CHAPTER - 9

TECTONO-METAMORPHIC EVOLUTION

> *"The geologist takes up the history of the earth at the point where the archaeologist leaves it, and carries it further back into remote antiquity."*
> Bal Gangadhar Tilak

This chapter attempts to discuss the tectono-metamorphic evolution considering petrographic evidence, geochronological evidence, *P-T-t* path, and geodynamic conditions. The metamorphic evolution of the study area around Daltonganj reveals of a wide variety of rocks, which are affected by four stages of metamorphism (M_1 to M_4). The M_1 occurred at about 1.87–1.66 Ga, the M_2 is considered to happen between 1.55–1.45 Ga, the M_3 varies from 1.2–0.93 Ga, and the last M_4 event lies between 0.87–0.78 Ga. Daltonganj area has well preserved the Mesoproterozoic and Neoproterozoic age, and it leads to the CGGC which was the part of Columbia and Rodinia supercontinent.

9.1. Metamorphic condition

Different methodologies are applied to extract the rock history, which provides crucial datasets constraining the evolution of Chhotanagpur granite gneiss complex (CGGC). The evolutionary accounts of granulite are preserved in different mineral assemblages and associations in different rock types, the fabrics and textural relations. In addition to the significance of the physical mineral textures, other imperative components such as major, trace and rare earth elements and their isotopic composition provide crucial information about the rock's genesis and evolution. The objective of estimating *P-T* and calculating mineral equilibria is to decipher relevant information on granulitic rocks which provides reliable information relating to their burial and exposure on the surface through the geologic time.

The area around Daltonganj has been studied based on different tools such as petrography, mineralogy, phase petrology, geothermobarometry, phase equilibria modelling, geochronology and geochemistry, based on this, construction of *P-T* path was done to divulge its metamorphic evolution.

9.1.1 Petrographic evidences

Metamorphic petrology has been employed to decoding the mineral assemblage and microstructural record of burial/exhumation and heating/cooling imprinted on pre-existing sedimentary, igneous and metamorphic rocks by processes such as subduction, accretion and collisional orogenesis. Petrologists address various activities, from the *P-T-t* evolution of a rock in space and time. The quantitative *P–T–t* paths provide information to parameterize subduction zone processes and collisional orogenesis. Incorporating this *P-T-t* information, it delivers information about the geodynamic and tectono-metamorphic evolution and consequently reveals the history of lithosphere evolution.

9.1.1.1 High-grade gneiss

9.1.1.1.a Prograde assemblage

Chlorite occurs in the form of medium to coarse flakes and associated with biotite or individual laths. It occurred as inclusion within gedrite and consumed to form garnet and gedrite. The inclusion of Al-rich biotite trail in gedrite grain (Fig.4.1d), which reacts with cordierite, suggests prograde metamorphic condition.

9.1.1.1.b Peak assemblage

Orthopyroxene forming reaction suggests the peak metamorphic condition as the formation of garnet-orthopyroxene-amphibole assemblage, with the reaction;

Amphibole + quartz → orthopyroxene + garnet + melt (1)

9.1.1.1.c Post-peak assemblage

At some places, orthopyroxene is partially rimmed by garnet, cordierite and amphibole (Fig.4.1L). It suggests a retrograde metamorphism, where orthopyroxene consumes to form garnet-cordierite-amphibole a new assemblage, with the reaction;

Orthopyroxene + melt → garnet + cordierite + amphibole (2)

9.1.1.2 Mafic granulite

9.1.1.2.a Prograde assemblage

An inclusion of clinopyroxene + amphibole + plagioclase + ilmenite +quartz present within garnet porphyroblast as the earliest distinct mineral phase (Fig.4.4a). The recrystallization of clinopyroxene develops this early assemblage; amphibole and plagioclase further maintain the equilibrium phase after the garnet formation. This prograde metamorphic association was developed from the pre-existing mineral assemblage presumed to derive from the older metamorphic or magmatic origin. At this stage, a stable mineral association indicates an upper-amphibolite facies.

9.1.1.2.b Peak assemblage

The peak metamorphic assemblage is characterized by the Grt + Cpx + Plg + Ilm + Qz. This peak stage is characterized by garnet porphyroblast coexist with a matrix of coarse-grained clinopyroxene, amphibole, plagioclase and quartz. It suggested that garnet and clinopyroxene formation at an equilibrium state of the peak stage.

9.1.1.2.c Post-peak assemblage

Clinopyroxene + orthopyroxene + plagioclase symplectite assemblages represented as the first retrograde stage of post-peak assemblages. Reaction texture and petrographic association (Fig.4.4e) delineate the metamorphic evolution of mafic granulite, and consequently, it consists of the retrograde assemblages under which garnet breaks in several stages.

9.1.1.2.d Late retrograde assemblage

The amphibole mineral dominates this late-retrograde assemblage at this stage hydrous phase dominated over the anhydrous mineral phases. These are the amphibolite-facies assemblage Amp + Plg + Ilm + Qz and this inferred to be cooling stage. Textural association shows that opx and cpx are replaced by the amphibole (Fig.4.4a).

9.1.1.3 Pelitic granulite

9.1.1.3.a Pre-peak assemblage

Fine-grained sizes of quartz, plagioclase, biotite and ilmenite minerals are present as inclusion in porphyroblastic garnet (Fig.4.2c). These minerals are present at the core portion of garnet, which indicates that garnet has developed from these minerals' consumption. Therefore, these mineral phases are known as a pre-peak assemblage of the M_0 metamorphic stage.

9.1.1.3.b Peak assemblage

The peak metamorphic stage of pelitic granulite shown by the appearance of garnet + sillimanite + plagioclase by the disappearance of biotite and quartz, this reaction texture is represented by the inclusion of biotite and quartz in the garnet grains where sillimanite laths are present to adjacent with the garnet porphyroblast (Fig.4.2d).

9.1.1.3.c Post-peak assemblage

The cordierite phase's appearance results from isothermal decompression, which is represented by the post-peak assemblage of pelitic granulites. The highest possible assemblages of pelitic granulites have appeared: garnet, cordierite, sillimanite, plagioclase, biotite, K-feldspar, melt, ilmenite, and quartz. Two possible reactions textural recognized for cordierite's appearance from Daltonganj pelitic granulites. The textural evidence shows as the corona, where cordierite grains are present around the garnet grains (Fig.4.2e).

9.1.2 Geochronological evidences

9.1.2.1 Age of the sediment deposition

The sedimentation period and their provenance and the post-depositional metamorphic stages play an essential role in uncovering the tectonic history of the Indian landmass. The isotopic nature of U-Pb in zircon from metapelites rocks plays a vital role in constraining the sedimentation age and tectonic history after the deposition [17,383]. Pelitic rock formed by the accumulation and diagenesis of the pre-existing rocks' weathering product. The analysis of U-Pb zircon dating is the best way to constrain the age of protolith deposition from the detrital and metamorphic zircons, however, in this study ~1800 Ma and ~1700 Ma age signified as the age of protolith and ~1630 Ma age represented as the first metamorphic event of CGGC. The detrital zircons show 2700 to 1700 Ma time gap with the four clusters of age domain as 2700-2400 Ma, 2150 Ma, 1900-1850 Ma, and 1750-1700 Ma [23]; whereas last two groups are dominant in the frequencies. There are also Archean to Early Paleoproterozoic age constrain by detrital zircon of the metapelites rocks from the Dumka area of NE CGGC, suggesting that sedimentation process lies between 1764 to 1650 Ma [22] and 1696 to 1678 Ma [23]. Along with these geochronological ages from NE CGGC, another age group have also found ~1800 Ma and ~1700 Ma from the NW part of CGGC. These geochronological data suggest that NW and NE part of CGGC was received sediments from the same provenance of Paleoproterozoic age. The protoliths of pelitic rocks deposited before the ~1640 Ma and further it experienced a vast tectonothermal activity during the Columbia assembly at ~1630 Ma as M_1 metamorphic event. The pelitic granulites from the NE of CGGC preserve three stages of metamorphic events at ~1640 Ma, ~1450 Ma, and ~950 Ma [22, 23]; similarly ~1630 Ma dominant age domain and two age domains of ~1400 Ma (1375 and 1468 Ma) are also found. The interpretations of geochronological age from different adjacent terrains are helpful to understand the source of sedimentary provenances. In present study, the ~1800 and ~1700 Ma age are obtained from the detrital zircon; however, rocks from Bundelkhand craton [470], Aravalli craton [471, 472], Lesser Himalaya [473], Eastern Ghat Mobile belt [44], Mahakoshal Supracrustal belt [4, 26, 474] and Baster craton [475] are preserved same age, so it is an excellent probability to sediments must have derive from these plausible sources.

9.1.2.2 Protolithic age of mafic granulites

The protolith of mafic granulites is recognized by the combined study of petrography and geochemistry, which states that the protolith is likely to be basaltic rocks. The basaltic magma is considered to have formed during the continent-continent subduction tectonic process. The geochronological constraints and evolution of the mafic granulite in the CGGC have not been totally settled. [74] reported first stage of metamorphism (1450 ± 37 Ma) of metamorphic zircon in mafic granulite from the Dumka region of CGGC, whereas the second stage of metamorphism has been occurred at ~950 Ma. In this contribution, the oldest mafic magma emplacement (1629 ±6 Ma) has been reported from the northwestern region of CGGC which occurs as an enclave form.

In this study, magmatic zircons yield a weighted mean age of 1629 ± 6 Ma; besides, 1450 Ma by LA-ICP-MS U-Pb dating [74] broadened the metamorphic time. The mafic granulites underwent high-pressure metamorphism with a clockwise P-T-t path during the tectonometamorphic evolution of the CGGC at ~1630 Ma. While granitic gneisses have the oldest continental crust of the CGGC, it was emplaced around 1750–1660 Ma [210, 253, 266] and experienced the first stage of metamorphism during 1450 Ma [74]. Both mafic granulites and granitic gneisss underwent metamorphism coevally, indicative of a regional tectonothermal event in the CGGC during 1700-1600 Ma.

9.1.2.3 The timing of metamorphic events

The CGGC has a complex metamorphic history, based on pre-existing geological information; the CGGC has been divided into four phases of metamorphic events (M_1–M_4). The M_1 metamorphic event is recorded at ~1870 Ma from granulite enclaves emplaced in felsic gneiss; furthermore, the M_2 metamorphic event was dated between 1628–1270 Ma, where felsic magma intrusion occurred and further metamorphosed to form the migmatitic felsic gneiss. The M_3 phase is a high-grade metamorphic event that occurred during 1200–930 Ma, followed by the M_4 event (870–780 Ma) with the emplacement of the mafic dyke ([72, 210] and references therein). The geochronological studies of various researchers from different localities of the CGGC, metamorphic phases (M_1–M_4), dating techniques and nature of rocks are compiled in table 3.1.

During the M_1 metamorphic stage of the granulite facies rocks, the *P-T* conditions are difficult to derive due to their complex history of successive metamorphic events. Prograde granulite facies metamorphism was reported in the enclave suite (750–850°C/4–6 kbar), and this event was reported at >1500 Ma age by [130]. The *P-T* condition and the petrographic reaction texture relations are preserved within the rocks of the CGGC, which suggest the two prominent metamorphic events M_2 and M_3 that correspond to

Mesoproterozoic and Grenvillian orogeny age [210]. These events represent the two different progressive metamorphism episodes separated by retrogressive metamorphic events [130], but the representative age is not distinguished. U-Pb zircon dating reveals that the age of intrusive A-type felsic magma (protolith of charnockite) is at 1447+11Ma [73], also during 1470–1450 Ma age, the emplacement of ferroan granitoids was reported in the north-eastern part of the CGGC [3]. A-type granitoid magmatism and fragmentation of the Columbia supercontinent are recorded during the Mesoproterozoic era [476, 477]. The monazite age (1424±64Ma) is revealed as the oldest age of the high-grade gneiss; it is signified as the age of gneissic protolith. The EPMA monazite ages 972 and 962 Ma (Grenville Orogeny) represent the high-grade granulite facies event recorded in the Daltonganj. Petrographical features show that recrystallization of the amphibole-rich magmatic rock to garnet-hypersthene-bearing gneiss. The hypersthene's appearance indicates that the low *P-T* condition has changed into a high *P–T* condition (M_3 event) of granulite facies. The *P-T* condition and reaction texture are interpreted from the mineral assemblage, which shows that gedrite and quartz are consumed to produce the garnet + hypersthene + cordierite mineral phases through the prograde metamorphism. Similar *P-T* condition and Grenvillian orogenic age (975±67 Ma) were obtained by [210] from the Chianki village of the Daltonganj area in the north-west of the CGGC.

9.1.3 P-T-t Path

Three types of thermodynamics methods were used to compute *P-T* conditions, i.e., conventional (mono-equilibrium) geothermobarometry, multi-equilibrium geothermometry, and forward modelling. These methods yielded more or less same results for granulites and high-grade gneisses of the Daltonganj area. *P-T-t* paths represent a rock or a terrain through

P-T space with time. It is the sequence of *P-T* conditions experienced by a rock unit during regional metamorphism. The *P-T* path can be grouped into two types viz., the clockwise and anti-clockwise path. Peak temperatures follow the peak pressures in clockwise *P-T* path and the peak temperature is succeeded by peak pressures in anti-clockwise path. To formulate the tectonic models for the evolution of granulite terrains, the proper evolution of *P-T* paths is essential. *P-T* paths can be inferred using estimates of pressure and temperature from the minerals' paragenetic sequence.

The data provided by geothermobarometry for the metamorphic rocks of the study area suggest that these high-grade rocks have witnessed and undergone various geodynamic processes through a various degree of change in pressure and temperature along with the Earth's history, this metamorphic evolution of granulites concerning time represents a *P-T-t* path of the rock. The determination of the pressure-temperature path of metamorphic rocks is one of the most critical aspects in understanding the rocks' evolution since it can reveal many constraints such as the heat and pressure achieved during peak metamorphism, local structural setting and tectonic process. Many workers have derived the *P-T* path in investigating the evolution of Orogenic belts through time [478-485]. Qualitative and quantitative methods can estimate the pressure and temperature experienced by metamorphic rocks during metamorphism and subsequent cooling or decompression during upliftment.

P-T path has been constrained for Daltonganj Granulite Belt (DGB), using three different rock types such as high-grade gneiss, pelitic granulites and mafic granulites. A combination of micro-textures, mineral prograde and retrograde reactions, and the *P-T* estimates derived from mineral chemistry data of coexisting mineral pairs have been utilized to evaluate the different metamorphism grades *P*-*T*-*t* paths. Based on geological, petrographic and micro-textural studies, it is inferred that the various rock types in the study area have undergone a granulite facies metamorphism and suggest a distinct near Isothermal Decompression (ITD) path. A *P*-*T*-*t* path has been constructed for al three studied rocks which is showing the different metamorphic stages (Fig.9.1).

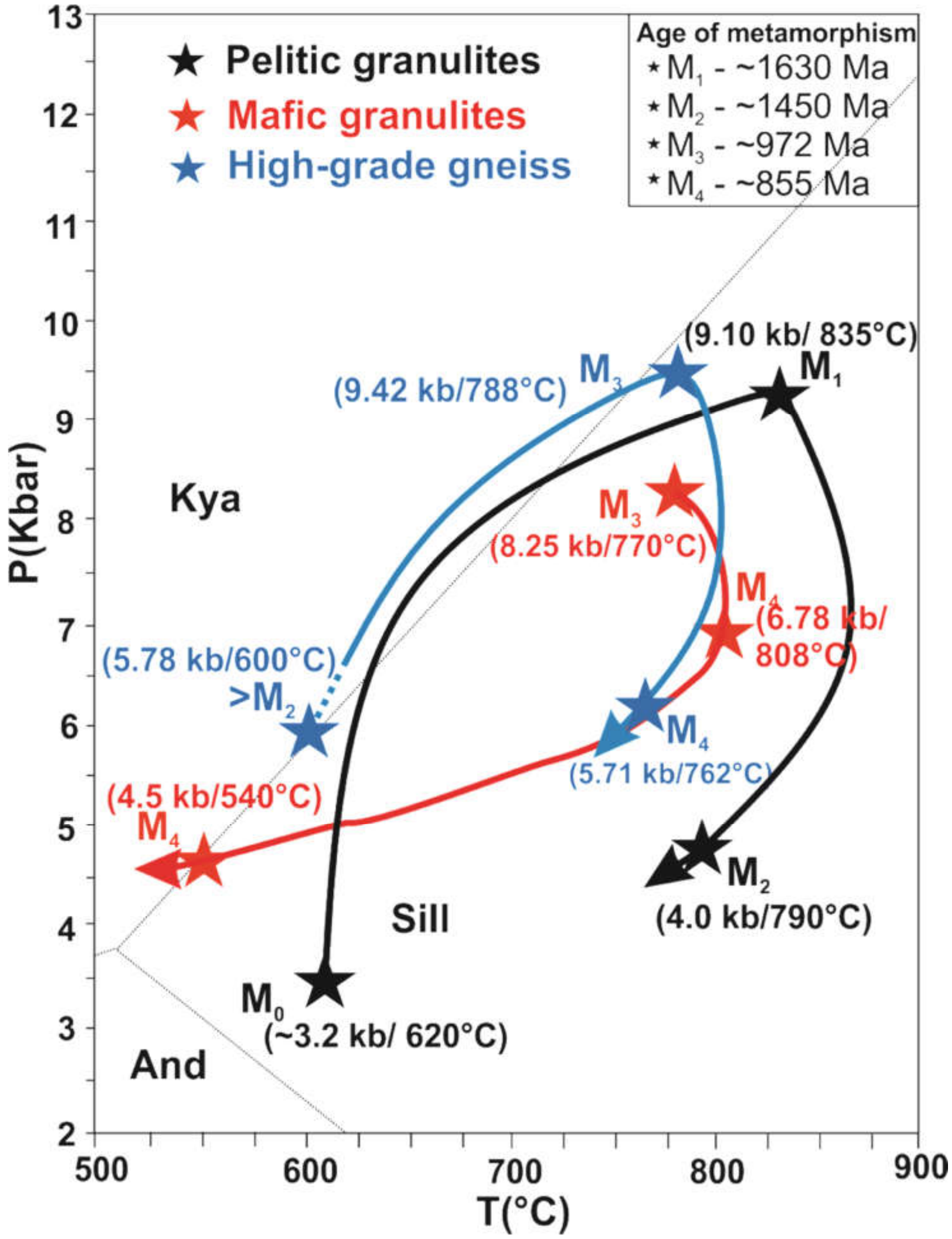

Figure 9.1 P-T-t path represents the metamorphic stages of all the three studied rocks.

9.1.3.1 High-grade gneiss

The clockwise *P-T-t* path has been obtained from orthopyroxene bearing gneiss by thermodynamic calculation and monazite geochronology. The Daltonganj region has experienced the magmatic emplacement of the protolith of high-grade gneisses at ~1434 Ma. The pre-peak metamorphic stage was recorded between the range of 5.78–6.15 kbar and 600–622°C, and the first stage Grt_1 developed under pressure conditions of 6.70 kbar. The age of this metamorphic stage has been depicted as after ~1424 Ma and before the Grenvellian orogeny. This rock undergoes further burial depth, and with a significant change in temperature conditions, this situation indicates an increase in pressure; hence it demarcated the peak metamorphic stage. During the Grenvellian orogeny (~972 Ma), the P-T conditions of this stage reached a high-pressure condition with a range of 8.65–9.42 kbar and 772–788°C, following a nearly isothermal decompression (ISD) path to achieve the post-peak stage. The post-peak stage was documented by the appearance of Crd, Grt_3 and Amp_3, and *P-T* conditions were reached at 5.71–6.18 kbar and 745–762°C. Furthermore, this stage occurred during the age of ~850 Ma and evolved along the CGGC terrain, exhumed to the shallow crustal level. The geodynamic significance of the peak (high-pressure) metamorphism from the Daltonganj region of the CGGC suggests subduction and exhumation in a single cycle as a complete clockwise *P-T-t* path with a time-span of ~1424 to ~855 Ma. Various P-T-t paths have been proposed from different localities within the CGGC, most of which represent the clockwise paths (Fig.9.1).

9.1.3.2 Mafic granulite

The metamorphic assemblages and textural relationship have been described with special emphasis for non-garnetiferous Daltonganj mafic granulites. The mafic granulites are characterized by the mineral assemblage orthopyroxene + clinopyroxene + plagioclase + amphibole + biotite + ilmenite + quartz. *P-T* pseudosection modelling shows mineral assemblage opx- cpx- amp- plg- bt- ilm- qz to be stable at the *P-T* range between >4.5 to 7.15 kbar and ~665 to 870ºC. Bulk rock composition modelling provides significant knowledge about mineral nucleation, development, and ingestion in multivariate mineral assemblages, as well as regarding alleged microstructures with prograde metamorphism until achieving the peak condition, it can be shown by comparative changes in the expected mineral abundances (in mol%) ([486] and references therein).

P-T estimation and pseudosection modelling in the NCKFMASHTO system was shown the mafic granulite experienced metamorphism of pentavariant stability field (opx, cpx, amp, plg, bt, ilm, qz) stable at the *P-T* range of 6.0 to 6.78 kbar and 775 to 808ºC. The PT_{av} was constrained by the internally consistent dataset of two-pyroxene mafic granulite at 6.7 kbar/ 814°C, where P_{av} ~6.84 kbar corresponds to the ~24 km (3.5 km/kbar) of crustal thickness. These mafic granulites would have exhumed on the surface due to tectonism and would have suffered from geological agencies' influence, which were attributed to being in the form of enclaves in the granitic gneisses country rocks. The mafic granulite was emplaced during Neoproterozoic ([74] and reference therein), and explained by continent-continent collision at the time of amalgamation of Rodinia supercontinent.

9.1.3.3 Pelitic granulite

The igneous zircons represent two geochronological age of pelitic protolith as ~1840 Ma, ~1707 Ma and metamorphic zircons contain a major metamorphic event ~1630 Ma. In the CGGC, only pelitic granulites have preserved the M_1 metamorphic event [249]. Pelitic granulites also preserved M_2 metamorphic events at ~1400 Ma, along with a huge felsic magmatic impulse ~1470–1400 Ma [249], this felsic magmatism engulfs the pre-existing pelitic granulites, after that, it remained as enclaves form. The pseudosection of pelitic granulite has plotted in the NCKFMASHTO system (Fig.8.9a,b), the pelitic granulite shown pre-peak metamorphism (M_0), then it reached peak metamorphism (M_1) and later underwent to isothermal decompression (ITD) path (M_2). The pre-peak metamorphism represents ~3.2 kbar and ~620ºC *P-T* condition, here tiny crystals of cordierite, biotite and quartz are embedded into garnet porphyroblast, and this leads to the formation of garnet. The peak metamorphic event (M_1) is characterized by garnet, sillimanite, plagioclase, biotite, K-feldspar, ilmenite, melt, quartz as stable mineral assemblage, with narrow temperature and large pressure range; however, it has required X_{Mg} isopleths of various minerals to constrain the appropriate *P-T* condition. The isopleths of Grt (X_{Mg}) = Mg/(Mg + Fe + Ca) and Bt(X_{Mg}) = Mg/(Mg + Fe) have plotted to estimate the peak metamorphic *P-T* condition which ranges from 7.40 to 9.10 kbar and 815 to 835°C (Fig.8.9b). Following these interpretations, we speculated that a limited period for deposition was observed for the pelitic protolith after ~1705 Ma, and then it buried into the deeper crust and metamorphosed to pelitic granulites as peak metamorphic event (M_1) during ~1629 Ma. Cordierite in this pelitic granulite was formed at the decreasing of pressure after the peak metamorphism by the reactions of Grt + Sill + Qz → Crd + melt. Sillimanite is present in pre-peak and peak metamorphic assemblages, along with garnet and cordierite assemblages in various stable phases. The high availability of bulk alumina in pelitic granulite is favorable for sillimanite formation. The cordierite appears below 6.4 kbar pressure. The isopleth line of Crd (X_{Mg}) = Mg/(Fe +Mg) and Grt (X_{Mg}) = Mg/(Mg + Fe + Ca) are contoured to represent the isothermal decompression stage, which lies at pressure ~4.0 kbar and temperature ~790°C. The retrograde metamorphic event (M_2) was recorded in pelitic granulites around ~1400 Ma, as well as intrusion of felsic magmatism during ~1470–1400 Ma [21]. The felsic magmatism engulfed pre-existing pelitic granulites; after that, it remained as an enclave.

The geochronological constraints and evolution of the mafic granulite in the CGGC have not been totally resolved. [21] reported the first stage of metamorphism (1450 ± 37 Ma) in mafic granulite from the Dumka region of CGGC, and the second stage of metamorphism has occurred at ~950 Ma. In this study, the oldest age of mafic granulites has been reported as magmatic emplacement from the northwestern region of CGGC. Magmatic zircon has yielded a weighted average $^{207}Pb/^{206}Pb$ age of 1629 ± 6 Ma, besides 1450 Ma age broadened the first metamorphism for mafic granulites.

9.2 Geodynamic condition

The lithospheric evolution and Earth's thermal evolution is a response to geodynamics. There are significant variations recorded in the geological and tectonic style between Archean and post-Archean crust. Tonalite–trondhjemite–granodiorite (TTG) and grey gneisses suites are dominated in the Archean terrains with volcano-sedimentary greenstone belts forming a minor component [487]. However, the Earth's thermal evolution is poorly constrained [488-492], it is likely that prior to Archean (3.0 Ga) heating was mainly due to decay of radioactive substances that would lead to surface heat loss, whereas post-Archean (ca 2.5 Ga) period was dominated by secular cooling [493].

9.2.1 High-grade gneiss

The maximum pressure is estimated ~9.0 kbar from P-T pseudosection; indicating that these high-grade gneisses were developed at a depth of about 30 km below the current surface level. If we assume the present crust's thickness to be 35 km in the East Indian shield, it means that the crust was 65 km thick during the Proterozoic period. The result of such an unusual thickness can be understood from the continent-continent collision. This thickness of the crust can be explained by the collision of Singhbhum microplate with CGGC microplate represents an overriding plate being under thrusted by the Singhbhum microplate [241].

9.2.2 Mafic granulite

Even though the CGGC from eastern India is a famous metamorphic terrain, the mafic granulites of CGGC are still debated. The different geotectonic setting has been suggested for the evolution of CGGC which are as follows: (i) Northward subduction of Singhbhum Mobile Belt beneath the southern CGGC followed by the mingling of the basaltic magma with the continental crust during a continent-continent collision [222], (ii) The emplacement of porphyritic granitoid gneisses (PGG) batholiths occurred during isothermal decompression [208], (iii) South Indian Block (SIB) and North Indian Block (NIB) collision was responsible for the formation of CITZ [15,216], and (iv) Mafic granulites of CGGC experienced an isothermal decompression stage (11 kbar to 5 kbar) around 990–940 Ma [70].

Mafic magma within the continental setting is generally linked to the lithospheric mantle extension [494-497]. Some of the workers have set up the relationship of generated magma due to the continent-continent collision between the Mahakoshal belt and northwestern part of CGGC [210, 253]. The subducted slab of Mahakoshal belt beneath the CGGC was promoted to mantle upwelling, partial melting and further generation of mafic magma [74] around 1450 Ma and simultaneously another felsic gneiss protolith emplaced

[73]. Th/Yb vs Nb/Yb discrimination diagram [341], the basaltic eruption is directly linked with volcanic arc setting. Basalt is 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 resulted from the CGGC-Mahakoshal belt convergence, where the Mahakoshal micro-plate subducted beneath the northwestern CGGC crustal domain and may be breakdown into the lower lithosphere. The La/Yb vs Nb/La (Nb/La <0.5) discrimination diagram [333] 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. In the study area, mafic granulites occur as enclaves within felsic gneisses was the metamorphic product (granulite facies) of basaltic protolith at ~1000–900 Ma [22, 23, 70, 73, 128-130, 210].

9.2.3 Pelitic granulite

The geotectonic setting model suggests two Archean cratons; Bundelkhand craton and Singhbhum craton with adjacent Baster craton rifted during late Archean Paleoproterozoic period, which leads to the separation of these two cratons and consequently leads to the development of the sedimentary basin. The rift portion developed as a sink basin for sedimentation which arrived from the different sources as older Craton and Mobile Belt. The geochronological age of detrital zircon demarcates the protolith of pelitic granulites and their origin source ([22, 249], and in this study). The clockwise *P-T* path is inferred that peak *P-T* condition ranges from 7.40 to 9.10 kbar and 815 to 835°C, and post-peak decompression *P-T* conditions varies from 5.40 to 5.80 kbar/ 810 to 900°C. A nearly isothermal decompression *P-T* path characterized the continental collision or overthrusting ([498] and references therein). The NW CGGC area's pelitic granulite underwent a progressive phase of tectonothermal processes where initially occurrence of crustal thickening (M_1) followed by quick exhumation of the crustal lithosphere (M_2), these both processes indicate that collision or subduction-related tectonic processes. The subduction process reported by the emplacement of felsic magmatism along the northern part of the CGGC (1.76–1.66 Ga: [253], also from the adjoining area on the northern extent of CGGC (1.69 Ga: [210]), and substantial magmatic emplacement recorded in Mahakoshal Belt (~1.8–1.7 Ga: [4]), which indicated that tectonothermal evolution of adjacent terrain of CGGC basin during the late Paleoproterozoic time. Before the ~1.65 Ga age, there was a development of oceanic environment and deposition of the sediments from the adjacent terrain which contains the Paleoproterozoic volcano-sedimentary rocks.

Moreover, it was a great chance to develop a rift basin or oceanic basin among the Singhbhum Mobile Belt and Mahakoshal Mobile Belt during the period of 1.86–1.65 Ga [249]. Different types of sediments were deposited in this oceanic basin and accompanied to the formation of HP/MT pelitic granulites at ~1.63 Ga; it was due to subduction of the oceanic lithosphere. The 1.63 Ga age considered the oldest metamorphic (M_1) age from the NW CGGC and Pelitic granulite is the only rock type that consists of the first stage of metamorphism. Cartoonographic diagram has shown the stages of the sedimentation of protolith of pelitic granulites and M1 stage of metamorphism of pelitic granulite which is present as patches within the granitic gneisses of CGGC (Fig.9.2).

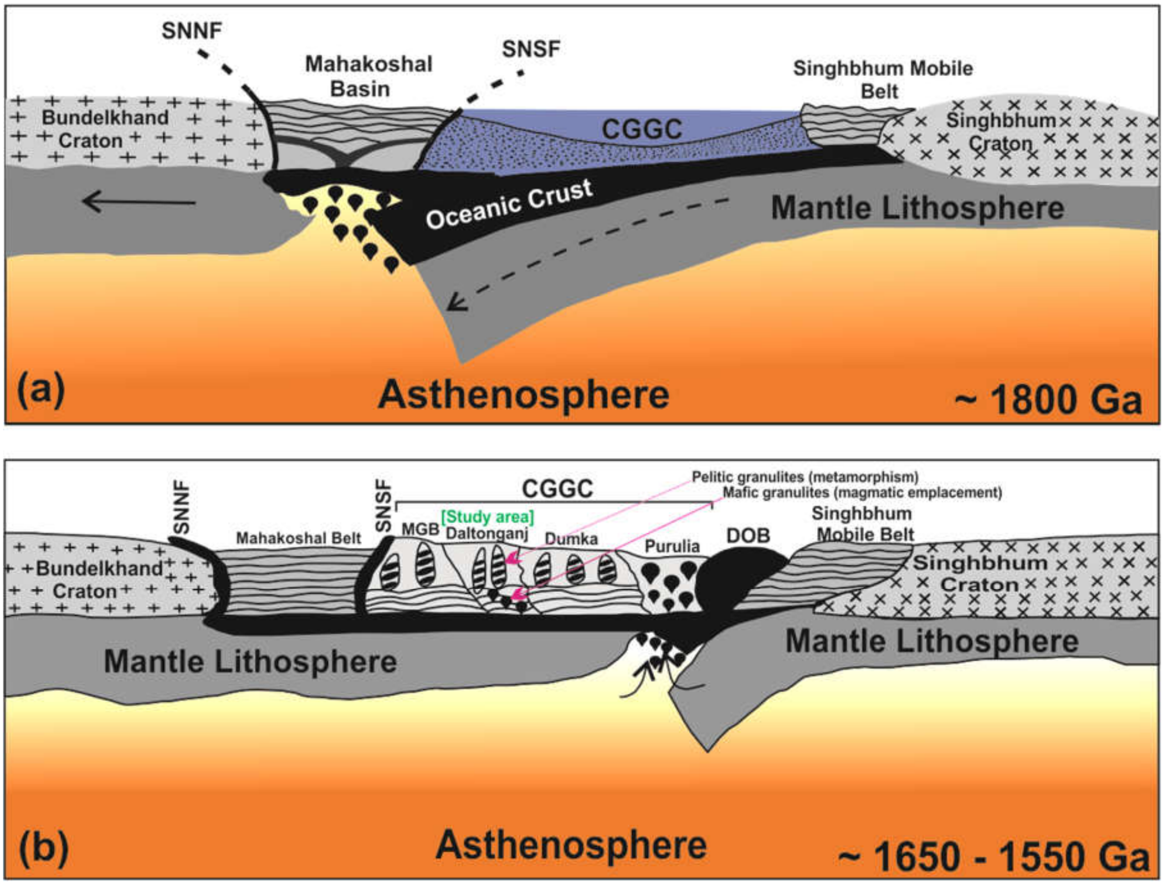

Figure 9.2 Cartoon diagram showing the stages of the (a) sedimentation of protolith of pelitic granulites and (b) M1 stage of metamorphism of pelitic granulite which is present as patches within the granitic gneisses of CGGC. [modified after [3, 4]].

9.3 Global correlation of CGGC

9.3.1 Correlation with the Columbia supercontinent

The Central Indian Tectonic Zone (CITZ) contains three EW trending eminent Supracrustal belt; the Mahakoshal Supracrustal Belt at the north, the Betul Supracrustal belt at the central part, and the Sausar Mobile Belt (SMB) at the south [211]. The CITZ is highly deformed tectonic zone of central India extending up to the Shillong Meghalaya Gneissic Complex (SMGC) in the NE of Indian Peninsular shield, along with the CGGC and North Singhbhum Fold Belt located at the central part [15, 211] whereas it constructed as continental suture zone among the south Indian block and north Indian block [15, 68, 211, 212]. The geochronological data has used to correlate the CGGC and other adjacent terrains with magmatic pulses and metamorphic events. Metamorphism and magmatic activities had been occurred simultaneously around ~1600 Ma in the CGGC, and also recorded in Sausar Mobile Belt [16, 212], as well as SMGC [19, 499, 500]. The Singhbhum craton and the North Singhbhum Fold Belt experienced metamorphic activity during the ~1660-1580 Ma [501], these geochronological evidence state that they are tectonically active with the CGGC terrain.

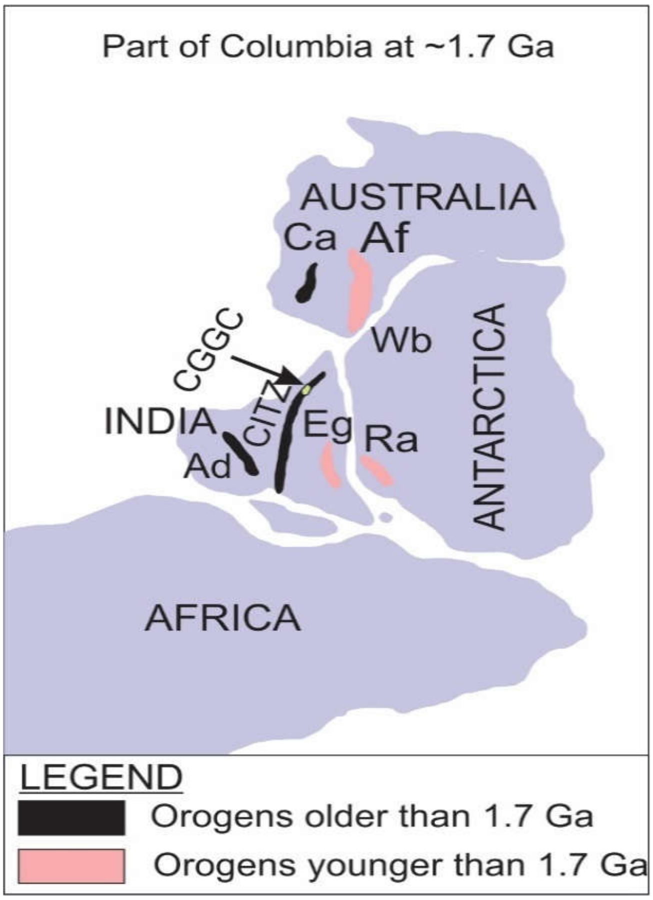

Figure 9.3 A schematic map is showing the Columbia supercontinent with the SMGC, as a continuation of the CITZ (modified after, [1, 2]). Abbreviations of orogens: Ad, Aravalli-Delhi; Af, Albany-Fraser; Ca, Capricorn; CITZ, Central Indian Tectonic Zone; Eg, Eastern ghat belt; Ra, Rayner; SMGC, Shillong-Meghalaya Gneissic Complex; Wb, Windmill Islands–Bunger Hills.

The E–W-trending CITZ belt preserved an orogenic crust of ~1650–1600 Ma. Late Paleoproterozoic orogenic belts have recognized from different part of the India i.e., the Eastern Ghats Mobile Belt [502, 503], Aravalli Delhi Fold Belt [471, 504-507], Himalayan [508], and this age also has been recorded from Antarctica (Kemp Land) of Napier Complex [509-511], these collectively leads to the formation of Columbia Supercontinent. However, finally, it concluded that Greater India and Antarctica plates amalgamated during Paleoproterozoic age as the Columbia supercontinent [1, 13, 512] (Fig.9.3).

9.3.2 Correlation with the Rodinia supercontinent

The age of formation, amalgamation, and reconstruction of central and eastern Indian terrain generates essential information regarding supercontinents' palaeogeographic condition. [1] proposed that the Columbia supercontinent amalgamation initiated ~1900–1800 Ma and achieved their highest packing strength at 1600–1500 Ma and started to rift after 1500 Ma. During this rifting period a lot of magmatic processes were obtained, viz., crystallization of anorthosite around 1550 Ma [128], khondalite emplaced in the quartzofeldspathic matrix around 1510 Ma [231], as well as charnockite gneiss emplacement during 1457 ± 63 Ma [208]. The development of Rodinia started from the Grenvillian orogenic age ~1100–900 Ma, and drifting was started after 750 Ma. The number of configurations and models of the Rodinia supercontinent have been proposed by different scientists, including [11, 14, 213, 513-515]. The age of fragmentation from 1200 to 800 Ma was interpreted within the southern Indian granulite blocks [516]. [120, 218] mentioned orogenic phases in the CGGC, named as the Chhotanagpur orogeny (1600–1500 Ma) and the Satpura orogeny (900–850 Ma). However, the CGGC of eastern India shows a shred of evidence of the Grenvillian orogeny age at 1100–900 Ma which is strongly preserved, and it postulates that the Grenvillian orogeny suture was very near the CGGC of India. In the previously proposed models, Greater India was emplaced along the western side of East Antarctica and the SW part of Australia to produce a substantial accretionary mass of western Rodinia [11, 213, 517]. They suggested that India was assembled with the Rodinia supercontinent through the continent-continent collision between 1000 and 900 Ma along the Eastern Ghats Mobile Belt (EGMB) and CGGC of the Indian subcontinent corresponds to East Antarctica's Rayner Province. [14] explained the palaeolatitudinal position between Greater India and the Australian landmass at ~770–750 Ma age due to the drifting of the Indian plate away from the Australia–East Antarctica continental plate by ca. 755 Ma. The Indian and Australian continental plates' transpressional movement may explain the 1100–1000 Ma metamorphic events investigated from the Pinjarra orogen [518, 519]. The (~1424 Ma) older age reveals felsic magmatism similar to the rocks of the other area of the CGGC that has been mentioned in Table 3.1. This rock was assumed to be the protolith of granulitic gneiss, formed by the high-grade metamorphism under granulite facies conditions ('Grenville-age' orogenesis, 1000–900 Ma) during M3 in Daltonganj, presumably during the assembly of Rodinia. The 1000 Ma high-grade metamorphism gives evidence of tectono-metamorphic episodes in the CGGC, CITZ and EGMB of India (Fig.9.4).

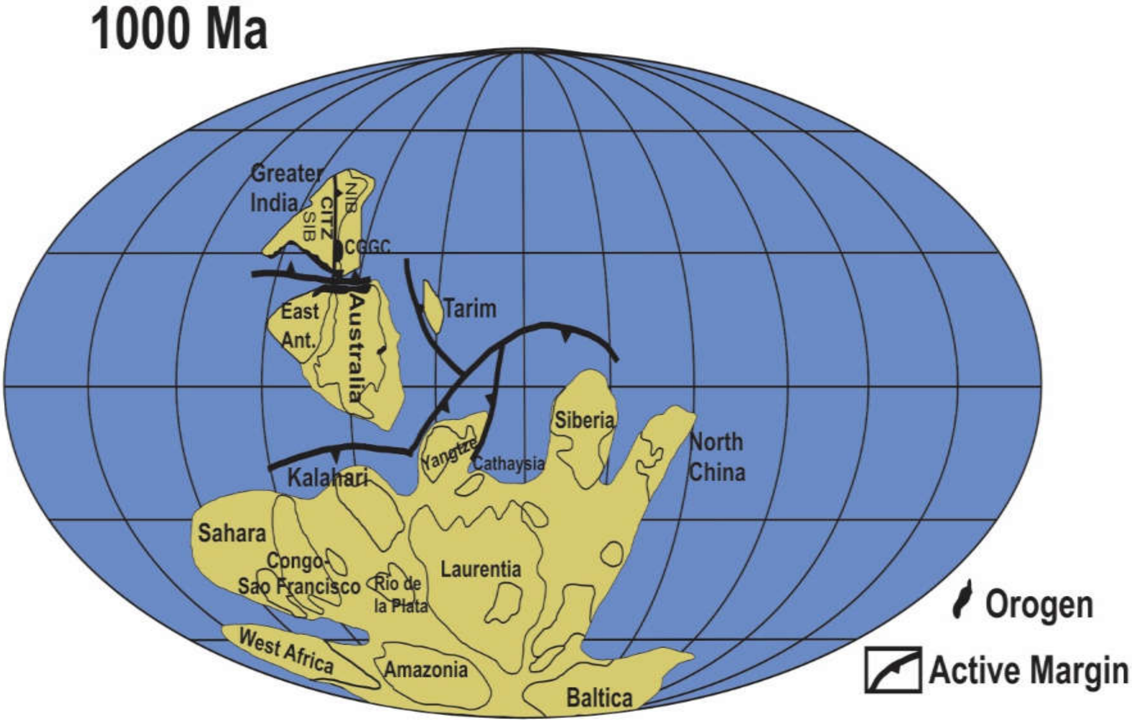

Figure 9.4 Cartographic picture showing the Rodinia assembly and position of India at ~1000 Ma (modified after [14]).