ABSTRACT

The Proterozoic Eastern Ghats Belt of eastern India is characterized by a complex evolutionary history punctuated by recurring magmatic, deformation and metamorphic episodes. The terrane is also characterized by extreme thermal structure that resulted from Proterozoic accretionary processes involving continental blocks of India and East Antarctica within the supercontinents Rodinia and Columbia. It consists of rocks that had undergone extreme ultrahigh temperature (UHT) metamorphism at deep crustal level. Due to its geological complexity, the terrane has been classified in terms of various crustal provinces and domains, each displaying distinct tectono-metamorphic characteristics. The centrally occurring Eastern Ghats Province (EGP) evolved during the later part of Proterozoic era. The central (Visakhapatnam domain), northern (Chilka Lake domain) and the northwestern (Phulbani domain) parts of the EGP are composed of migmatitic felsic gneiss, aluminous granulite, fine grained charnockite, felsic augen gneiss, mafic granulite and calc-silicate granulites which are metamorphosed to UHT condition. Following the attainment of peak-UHT condition, all these rocks underwent cooling along a near-isobaric trajectory.

The dominant lithological units of the EGP are the orthogneissic rocks, represented by felsic gneiss, charnockite and mafic granulite. Compared to the other rock types like the aluminous granulite and calc-silicate granulite, which are mostly paragneissic in character, geological history of the orthogneissic rocks of this province is poorly known. In a granulite terrane, orthogneissic rocks are essential components of the Earth's lower continental crust and they play crucial roles in the orogenic processes. While mafic granulites are associated with the deeper sections of regional granulite belts, granitic rocks typically occur at lower to mid-crustal levels. Charnockite is diagnostic of Precambrian orogenic belts indicating a connection to the subduction-collision tectonics. Despite their prevalence in the EGP, very few studies have been conducted on mafic granulite, charnockite and felsic gneisses, posing a significant gap in knowledge. This study aims to investigate the geological evolution of orthogneissic rocks, from the central and northern regions of the EGP. By examining their field relationships, mineral evolution, geochemistry, geochronology, and fluid character, this work aims at unravelling the tectonic history of the EGP which is pertinent to the shared geological history of India and East Antarctica. Ultimately, the findings will contribute to the understanding of magmatic and

anatectic processes in orogenic crusts and the tectonic evolution of the EGP in the context of the India-East Antarctica correlation.

Massif type charnockite was intruded into the lower crust of the EGP and is currently exposed across a vast geographical expanse. The present work is based on charnockite samples collected from different localities of the Visakhapatnam and Phulbani domains of the EGP. These two domains occupy the major part of the central and northwestern part of the province. The rock exhibits distinct signs of its magmatic intrusion into lower crustal metasedimentary rocks, which are preserved as enclaves within the charnockite. The rock displays a range of deformation signatures, spanning from nearly undeformed varieties to highly deformed mylonitized types. The rock comprises primary minerals like orthopyroxene, quartz, K-feldspar (perthitic), plagioclase, ilmenite, ± garnet ± clinopyroxene. Secondary phases in the rock consist of hornblende and biotite. In the relatively less-deformed charnockite samples, magmatic features such as subhedral plagioclase (with primary zoning) and orthopyroxene are preserved. In contrast, the deformed samples exhibit a dynamically recrystallized fabric that shows local transition to a mylonitic fabric characterized by the presence of quartz ribbons. Textural observations indicate that the charnockite magma underwent a process of sub-solidus cooling, followed by metamorphism to granulite facies, reaching temperatures of approximately 910°C at pressures of 9 kbar as estimated from the garnet-orthopyroxene-plagioclase-quartz assemblage. Additionally, this rock preserved some metamorphic texture indicative of potential reworking associated with the second (M_2) cycle of metamorphism of the EGP, which has been dated as ca. 950-900 Ma. Geochemical data indicate that the charnockite magma show varying chemical compositions, that possibly resulted from differentiation processes and contamination with the supracrustal materials. This rock exhibits a range of SiO_2 content, including both high- and low-SiO_2 varieties, displaying characteristics that vary from weakly peraluminous to metaluminous. Notable features include LREE enrichment, HREE depletion, and distinctive trace element patterns. The rock shows enrichment in Ba and positive anomalies of Pb, La, Nd, and Gd, along with negative anomalies of Nb, Ta, Sr, and Ti. Slightly negative Ce and Y anomalies further support evolution of the magma in a post-collisional arc setting. Theoretical modelling indicates that melting of a hydrated basaltic slab in presence of a CO_2-rich fluid could be a suitable process for the generation of the charnockite magma.

Felsic (granite) gneisses are characterized by porphyritic textures with similar mineralogy like charnockite except absence of orthopyroxene. It has a similar geochemical composition to charnockite, with SiO_2, FeO_T, and MgO values spanning a broad range and higher K_2O concentration. These rocks are predominantly peraluminous, featuring enrichment in LREE and depletion in HREE, with a negative Eu anomaly. Trace element behavior also signifies their evolution in an arc setting. Based on geochemical and intimate field relation of charnockite and felsic gneiss, it can be inferred that these two rocks are differentiated products of same felsic magma under contrasting fluid regimes. The relatively dry nature of the charnockite magma alongside the contemporaneous granite magmatism speaks for the fluctuations in the fluid regime, particularly concerning CO_2-H_2O components.

On the other hand, mafic granulitic rock is less voluminous, occur as enclaves or xenolith within charnockite and felsic gneiss but it plays a pivotal role in the lithological diversity of the EGP. Two distinct types of mafic granulite obtained in this study display somewhat different mineral assemblages and compositions. The two-pyroxene granulite (massive type) contains minerals orthopyroxene, clinopyroxene, plagioclase, magnetite, ilmenite, pyrite, and pyrrhotite. In contrast, the garnet bearing mafic granulite (migmatitic variety) includes an additional phase, garnet. Textural characteristics of both oxide and sulfide minerals differ between these two varieties. Through textural analysis and inferred mineral reactions, it is apparent that the variations in oxide-silicate, oxide-sulfide, and sulfate relationships are associated with changes in oxygen fugacity (fO_2) during the pre-peak, peak, and post-peak stages of metamorphism. The determined fO_2 values span from a maximum of +4 log units in relation to the QFM (quartz-fayalite-magnetite) buffer for most of the samples, with the exception of a single sample that exhibits lower values, approximately -10 log units concerning the FMQ (fayalite-magnetite-quartz) buffer. The enduringly elevated fO_2 state in the lower crust may be attributed to various factors, with the influence of an externally sourced fluid being a credible explanation. The oxidation and localized metasomatism of the mafic lower crust could potentially be explained by the presence of a hot brine solution containing $CaCl_2$ species, despite not being directly confirmed through methods such as fluid inclusion analysis. Sulphide-sulphate relation is also used to understand the fluid regime in shallower crustal level.

Zircon U-Pb (LA-ICPMS) obtained in this study from the massif type charnockite from extensive region to understand the precise timing of crystallization of the magma. Crystallization ages were obtained through U-Pb analysis on oscillatory zoned zircon domains from eight samples. Among the majority of the samples, crystallization ages were observed within the range of ca. 980-940 Ma, with specific ages of 978 ± 16 Ma, 968 ± 22 Ma, 951 ± 9 Ma, 954 ± 8 Ma, 951 ± 13 Ma, and 939 ± 27 Ma, respectively. Two samples of charnockite show crystallization age of 1002 ± 13 Ma and 1020 ± 16 Ma. This implies that the emplacement of the charnockite magma was characterized by two distinct phases, and these phases can be associated with the tectono-metamorphic evolution of the province. The earlier phase of charnockite magmatism is indicated to be broadly concurrent with the first cycle (M_1) of metamorphism, while the later phase occurred when the lower crust was still experiencing elevated temperatures. The timing of the two charnockite magmatic events aligns closely with the Mawson charnockite in the Rayner Province of East Antarctica. This suggests that the extensive charnockite magmatism in the combined Rayner-Eastern Ghats Province can be attributed to the process of arc-continent accretion and the collision between India and East Antarctica that occurred approximately during ca. 1030-900 Ma.