMB (After Bhowmik, 1997)

Deformation Phase	Structure
D_1	Gneissic Foliation (S_1) characterized by segregation of granulite facies minerals
D_2	Intrafolial isoclinal folds (F_2) on S_1 in calc-silicate granulites and khondalites (S_2)
D_3	F_3 folds close inclined to upright developed on S_1/S_2 structures
D_4	E-W cross fold (F_4) developed on F_2/F_3 folds characterized by gentle, upright, horizontal to moderately plunging warps
D_5	Intense strain localization along narrow shear zones resulting hearing and fracturings

Table 2: Details of Different Phases of the Metamorphic Episodes in EGMB (modified after Bhowmik, 1997)

Metamorphic Episodes	Mineral Assemblage	Deformation	P-T Condition
M_1	Gt(P) + Si + Kfs + Qtz + Bt ± Spl	D_1	9 kb, 970-^{0}C
	Gt(P) + Opx + Kfs + Qtz + Plag + Bt		
	Gt(P) + Cpx + Scp + Qtz + Cc		
M_2	Gt(P)+ Gt(C) + Si +Kfs +Qtz +Bt + Spl	D_2	7 kb, 730^{0}C
	Gt(C) + Qtz + Opx + Plg		
	Gt(C) + Scp + Cc + Wo		
M_3	Gt(C) + Qtz + Cc + Scp	D_3-D_4	4.7-4.2kb750^0-620^{0}C
M_4	Gt(P) + Cpx +Qtz + Mt + Cc	D_5	3 kb, 600^{0}C

as Zonal Classification (Figure 1). The four longitudinal lithologic zones of EGMB from west to east are Western Charnockite Zone (WCZ), Western Khondalite Zone (WKZ), Central Migmatite Zone (CMZ) and Eastern Khondalite Zone (EKZ). This classification does not satisfy the following points:

- This classification does not through light on the other rock types which are commonly associated with the major rock types within each zone.
- It does not consider the evolutionary history and age of rock types while it takes WCZ as the basement of EGMB.
- In this classification, the boundary between Bastar craton and EGMB is marked as transition zone and is not accepted by some other authors.
- All the khondalites of EGMB are grouped under WKZ and EKZ on the basis of localization in the belt. To the south of Godavari River, whether the khondalites are grouped under WKZ or EKZ is remains a question.
- It did not classify the Mg-Al granulites that fall under CMZ.

Domain Classification: Rickers *et al.* (2001) proposed the Domain classification based on the available isotopic data. He classifies the EGMB into four crustal Domains i.e., Domain I, II, III and IV. Domain I is further subdivided into Domain IA and Domain IB (Figure 2a). These Domains are comparable in parts with the lithological subdivisions (Ramakrishna *et al.*, 1998) and demarcated by some of the shear zones (Chetty and Murthy, 1994) identified in the belt. The important points of this classification are as follows:

- As far as the availability of geological data is concerned, Domain III of EGMB is the least studied one. Due to lack of sufficient geological data in respect of Domain III, its comparison with other Domains seems insignificant.
- In Domain I, the age of crustal residence time is very large, i.e., 2.3 Ga to 3.9 Ga.
- Apart from different protolith age, diverse metamorphic event and dissimilar crustal residence time for the rocks of Domain IA and Domain IB, both the Domains are placed under one Domain.
- Even the metamorphic event (1.6-1.7 Ga) found in Domain IA is not frequently occurring in Domain IB.
- The crustal residence age of para-gneisses from entire EGMB is quite similar (1.8 Ga to 2.8 Ga). So, it may be considered that all meta-sediments of EGMB have formed during a single event.

Terrane Classification: Another classification of EGMB was proposed by Chetty (2001) based on the presence of shear zones, stretching lineation, different fold styles and axial planes of early formed folds. This structural classification is termed as Terrane Classification. It divides the EGMB into 9 distinct terranes that are merged along the shear zones and lineaments (Figure 2b). The salient features of this classification are as follows:

- In some cases, shear zones are not strictly present in between the terranes like Godavari terrane and Vizianagaram terrane.
- Different age group of lithology goes under one structural readjustment and that is why they show similar deformation. So, it is difficult to define the evolutionary history of different

terranes on the basis of structural adjustment only.

Province Classification: Later, Dobmier and Raith (2003) introduced the Province classification. This classification is quite different from others because previous authors mark the extent of EGMB on the basis of granulite facies metamorphism, while Dobmeier and Raith (2003) identified 4 crustal provinces based on geology, isotopic data over large areas as well as widely different history of geologic evolution. These are Krishna Province, Jaypur Province, Eastern Ghat Province and Rengali Province. For detail study, these provinces are further classified in to 12 Domains based on lithology, structure and metamorphic grade. The Domain 1 and 9 stands for Rengali and Jaypur provinces respectively, Domain 2 to 8 falls under Eastern Ghat Province while Domain 10 to 12 belongs to Krishna Province (Figure 3).

Figure 2: Map showing classifications of EGMB (a) Isotopic Domains Map (after Rickers *et al.*, 2001) and (b) Terrane Classification Map (after Chetty, 2001)

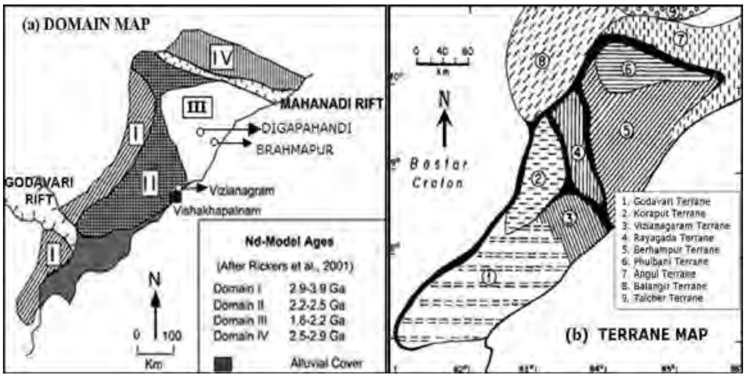


Figure 3: Province Map showing different Domains of EGMB. List of Domains: 1-Rengali, 2-Angul, 3-Tikarpara, 4-Khariar, 5-Rampur, 6-Phulbani, 7-Chilka Lake, 8-Visakhapatnam, 9-Jaypur, 10-Ongole, 11-Vinjamuru, 12-Udayagiri (after Dobmier and Raith, 2003)

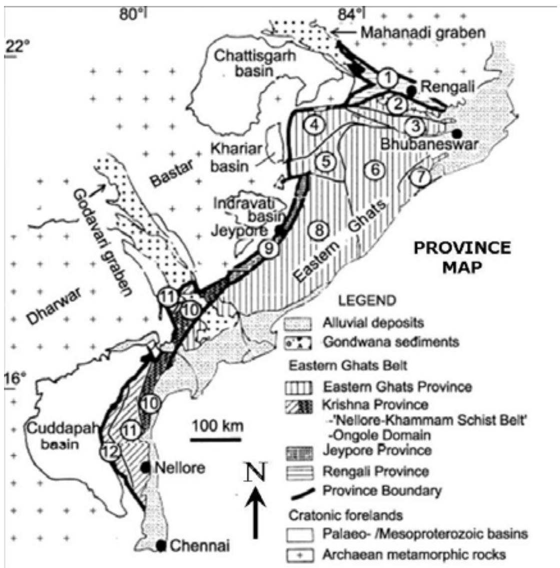


Table 3: Comparative Divisions of the EGMB by Different Authors

Ramkrishnan et al.(1998)	Rickers et al.(2001)	T R K Chetty(2001)	Dobmeier & Raith(2003)
Western Charnockite Zone(WCZ)	Domain IA & IB(Age- 2.9 to 3.9 Ga)Domain –IV(Age- 2.5 to 2.9)	Godavari Terrain Koraput Terrain Balangir Terrain	Krishna Province & Jeypore Province
Western Khondalite Zone (WKZ)	Domain – II & III(Age- 2.2 to 2.5)& (1.8-2.2 Ga)	Vizainagaram Terrain Rayagada Terrain	Jeypore Province & Rengali Province
Central Migmatite Zone (CMZ)	Domain – II & III (Age- 2.2 to 2.5)& (1.8-2.2 Ga)	Anugul Terrain Talchir Terrain	Eastern Ghats Province
Eastern Khondalite Zone (EKZ)	Domain – II & III (Age- 2.2 to 2.5)& (1.8-2.2 Ga)	Berhampur Terrain Phulbani Terrain	Eastern Ghats Province

The key features of this classification are as follows:

- The boundary between Bastar Craton and EGMB was marked as transition zone and are not included in the EGMB by previous authors but the current classification mark the zone as Jaypur Province that is a part of EGMB.
- The Krishna Province is combination of Nellore-Khamam Schist Belt and Ongole Domain.

DISCUSSION

Till date different classification schemes have been proposed by different workers in order to classify the EGMB but none of these models have been accepted unanimously. The divisions of EGMB proposed by different authors are tabulated below for comparison (Table 3).

However, as compared to the other classification, Province Classification proposed by Dobmeier and Raith (2003) provide more reliable information and justification. In this classification, various Provinces formed in diverse time period and their metamorphic histories are also different from each other. This classification validates the super continent cycles and describes the Indo-Antarctica orogeny process with geological time framework. The available geo-chronology data also support this Classification. A drawback of this classification is related to Easternghat province and its disputed age. As per this classification, the Easternghats province is a combination of Domain II and Domain III of Domain classification proposed by Rickers *et al.* (2001). The Nd-model ages of Domain II is 2.2-2.5 Ga and of Domain III is 2.5-2.9 Ga. Similarly, on lithological point of view, Domain II comprises of leptynite and khondalite while Domain III is rich in leptynite. Therefore, the relative differences between Domain II and Domain III may exist if consider about the availability of data. Domain II is extensively studied crustal block as compare to Domain III. Hence by considering the above fact both the Domains can be put together under one province.

CONCLUSION

In present scenario it seems that the Province classification of EGMB proposed by Dobmeier and Raith (2003) is more suitable to explain the evolutionary history of EGMB through geological time. However, the detailed future studies in the Domain III will enhance the available geological data which may lead to the further refinement of the classification schemes of EGMB.

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