Petrology, Geochemistry and Metamorphic Evolution of the Amphibolite to Granulite facies of rocks around Betul, M.P., India

Thesis Submitted in partial fulfilment
for the Award of Degree

Doctor of Philosophy

By

Manish Srivastava

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
INDIA

Roll No. 16061008 **2023**

CHAPTER-9

SUMMARY AND CONCLUSION

The Central Indian Tectonic Zone (CITZ) is a significant mobile belt that traverses the Indian Craton, creating a division in an east-west orientation. The region under consideration is accountable for the consolidation of the northern and southern Indian cratonic blocks, leading to the creation 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 trans-continental nature of the CITZ has been observed through its extension westward to Madagascar and eastward to Western Australia, specifically through the Pinjara craton and Albani-Fraser orogen. The significance of the Central Indian Tectonic Zone (CITZ) lies in its potential association with the Circum-Antarctic orogenic belt, facilitated by the Eastern Ghats Mobile Belt (EGMB). This relationship suggests that the CITZ holds considerable importance in the geological reconstruction of Rodinia and East Gondwana.

The ENE-WSW trending Betul belt is situated in the region between the Mahakoshal band to the north and the Sausar belt to the south. It is delineated by gneissic basement rocks, which are partially overlain by younger Phanerozoic strata belonging to the Gondawana Supergroup and/or the Deccan Trap lava flows. The Gavilgarh-Tan shear zone (GTSZ), which will be discussed in further detail in a subsequent section, is provisionally regarded as the southern boundary of the Betul belt. The Betul belt encompasses a characteristic assemblage of Precambrian gneiss and supracrustal rocks within the Central Indian Tectonic Zone (CITZ). The geological region known as the Betul belt exhibits a diverse lithostructural assemblage consisting of many rock types, including banded biotite gneisses, pillow basalts, rhyolites, meta-exhalites, quartzites, metapelites, and calc-silicates. The geological formations in question consist of intrusive younger granites, syenites, and mafic-ultramafic rocks. Within this complex litho-suite of rocks, the granulites have been reported which occur in the form of enclaves and patches within the country rocks of betul Group. The mafic granulites have been reported and studied from the adjoining areas around Chicholi, Nimpani and Bargaon whereas the pelitic granulites have been reported and studied from the areas around Biskhan and Sonaghati. The mafic granulites occur as discontinuous and scattered enclaves within the granite gneisses throughout the areas whereas the pelitic granulites occur as enclaves within the older granitoids and acid volcanics.

Electron microprobe analyses (EPMA) of minerals from the different mineral assemblages are given. Garnet consists of 37.55 to 79.07 almandine, 12.24 to 22.44 pyrope, 0.34 to 17.26 grossularite, 0.87 to 28.72 spessartite end-member (in mol%). The X_{Mg} of garnet in the different rock types varies from 0.18–0.31, and show the following trends: mafic granulites > pelitic granulites. Cordierite has a variable range of X_{Mg}, which ranges from 0.61 to 0.68 which shows the consistent values within the pelitic granulites. The X_{Mg} of biotite displays a wide range from 0.39 to 0.61 and is affected by octahedron occupancy of Ti and Al^{VI}, and show a significant decrease in X_{Mg} with an increase in Ti. Higher content of TiO_2 in biotite from mafic granulites (More than 4 wt%) is similar to other granulite facies terrains. The X_{Mg} in hornblende ranges from 0.42 to 0.50 and show a decrease of X_{Mg} with an increase of its Al^{VI} contents. The analyzed pyroxenes from mafic granulites are plotted in a triangular end-member diagram $CaSiO_3$-$MgSiO_3$-$FeSiO_3$ orthopyroxene lies close to hypersthene and coexisting clinopyroxene plots within the diopside and augite field. The X_{Mg} of orthopyroxene and clinopyroxene ranges between 0.29 to 0.52 and 0.52 to 0.65 respectively. The orthopyroxene from the investigated areas has relatively poor Al content (0.81 to 1.65 wt%) compared to other terrains. 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 pelitic granulite's protolith 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 ferroan character, and most samples are peraluminous 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 plot depicts the compositional characteristics of shoshonitic and ultra-potassic composition, but the SiO_2 vs K_2O diagram clarifies that all the samples are of shoshonitic nature. The primitive mantle-normalized trace element patterns of the mafic granulites of Betul Belt 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, Ta) is small, the observation suggests that the rock originates from a mafic source. Nb has negative anomalies that showed crustal contamination. The Zirconium (Zr) against Niobium/Zirconium (Nb/Zr) diagram provides evidence that the pelitic granulite's protolith experienced a tectonic environment characterised by collision and subduction processes. 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 link between the $(Y/Nb)_N$ against $(Th/Nb)_N$ diagram has been utilized to discern between oceanic islands, continental crust, and rocks from convergent margins. All samples analyzed in this study are situated within the field corresponding to convergent margin rocks. The sub-parallel REE patterns of mafic granulites suggest that compositional variation resulted from crystal fractionation. The degree of fractionation expressed by the $(La/Yb)_N$ ratios varies from 0.40 to 2.18, relatively low for these rocks. Mantle-derived magma is also identified by the HFSE/LREE proxy and Nb/La (< 0.37) ratio, lower for the Betul basaltic protolith, and represents the provenance of 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, namely mid-ocean ridge basalts (MORB), have elevated K/Rb ratios, frequently surpassing 1000. It is evident that these high ratios and the considerable heterogeneity observed in the granulites cannot be attributed to basic igneous characteristics. There is a consensus among scholars that this phenomenon is associated with granulite facies metamorphism. In the context of pelitic granulites, certain sedimentary characteristics can indicate specific geological processes. For instance, the presence of an overall enrichment of the sum of rare earth elements (REE) may suggest the accumulation of immobile REE during transportation and sedimentation. Additionally, a low concentration of strontium (Sr) can be attributed to leaching effects. Furthermore, the low levels of titanium dioxide (TiO_2) and the high concentrations of aluminium (Al), potassium, Strontium (Sr) depletion occurs due to its high mobility and ease of transportation during the process of sediment dehydration.

Metapelites have elevated concentrations of Rb and Ba due to the significant role played by feldspar in hosting these elements within terrigenous sedimentary formations.

A pseudosection of mafic granulite was created using the NCKFMASHTO method. The stability of garnet-absent assemblages was observed to be prominent under conditions of low pressure, while assemblages containing orthopyroxene were found to occur at elevated temperatures. The mineral assemblages obtained from petrographic research were found to be stable within a pressure-temperature (PT) range of greater than 4.5 to 7.15 kilobars and approximately 665 to 870°C. The peak mineral assemblages were most accurately characterised by the pentavariant field, which encompassed clinopyroxene, orthopyroxene, hornblende, plagioclase, biotite, ilmenite, and quartz. The P-T pseudosection for mafic granulite was constructed by delineating the contours of X_{Mg} isopleths for Opx and Cpx minerals. Additionally, the P-T conditions were determined based on the isopleth lines. The isopleth line for orthopyroxene with X_{Mg} values ranging from 0.403 to 0.468, and for clinopyroxene with X_{Mg} values ranging from 0.590 to 0.635, was established to delineate a pressure-temperature (PT) range of 7.0 to 7.5 kbar and a temperature range of 680 to 720ºC. The recognised stability of this mineral phase within the peak host assemblage was seen throughout a range of pressure and temperature conditions. Additionally, the PT pseudosection reveals the presence of magnetite-bearing domains that occur at lower temperatures. The presence of magnetite in the mineral assemblage of mafic granulites indicates that a retrograde evolution of mafic granulite occurred at lower temperatures (~540ºC) and pressures (~4.5 kbar) within the magnetite-bearing region. The selection of the pelitic granulites involves the use of a similar technique as that of mafic granulite. The pseudosection exhibits significant variability in garnet-bearing domains, with a high variance ranging from F = 3 to 6. The pre-peak metamorphic conditions are observed at around 4.2 kilobars of pressure and 620°C. These conditions are determined based on the X_{Mg} isopleth contour lines of garnet and cordierite, which closely match the analysed microprobe data. The pressure-temperature stability range for the peak assemblage, consisting of garnet, biotite, orthopyroxene, sillimanite, potassium feldspar, melt, ilmenite, and quartz, spans from 6.8 to 7.2 kilobars and 750 to 800°C. The pseudosection is predominantly characterised by the presence of tetravariant fields. The analysis of the textural characteristics indicates that the retrograde metamorphic assemblage in the P-T pseudosection consists of garnet (grt), cordierite (crd), biotite (bt), plagioclase (plg), potassium feldspar (kfs), melt, ilmenite (ilm), and quartz (qz). These minerals remain stable at a pressure of around 5.5 kilobars and a temperature of around 800°C.

The geotectonic setting model suggests two Archean cratons; Bundelkhand craton and Bastar craton and their suturing during the Paleoproterozoic period, due to which sedimentary basins were formed is a consequence of certain geological processes. The arc setting functions as a depositional basin for sedimentation, receiving material from various sources such as older cratons and mobile belts. 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 La/Yb vs Nb/La (Nb/La <0.5) discrimination diagram is deduced the source of magma generated from the lower lithospheric mantle. Partial melting of subducted materials in the lithospheric mantle was formed as a basaltic magma rich in LREE and LILE but depleted in Nb, Sr, and Ti, 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 process of crustal thickening, alongside underplating, intraplate magmatism, metamorphism, and tectonism. These processes may have also had a role in facilitating the evolution of the granulites. Moreover, it is plausible that these specimens were brought to the surface as a result of tectonic activities and subsequently experienced erosion caused by geological forces, which undoubtedly contribute to their current presence as scattered patches on the surface.

The crustal growth and tectonothermal evolution of the Betul belt in the CITZ based on the field geology, petrography, metamorphism, geochemistry, and geochronological history of representative lithounits allows us to assess the Paleo-Mesoproterozoic geodynamics. Utilizing recent data and prior research, we present a comprehensive model outlining the tectonic development of the Betul belt within the CITZ. The ca. 2167-2051 Ma and ~1040-954 Ma orogenic episodes in the Betul belt in the central region of the CITZ signify the first and ultimate accretion processes. Following the emplacement of the Betul gneisses, a protracted accretionary orogenesis with arc magmatism and a rifting phase characterized by the emplacement of A-type granite and the extrusion of hornblende rhyolite occurred between approximately 1715 and 1671 Ma. A lengthy history of crustal evolution between approximately 2167 Ma and 934 Ma is indicated by the U-Pb zircon, Th-U monazite, and Sm-Nd whole-rock isotopic studies of representative rocks of the Betul belts. There are multiple episodes of magmatism, deformation, and metamorphism at 2167 Ma, 1715–1671 Ma, 1400–1320 Ma, and 1079–954 Ma. These occurrences fit very nicely with the construction and disintegration of other supercontinents like Rodinia and Columbia. The regional metamorphism in the Mahakoshal and Sausar mobile belts is comparable to the metamorphic age of 954 Ma seen in the Betul belt. The collision-accretion of Australia, Antarctica, and India along the Pinjara Orogen within the framework of the Rodinia supercontinent is most likely connected to the Grenville-age metamorphic overprint, which occurred in the Betul belt around 1.0 Ga.