Preface

The Central Indian Tectonic Zone (CITZ) is a prominent mobile belt that runs in an east-west direction and cuts through the Indian craton. This zone played a crucial role in the amalgamation of the North Indian Block (NIB) and the South Indian Block (SIB) during the Proterozoic era. The NIB consists of the Bundelkhand-Marwar craton (BKC), while the SIB comprises the Bastar-Dharwar-Singhbhum craton (BC). The amalgamation of these blocks resulted in the formation of the Greater Indian Landmass (GIL). The Central Indian Tectonic Zone (CITZ) stretches eastward, encompassing the Chhotanagpur Gneissic Complex (CGC) and extending to the southern region of the Shillong plateau. The expansion of the CITZ has been observed to extend westward to Madagascar and eastward to Western Australia via the Pinjarra craton and Albany-Fraser orogen, thereby demonstrating its trans-continental characteristics. The CITZ has been proposed to have a connection with the Circum-Antarctic orogenic belt, specifically through the Eastern Ghats Mobile Belt (EGMB). This connection highlights the significance of the CITZ as a crucial tectonic feature for the reconstruction of Rodinia and East Gondwana. The geological and geochronological information obtained from various regions of the CITZ up until the present scenerio suggests a tectonothermal evolutionary timeline of approximately 1000 million years, ranging from the Paleoproterozoic to the Neoproterozoic era. The history of CITZ coincided with the formation and breakup of two supercontinents, namely Columbia (about 2.1-1.8 billion years ago) and Rodinia (approximately 1.2-0.9 billion years ago). The investigation of the tectonothermal history of CITZ and its spatial and chronological relationship with other significant continental mobility belts has become highly significant in comprehending the Proterozoic supercontinent cycle.

In contrast to the extensive research conducted on the Aravalli-Delhi Mobile

Belt (ADMB) and the Eastern Ghats Mobile Belt (EGMB), the Comprehensive Indian Tectonic Zone (CITZ) has received comparatively less attention, despite its geological importance and potential.

The Central Indian Tectonic Zone (CITZ) has a maximum width of around 200 km and tends E-W to ENE-WSW. From north to south, it consists of three large supracrustal belts, namely the Mahakoshal, Betul, and Sausar belts, set in a wide country of undifferentiated gneiss-migmatite-granitic rocks known variously as Tirodi Biotite Gneiss, Amgaon Gneiss, Betul Gneissic Complex etc. Many important tectonic lineaments run across the CITZ, usually parallel to its length, including the Son-Narmada North Fault (SNNF), Son-Narmada South Fault (SNSF), Gavilgarh-Tan Shear Zone (GTSZ), and Central Indian Suture/Shear (CIS). While the Mahakoshal belt is limited between SNNF and SNSF, GTSZ separates the Betul belt from the Sausar Belt, and CIS is the southern limit of CITZ, south of which the N-S structural grain of the Bastar craton is visible. Within CITZ, three granulite belts have been identified: Makrohar granulite (MG) to the south of Mahakoshal belt, Ramakona-Katangi granulite (RKG) to the north of Sausar belt, and Balaghat- Bhandara granulite (BBG) to the south of CIS (Fig. 1). Although geological evidence from Makrohar granulite is scarce, much information on the tectonothermal evolution of the RKG and BBG belts has now been documented well.

The ENE-WSW trending Betul belt is situated in the middle of the Mahakoshal belt to the north and the Sausar belt to the south. It is separated from both belts by gneissic basement rocks. The Betul belt is partly overlain by younger Phanerozoic rocks, which belong to the Gondawana Supergroup and/or the Deccan Trap lava flows. The Gavilgarh-Tan shear zone (GTSZ) is provisionally regarded as the southern boundary of the Betul belt. The lithological composition of the Betul belt consists of a basement complex characterized by gneiss and granitoid rocks, supracrustals that have undergone low to medium grade metamorphism, and intrusions of mafic-ultramafic, diorite, and granitic rocks. The belt exhibits a division into two distinct domains, namely the northwestern and southeastern domains, which are distinguished by their unique lithological characteristics. These domains are demarcated by a significant fault/shear zone. The southeastern region is primarily characterized by a supracrustal assemblage and a basement complex, whilst the northwestern region showcases the Padhar mafic-ultramafic complex, as well as intrusive formations of diorite and granite, occasionally containing enclaves of high-grade granulite facies rocks. Supracrustal rocks are characterized by a bimodal volcanic assemblage consisting of basic and acidic lava with pillow structures, as well as tuffs/pyroclastics, metapelite, quartzite, secondary calc-silicate rock, and BIF. The contact between the gneissic basement (?) complex and the supracrustals is tectonic in nature marked by faults or shear zones. The dominant planar fabric observed is a sub-vertical transposed schistosity with an ENE-WSW strike. This fabric is axial planar to a series of folds. Certain shear zones exhibit a correlation with the simultaneous movement of granite, displaying pronounced mylonitic foliation and elongation lineation. The lineation observed on the mylonite planes exhibits a range of orientations, suggesting the occurrence of "sub-simple shear" deformation. The gneissic complex potentially corresponds to a modified underlying foundation consisting of metamorphic assemblages of amphibolite facies, which may include more recent granitoids of uncertain chronological origin. The occurrence of base metal mineralization is seen among basic and acid volcanic rocks, as well as metapelites.

The geographical region encompassing Betul is situated in the northwestern portion of the CITZ and confined within the Betul supracrustal belt comprising of Betul

Group of rocks. The geographical region under investigation is situated within specific latitudinal coordinates 21º55’50’’N to 22º00’50’’N and longitude 78º05’00”E to 78º25’00’’E in the Survey of India Toposheet number 55F/15. The study region encompasses a wide range of spatial extent linearly for about 150 km in ENE–WSW strike from Chicholi in the west to Biskhan in the east, having a width varying from 12 to 14 km. The study area is located 26 km away from Betul in the southeastern part. The study area consists of mafic granulite, pelitic granulite, granite gneiss, massive granite, amphibolite, pillowed metabasalt, foliated rhyolite and mafic-ultramafic dykes in the localities around Chicholi, Nimpani, Bargaon, Biskhan and Sonaghati.

Electron microprobe analyses (EPMA) of minerals from the different mineral assemblages are used to observe the characteristics of mineral phases. The XMg of garnet in the different rocks show the following trends: mafic granulites (0.21–0.31) > pelitic granulites (0.18–0.23). The higher content of TiO_2 in biotite from mafic granulites (More than 4 wt%) is similar to other granulite facies terrains. Cordierite has a variable range of X_{Mg}, ranging from 0.61 to 0.68. The X_{Mg} ratio of hornblende ranges from 0.42 to 0.50, and Al^{IV} and Al^{VI} content varies from 1.453 to 1.875 and 0.0 to 0.478 p.f.u. respectively. In mafic granulites, orthopyroxene lies close to hypersthene and coexisting clinopyroxene plots within the diopside and augite field. The X_{Ca} = (Ca/Ca+Na+K) ratio of plagioclase from mafic granulites range from 0.48 to 0.78.

The mafic granulites are classified based on total alkali versus silica (TAS) plot, on this classification scheme, all of them lie in the basalt field, and pelitic granulites (PG) display diorite and monzonite, whereas few samples are gabbroic means that the the protolith of pelitic granulite originated from diverse sedimentary sources. Major oxides of mafic granulites are plotted against the MgO wt% to reveal magmatic evolution through elemental partitioning. All pelitic granulite samples have a Ferron character, and most samples are per aluminous with two sample is metaluminous. However, these are calc-alkalic to alkali-calcic variable composition, but a sample has calcic composition. Na_2O vs K_2O diagram can be classified as shoshonitic and ultra-potassic in nature; but the SiO_2 vs K_2O diagram clarifies that all the samples are of shoshonitic nature. The trace element patterns of the mafic granulites of the Betul Belt, when normalized to the primitive mantle, are being examined show a negative peak for Ti, K, Nb, Sr and positive peak for U, Ta, and Hf, which reveals a rich LILE pattern. High elemental concentrations of Mg, V, Cr, and Co suggest that they be derived from primary magmatic sources. The amount of HFSE (Y, U, Pb, Hf, Nb, and Ta) is small, indicating that the rock is derived from the mafic source. Nb has negative anomalies that showed crustal contamination. The Zr versus Nb/Zr diagram provides evidence that the protolith of pelitic granulite underwent a tectonic setting characterized by collision and subduction. The Y vs Nb and Rb vs (Y+Nb) tectonic discrimination diagram reveals that the protolith has an affinity towards the Volcanogenic Anorogenic granites and syn-collisional type tectonic setting (VAG and syn-COLG). The relationship between the $(Y/Nb)_N$ against $(Th/Nb)_N$ diagram has been employed to discern between oceanic islands, continental crust, and rocks from convergent margins. All analyzed samples are situated within the field corresponding to convergent margin rocks. The mafic granulites exhibit sub-parallel patterns of rare earth elements (REE), indicating that the observed variations in composition can be attributed to the process of crystal fractionation. The range of $(La/Yb)_N$ ratios observed in these rocks has a degree of fractionation that spans from 0.40 to 2.18, which can be considered quite low. The identification of mantle-derived magma is also accomplished by the use of the HFSE/LREE proxy and the Nb/La ratio, which is lower than 0.37 for the Betul basaltic protolith. These characteristics serve as indicators of the origin of the lithospheric mantle. The Nb/U versus Nb discrimination diagram for the mafic granulites is lower than the MORB and OIB (Nb/U ~ 25), which refers to the melt phase originating from the subducted slab and being metasomatized from the mantle source. The subduction influenced source is also sustained by high Th/Yb and low Nb/Yb content; these rock data are beyond the MORB-OIB array in field of intraoceanic arc basalt. Oceanic tholeiites (MORB) have high K/Rb ratios (typically >1000), which rule out their being major igneous features given the high ratios and considerable variance in the granulites. There is a consensus among scholars that this phenomenon is associated with granulite facies metamorphism. Within pelitic granulites, certain sedimentary characteristics can be observed. These include an overall increase in the total rare earth element (ΣREE) concentration, which may be attributed to the accumulation of immobile REEs during transportation and sedimentation. Additionally, these granulites exhibit a low concentration of strontium (Sr), which can be attributed to a leaching effect. Furthermore, they display low levels of titanium dioxide (TiO2) and high concentrations of Aluminium (Al), Strontium (Sr) is depleted due to its high mobility and susceptibility to transportation during the process of sediment dehydration. Metapelites exhibit a notable abundance of Rb and Ba, owing to the significant role played by feldspar in serving as a primary reservoir for Rb and Ba in terrigenous sedimentary formations.

The P-T conditions of mafic granulites have been calculated by various conventional geothermobarometry. The temperature conditions at a fixed pressure of 7 kbar were determined using the clinopyroxene-orthopyroxene conventional geothermometer. The temperature range observed in mafic granulite was found to be between 845 and 904°C. The temperature range for the exsolution texture of Opx-Cpx is observed to be between 811 and 945°C. Results of estimated P-T condition provided peak temperature at 945°C, whereas other models provided comparatively low temperatures. Garnet clinopyroxene geothermometer is used to calculate temperature condition and the estimated temperature varies from 804–893°C, and garnet-clinopyroxene-plagioclase-quartz geobarometer inferred that the pressure lies between 8.19–8.99 kbar. The T_{av}, P_{av}, and PT_{av} were determined through the use of metamorphic phases with distinct reactions (THERMOCALC) using garnet, orthopyroxene, clinopyroxene, plagioclase, and amphibole end member minerals. The T_{av} calculation was conducted at a pressure of 7 kilobars, with an H_2O activity of 0.25, as a result of the inadequate H_2O activity in the mineral phase. The T_{av} was computed at 899°C (σfit = 1.03). However, Pav was computed at 800°C with the same H_2O activity, yielding 8.99 kbar (σfit = 1.07). Additionally, the PT_{av} was 8.66 kbar/900°C, and σfit was 1.08. Pseudosection modelling of mafic granulites in the NCKFMASHTO system using Perple_X software yields consistent phase equilibria results at peak conditions (8.0-8.5 kbar and 700-850°C) compared to the study that focuses on the concepts of multi-equilibrium and conventional thermobarometry. The retrograde trajectory is delineated within the pressure range of approximately 6.5 kilobars and the temperature range of approximately 650°C. Peltic granulites use the same model system as mafic granulite. The pseudosection has huge, high-variance garnet-bearing fields (F = 3-6). The garnet-biotite geothermometer provides an estimation of temperature ranging from 766 to 806°C, whilst the garnet-biotite-plagioclase-quartz geobarometer assesses the pressure at 7.21. The pre-peak metamorphic conditions, as determined from the X_{Mg} isopleth contour lines of garnet and cordierite, correspond to approximately 4.2 kilobars of pressure and 620 degrees Celsius. These values are consistent with the microprobe data obtained. The pressure-temperature stability range for the peak assemblage consisting of garnet, biotite, plagioclase, sillimanite, potassium feldspar, melt, ilmenite, and quartz is seen to be between 6.8 and 7.2 kilobars of pressure and 750 to 800 degrees Celsius in temperature. The pseudosection is primarily characterized by the presence of tetravariant fields. The P-T pseudosection displays a retrograde metamorphic assemblage including of stable minerals including garnet (grt), cordierite (crd), biotite (bt), plagioclase (plg), potassium feldspar (kfs), melt, ilmenite (ilm), quartz (qz), and magnetite (mag). This assemblage is observed at a pressure of around 4.0 kilobars and a temperature of around 790 degrees Celsius, as inferred from textural analysis. The utilization of geothermobarometric methods serves as the most effective means to determine the development of high-grade metamorphic rocks. Our findings provide new boundaries for the Paleoproterozoic to Neoproterozoic progression of the CITZ.

The geotectonic setting model suggests two Archean cratons; Bundelkhand craton and Bastar craton and their amalgamation during the Paleoproterozoic period creating arc type of settings which acted act as a sink basin for sedimentation which arrived from the different sources as older craton and mobile belt. It is inferred that the CITZ area's pelitic and mafic granulites underwent a progressive phase of tectonothermal processes where initially occurrence of crustal thickening (M1) followed by persistence of the high PT conditions due to burial and crustal thickening (M2), and their exhumation (M3) giving a clear picture that collision or subduction-related tectonic processes led to the formation of granulites. Mafic granulites are calc-alkaline and their generation related to island arc as well as subduction-related setting. Our study's result emplacement of the basaltic protolith was during the orogenic (compressive) tectonism at active margins of island arcs, and their regime was subduction-related and enrichment of lithospheric-mantle source region. The basaltic magma was formed at the orogenic tectonic environment; it was a result of convergence of the Bastar craton and Bundelkhand craton and their prolonged suturing along the

CITZ, where Bastar craton subducted beneath Bundelkhand crustal domain and may be breakdown into the lower lithosphere. The PT_{av} condition of the mafic granulites indicate that they were developed at a depth of about 30 km below the current surface level. If we assume the thickness of the present crust to be 35 km in the East Indian shield, it means that the crust was 65 km thick during the Proterozoic period. This suggests that the crust experienced a dual thickening process, reaching a thickness of 65 km, during the period of maximum heat and pressure associated with the formation of granulites and the joining of the Northern Indian block and Southern Indian block along the Central Indian Tectonic Zone. In addition to the aforementioned factors, it is plausible that the horizontal movement of lower crustal rocks had a role in the thickening of the Earth's crust, alongside underplating, intraplate magmatism, metamorphism, and tectonic processes. These processes may have also had a role in facilitating the evolution of the granulites.

We can evaluate the Paleo-Mesoproterozoic geodynamics by looking at the crustal growth and tectonothermal evolution of the Betul belt in the CITZ based on the field geology, petrography, geochemistry, metamorphism, and geochronological history of representative lithounits. We provide an extensive model detailing the tectonic evolution of the Betul belt in the CITZ using both modern and historical data. The initial and last accretion processes are represented by the ~1040-954 Ma and ~2167-2051 Ma orogenic occurrences in the Betul belt in the central region of the CITZ. After the Betul gneisses were deposited, there was a long-lasting accretionary orogenesis with arc magmatism and a rifting phase that was marked by the hornblende rhyolite extrusion and the emplacement of A-type granite between around 1715 and 1671 Ma. The results of whole-rock isotopic analyses of typical rocks from the Betul belts, including U-Pb zircon, Th-U monazite, and Sm-Nd, indicate a prolong history of

crustal evolution between roughly 2167 Ma and 934 Ma. Magmatism, deformation, and metamorphism occurred in several phases around 2167 Ma, 1715–1671 Ma, 1400–1320 Ma, and 1079–954 Ma. These events are consistent with the formation and breakup of other supercontinents, such as Columbia and Rodinia. Similar to the metamorphic age of 954 Ma observed in the Betul belt, the Mahakoshal and Sausar mobile belts have undergone regional metamorphism. The Grenville-age metamorphic overprint in the Betul belt approximately 1.0 Ga is most likely related to the collision-accretion of Australia, Antarctica, and India along the Pinjarra Orogen within the framework of the Rodinia supercontinent.