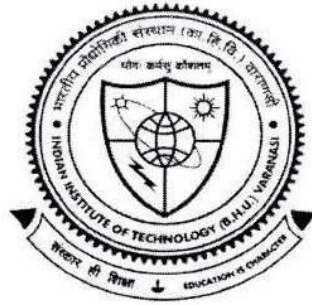



Extended Abstract on  
“Metamorphic evolution of granulite facies rocks of areas  
around Makrohar (Singrauli), Madhya Pradesh, India”



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Submitted by  
Vikas Pandey

  
Supervisor

Prof. S.B Dwivedi

Professor  
Supervisor  
Department of Civil Engineering  
Indian Institute of Technology (IIT) Varanasi  
Varanasi-221005

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

Roll no- 17061011

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## **EXTENDED ABSTRACT**

The Chhotanagpur Granite Gneiss Complex (CGGC) is a region of high-grade metamorphic basement with metasedimentary enclaves and mafic to ultramafic rocks. It covers about 100,000 km<sup>2</sup> and is located at the eastern extension of the Central India Tectonic Zone (CITZ). The CGGC terrain is bounded in the north by the Mahakoshal Mobile Belt and in the south by the North Singhbhum Mobile Belt (NSMB). The Chhotanagpur Granite Gneiss Complex CGGC consists of granite gneisses and migmatites with enclaves of metasedimentary and metaigneous rocks. The study area around Makrohar lies in the northwestern extremity of Chhotanagpur Granite Gneiss Complex (CGGC) and occurs as a tongue parallel to the Son Narmada South Lineament. The Makrohar granulite belt comprises high-grade metamorphic rocks including pelitic granulites, mafic granulites, calc-silicate granulite, amphibolite, garnet-bearing gneisses, dolerite, and metabasalt are exposed as major rock types.

Microprobe analysis of the minerals and calculation of their structural formula, reveal several characteristics of element distribution and variation among the mineral phases. Garnet compositions range between 24.35 and 84.86 mol% almandine, 0.34 to 17.93 mol% pyrope, 3.17 to 73.25 mol% grossularite, and 1.97 to 3.98 mol% spessartite. Garnet  $X_{Mg}$  in different rock types varies from 0.01 to 0.28, exhibiting trends: garnetiferous amphibolite > garnet-bearing gneisses > pelitic granulites > calc-silicate granulites. Cordierite shows  $X_{Mg}$  ranging from 0.63 to 0.66, with traces of Na<sub>2</sub>O (0.46–0.89 wt%) and K<sub>2</sub>O (0.04–0.16 wt%). Biotite  $X_{Mg}$  varies widely (0.30–0.69) influenced by Ti and Al<sup>VI</sup> occupancy in the octahedron, with a notable decrease in  $X_{Mg}$  as Ti increases.  $X_{Mg}$  of amphiboles vary from 0.38 to 0.71, while amphibole's Al<sup>IV</sup> and Al<sup>VI</sup> content vary (0.32–1.45 and 0.13–0.60 p.f.u., respectively). Analyzed pyroxenes plot on a

CaSiO<sub>3</sub>-MgSiO<sub>3</sub>-FeSiO<sub>3</sub> diagram, with orthopyroxene close to hypersthene and coexisting clinopyroxene within the diopside and augite field in mafic granulites, and the hedenbergite field in calc-silicate granulites. Orthopyroxene and clinopyroxene X<sub>Mg</sub> range between 0.44–0.49 and 0.29–0.70, respectively, with relatively lower Al<sub>2</sub>O<sub>3</sub> content (0.32–0.69 wt%) in the investigated areas compared to other terrains. Feldspar compositions vary between oligoclase in pelitic granulite to anorthite in calc-silicate granulites, respectively.

EPMA dating has delineated two distinct age ranges for monazite: 1529 to 1743 Ma and 874 to 1111 Ma from pelitic granulites, while garnet bearing gneisses preserves ages from 822 to 1014 Ma. Weighted mean age distributions obtained using the ISOPLOT program (Figure 5.8a–d) depict a metamorphic peak at an estimated  $1655 \pm 30$  Ma (n = 14, MSWD = 4.3) and a retrograde metamorphism at  $910 \pm 31$  Ma (n = 19, MSWD = 9.3). Geochemical analysis of metabasics exhibit considerable variability in major oxide composition. The Zr/Ti vs Nb/Y diagram places garnetiferous amphibolites in the sub-alkaline basalt field and mafic granulites in the basaltic-andesite field, signifying both spreading and subduction characteristics. The petrogenesis of rocks, evaluated through immobile trace elements, indicates minimal crustal contamination. Discrimination diagrams (Th/Nb vs Ba/Nb, Nb/Th vs Zr/Nb) suggest arc-like settings for metabasics, corroborating subduction influences. These samples align with intra-oceanic arc basalt and arc basalt fields. Basaltic protolith formation during orogenic tectonism at active island arc margins, related to subduction, is indicated. Evidence suggests metabasic generation in back-arc regions during extensional regimes. These findings suggest metabasics formation during subduction and arc-related settings, participating in collisional tectonism. Metabasic patches experienced peak to post-peak metamorphism and interacted with subduction-derived fluids, leading to geochemical changes. Retrograde metamorphic processes occurred during their exhumation.

Various traditional geothermobarometry methods, including garnet–biotite and garnet–

cordierite thermometers, have been applied to assess temperature and pressure conditions in pelitic granulites (Grt-Crd-Bt-Sil-Pl-Qz). For pelitic granulites, estimated temperatures using Gt-Bt thermometry suggest prograde temperatures of  $690 \pm 62$  °C at a fixed 6 kbar pressure, while the garnet-biotite-plagioclase-quartz geobarometer (GBPQ) indicates pressures of 6.2 kbar at 600°C. Garnet-bearing gneisses show temperatures of  $566 \pm 33$  °C using Gt-Bt thermometry at 6 kbar pressure and 5.11 kbar at 600°C via GBPQ. Similarly, Grt-Crd thermometry shows post-peak temperatures of  $575 \pm 28$  °C at 5 kbar pressure, while garnet-cordierite-sillimanite-quartz geobarometry indicates pressures of  $5.55 \pm 0.73$  kbar at 600°C.

The average conditions involving garnet, biotite, plagioclase, cordierite, and sillimanite are estimated at  $679 \pm 63$  °C/ $5.3 \pm 0.9$  kbar with  $(\text{H}_2\text{O}) = 1$ . Temperature and pressure conditions for calc-silicate granulites were determined using conventional garnet-clinopyroxene exchange geothermometers and garnet-clinopyroxene-plagioclase-quartz geobarometers. Temperatures estimated through garnet-clinopyroxene exchange thermometry suggest  $675 \pm 89$  °C at 7 kbar pressure. The average conditions with garnet, clinopyroxene, plagioclase and quartz are  $624 \pm 97$  °C/ $5.6 \pm 0.8$  kbar for  $(\text{H}_2\text{O}) = 1$ . Mafic granulite pressure-temperature conditions were assessed using orthopyroxene-clinopyroxene conventional exchange geothermobarometers. Peak temperatures reached  $887 \pm 62$  °C at 6 kbar, with peak stage pressures estimated at  $6.15 \pm 0.3$  kbar. Post-peak metamorphic stage pressures, derived using the aluminium-in-amphibole barometer, were estimated at  $2.28 \pm 0.15$  kbar. Pressure-temperature conditions for garnetiferous amphibolites were determined using garnet-clinopyroxene conventional geothermobarometers.

Peak temperatures reached  $643 \pm 51$  °C at 5.0 kbar pressure. Post-peak metamorphic stage pressures were estimated at  $4.30 \pm 0.28$  kbar for garnetiferous amphibolites and  $5.26 \pm 0.21$  kbar for garnet absent amphibolites. In the study, P-T pseudosections were computed for

various granulite types using different chemical systems. The pelitic granulite displayed equilibrium, peak, and retrograde mineral assemblages at distinct temperature and pressure ranges. Similarly, the mafic granulite exhibited mineral assemblages across varying P–T conditions. Isobaric T–X (CO<sub>2</sub>) pseudosections for calc-silicate granulites constrained CO<sub>2</sub> mole fractions and temperature conditions for specific mineral assemblages. Garnetiferous amphibolites were also analyzed, showing distinct metamorphic stages marked by specific mineral compositions at different P–T conditions. The peak metamorphic stage was characterized by higher P–T settings, while the post-peak stage had different mineral compositions at lower P–T conditions, as delineated by amphibole and biotite isopleths. Overall, various traditional geothermobarometry methods were employed to estimate temperature and pressure conditions for different rock types, providing insights into their metamorphic histories and mineral assemblage stability ranges at different stages. Three thermodynamics approaches were utilized to determine temperature and pressure (P–T) conditions: conventional geothermobarometry, multi-equilibrium geothermometry, and forward modeling. These methods yielded comparable results across garnet-bearing gneisses, granulites, and amphibolites in the study area. P–T–t paths trace a rock's trajectory through P–T space over time. For pelitic granulites, thermodynamic calculations and pseudosection modeling unveiled a clockwise P–T–t path. During the peak stage, the rock experienced burial, marked by temperature changes indicating increased pressure. This phase reached high-pressure conditions, 7.40 to 6.70 kbar, and temperatures of 760 to 740°C. Subsequently, the rock followed an almost isothermal decompression path (ITD) into the post-peak stage, marked by garnet and cordierite, at pressures of 4.80 to 4.60 kbar and temperatures of 730 to 725°C. Similar clockwise P–T–t paths were deduced from garnetiferous amphibolites. During the peak stage, the rock exhibited a mineral assemblage stable at 7.3–7.1 kbar/810–790°C. The post-peak stage featured different minerals at 4.5–4.1 kbar/610–590°C due to decompression, suggesting exhumation.

The mafic granulites in the Makrohar area displayed a clockwise P-T path as well. Peak temperatures reached  $887^{\circ} \pm 62^{\circ}\text{C}$  at 6 kbar, while post-peak conditions were estimated at  $2.28 \pm 0.15$  kbar/ $593 \pm 50^{\circ}\text{C}$ . Two metamorphic events were identified from the Paleoproterozoic to Neoproterozoic periods, delineating the complex evolution of the CGGC terrain. Dating monazite revealed two ages for the pelitic protolith at  $\sim 1655$  Ma and  $\sim 910$  Ma, with only pelitic granulites preserving the peak metamorphic event (M1) during late Paleoproterozoic and retrograde metamorphism during Neoproterozoic era. Various magmatic intrusions were recorded in the CGGC, indicating a diverse geological history involving subduction and collision-related tectonic processes. The study area geodynamic interpretation suggests interactions between Archean cratons, rift development, sedimentation, and subduction-related tectonics. The CGGC metamorphic events provide insight into crustal thickening, and subduction processes, shaping the regions geological history during the Paleoproterozoic and subsequent exhumation during Neoproterozoic era. The findings align with the formation of supercontinents and various orogenic events, contributing to the broader understanding of continental movements and geological changes during different geological eras.