

Metamorphic Evolution of Mafic Granulite Enclave, Clinopyroxene-Plagioclase-Ilmenite Symplectite Formed by Garnet Breakdown, of Chotanagpur Gneissic Complex (CGC), Jharkhand, India

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ABSTRACT

Porphyroblastic garnet grains are found in the mafic granulite enclave in the eastern region of the Chotanagpur Gneissic Complex (CGC). Grain composition varies from the core to the rim of this porphyroblastic garnet. According to the petrography and geothermobarometry investigation, there is a breakdown symplectite texture and temperature change from the garnet grain's centre to its rim. These occurrences demonstrated that this rock would undergo decompression once it reaches its peak metamorphic state. Garnet porphyroblasts in a retrogressed mafic granulite enclave create Cpx-Plag-Ilm intergrowth as a result of decompression and cooling. The chemical composition of the core, rim, and symplectite section clearly differs, according to Electron Micro Probe Analysis (EPMA). Garnet from symplectite (Cpx-Plag-Ilm) and high-grade granulite facies rock breakup is an obvious sign of isothermal decompression or rock upliftment.

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Introduction:

Paleo to Meso Proterozoic rocks may be found in the eastern portion of the Chotanagpur Gneissic Complex (CGC) in and around Ranchi, Jharkhand, India. The Precambrian East Indian Craton includes this CGC. The low-lying country rock in the region is mostly composed of orthofelsic gneiss, which was invaded by amphibolites dyke and a porphyritic charno-enderbitic rock (Fig:1). The primary rock type under investigation is a mafic granulite enclave that is discovered as a disconnected raft inside the felsic gneiss host. The stabilisation of early assemblages of porphyroblastic garnet+Opx+Ilmenite[1]+Plagioclase[1] is confirmed by petrographic analysis. The disintegration of garnet porphyroblast into symplectite intergrowth of Cpx+Plagioclase[2]+Ilmenite[2] may have resulted from decompression of the peak assemblage. Hornblende, amphibole, and biotite eventually replace the early assemblage during cooling and hydration. Gibbs free energy minimisation combined with thermobarometric analysis The P-T condition of metamorphism of these early granulite enclaves was constrained using a pseudosectional technique. This might be helpful in limiting the impact of polymetamorphism in the research region. Based on petrographic observation and Electron Micro Probe Analysis (EPMA) of Cpx, Ilm, Plag, and Garnet, the authors of this debate highlight the development of a Cpx-Plag[2]-Ilm[2] symplectite texture in mafic granulite enclave.

Geology of the study area:

There are several types of rocks in this research area. Fine-grained felsic gneiss with early migmatization is the most common rock type in the study region (Acharyya 2003). A

felsic porphyritic rock unit and basic igneous rocks—now amphibolites—have invaded this country rock (Mahadevan,2002). High-grade granulite felsic rocks can be found in isolated pods within the felsic gneiss country rock. There are pegmatite veins everywhere, and these veins frequently include tourmaline grain (Baidya et al 1989).

The primary constituents of fine-grained felsic rock (retrogressed charnockite) include quartz, feldspar, orthopyroxene, amphibole, biotite, and pink potash feldspar (Bhattacharyya et al,1987). The rock has medium to coarse grains in nature. This garnet with leucosome segregations parallel to the gneissic foliation is evidence of early migmatization. Alternative bands of bright and dark colours indicate the noticeable gneissic banding. The mineralogical assemblage indicates that the rock is granitic, with a higher amount of potash feldspar than plagioclase. The rock can be referred to as charnockite as it contains primary Opx. Enderbite is the most significant kind of intrusive found in Charnockite Country Rock. The rock has a greasy appearance and is black in nature. Schistosity is not highly developed in this rock. It has a roughly enormous look with sporadic gneissic fabric development. Opx, Cpx, Quartz, Plagioclase, and Potash feldspar make up this rock. According to its mineralogical composition, this porphyritic gneiss is granite to granodioritic in nature, with a higher proportion of plagioclase feldspar than potash feldspar. We may conclude that this porphyritic felsic gneiss body was intruded at a later period since xenoliths of country rock have demonstrated their intrusive character. Granulite and high-grade felsic metamorphosed rock are two types of enclave rocks found in the nation.

The enclave types of rock include magnesium-aluminum granulite, mafic granulite, calcareous granulite, and

khondalite or cordiorite gneiss. However, we focus on the mafic granulite enclave in our discussion. Dark-coloured garnetiferous mafic granulite rock is exposed at ground level at Rangalia hamlet close to the Jeebanpur-Bagnal route. Cpx, quartz, K-feldspar, and garnet make up the majority of this mafic rock. This black, medium-to-coarse-grained rock is mostly composed of mafic and plagioclase minerals. There is a cluster of garnet grains here, and there is a thin leucocratic white ring outside of them (Fig:2A to 2D). Amphibole grain takes the place of this garnet in the second step. This amphibole has a prismatic form, a dull sheen, and a parallel orientation.

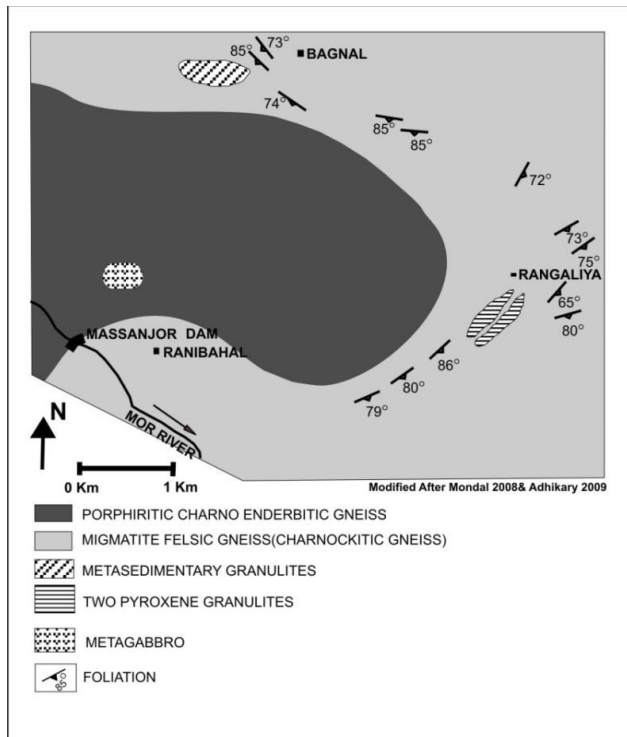


Fig:1 Geological map of the study area (after Sanyal et al,2012)

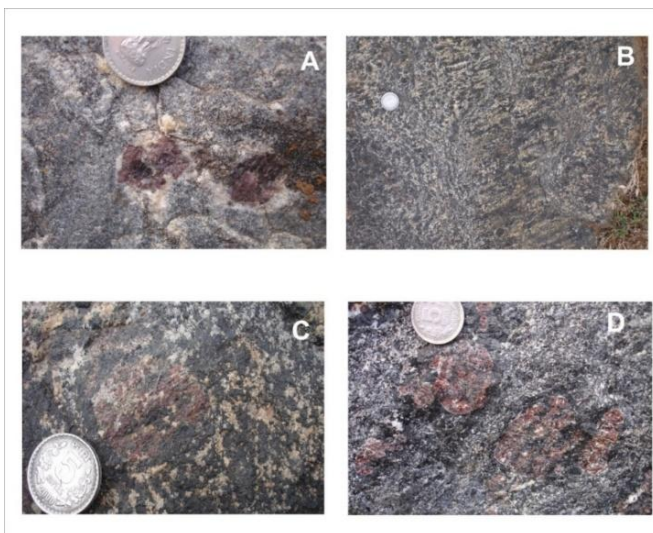


Fig:2 A) Garnet cluster in retrogressed mafic granulite rock. B) Alignment of amphibole in retrogressed mafic granulite rock. C) Thin white colour rim outside the garnet cluster. D) Dark appearance in the retrogressed mafic granulite rock.

Structure:

Rocks with signs of multipal phase deformation may be found in and around Massanjore. The typical country rock in this area is felsic gneiss, which is the most prevalent rock type in the research area (Dunn 1929 & 1942). It has the telltale signs of an early migmatization that caused the rock to develop a noticeable gneissic banding (Chatterjee et al 2008 &2010). This gneissic banding is primarily defined by quartz-kfs-plag bearing segregations and alternating Gt-Opx bearing layers. Textural analysis verifies that early opx and Gt are replaced in this rock by amphibole and subsequently biotite. A widespread planner fabric in the rock is seen in this secondary amphibole and Bt grains, and the older gneissic banding has entirely been replaced by this newly formed planer structure. This is really the most common fabric in the research area. A few E-W chosing acute hinged folds with a gneissic banding form surface have been seen in field observations; parallel to the axial plane of these folds, an E-W trending schistosity has evolved (Ghosh 1983 & 1992). Amphibole and/or biotite in various rocks consistently characterise this E-W fabric. The production of E-W striking planer fabric in the research region is really caused by these F2 folds. The gneissic banding axial planer cleavage caused by the F1 fold is incredibly uncommon in the region. In the last step of deformation, the E-W foliation was folded once again to create a weakly developed N-S striking foliation. However, because the final deformation was not highly penetrative, this N-S fabric is extremely weakly developed. A well-developed gneiss banding deformed by anhydrous minerals is preserved in the granulite-grade rocks that occur as lenses or pockets within the incipiently migmatized felsic gneiss. This gneissic banding is significantly at odds with the gneissic structure linked to F1 folding (D1 deformation) in migmatitic felsic gneiss. Therefore, there is no genetic connection between the younger structure and the gneissic planer fabric seen inside the granulite pockets, which are unquestionably older structures. Since the minerals that define the fabric are all of the grade, the F2 folding during D2 deformation that resulted in E-W fabric must have taken place in an amphibolites facies state (Ray et al, 2010 and Sanyal et al,2010). The porphyritic Charno-enderbitic rock that has intruded the migmatitic Felsic Gneiss (country rocks) has the impression of following D2 and D3 deformation but lacks the characteristic of F1 folding (magmatism linked with D2). This clearly shows that the migmatitic Felsic gneiss has been displaced (intruded) by the porphyritic Charno-Enderbitic gneiss in a post-D1-pre-D2 stage.

Petrography:

To comprehend the mineralogical development of the rock under investigation, a detailed petrographic description of the retrogressed mafic granulite has been recorded. In order to maintain a metamorphic evolutionary framework of the region, the petrography of felsic gneiss, the widely distributed country rock of the study area, as well as its enclave suite of rock (the different granulite grade gneisses, including the mafic granulite), and the later intrusive within it are also described here (Kumar et al,2007). It is a dark-coloured, coarse-grained rock with little to no gneissic banding. Garnet, amphibole, plagioclase, clinopyroxene, ilmenite, and sphene make up the majority of this rock. Garnet (30%), amphibole (25%), plagioclase (25%),

clinopyroxene (12%), ilmenite (6%), and sphene (2%) make up the modal fraction of the minerals. The characteristics of these minerals in this rock include garnet, which creates several distinct pink-colored clots within a dark-coloured matrix that give the rock type a meassels-like appearance. The majority of garnet grains have a resorbed corroded grain edge and are subidioblastic to xenoblastic in form. A coarse simplectic intergrowth of cpx-pl-ilt that exhibits severe indentation inside the garnet grain border surrounds the garnet porphyroblasts throughout.

Within such a symplectic mass of cpx-pl-ilm (Fig:3A & 3B), a few tiny garnet grains are occasionally observed floating as undigested rafts. When amphibole grains come into direct touch with garnet, they also have a dispersed grain border that is not conformable. There are two distinct forms of plagioclase in the rock. (1) As a heated, fine-grained component of the intergrowth that surrounds garnet porphyroblasts in a simplectic corona with cpx and ilmenite. (2) Coarse grains with a prominent polygonal recrystallised border that is somewhat separated from the intergrowth. Deformed twinned lamellae are seen in these recrystallised plagioclase grains. Similar to plagioclase, cpx is found in the rock in two opposing modes. Coarse, short lenticular bodies orientated at a high angle to the adjacent garnet porphyroblast border are one common way of formation. These dumbbell to vermicular masses of cpx, which frequently exhibit branching, typically form intergrowths with ilmenite

and plagioclase around garnet grain. It has been identified that amphibole replaces both the coarse cpx grains away from intergrowth and the cpx grains within the coarsed cpx-ilm-pl-simplectic corona surrounding garnet porphyroblasts. Here, amphibole occasionally fully pseudomorphs the cpx grains, while in other locations, relict cpx is detected at the core of the amphibole that is being replaced. Garnet is frequently seen to be replaced at the edge by amphibole. The rock contains two different kinds of ilmenite.

One variety has fine, worm-like grains that form simplectic intergrowth with cpx, ilmenite, and garnet porphyroblast, while the other is coarse-grained and occurs with recrystallised plagioclase and cpx grains.

Coarse cpx-pl-ilm-gt is clearly the early assemblage in the rock that has stabilised at the peak condition of metamorphism, according to petrographic research. Such an anhydrous mineral is clearly indicative of a high-grade granulite facies metamorphism that has impacted the research area's lithology. The early stabilised garnet grains then broke down into simplectic intergrowth of cpx₂-ilm₂-pl₂ under the altered physical state of metamorphism, forming a coronitic envelope surrounding the resorbed Gt porphyroblasts (Fig:3C & 3D). The rock under investigation has undoubtedly been impacted by late-stage hydration and cooling, which resulted in the development of retrogressed amphibole grains after cpx-Gt and Ilm.

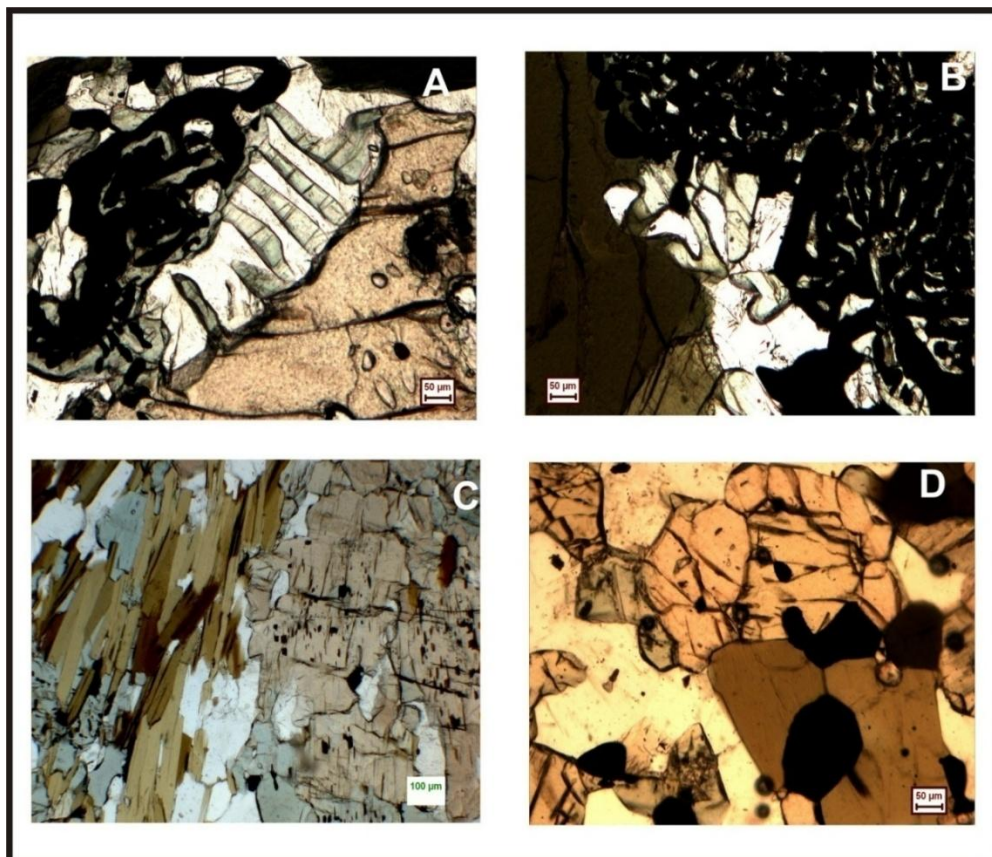


Fig:3 A) Clinopyroxene simplectic intergrowth beside Garnet porphyroblast. B) Ilmenite intergrowth within mafic granulite rock. C) Biotite within country rock and D) Garnet porphyroblast within country rock.

Phase Chemistry:

Using a CAMECA SX-100 electron microprobe, of G.S.I., Faridabad, evaluated the chemical composition of

coexisting mineral phases in retrogressed mafic granulite of the Massanjore region. Both instruments were configured to operate at 1 mm beam diameters, 15 KV accelerating voltage, and 12 NA specimen current.

Natural and artificial minerals were employed as standards in the PAP rectification program. Phase chemistry is crucial to comprehending how metamorphic minerals remain stable in rocks. Understanding the phase chemistry of each individual mineral phase is essential because metamorphic minerals interact with one another in a mineral assemblage under certain conditions.

Garnet in the past in essence, Mafic Granulite is a solid solution of Almandine and Grossular with little Pyrope content. The rock contains negligible amounts of andradite and spessartine. While the pyrope content is essentially unchanged, the porphyroblastic Gt exhibits a clear chemical variation in terms of almandine and grossular contents from the core section of the grains to the rim region (Table:1). All of the core Gt is grossular rich ($X_{gr}=0.29$) and almandine poor ($X_{alm}=0.44$), but the rim portion of the Gt porphyroblast is in direct contact with the simplectic Cpx-Pl-Ilm intergrowth, where its grossular content decreases to 0.22 and its almandine content increases to $X_{alm}=0.54$. Isolated recrystallised crystals of plagioclase feldspars have while the specific

Pl that occurs as a number of the simplectic intergrowth with Cpx&Ilm (Table:5) surrounding Gt porphyroblast is more calcic in composition with X_{an} ranges in the range of 0.83 to 0.86, X_{alm} ($=Ca/Ca+Na+K$) varies in the range of 0.77-0.78. In this rock, clinopyroxene is found in many simplectic intergrowths with Pl and Ilm around garnet porphyroblast. X_{En} and X_{Fs} are its two components. The X_{En} and X_{Fs} components fluctuate between 0.36 and 0.40 and 0.08 and 0.15, respectively (Table:2).

The retrogressed mafic granulite rock contains amphibole. In this case, every amphibole (Table:4) is a secondary product that forms during retrogression. Every amphibole found in this rock belongs to the calcic group. There are three types of calcic amphibole found here: magnesium hastingsite, pargasite, and gedrite. In this rock, ilmenite is found in many simplectic intergrowths with Pl (Table:3) and Cpx around the garnet porphyroblast. All of the iron content in this instance is in the Fe+2 form, and the quantity of iron in each ilmenite grain is almost the same.

Table 1: Cation calculation table of the garnet mineral:

Mineral name	Gt within cpx+ilm	Gt -p rim^PI	Gt-p core	Gt-p rim^cpx+ilm	Gt-p-away from sympl	Gt-small^amph	Gt-rim
SiO ₂	37.02	37.46	37.38	38.26	38.06	37.97	38.22
TiO ₂	0.08	0.02	0.05	0.03	0.1	0.05	0.06
Al ₂ O ₃	21.21	20.88	20.92	21.09	21.54	21.36	21.42
Cr ₂ O ₃	0.01	0.05	0.05	0	0.04	0.04	0
V ₂ O ₃	0	0	0	0	0	0	0
Fe ₂ O ₃	3.38	2.52	4.39	2.17	2.29	2.67	2.63
FeO	25.40	24.70	22.35	25.68	23.35	26.55	24.38
MnO	1.48	1.37	1.43	1.21	1.37	1.25	1.19
MgO	3.88	4.01	3.94	4.02	3.72	4.1	4.01
NiO	0	0	0	0	0	0	0
ZnO	0	0	0	0	0	0	0
CaO	8.21	8.89	10.67	9.03	11	8.03	10.16
Na ₂ O	0	0.04	0.04	0.03	0.03	0	0
K ₂ O	0	0	0.02	0	0	0.01	0
Total	100.68	99.94	101.24	101.52	101.50	102.04	102.07
Si	2.91	2.95	2.91	2.97	2.95	2.94	2.95
Ti	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Al	1.97	1.94	1.92	1.93	1.97	1.95	1.95
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe+3	0.20	0.15	0.26	0.13	0.13	0.16	0.15
Fe+2	1.67	1.63	1.46	1.67	1.51	1.72	1.57
Mn	0.10	0.09	0.09	0.08	0.09	0.08	0.08
Mg	0.45	0.47	0.46	0.47	0.43	0.47	0.46
Ni	0	0	0	0	0	0	0

Zn	0	0	0	0	0	0	0
Ca	0.69	0.75	0.89	0.75	0.91	0.67	0.84
Na	0.00	0.01	0.01	0.00	0.00	0.00	0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	8	8	8	8	8	8	8
Adr	0.09	0.07	0.12	0.06	0.06	0.07	0.07
Py	0.14	0.15	0.14	0.15	0.14	0.15	0.14
Alm	0.52	0.51	0.44	0.53	0.48	0.54	0.49
Grs	0.22	0.24	0.27	0.24	0.29	0.21	0.26
Spss	0.03	0.03	0.03	0.03	0.03	0.03	0.02

Table 2: Cation calculation table of the Cpx mineral:

Mineral Name	Cpxsym+Ilm	Cpxsym+Ilm	Cpxsym+Ilm	Cpxsym+Ilm
SiO ₂	51.59	51.79	51.28	52.6
TiO ₂	0.48	0.44	0.24	0.29
Al ₂ O ₃	1.22	1.3	1.26	1.39
Cr ₂ O ₃	0	0	0.06	0.13
Fe ₂ O ₃	0.000	0.000	0.000	0.000
V ₂ O ₃	0.000	0.000	0.000	0.000
MgO	12.86	12.52	12.93	12.41
FeO	10.48	10.43	10.86	10.15
CaO	23.34	23.44	23.57	23.5
MnO	0.25	0.17	0.22	0.24
CoO	0.000	0.000	0.000	0.000
NiO	0.000	0.000	0.000	0.000
ZnO	0.000	0.000	0.000	0.000
Na ₂ O	0.23	0.3	0.31	0.2
K ₂ O	0	0	0	0
Total	100.450	100.390	100.730	100.910
oxygen basis	6.000	6.000	6.000	6.000
fl	2.261	2.261	2.263	2.242
# Si	1.942	1.949	1.931	1.963
# Ti	0.014	0.012	0.007	0.008
# Al	0.054	0.058	0.056	0.061
# Cr	0.000	0.000	0.002	0.004
# Fe ³⁺	0.000	0.000	0.000	0.000
# V	0.000	0.000	0.000	0.000
# Mg	0.721	0.702	0.726	0.690
#total Fe	0.330	0.328	0.342	0.317
# Ca	0.941	0.945	0.951	0.940
# Mn	0.008	0.005	0.007	0.008
# Co	0.000	0.000	0.000	0.000
# Ni	0.000	0.000	0.000	0.000
# Zn	0.000	0.000	0.000	0.000
# Na	0.017	0.022	0.023	0.014
#K	0.000	0.000	0.000	0.000
Cation	4.026	4.021	4.044	4.004

EXPECTED CATION	8.000	8.000	8.000	8.000
CATION TOTAL(Fe=Fe+2)	4.026	4.021	4.044	4.004
Fe+3 DROOP	-11.844	-11.874	-11.737	-11.976
calculated Fe⁺³	0.000	0.000	0.000	0.000
Total Fe	0.330	0.328	0.342	0.317
EqFe+2	0.000	0.000	0.000	0.000
Fe+2	0.330	0.328	0.342	0.317
calculated Fe⁺²	0.330	0.328	0.342	0.317
Cation total after droop correction	4.026	4.021	4.044	4.004

Table 3: Cation calculation table of the Plagioclase mineral:

Mineral Name	Pl ^{gt26}	Pl	PI	Pl	Pl sympl +Ilm
SiO ₂	47.05	44.51	48.03	49.04	46.15
TiO ₂	0	0	0	0.01	0.07
Al ₂ O ₃	33.94	35.33	32.61	32.85	34.31
Cr ₂ O ₃	0	0.03	0	0.1	0
Fe ₂ O ₃	0	0	0	0	0
V ₂ O ₃	0	0	0	0	0
MgO	0	0.01	0	0.02	0
FeO	0.13	0.08	0.16	0.2	0.21
CaO	17.32	18.99	16.56	16.24	17.91
MnO	0.02	0	0	0.04	0
CoO	0	0	0	0	0
NiO	0	0	0	0	0
ZnO	0	0	0	0	0
Na ₂ O	2.02	1.14	2.57	2.73	1.59
K ₂ O	0.01	0.01	0	0.03	0.01
Total	100.49	100.1	99.93	101.26	100.25
oxygen basis	8	8	8	8	8
f1	2.75	2.78	2.76	2.72	2.76
# Si	2.15	2.06	2.21	2.22	2.12
# Ti	0.00	0.00	0.00	0.00	0.00
# Al	1.83	1.93	1.77	1.75	1.86
# Cr	0.00	0.00	0.00	0.00	0.00
# Fe ³⁺	0	0	0	0	0
# V	0	0	0	0	0
# Mg	0	0.00	0	0.00	0
#total Fe	0.00	0.00	0.01	0.01	0.01
# Ca	0.85	0.94	0.82	0.79	0.88
# Mn	0.00	0.00	0.00	0.00	0.00
# Co	0	0	0	0	0
# Ni	0	0	0	0	0
# Zn	0	0	0	0	0
# Na	0.18	0.10	0.23	0.24	0.14
#K	0.00	0.00	0.00	0.00	0.00
Cation	5.02	5.03	5.02	5.02	5.02
EXPECTED CATION	8	8	8	8	8

CATION TOTAL(Fe=Fe+2)		5.02	5.03	5.02	5.02	5.02
Fe+3 DROOP		-9.50	-9.44	-9.48	-9.50	-9.51
calculated Fe ⁺³		0	0	0	0	0
Total Fe		0.00	0.00	0.01	0.01	0.01
EqFe+2		0	0	0	0	0
Fe+2		0.00	0.00	0.01	0.01	0.01
calculated Fe ⁺²		0.00	0.00	0.01	0.01	0.01
Cation total after droop correction		5.02	5.03	5.02	5.02	5.02
Xab		0.17	0.10	0.22	0.23	0.14
Xan		0.83	0.90	0.78	0.77	0.86

Table 4: Cation calculation table of the Amphibole mineral:

Mineral name	Amph ^{pl30}	Amph	Amph	Amph
Si	6.27	6.18	6.24	6.33
Al (IV)	1.73	1.82	1.76	1.67
Ti	0	0	0	0
Sum T	8	8	8	8
Al (VI)	0.49	0.49	0.418	0.46
Ti	0.24	0.23	0.205	0.17
Cr ⁺³	0.002	0.01	0.015	0.00
Fe ⁺³	0.18	0.31	0.429	0.39
Mg	2.12	2.16	2.206	2.24
Fe ⁺²	1.96	1.81	1.726	1.73
Mn	0	0	0	0
Li	0	0	0	0
Sum C	5	5	5	5
Mg	0	0	0	0
Fe ⁺²	0.043	0.049	0.058	0.06
Mn	0.008	0.019	0.008	0.01
Li	0	0	0	0
Ca	1.891	1.86	1.86	1.86
Na	0.058	0.08	0.07	0.07
Sum B	2	2	2	2
Ca	0	0	0	0
Na	0.54	0.54	0.48	0.5
K	0.09	0.09	0.09	0.1
Sum A	0.63	0.63	0.57	0.5
TOTAL	15.63	15.63	15.57	15.5

Table 5: Cation calculation table of the Ilmenite mineral:

Mineral name	Ilm	Ilm	Ilmsyml +pl
SiO ₂	0	0	0.03
TiO ₂	51.46	50.94	51.78
Al ₂ O ₃	0	0.07	0.04
Cr ₂ O ₃	0	0	0
Fe ₂ O ₃	0	0	0
V ₂ O ₃	0	0	0
MgO	0.76	0.92	0.63
FeO	48.03	47.03	46.45
CaO	0.21	0.25	0.06

MnO		0.37	0.39	0.47
CoO		0	0	0
NiO		0	0	0
ZnO		0	0	0
Na ₂ O		0	0	0.02
K ₂ O		0	0	0.01
Total		100.83	99.6	99.49
oxygen basis		3	3	3
f1		1.51	1.53	1.52
# Si		0.00	0.00	0.00
# Ti		0.97	0.97	0.99
# Al		0.00	0.00	0.00
# Cr		0	0	0
# Fe ³⁺		0	0	0
# V		0	0	0
# Mg		0.03	0.03	0.02
#total Fe		1.01	1.00	0.99
# Ca		0.01	0.01	0.00
# Mn		0.01	0.01	0.01
# Co		0.00	0.00	0.00
# Ni		0.00	0.00	0.00
# Zn		0.00	0.00	0.00
# Na		0.00	0.00	0.00
#K		0.00	0.00	0.00
Cation		2.03	2.03	2.01
EXPECTED CATION		8	8	8
CATION TOTAL(Fe=Fe+2)		2.03	2.03	2.01
Fe+3 DROOP		-17.69	-17.70	-17.86
calculated Fe ⁺³		0.00	0.00	0.00
Total Fe		1.01	1.00	0.99
EqFe+2		0.00	0.00	0.00
Fe+2		1.01	1.00	0.99
calculated Fe ⁺²		1.01	1.00	0.99
Cation total after droop correction		2.03	2.03	2.01

Geothermobarometry:

Garnet-Plagioclase feldspar-Clinopyroxene-Ilmenite-Amphibole is the mineral assemblage of the retrogressed mafic granulite. The near peak condition of metamorphism in this mineral association is determined using the Fe-Mg exchange thermometry between coexisting Gt-Cpx. However, as the Gt-Cpx-Pl net transfer reaction is more sensitive to changes in pressure than temperature, it is employed to calculate the baric state of metamorphism. When the Ganguly (1979) approach is applied, the Gt-Cpx thermometry records a higher temperature in the region of 825^oC. However, Ellis and Green's (1979) invention of the Gt-Cpx thermometer records somewhat lower temperatures in the 625^oC–650^o C range (Table:6).

In the instance of barometry, the Gt-Cpx-Pl assemblage recorded pressure in the 8.5 Kb range in the garnet's core composition. Additionally, the pressure condition in the rimal composition is about 5 Kb. Retrogressed mafic granulite P-T condition variation was found in the garnet core and rim portion of the investigated rock. P-T conditions in the porphyroblastic garnet core section range from 8.5Kb to (825^oC-830^oC). P-T conditions in the porphyroblastic garnet rimal portion range from 625^oC to 650^oC and 5 kb. Thus, this study clearly demonstrates a decompression feature, which is also demonstrated in the textural section.

A temperature of 825^oC and a pressure of 8.5Kb may be determined for the stabilisation of the peak assembly in the rock by taking into account the P-T estimates of all

geothermobarometry. This is the P-T condition of metamorphism that has impacted the rock; however, this P-T condition is undoubtedly lower than the actual peak

condition of metamorphism because the composition of coexisting ferromagnesium minerals, such as garnet-cpx, is highly susceptible to low temperature readjustment.

Table 6: Geothermometry calculation of the studied rock:

Textural specification	23 / 1 .	29 / 1 .	22 / 1 .	27 / 1 .	20 / 1 .	26 / 1 .	23 / 1 .	40 / 1 .	GT-27	CPX-23	GT-25	CPX-22	
	Cpxsym+Ilm	Gt-p-away from sympl	Cpxsym+Ilm	Gt-p core	Cpxsym+Ilm	Gt -p rim ^{PI}	Cpxsym+Ilm	Gt-rim	CORE		RIM		
Fe+2(24O2)Gt	3.02	3.02	2.92	2.92	3.26	3.26	3.14	3.14		2.92	2.92	3.34	3.34
Mg(24O2)Gt	0.86	0.86	0.92	0.92	0.94	0.94	0.92	0.92		0.92	0.92	0.90	0.90
Ca(24O2)Gt	1.82	1.82	1.78	1.78	1.50	1.50	1.68	1.68		1.78	1.78	1.38	1.38
Mn(24O2)Gt	0.18	0.18	0.18	0.18	0.18	0.18	0.16	0.16		0.18	0.18	0.20	0.20
Fe+2(12O2)Gt	1.51	1.51	1.46	1.46	1.63	1.63	1.57	1.57		1.46	1.46	1.67	1.67
Mg(12O2)Gt	0.43	0.43	0.46	0.46	0.47	0.47	0.46	0.46		0.46	0.46	0.45	0.45
Ca(12O2)Gt	0.91	0.91	0.89	0.89	0.75	0.75	0.84	0.84		0.89	0.89	0.69	0.69
Mn(12O2)Gt	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08		0.09	0.09	0.10	0.10
XCaGt	0.31	0.31	0.31	0.31	0.26	0.26	0.28	0.28		0.31	0.31	0.24	0.24
XFe+2Gt	0.51	0.51	0.50	0.50	0.55	0.55	0.53	0.53		0.50	0.50	0.57	0.57
XMnGt	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03		0.03	0.03	0.03	0.03
XMgGt	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16		0.16	0.16	0.15	0.15
Fe+2(6O2)Cpx.	0.30	0.30	0.20	0.20	0.25	0.25	0.30	0.30		0.30	0.30	0.14	0.14
Mg(6O2)Cpx.	0.69	0.69	0.72	0.72	0.70	0.70	0.69	0.69		0.69	0.69	0.73	0.73
Mn(6O2)Cpx	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01
XFe+2Cpx	0.30	0.30	0.22	0.22	0.26	0.26	0.30	0.30		0.30	0.30	0.16	0.16
XMgCpx	0.69	0.69	0.77	0.77	0.73	0.73	0.69	0.69		0.69	0.69	0.83	0.83
(ln Kd)	2.09	2.09	2.44	2.44	2.27	2.27	2.06	2.06		1.99	1.99	2.96	2.96
P(in KBar)	6.00	7.00	6.00	7.00	6.00	7.00	7.00	6.00		6.00	7.00	6.00	7.00
T(C) (Ganguly,1979)	802.59	805	732.38	734	747.92	750	802	799.94		823.97	826.22	624.45	626.33
T(C) (Mysen&Heier,1972)	589.37	589	496.37	496	537.35	537	598	598.01		620.87	620.87	388.10	388.10
T(C) (Mori&Green,1978)	580.92	581	499.22	499	535.50	535	588	588.40		608.09	608.09	401.25	401.25
T(C) (Raheim&Green,1974)	599.62	606	536.10	542	564.70	571	612	605.28		620.06	626.62	455.56	460.92
T(C) (Ellis & Green,1979)	742.91	746	659.82	662	657.66	660	734	730.81		767.22	770.01	514.31	516.54
T(C)(Dahl,1980)	689.10	689	543.78	544	586.36	586	686	686.24		727.87	727.87	385.92	385.92
T(C)(Krogh,1988)	717.53	720	625.77	628	619.57	622	707	703.72		744.88	747.83	463.03	465.33

Pseudosectional study to ascertain Metamorphic condition:

The mineralogical development of rocks as a consequence of shifting pressure, temperature, fluid composition, or local bulk chemical change can be effectively constrained via pseudosection. This approach uses the Gibbs free energy minimisation methodology to create numerically calculated phase diagrams at a constant bulk (P-T diagram) or at a changing bulk (P-X or T-X diagram). In this work, pseudosections for the retrogressed mafic granulite were constructed using PERPLEX 2007 Program. Stability fields of various mineral assemblages in a well-constrained pseudosection are inherently sensitive to the input bulk composition, including the H₂O concentration, for the purposes of the PERPLEX program. Nonetheless, despite significant variations in the bulk composition and presumed fluid content, the relative positioning of the stability field essentially stays constant. The mafic granulite in this study is a coarse-grained heterogeneous rock, therefore using XRF analysis to determine the rock's bulk composition is not entirely reasonable. Thus, the modal abundance of various minerals present and their phase

chemistry data gathered by Electron Micro Probe Analysis (EPMA) are used to compute the effective bulk of this coarse-grained rock. The model Na₂O-CaO-FeO-MgO-Al₂O₃-SiO₂-H₂O (NCFMASH) system provides a sufficient explanation for the mineral association of the retrogressed mafic granulite.

However, a pseudosection is also constructed for the same rock using dry bulk in the NCFMAS system to understand the stabilisation of the peak anhydrous mineral assemblage because petrographic study confirms the appearance of amphibolites in this rock in an event that occurs subsequent to the stabilisation of a peak anhydrous mineral assemblage.

A construction file was initially created for the rock using the dry bulk composition of the rock in the NCFMAS system. This build file creates a plot file when it is executed in the VERTEX sub-program of PERPLEX 2007. The Psvdraw subprogram of PERPLEX 2007 is then used to see this plot file(Fig:4 &5). Plagioclase-garnet-clinopyroxene-ilmenite stability and the stability fields of other assemblages are formed in the numerically calculated P-T phase diagram for the rock for a given

bulk composition in the NCFMAS system. Two phase boundaries with a mild to moderate positive slope separate this assemblage from plagioclase-garnet-clinopyroxene-rutile-ilmenite (rutile is present) on the higher pressure side and plagioclase-garnet-orthopyroxene-clinopyroxene-ilmenite (orthopyroxene is present) on the low pressure side. The garnet composition isopleths (Fig:6) for Xalm, Xpy, and Xgr were calculated using the same plot file (generated earlier) in the WERAMI sub-program of PERPLEX 2007 in order to zoom in on the actual P-T window of metamorphism that stabilised plagioclase-garnet-clinopyroxene-ilmenite assemblage during peak metamorphism condition in the rock.

The isopleths line in this diagram varies from 0.52 to 0.54 in Xalm, from 0.22 to 0.28 in Xgr, and from 0.14 to 0.17 in Xpy. The isopleths interval is 0.01 in each of these situations. When these Gt composition isopleths are placed in a single P-T diagram, it is discovered that the intersection of the Xalm=0.54, Xpy=0.14, and Xgr=0.22 isopleths occurs inside the reported Gt-cpx-Pl-Ilm stability field at a P-T window of 5.5-5.7 Kb and 690°C-710°C. This temperature estimate is in good agreement with the independent temperature evaluation obtained using several geothermometers (670°C-740°C). Nevertheless, the pressure estimate is somewhat lower than that obtained using geobarometers (6.5-7Kb). A stability field consisting of Gt-cpx-Pl-Ilm-Amp is generated at the same P-T condition as stabilised Gt-cpx-Pl-Ilm when pseudosections are constructed for the same rock with about 0.8 weight percent H₂O within the same dry bulk composition. By substituting Cpx-Ilm and Gt, this validates the textural observation of amphibole production.

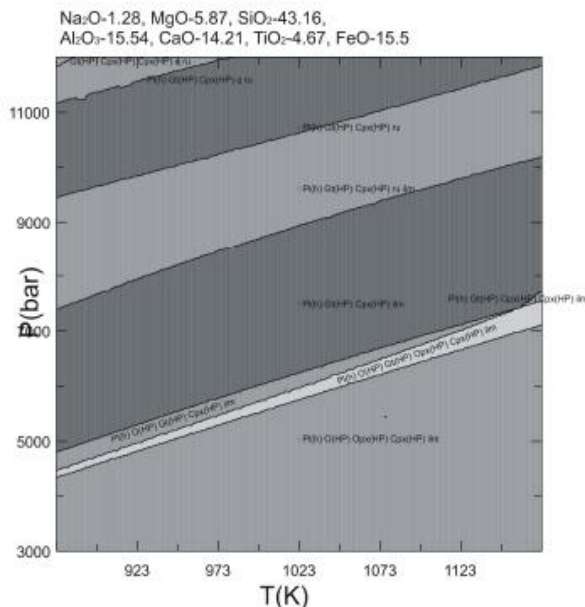


Fig:4 Metamorphic condition of the dry system in the studied rock.

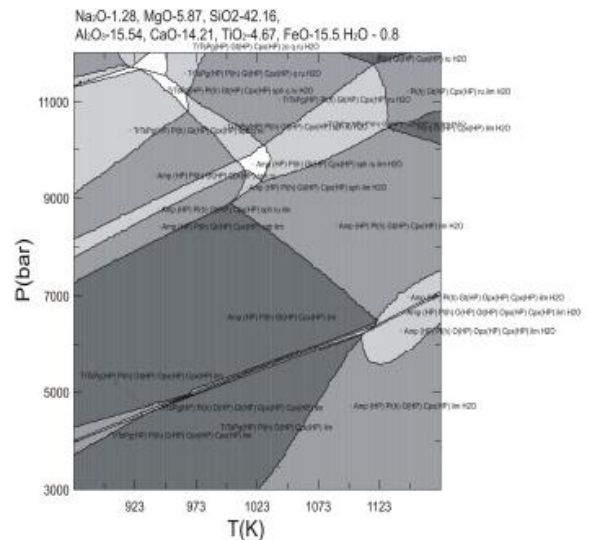


Fig:5 Metamorphic condition of the wet system in the studied rock.

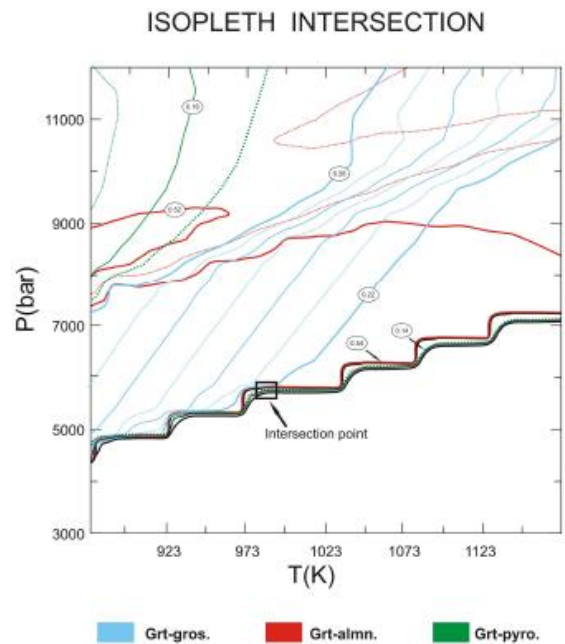


Fig:6 P-T condition from the garnet composition in the studied rock.

Conclusion:

A metamorphic and deformational history for the rock type of the research region may be clearly established from the lithological disposition and structural analysis in the field, extensive petrographic investigation of various rock types, pseudosectional approach, phase chemistry, and geothermobarometry.

In this research, the country rock has enclaves of calc granulite, Mg-Al granulite, and retrogressed mafic granulite. These enclaves have early gneissic banding that forms an angle with the country rock's gneissic foliation. While alignment of hydrous phases defines the gneissosity of the country rock, anhydrous minerals define crude banding in enclaves. Anhydrous minerals determine the sort of rock banding (crude foliation) in this enclave, whereas hydrous minerals define rock banding throughout the nation. Granulite-grade metamorphism and the formation of granulite-grade gneissic structure occur in this enclave suite of rocks. Folding on the granulite grade gneissic banding is caused by granulite grade deformation (folds inside the enclave). The displacement of opx-containing felsic magma inside this granulite body occurs in the subsequent stage. The country rock in the research region, charnockitic rock, is formed by this magma. The granulite xenoliths form a decompression structure as a result of the felsic magma rising beside them. The breakdown and formation of Cpx-Pl-Ilm intergrowth in the textural portion of retrogressed mafic granulite Gt provides evidence of this subject. The country rock exhibits alternating bands of dark and light-colored minerals, which are the result of a deformation event (this is the first deformational event for country rock). This country rock underwent metamorphism from higher amphibolites to lower granulite facies. Porphyritic charno-enderbitic rock will be replaced in this country rock in the next stage. This charno-enderbitic rock has undergone amphibolite facies metamorphosis. A deformation event occurs following all displacement, creating the N-S trending fabric. Granulite enclaves containing felsic gneiss must have experienced retrogressed amphibolite facies metamorphism whereas country rock and charno-enderbitic rock underwent prograde amphibolite facies metamorphism. This evidence is also supported by the textural portion. The anhydrous mineral assemblage that forms at the peak metamorphism condition is the early stabilised assemblage in retrogressed mafic granulite. Additionally, the later hydrous face develops throughout the retrogression period.

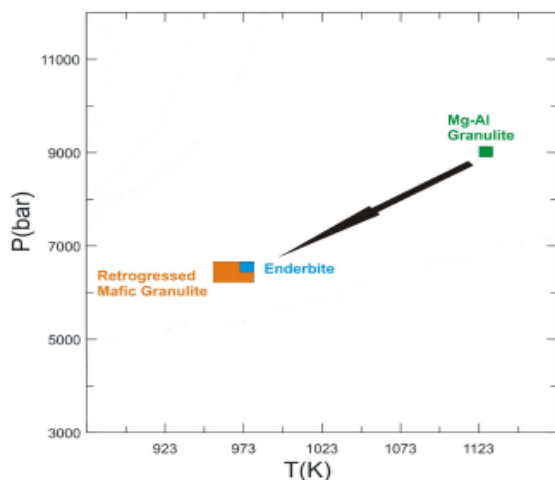


Fig:7 Retrograde metamorphic path of the studied rock.

Porphyroblastic garnet grains' peak temperature (825⁰C–850⁰C) and pressure (8–8.5)Kb match the peak metamorphism condition of Mg–Al granulites (9Kb and 875C) in a geothermobarometry investigation of retrogressed mafic granulite rock (Mondal, S. 2008). The (P,T) porphyritic charno-enderbitic gneiss rock peak metamorphism condition (5.5-6Kb and 700⁰C) is compatible with temperature (625⁰C-650⁰C) and pressure (5-5.5)Kb during rim composition (Mondal.,A 2008). This rock is going to decompress after reaching peak metamorphism conditions, as evidenced by the temperature gradient from the core to the rim and the garnet breakdown texture (Fig:7). Another name for this is decompression texture. Garnet porphyroblast in retrogressed mafic granulite forms cpx-Pl[2]-Ilm[2] intergrowth as a result of decompression and cooling. I computed the condition of time of metamorphism (dp/dt) from the temperature change from core to rim. The temperature drops by 200⁰C and the pressure drops by 3.5 Kb in the core to rim section. According to the pseudosectional investigation, the P-T condition of 5.7 Kb and 710⁰C is where the junction of three garnet solid solutions is located. Additionally, it matches the rim composition of thermobarometry rather well. Due to the disintegration of the early assemblage in retrogression, peak conditions in pseudosection studies are not well constrained. It clearly shows that earlier granulite crust was reworked during a different orogenic event.

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References:

- ACHARYYA, S. K. 2003. A plate tectonic model for Proterozoic crustal evolution of Central Indian Tectonic Zone. *Gondwana Research*, 7, 9-31.
- ADHIKARY, D. 2009. Metamorphic evolution of Mafic Granulite onclave within a Felsic Gneiss country in parts of Chotanagpur Granite Complex (CGGC) near Rangalia, state Jharkhand, India. *Unpublished M.Sc thesis, Jadavpur University*.
- BAIDYA, T.K., MAITY, N. & BISWAS, P. 1989. Tectonic phases and crustal evolution in a part of the Eastern Chotanagpur Gneissic Complex. *Journal of Geological Society of India*, 34, 318-324.
- BHATTACHARYYA, P.K. & MUKHERJEE, S. 1987. Granulites in and around the Bengal anorthosite, eastern India: genesis of coronal garnet and evolution of the granulite-anorthosite complex. *Geological Magazine*, 124, 21-32.

- CHATTERJEE, N., BANERJEE, M., BHATTACHARYA, A. & MAJUMDAR, A. K. 2010. Monazite chronology, metamorphism-anatexis and tectonic relevance of the mid-Neoproterozoic Eastern Indian Tectonic Zone. *Precambrian Research*, **179**, 99-120.
- CHATTERJEE, N., CROWLEY, J. I. & GHOSE, N. C. 2008. Geochronology of the 1.55 Ga Bengal anorthosite and Grenvillian metamorphism in the Chotanagpur Gneissic Complex, eastern India. *Precambrian Research*, **161**, 303-316.
- DUNN, J. A. & DEY, A. K. 1942. Geology of Eastern Singhbhum. *Geological Survey of India Memoirs*, 69(2), 452pp.
- DUNN, J. A. 1929. The geology of north Singhbhum including parts of Ranchi and Singhbhum districts. *Geological Survey of India Memoirs*, **54(2)**, 1-280.
- ELLIS, D. J., & GREEN, D. H. (1979). An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. *Contributions to Mineralogy and Petrology*, **71(1)**, 13-22.
- GANGULY, J. (1979). Garnet and clinopyroxene solid solutions, and geothermometry based on Fe-Mg distribution coefficient. *Geochimica et Cosmochimica Acta*, **43**, 1021-1029.
- GHOSE, N. C. 1983. Geology, tectonics and evolution of the Chhotanagpur granite-gneiss complex, Eastern India. *Recent Reserches in Geology*, **10**, 211-247.
- GHOSE, N. C. 1992. Chhotanagpur Gneiss-Granulite Complex, Eastern India: Present status and future prospect. *Indian Journal of Geology*, **64(1)**, 100-121.
- KUMAR, A. & AHMAD, T. 2007. Geochemistry of mafic dykes in part of Chotanagpur gneissic complex: Petrogenetic and tectonic implications. *Geochemical Journal*, **41**, 173-186.
- MAHADEVAN, T. M. 2002. *Geology of Bihar & Jharkhand*. Geological Society of India, Bangalore, 563pp.
- MONDAL, A. 2008. Petrological characterisation of Porphyritic Charnoenderbitic Gneiss in and around Massanjore, Jharkhand, India. *Unpublished M.Sc thesis, Jadavpur University*.
- MONDAL, S. 2008. Metamorphic evolution of Mg-Al Granulite from parts of Chotanagpur Granite Gneiss Complex (CGGC) near Massanjore, Jharkhand, India: a pseudosectional approach. *Unpublished M.Sc thesis, Jadavpur University*.
- RAY, S., SANYAL, S. & SENGUPTA, P. 2010. Mineralogical control on rheological inversion on a suite of deformed mafic dykes from parts of the Chotanagpur Granite Gneiss Complex of east India. In: *Srivastava, R.K. (Eds.) Dyke swarms: keys for geodynamic interpretation*, Springer, 550pp.
- SANYAL, S., SENGUPTA, P. & GOSWAMI, R. 2007. Evidence of Mesoproterozoic ultra-high temperature metamorphism from parts of CGGC, Jharkhand, India. In: *Abstract volume of International Conference on Precambrian sedimentation and tectonics, IIT, Bombay*, 62-63.
- SANYAL, S., SENGUPTA, P. Metamorphic evolution of the Chotanagpur Granite Gneiss Complex of the East India Shield: Current Status : Geological Society, London, Special Publication, 2012, 365 : 117-145.