CHAPTER - 3

GEOLOGICAL SETTING

"A rock is ingrained with geological and historical memories"
Andy Goldsworthy

3.1 Introduction

The Chhotanagpur Granite Gneiss Complex (CGGC) is a high-grade metamorphosed terrain and eastward extension of Central Indian Tectonic Zone (CITZ) [211] which covers a massive area of eastern India, approximate 100,000 km^2 (Fig.3.1). The widespread occurrence of Phanerozoic sediment deposited at the western part of the CGGC provides an interrelationship between the CGGC and CITZ [3]. The CITZ situated in Central India with the two parallel east-west trending belts: the Sausar Mobile Belt (SMB) and the Mahakoshal Mobile Belt (MMB) (Fig.3.1). The CITZ has three parts along the western to eastern extension; the central mainland region is located among the MMB in the north and the SMB in the south, whereas, the CGGC situated at the east of the central region and the eastern fringe is known as Shillong Meghalaya Gneissic Complex (SMGC) [211, 212]. The Monghyr-Saharsa Ridge Fault and the South Purulia Shear Zone are bounded at the northern and southern periphery of the CGGC, respectively [73]. At the eastern extension of CITZ; the MMB lies toward the north of the CGGC, whereas Singhbhum Craton (SC) present along the south of the CGGC and it is separated by the North Singhbhum Mobile Belt (NSMB). The CITZ is situated along the central portion of the Indian peninsular shield, which was formed by Indian-Antarctica collision during amalgamation of Columbia supercontinent [11, 14, 15, 68, 211-213]. The CITZ has extensive suture zone which was formed around 1600 Ma due to the collision of the South Indian Block (SIB) and North Indian Block (NIB), where SIB subducted beneath NIB to form the Great Indian Peninsular shield [15, 16].

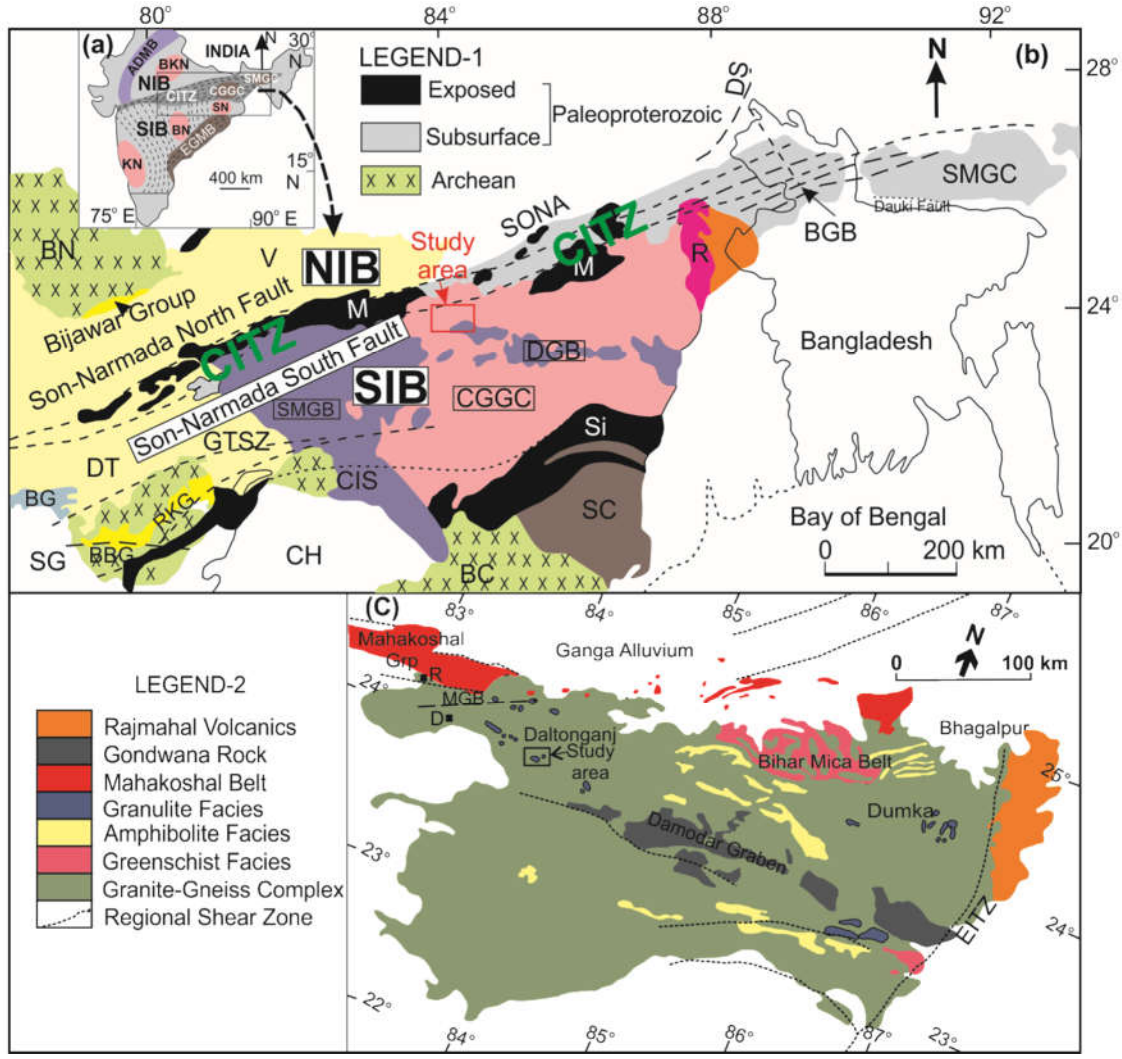

Figure 3.1 (a) Inset map showing the location of the Chhotanagpur Granite Gneiss Complex (CGGC) in India. The NIB and SIB contain the Archean nuclei of Bundelkhand (BKN) and Singhbhum (SN)- Bastar (BN)- Karnataka (KN), respectively [Abbreviations: ADMB- Aravalli-Delhi Mobile Belt; CITZ- Central Indian Tectonic Zone: CGGC- Chhotanagpur Granitic Gneissic Complex; SMGC- Shillong- Meghalaya Gneissic Complex; EGMB- Eastern Ghats Mobile Belt] (after [14]). (b) The geological map is showing different lithological units and tectonic elements of Central Indian Tectonic Zone (CITZ) (after [209,7,212]). Abbreviations; BC: Bastar Craton, BG: Betul Group, BBG: Balaghat-Bhandara Granulite, BGB: Barapukuria Gondwana Basin, BN: Bundelkhand Craton, CGGC: Chhotanagpur Granite Gneiss Complex, CH: Chhattisgarh, CIS: Central Indian Shear Zone, DGB: Damodar Gondwana Basins, DS: Darjeeling-Sikkim Himalaya, DT: Deccan Trap, GTSZ: Gavligarh Tan Shear Zone, KG: Karimnagar Granulite Belt, M: Mohakoshal and equivalents, R: Rajmahal Trap, RKG: Ramakona-Katangi Granulite, SG: Sausar Group, SC: Singhbhum Craton, Si: Singhbhum (Paleoproterozoic), SMGB: Son Mahanadi Gondwana Basins, SONA: Son Narmada Lineament, V: Vindhyan. The rectangle represents the Shillong-Meghalaya Gneissic Complex located in the western part of the NE India. (c) Geological map of the CGGC (modified after [209,129,208]). Abbreviations: CGGC- Chhotanagpur Granite Gneiss Complex, EITZ- Eastern Indian Tectonic Zone, D- Dudhi, MGB- Makrohar Granulite Belt, R- Rihand-Renusagar area.

However, [214, 215] recommended that the NIB underwent to the SIB, whereas double-sided subduction model has been proposed by the [216]. The Columbia supercontinent achieved their peak strength during ~2100–1600 Ma, and successively their rifting had initiated after the ~1500 Ma age; consequently, the fragmented portion of Columbian plate accreted to form the Rodinia supercontinent during the Grenvillian orogeny (~1000–900 Ma) [1, 14]. Chemical age 972 Ma reveals CGGC was the part of the Rodinia, and it amalgamated with East Antarctica (Prydz Bay) [18, 210].

The CGGC contains mainly gneissic rocks and lies to the North of Dalma Ophiolite Belt (DOB) and the Precambrian rocks of the Singhbhum-Orissa craton. It covers eastern India across the Jharkhand, Madhya Pradesh, West Bengal, Bihar and Orissa and is divided into northern and southern belts by Gondwana sediments of the Damodar valley. Gondwana fluviatile deposits border the western part of the CGGC. The NW axis is surrounded by the MMB and Vindhyan sedimentary rocks along with the Son lineament. The Singhbhum-Dalma mobile belt surrounds the southern margin. The northern end of the eastern portion is hidden under the alluvial deposits of the Ganges valley. The Rajmahal basalt of Jurassic age borders the north-eastern portion, and the south-east region is covered by the West Bengal Tertiary deposits.

3.2 Classification

Over the past two decades, a number of efforts have been used in the classification of CGGC rocks. [120, 217, 218] categorized the litho ensemble of the CGGC in three different lithostratigraphic units – i.e., crystalline basement; older metasediments; and late intrusives and these lithological units are believed to be yields of three major orogeny processes, namely the Chhotanagpur orogeny (~1600–1500 Ma), Satpura orogeny (950–850 Ma) and Munger orogeny (420–350 Ma). [219] stated that CGGC rocks could only be classified based on lithodemic subdivisions, as rocks generally do not follow the 'rule of superposition'. He has also recommended three groups of classifications where the CGGC is known as the oldest member, ahead are the Kodarma Group and the Rajgir Group.

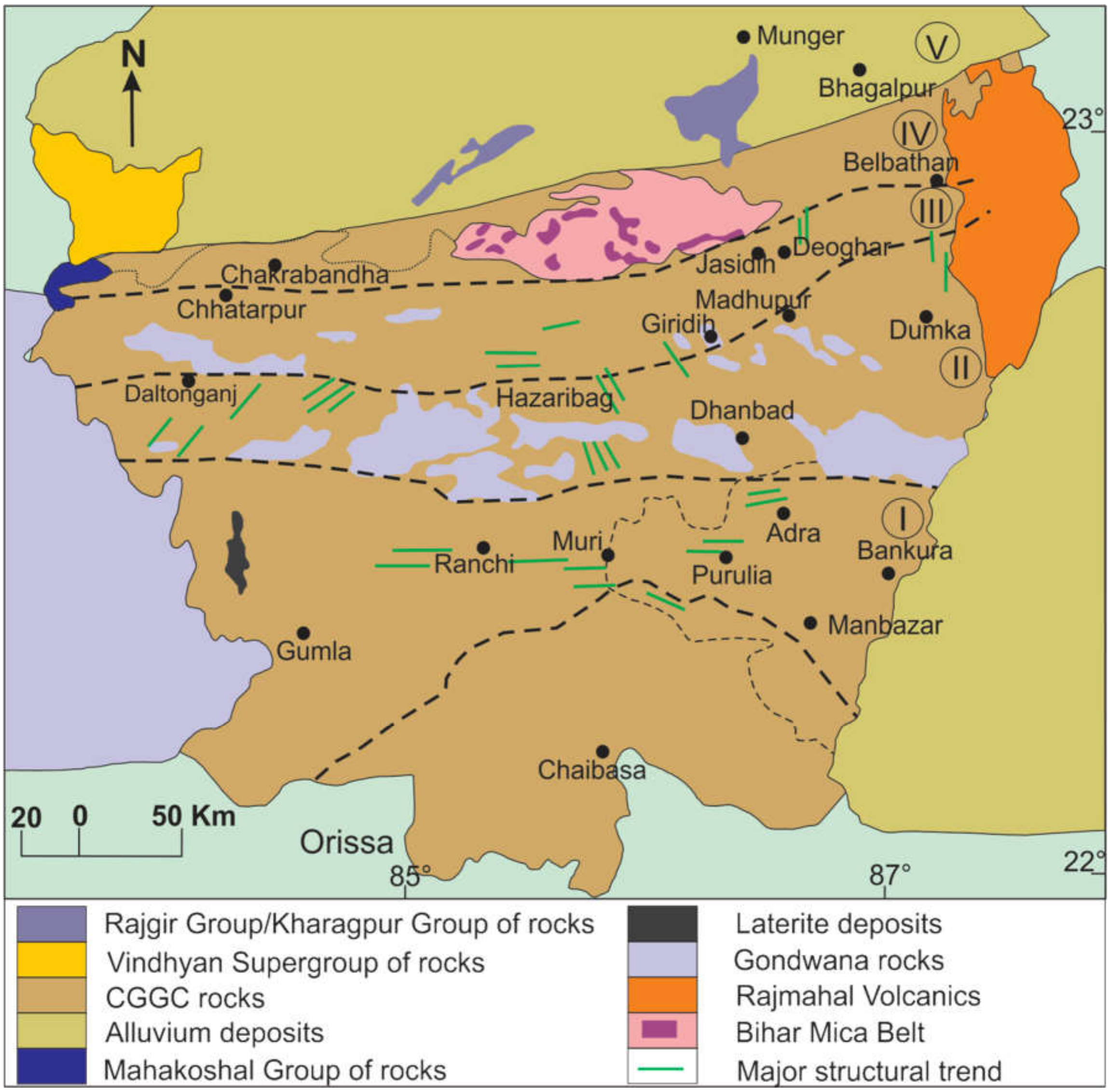

Figure 3.2 Geological map of the Chhotanagpur Granite Gneiss Complex (CGGC) and the adjoining areas showing major subdivisions proposed by [67,70]). (I) Ranchi–Purulia subdivision; (II) Hazaribagh–Dumka subdivision; (III) Giridih–Deoghar subdivision; (IV) Bihar Mica Belt subdivision; (V) Rajgir–Kharagpur subdivision.

The CGGC is classified into another three suites: (a) granulite rocks occur as enclave suite in the Dumka, Daltonganj and Purulia regions, with amphibolite, low to medium-grade schist, BIF and marbles from Chakrabanda, Sua and many localities; (b) the Chatra Gneiss suite consists of granites, tonalitic gneisses and migmatites; and (c) the intrusive suite comprises pegmatite, haplogranite, and quartz veins.

Another classification scheme was proposed by [69], in five east-west trending belts, which is based on broad lithological ensemble, with the Chhotanagpur Plateau, Gondwana basin, Damodar and Koel River as reference frames (Fig.3.2). The belts are:

i. The South Palamau-Gumla-Ranchi-Purulia Belt south of the Damodar Valley basins;
ii. The Daltonganj (North Palamau)-Hazaribagh-Dumka Belt between the Damodar and Koel river basins;
iii. The North Garhwa-Chatra-Giridih-Deoghar Belt north of the Koel River Basin;
iv. The Bihar Mica Belt (BMB) north of the Chhotanagpur plateau;
v. The Rajgir–Kharagpur Belt north of the BMB.

The granulite-facies rocks are prograde to retrograde metamorphic condition reported within I–III subdivisions [69].

The eastern part of Ranchi–Purulia Belt is the most studied area, and various scientists have worked since the early 1970s [71, 72, 130, 177, 220-223]. The Ranchi-Purulia Belt represents a progressive alteration from greenschist to granulite belt and is showing similar characteristics to the other granulite belt of peninsular India. The CGGC terrain consists of four phases of metamorphism (M_1–M_4) and three phases of deformation (D_1–D_3) [130]. A Barrovian metamorphic sequence is recognized in Purulia which ending with the charnockitic rocks. D_1 and D_2 deformations were developed by the anorthositic (Bengal anorthosite) emplacement [71, 130] at ~1550 Ma [128], whereas D_2–D_3 deformations accompanied with amphibolite-facies assemblages (M_2-M_3), which replaced the granulite-facies minerals of M_1 stage [130]. M_4 stage of metamorphism is recognized by the symplectic growth of ilmenite and quartz, and formation of coronal garnet within anorthosite and granites [72].

The Daltonganj–Hazaribag–Dumka belt lies north of the Damodar Valley, and it ranges from the eastern extremity of the CGGC, i.e. Massanjor area of Mor valley to the westernmost part up to Ramanujganj-Tatapani of Chhattisgarh (Fig.3.2). The western part is bounded by Palaeoproterozoic rocks of Mahakoshal Mobile Belt, whereas Daltonganj is situated at the central part of this belt. Daltonganj consists migmatitic to gneissic rock, and it is intruded by granite [224] along with enclaves of graphite-bearing khondalite and calc-silicate rocks within gneiss. Amphibolite to granulites facies rocks have been reported from Daltonganj area, and also the southern portion is contained base-metal deposit in the ultramafic host rock [217]. Daltonganj is located NW margin of the CGGC and basement rocks are dominated by granitic gneiss in which pelitic as well as mafic granulites present in the form of enclaves (Fig.3.3). The Massanjor-Baglan-Rangalia area of the eastern extremity is dominated by migmatitic charnockite (garnet + orthopyroxene + plagioclase + K-feldspar + ilmenite) which further retrogressed to form hornblende-biotite bearing quartzofeldspathic gneiss. These rocks contain enclaves of khondalite (garnet + sillimanite + plagioclase + quartz + K-feldspar + ilmenite), mafic granulite (clinopyroxene + garnet + hornblende + plagioclase + titanite + ilmenite), calc-silicate (clinopyroxene + plagioclase + K-feldspar + sphene + quartz), and Mg-Al granulite (garnet + orthopyroxene + cordierite + sillimanite + plagioclase + biotite + quartz + perthite + ilmenite) [72]. These rocks consist of three deformation stages (D_1–D_3) after the emplacement of the protolith of migmatitic charnockite. E-W trend of migmatites layer in charnockite developed during D_1, however Porphyritic nature of charnockite was intruded between D_1 and D_2 phases. Few of the mafic dykes were emplaced across this foliation and shown N-S closing D_3 folds. The western part of this belt has limited geological information, has a NW-SE trending domal structure in the vicinity of Ramanujganj (Tatapani) and is dominated by metapelites, where garnet is rich in spessartine (24 wt% MnO), rather than some other rock types are psammopelites, ferroactinolite, grunerite and metacarbonate have also been reported [225, 226]. This area shows regional metamorphism with an increase in metamorphic grade along NW direction where andalusite metamorphosed to sillimanite within metapelites [72]. Felsic magmatism forms granitic to granodioritic rocks that intruded in preexisting metasedimentary rocks along the western and northern portion of domal structure. The D_1–D_3 set of folds have affected the metasedimentary (metapelites, psammopelites and quartzite) rocks. Interference of D_2 and D_3 folding formed dome and basin geological structure [226]. A rare calc-silicate rock assemblages vesuvianite + grossular garnet + diopside + wollastonite + quartz, are reported in this area with *P-T* stability is ~4 kbar and 590–650°C.

The North Garhwa–Chatra–Giridih–Deoghar Belt consists of Deoghar–Josidih–Rohini sector and Dumka–Jamua–Gormar sector; these are surrounded by the Mesozoic Rajmahal trap to the east (Fig.3.2). Josidihi and Deoghar area has preserved the Augen gneiss, which is metamorphosed from the porphyritic granitoids, as intrusion mass within the quartzofeldspathic gneiss [227, 228]. Also, metamorphism occurred in mafic dykes with rheological inversion, where clinopyroxene react to form retrograde product amphibole and biotite [228]. There are two metamorphisms (M_1 & M_2) was recognized based on mineralogy and structure. I have not found any available *P-T* condition recorded for M_1, whereas M_2 metamorphism culminated at ~7 kbar and 600–750°C [228]. Dumka area was detail investigated and mapped with lithological distribution by [229, 230]. As like other belts of CGGC, this area also contains various mappable enclaves within migmatitic quartzofeldspathic gneiss like; khondalite, pelitic granulites, mafic granulites, high-grade gneiss, amphibolite and calc-silicate rocks. Ultrahigh-temperature (UHT) condition was signified from khondalite in Dumka area with *P-T* condition was 5–6 kbar and 930–950°C [231]. However, high-pressure (9–12 kbar) and medium temperatures (730–800°C) were obtained from the same area in quartzofeldspathic gneiss [129].

The Bihar Mica Belt (BMB) lies to the north of the Hazaribagh Plateau and is detached from the gneissic complex by the deposited sediments of Barakar Valley. This belt is also made up of gneissic basement, over which there is a deposition of metasedimentary rocks of the Koderma Group, consisting of conglomerate, quartzite, BIF, quartz-schist, mica schist, hornblende schist, calc-silicate rocks and amphibolite [232]. A conglomerate horizon was deposited at the basal part, and it contains high-grade gneissic rocks similar to other localities of the CGGC [221]. This characteristic shows that BMB has same sedimentary source as CGGC. Mica schists and pegmatites are a great source of reserves of the rare minerals and rare earth elements (REEs) [217, 233]. The Rajgir-Kharagpur Belt is situated at north of the BMB and northern end of the CGGC; this belt is covered by a thick deposit of Gangetic alluvium sediments [69].

3.3 Regional structure

The Satpura trend (ENE-WSW) of the Chhotanagpur continues up to the Shillong plateaus of the Assam [234]. This trend, however, takes a northerly swing from north-east to the north of Santhal Parganas [235]. The occurrence of charnockite, granulite, khondalite and leptynite in the eastern as well as western CGGC provides evidence for the extension of the Eastern ghat mobile belt trends (NE-SW) in the CGGC [120].

The CGGC has a general strike trend E-W to ENE-WSW of gneissic foliation with moderate northerly dip. The regional foliation trend of E-W turns to the NE (NW areas of Gomoh, SW of Daltonganj and west of Hazaribagh) and the NW (SE areas of Hazaribagh dist. and western part of Giridih). The intensity of E-W compression is extreme in the areas towards the eastern part of CGGC around Jamua-Dumka and Josidih-Deoghar. This regional foliation has axial-planar nature and folded into the isoclinal fold, with N to NNE striking trend and moderate easterly dip [129, 230].

Structural studies have been carried out in several isolated areas (Muri-Silli-Jhalinda, Ranchi and Purulia district) [236], the central part of Santhal Paraganas district [235, 237, 238], Jammu–Kakwara–Bhitea of Satpura Orogeny, Bhagalpur district [120, 217, 239-242], Bihar Mica Belt [224], Murhu Ranchi district [243]. These reveal three generations of deformation producing the F_1, F_2 and F_3 folds. The first deformation produced F_1 isoclinal folds on the bedding planes (S_1) and a strong regional axial plane schistosity/foliation (S_2). The F_1 fold axes show much scattering because of superposition by the later generation of folding (F_2 and F_3). S_2 occurs as schistosity in meta-pelites, para-amphibolites and some calc-silicate rocks and as foliation in the gneisses and migmatites. In general, S_2 has E-W strike with a steep dip toward the north, but locally it varies from this regional attitude because of later folding. The F_2 folds usually have a very steep plunge in the central part of the terrain (Ranchi and Hazaribagh district).

In the north-east (Santhal Paraganas) the axial surface of this fold strikes NNE-SSW. The third fold (F_3) is very dominant in the eastern and central regions (Ranchi and Purulia districts) and have subhorizontal or shallow axial plunge toward E and W with moderate steep northerly deeping axial planes. All the structural features indicate a general N-S compressive stress in the region.

During the second phase of deformation, a suite of mafic igneous rocks intruded as small syntectonic bodies throughout the granitic-gneiss complex. The mafic rocks have shared high-grade regional metamorphism of the amphibolites facies in most parts and also granulite facies in certain areas. The emplacement of the granite rocks was syn-to-late kinematic and mostly followed the axial plane of synformal or antiformal structures.

The third phase deformation (D_3) are observed as large scale arculation of the axial traces of F_2 folds and also in the form of open and broad warps with a set of related puckers that have developed locally. Because of the absence of any axial planar schistosity and indistinct chronological relationship with the F_2 structures, it is difficult at places to record the F_3 as a distinct and separate structure.

3.4 Stratigraphy

[244] regarded the CGGC as "unsurveyed and unclassified" crystalline rocks of the Dharwarnian age. The rocks were described by [245] as being younger than the Dharwarnian rocks of southern India. [244] contended that acute folding and concomitant metamorphism of the sediments was followed intrusion of granitic magma in the CGGC. [246] observed that gneisses are the oldest Achaean rocks in which granites are intruded. [247] considered two types of these granites, namely; older coarse-grained diorite, and an intrusive medium to coarse-grained granite (including porphyritic ones).

The older metasedimentary rocks occur as enclaves form in the gneissic country rocks [23, 74, 242, 248, 249] and consist of meta-pelites, khondalites, quartzites and carbonates of variable metamorphic facies, which ranges from amphibolite to granulite facies.

The medium-grained pelitic schists contain garnet, cordierite, plagioclase, muscovite, biotite, chlorite, sillimanite, quartz and graphite [72, 120, 130]. Major minerals in the carbonates rocks include diopside, calcite, grossularite, dolomite, serpentine, phlogopite, talc, plagioclase, tremolite and forsterite [126, 242].

Amphibolites also associate with the older metasedimentary rocks and contain uniform mineral assemblages mainly of hornblende, plagioclase and actinolite [120, 217].

The older metasedimentary rocks were faced massive deformation during the Satpura orogenic process. Ultramafic magma in the supracrustal region was emplaced prior to D_1 deformation, and emplacement mafic magma appears to be syntectonic. The mafic bodies now occur as amphibolites, mafic granulite, meta-gabbros, meta-norites, and meta-dolerites [217]. The large scale syn-to-late tectonic was regarded as regional metamorphism and accompanied by D_1 granite emplacement.

3.5 Geochronology and tectonothermal events of CGGC

The available geochronological data and four stages of metamorphic events are shown in Table 3.1. In comparison to adjoining Singhbhum terrain, geochronological observation on CGGC is very scanty. Consultation of existing literature that has not been a systematic study made so far on the junction between the Singhbhum mobile belt and the CGGC. Details structural studies by [250] around Murhu in Ranchi district have revealed that the CGGC and the overlying Singhbhum group of rocks were deformed and metamorphosed together. According to [251], Khatra-Tamar overthrust could be a boundary thrust that marks the boundary between CGGC and Singhbhum Mobile Belt. The salient features of these data are summarized as follows:-

The metamorphic history of the CGGC infers complex evolutionary history along with the Indian peninsular shield; four stages of metamorphism (M_1–M_4) have recognized between the Paleo- to Neoproterozoic, i.e., the M_1 occurred at about 1870–1660 Ma, the M_2 is considered to happen between 1550–1450 Ma, the M_3 varies from 1200–930 Ma, and the last M_4 event lies between 870–780 Ma [18, 22, 23, 72-74, 222, 223, 249, 252-254]. (1) The significant metamorphic evidence is recorded in pelitic granulites ~1600 Ma with U-Pb zircon dating [22, 23, 249, 255] as well as the EPMA chemical dating [129, 231]. It considered as the oldest basement of CGGC was formed during the Paleoproterozoic period at ~1750–1660 Ma [129, 208, 210, 253, 256]. This same age has recorded from the Mahakoshal Mobile Belt (MMB), it represents that granites of the northern part of CGGC were an extension of MMB [4, 210, 253]. The protolith of metapelites rocks derived from the adjacent continental masses; Eastern Ghats Belt, Aravalli Craton, and Lesser Himalaya, which recorded 1900 to 1700 Ma age [22, 23], further this deposited sediments experienced the first metamorphic event (M_1) during ~1680–1580 Ma with the formation of; garnet + sillimanite + plagioclase + K-feldspar + quartz + ferrian-ilmenite mineral assemblages at the high-temperature (>850°C) condition [249]. (2) The M_2 metamorphic event recorded in various types of rock assemblages; the Th-U-total Pb EPMA monazite dating revealed that garnet–hypersthene–gedrite–cordierite gneiss contains 1424±64 Ma age [18]. Zircon U–Pb dating disclosed A-type volcanic felsic magma emplaced at 1447 Ma [73], and other granitoid rocks emplaced at 1470–1450 Ma in the NE portion of the CGGC [3]. The M_2 event also recorded in the Pelitic granulites which occur as enclaves form in the host felsic orthogneiss during ~1470–1400 Ma [249]. The M_2 event of pelitic granulite considered as M_1 event for felsic orthogneiss, where pelitic granulites contain mineral assemblages; Garnet + sillimanite + biotite + plagioclase + rutile + K-feldspar + quartz + melt, as peak metamorphic condition [249]. However, the first metamorphism in mafic granulites was recorded in ~1450 Ma at peak metamorphic condition at 12 kbar and 800°C [74]. In contrast with these metamorphic events, few magmatic intrusions also occurred in the CGGC, where the anorthositic magmatic activity recorded in older metasedimentary granulites during ~1550 Ma [128]. (3) A tremendous metamorphic event (M_3) occurred in the CGGC during the Grenvillian orogeny (1100–900 Ma), where the majority of continental crusts (host rocks and enclaves) were undergoing granulite phase of metamorphism [18, 22, 70, 73, 128, 130, 210, 223, 257]. EPMA monazite dating of felsic orthogneiss and pelitic (khondalite) rock enclaves from the NE CGGC area was showed 1100–930 Ma age of metamorphism [128, 129, 231]. (4) Finally, M_4 metamorphic event represented as retrograde metamorphism where granulitic rocks metamorphosed to the amphibolite facies condition at ~870–780 Ma [72, 228, 252, 257]. The monazite dating provides high-pressure metamorphism event occurred at 880–830 Ma [129], and also regional metamorphism recorded in 850–780 Ma with the development of north-south fabric within the Dumka-Jamua-Ghormara sector [231]. This metamorphic event considered the last significant metamorphism and deformation of the CGGC [129, 257]. The granitic activities in Latehar- Richughuta-Kurri-McCluskieganj areas of the western CGGC have been dated from 800–878 Ma [125] which may be correlated with metamorphism and granitic activity of the Ranchi-Muri sector (980–890 Ma) of the eastern CGGC [258]. U-Pb isochron ages of some radioactive minerals from the pegmatite of Bihar mica belt also indicate the age of 960±50 Ma [259]. They are correlated with K-Ar ages of mica from metamorphic and granite gneiss of Gurpa (934–917 Ma), Muri-Silli (970–890 Ma) area [124] and porphyritic biotite granitoid (from biotite) and massive leucogranitoid (from primary muscovite) in Belamu-Nawahatu sector of Puruliya, West Bengal 870±40 and 810±40 Ma, respectively [260]. The Rb-Sr data on K-feldspar, biotite and plagioclase separated from the sample, it gives a mineral isochron age of 855±30 Ma [261] from Bihar mica belt, suggesting that the granite have been affected by later metamorphic events leading to re-equilibration of Sr isotopes among the minerals without any significant effect on the whole rock.

The 1700–1500 Ma age corresponds to the Tirodi gneiss of the Sausar group and Koskal granite of Baster by Rb-Sr isochron ages [209]. The 800±100 Ma event is reflected in various Rb-Sr and K-Ar ages from the Sausar, Sakoli, Khairagarh Belts. This event has possibly generated S-type granites at a place in the Satpura belt by crustal anatexis.

Based on the above discussion author has concluded that the CGGC affected by D_1 deformation (> 1600 Ma) is related with M_1 episode of the metamorphism. The M_1 episode of metamorphism shows the migmatization by regional metamorphism of older metasediments, mafic granulite and charnockite. Rocks of M_1 episode show prograde metamorphism and this metamorphism was the result of Columbia supercontinent assembly. Further, the breakdown process of Columbia supercontinent was started after ~1500 Ma age, and this leads to the retrograde metamorphic stage (M_2) with another phase of magmatism under which felsic magma emplacement occurred. These dates give the evidence of the latest events of orogeny related to D_2 deformation and M_3 episode of metamorphism (1000±50 Ma) associated with Grenvillian orogeny. The M_3 episode of metamorphism shows prograde metamorphism from mafic granulites to amphibolite and high-grade gneisses. The M_4 episode of metamorphism has marked the end of regional metamorphism in the CGGC.

3.6 Geological setting around Daltonganj

The study area around Daltonganj lies in the NW extremity of the CGGC within the Daltonganj (North Palamau)-Hazaribagh-Dumka Belt (Fig.3.3). The investigated area falls between latitude 23º54’50’’N to 23º58’30’’N and longitude 84º02’E to 84º06’30’’E in the Survey of India Toposheet number 73A/1. The study area, its extension up to Renukoot and it separated to Mahakoshal belt by the CITZ, and in NNW direction the CGGC extend to Japala of Garhawa district. It separated by a thrust to Vindhyan Supergroup which lies in Sasaram. The study area is located 14 km away from Daltonganj in the southwestern part. It consists of quartzofeldspathic gneisses, granitoid and migmatites with enclaves of high-grade metasedimentary rocks as well as meta-mafic rocks and basic to intermediate intrusive rock types ([18, 120, 217, 262] and references therein). The granitic rocks of NW CGGC have been considered to be of anatectic origin [120]. The granitic gneisses and migmatites are abundant rock assemblages in the CGGC. The granulites facies rocks are characterized by the presence of orthopyroxene-garnet gneisses, and are also reported in the Bengal-Jharkhand boundary area and Palamau district [217, 263, 264]. The porphyritic granitoid and granitic gneisses are present as country-rock of the study area. It contains mafic granulite, pelitic granulite, high-grade gneiss (garnet-cordierite-gedrite gneiss, garnet-cordierite-orthopyroxene gneiss), migmatitic granite gneiss, massive granite, charnockite, khondalite (garnet-cordierite-sillimanite-graphite gneiss), amphibolite, meta-norite, dolomitic marble and mafic dyke in the localities around Datam, Sokra, Dokra, Nawa, Mahawat-Muria, Kui, Rakh Pahar and Khatauni (Fig.3.3). The Proterozoic country rocks are not continuous but dispersed throughout the areas in small lenticular patches and occur as enclaves within granite gneisses. The granites of the area are divisible into two main types (i) older migmatized granite (ii) younger granite. These granites are younger to the country rocks which are considered to be the oldest formation of the area.

3.6.1 Structure

Two generations of structural events are imprinted on the rocks of the area under discussion. Both planar and linear structures have been recorded in the area.

3.6.1.a Planar structures

The planar structure in the areas is the axial plane or the schistosity (S_2) and bedding plane (S_1) concerning the first fold (F_1) related to the D_1 deformation. This schistosity (S_2) exhibits a regional strike NW-SE and dips moderate to high angle (35°-

70º) either towards south-west or towards north-east. The S_3 developed on S_2 and related to the second generation of folds (F_2), and deformation D_2 are less developed in the area in comparison to the S_2. The general strike directions of these (S_3) planes are NE-SW, and they dip at moderate to high angle (35º–75º) either towards north-west or north-east.

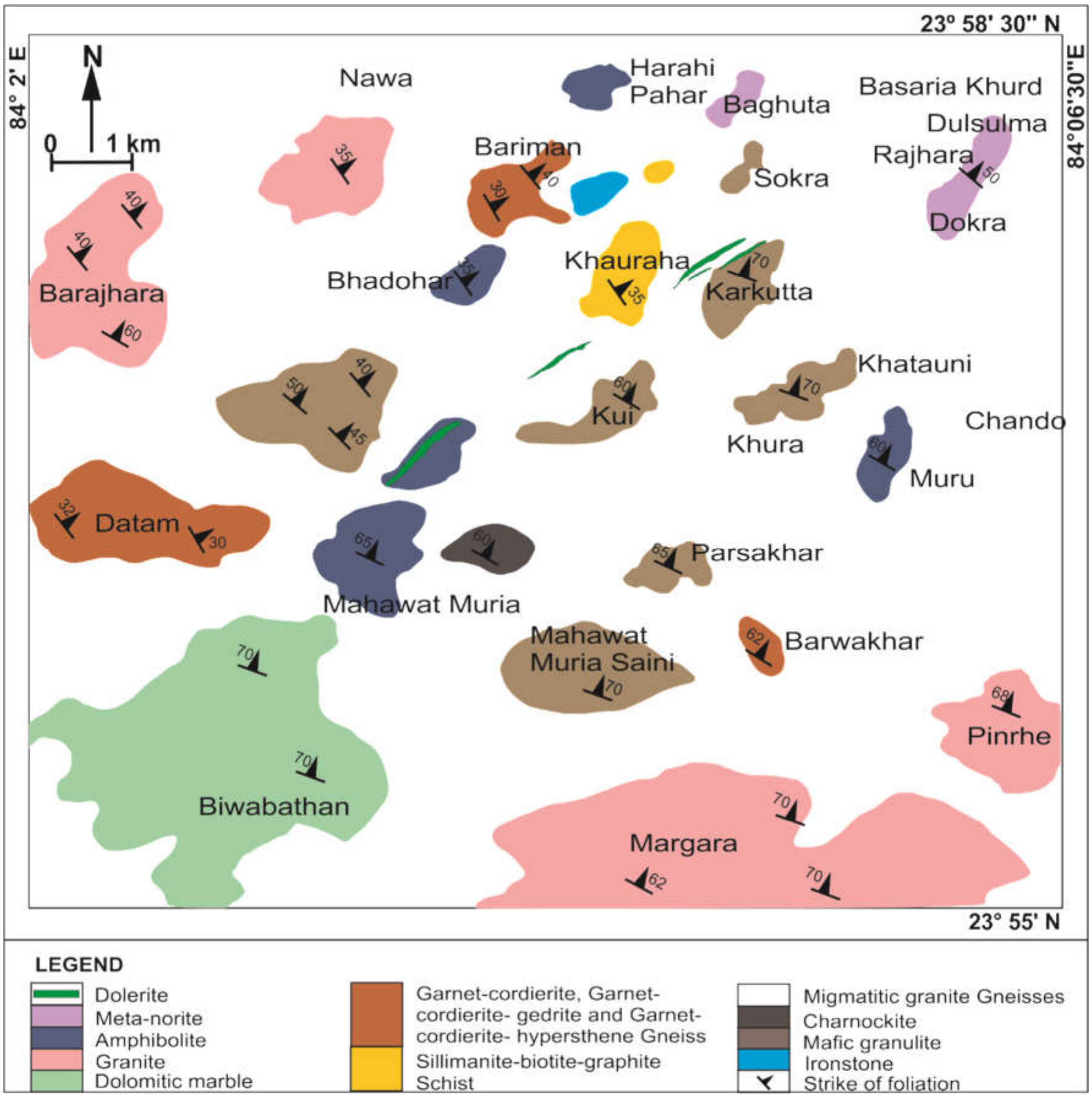

Figure 3.3. Local geological map of the area around the south-west of Daltonganj, District Palamau (Jharkhand) India (after [262]).

3.6.1.b Linear structure

The folds of the first generation (F_1) are tight isoclinal in nature and developed on a mesoscopic scale. The fold hinge of those folds (F_1) exhibits a variation of the plunge from 10º to 60º either towards south-east or south-southeast. The folds of the first generation (F_1) are better developed than the second generation of folds (F_2) in the investigated area. The folds of the second generation (F_2) are developed on S_2 and are less common in the area in comparison to F_1 folds. The F_2 folds plunge at 30º-60º towards NE direction.

3.7 Metallogeny events in CGGC

The CGGC is generally considered to be devoid of any significant mineralization except in the Bihar Mica Belt (BMB), which is well known for commercial variety of mica and associated rare minerals in pegmatite. No systematic approach has yet been made to study the entire belt in search of economic minerals apart from mica. A close scrutiny on the occurrences of different metallic and non-metallic minerals suggest five distinct phases of mineralization controlled chiefly by lithology and tectonics:

3.7.1 Pre-tectonic: Those associated with meta-sediments and meta-ultramafic rocks e.g., Cu-Pb-Zn-Ag, magnetite, limestone, dolomite, graphite, vermiculite and asbestos.

3.7.2 Syn-tectonic: Those associated with gabbro-anorthosite e.g., vanadiferous magnetite and ilmenite, and with migmatites-anatectic granite e.g., U and Th.

3.7.3 Post-tectonic: Those associated with pegmatite and greisen zones e.g., mica, feldspar, garnet, beryl, arsenic, apatite, columbite-tantalite, rare earth, Sn-W, etc.

3.7.4 South Purulia Shear Zone (Tamar-Poropahar shear zone): Occurrences of base metal, tungsten, radioactive minerals, phosphate, apatite and kyanite have been reported in detached patches due to hydrothermal activity in the fault/shear zone and are comparable to Singhbhum shear zone situated to its south; Nb and REE in association with carbonatite.

3.7.5 Placer: Gold, diamond, tin, ilmenite and rutile.

3.8 Rock types and their field relations

3.8.1 Mafic granulites

These rocks occur as enclaves within granitic gneiss and are dark grey to black, coarse to medium grained with granulitic texture. It appears as discontinuous, scattered, lenticular patches throughout the area. The strike trend of the mafic granulite throughout the region is NE-SW direction. In the north-eastern part of the investigated area, mafic granulites occur as large lensoide patches within granite gneiss. The main constituents are orthopyroxene, clinopyroxene, garnet, hornblende, plagioclase, cummingtonite and quartz, whereas magnetite, ilmenite, apatite etc. are present in minor amount.

3.8.2 Pelitic granulites

These rocks are massive and medium to coarse grained with grey to pinkish colour due to the abundance of garnet and having a greasy appearance and show a granulitic texture. The large size of garnet grains has appeared on the rock surface. The pelitic rock mainly consists of garnet, cordierite, sillimanite, biotite, plagioclase, K-feldspar, quartz, and opaque minerals (ilmenite and magnetite).

3.8.3 High-grade gneisses

Garnet-cordierite-orthopyroxene gneiss and Garnet-cordierite-gedrite gneiss are known as high-grade gneisses, and these are not extensively developed throughout the investigated area. It occurs as lenticular patches around NW and NE of Datam trending NW-SE direction and small patches near Mahawat-Muria and Sokra within granitic gneisses. The reddish tinge colour has appeared due to abundantly presence of garnet. These are fine to coarse-grained and dark in colour. As these rocks are composed of hard minerals which are not easily disintegrated, they are found lying loose on the ground due to weathering. They are composed of garnet, cordierite, gedrite, biotite, sillimanite and quartz as major constituents. Magnetite, ilmenite, graphite, apatite etc. are as minor amounts. Feldspar (K-feldspar and plagioclase) are present in lesser amounts.

3.8.4 Migmatitic gneiss

The major part of the area is occupied by migmatitic gneisses as the dominant rock type. The migmatitic granitic gneisses include the following varieties: biotite-granite gneiss, hornblende-biotite-granite gneiss and range in composition from granite to granodiorite. They are younger than the garnet-cordierite gneisses and garnet-gedrite gneisses. Mafic granulite and charnockite are frequently shown an intrusive relationship with them.

3.8.5 Sillimanite- biotite- graphite schist

The rocks occur as a small lenticular patch within granitoid gneiss from 1.5 Km SW of Sokra. It is fine to medium-grained, light grey colour rocks. It consists of biotite, sillimanite, quartz, graphite etc.

3.8.6 Amphibolite

These rocks types are well-developed round Baghauta, Rajhara, and Dokra, and occur as dyke like body within the gneissic foliation of the surrounding country rocks. The amphibolite is medium to coarse-grained. It consists of plagioclase, augite, hornblende etc.

Table 3.1 Four stages of metamorphism (M1-M4) are representing from different localities of the CGGC (modified after [16]).

Age (Ma)	Type of Metamorphism	Dating Technique	Type of Rocks	Locality	Authors
M_1 (Palaeo-proterozoic)					
1870-1691; Mnz core 1824-1659; Mnz core Grt hosted 1720±31; Mnz core	-UHT metamorphism -HP (9-12 kbar) and MT (730-800°C)	U-Th-Pb monazite	Khondalite enclaves Migmatitic quartzofeldspathic gneiss Metapelitic granulite	Southern CGGC margin NE of Dumka near the northern CGGC margin	[129]
1800		U-Th-Pb monazite	Metapelitic granulite	Purulia	[70]
1752-1686	Granite Magmatism	U–Pb (ID-TIMS)	Bathani Volcano Sedimentary sequence (Granite)	Bathani Village, Gaya	[253]
1754±116		Rb-Sr whole-rock isochron age dating	Granite	Dubha	[265]
1741±65	UHT metamorphism	Rb-Sr whole-rock isochron age dating	Granite	NW CGGC	[208]
1710-1630	Felsic magmatism	Lu-Hf zircon	Augen gneiss	Dumka	[266]
1710	UHT	Rb-Sr whole-rock isochron age dating	Gneiss	South of mica belt	[256]
1700-1650	UHT metamorphism (sulphide mineralization)	Pb-Pb mineral age dating	Galena from sulphide-bearing metasediments	Hesatu-Belbathan area	[255]
1697±17 1583±50	Retrograde metamorphism	U-Th-Pb monazite U-Th-Pb xenotime	Porphyritic granite	NW CGGC (Gaya)	[210]
1680-1580 1470-1400	High Temperature (>850°C) Mafic magma emplacement	U-Pb zircon (LA-ICP-MS)	Pelitic granulite Mafic granulite	Dumka	[249]
1680-1520	Older metamorphism	U-Pb zircon (LA-ICP-MS)	Pelitic granulite	NE CGGC	[22, 23]
1624-1585	Age of crystallization (HT/MP)	Zircon dating	Charnockite		[211]

M_2 (Paleo- to Mesoproterozoic)					
1628: Mnz core 1518: Mnz core	UHT metamorphism (5-6 kbar/ 930-950°C)	U-Th-Pb monazite	quartzofeldspathic granulite and khondalite	East of Trikut Pahar near Deoghar	[231]
1624±5, 1000 1515±5, 1000 1515	Isobaric cooling path (IBC)	Rb-Sr whole-rock isochron age dating	Hy-granite gneiss Massive charnockite Mafic granulite	Jamua-Dumka	[208]
1599-1522	UHT metamorphism	Rb-Sr whole-rock isochron age dating	Felsic gneiss	Mor Valley	[256]
1590±30		Rb-Sr whole-rock isochron age dating	Granite	Bhallupahari-Nirupahari	[261]
1550±12	UHT metamorphism	U-Pb zircon (ID-TIMS)	Gabbroic anorthosite	Saltora (West Bengal)	[128]
1457±63 1331±125	Isobaric cooling path (IBC)	Rb-Sr whole-rock isochron age dating	Charnockite gneiss Syenite	Jamua-Dumka	[208]
1465±17 1447±11	Isothermal decompression	U-Pb zircon (LA-ICP-MS)	Ferroan granitoid A-Type granitoid	Between Dumka and Deoghar	[3, 73]
1442-1305:Mnz core 1272±35: Mnz core	Prograde metamorphism	U-Th-Pb monazite	Granite gneiss Porphyritic granite	-Southern CGGC -NE of Dumka,	[129]
1416-1246	UHT metamorphism and granitization	K-Ar whole-rock age dating	Hornblende from amphibolite enclaves within granite gneiss	Simultala area of Monghyr, NE CGGC	[124]
1331±42		Rb-Sr whole-rock isochron age dating	Granite	Nagam	[267]
1300-1110	UHT metamorphism (Intrusive granite)	Rb-Sr whole-rock isochron age dating	Migmatitic granite gneiss	Hesatu–Belbathan area	[261]
M_3 (Meso- to Neoproterozoic)					
1190±26: Mnz rim Gt 995±24:Mnz rim Gt 950±20:Mnz in matrix	Prograde metamorphism (7-10.5 kb/775-825°C)	U-Th-Pb monazite	Metapelitic granulite	NW of Dumka	[128]

947±27	High-grade metamorphism (8.5-11 kb/950-900°C)	U-Pb zircon (ID-TIMS)	Gabbroic anorthosite	Saltora (West Bengal)	[128]
1178±61 1071±64	Isothermal decompression path (ITD)	Rb-Sr whole-rock isochron age dating	Migmatitic granite gneiss Porphyritic granite	Jamua-Dumka Bero-NE Purulia	[208]
1176±9: Mnz in Gt 1082±9:Mnz inMatrix 1041±20: Mnz in Gt 981±26:Mnz in matrix	Prograde metamorphism (750-850°C/ 4-6 kbar)	U-Th-Pb monazite	Garnetiferous metapelitic gneiss	Bero-Saltora (W.B)	[130]
1119±24		Rb-Sr whole-rock isochron age dating	Gneissic granite	Chianki, Daltonganj	[209]
1138±193 1065±74 1059±104		Rb-Sr whole-rock isochron age dating	Diorite Pink granite Alkali syenite	Kailashnath gufa Marne	[268]
1021±26: Mnz in Grt 992±11:Mnz in matrix 977±15: Mnz in Grt 967±11:Mnz in matrix	Prograde metamorphism	U-Th-Pb monazite	Foliated granite	Bero-Saltora (W.B)	[130]
1118 & 1088: Mnz outer core in a matrix 979 & 942: Mnz rim in a quartzose matrix		U-Th-Pb monazite	quartzofeldspathic granulite and khondalite	East of Trikut Pahar near Deoghar	[231]
1086-893	Regional metamorphism and Insitu granitization	K-Ar whole-rock dating	Hornblende from amphibolite	Gomoh Dhanbad area	[124]
1048±135 1025±11		Rb-Sr WRI	Granite	Gumla Ekma	[269, 270]
1005±51	UHT metamorphism	Rb-Sr whole- rock dating	Grey granite gneiss	Raikera-Kunkuri, Jashpur (Chhattisgarh)	[233]
990-940	Isothermal decompression path (ITD) (11 to 5 kbar)	U-Th-Pb monazite	Mafic granulites	Bero-NE Purulia	[70]
984-930: Mnz in Gt	Isothermal Decompression	U-Th-Pb monazite	Migmatitic quartzofeldspathic	NE of Dumka near the	[129]

and matrix 954±32: Mnz rim 940-924: Mnz rim			gneiss Porphyritic granite Metapelitic granulite	northern CGGC margin	
967-939: Mnz core 965±51: Mnz rim 937±30	Retrogression metamorphism	U-Th-Pb monazite	Granite gneiss Porphyritic granite Metapelitic granulite	near the southern CGGC margin	[129]
980		U-Pb Allanite		Ranchi	[271]
975±67	High grade prograd	U-Th-Pb monazite	Pink granite	NW CGGC	[210]
970 890		K-Ar	Muscovite from metamorphites Biotite from granite & gneisses	Muri-Silli-Jhaldi area Ranchi Dist	[272]
970	Regional metamorphism	K-Ar	Amphibolite	Richughuta, Palamau	[125]
960±50		U-Pb Monazite	Samarskite, Columbite etc. from Pegmatites	Pichili pegmatite, Bihar Mica Belt	[259]
965		U-Pb Uranite		Singar, Gaya	[273]
948±22 943	Prograde metamorphism until peak (high pressure)	U-Pb zircon (LA-ICP-MS)	Amp-Bt-gneiss Charnockitic gneiss	Between Dumka and Deoghar	[3, 73]
941, 932 and 886		Rb-Sr mica	Pegmatite	Dumhat	[261]
910±19		U-Pb, Pb-Pb min	Pegmatite Cb-Ta	Dhajua pegmatite etc.	[274]
M_4 (Neoproterozoic)					
902±10 Ma	Retrograde metamorphism	LA–ICP–MS U–Pb dating of zircon	Charnockitic gneiss	around Deoghar–Dumka	[73]
890	Regional Metamorphism	K–Ar whole-rock age dating	Amphibolite	-Ranchi-Muri sector (Eastern CGGC	[124]
880±13	Retrograde metamorphism	LA–ICP–MS U–Pb dating of zircon	Pelitic gneiss	around Deoghar–Dumka	[249]
876–780	Retrograde metamorphism	U–Th–Pb monazite	Pelitic gneiss	NE of Dumka near the northern CGC margin	[257]

876–828; Mnz in Gt and matrix	Retrograde metamorphism	U–Th–Pb monazite	Migmatitic quartzofeldspathic gneiss	NE of Dumka near the northern CGC margin	[129]
859±87: Mnz core 860-778: Mnz rim			Granite gneiss Porphyritic granite	near the southern CGGC margin	
878-805 (Bt) 800-765 (Bt, Hbl)	Metamorphism and granitic intrusion Age of orogeny/cycle	K–Ar whole-rock age dating	Granite Amphibolite (hbl)	Latehar (western CGGC) Palamau (Jharkhand)	[125]
870±40 810±40	Intrusive Pegmatite	K–Ar whole-rock age dating	Biotite of porphyritic granite muscovite of Leucogranite	Puruliya (WB)	[260]
862: Mnz in biotite 842: Mnz in biotite 788: Mnz in matrix		U–Th–Pb monazite	Quartzofeldspathic granulite and khondalite	East of Trikut Pahar near Deoghar	[231]
856-775	Decompression metamorphism	U–Th–Pb monazite	Migmatitic gneiss	Purulia (WB)	[70]
855±25	Later metamorphic and magmatic activity	Rb-Sr isochron	Granite Mica	Bhallupahari-Nirupahari (Bihar Mica Belt)	[261]
825±26: Mnz in Grt 818±9: Mnz in Matrix	Prograde metamorphism (650±50°C/ 4-5 kbar)	U–Th–Pb monazite	Garnetiferous metapelitic gneiss	Bero-Saltora (WB)	[130]
815±47	Metasomatism	Rb–Sr isochron	Pink granite	Raikera-Kunkuri, Jashpur (Chhattisgarh)	[233]
870 ±40 810 ±40	Magmatic activity	K–Ar whole-rock age dating	Biotite from porphyritic Muscovite from leucogranite	Belamu-Nawahatu (Purulia)	[275]
768±19	Retrograde metamorphism	U–Th–Pb monazite	biotite–granodiorite gneiss	Bhagalpur	[210]
830 760	(Metasomatism) Fission track	Fission-track age dating	Garnet in mica pegmatite Muscovite in mica pegmatite	Hesatu–Belbathan area (Bihar Mica Belt)	[276]