# A NEW REPORTING OF CALC-GRANULITES AT BARADGATTA AREA FROM THE MAKROHAR GRANULITE BELT IN CHOTANAGPUR GRANITE GNIESS COMPLEX, CENTAL INDIA.

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**Abstract**
We are reporting a new locality of calc-granulite from the Baradgatta area of the Makrohar granulite belt including the mineral assemblage garnet – clinopyroxene – plagioclase – sphene - clinozoisite. The Makrohar granulite belt (MKG) is located northwest extension of the chotanagpur granite gneiss complex along the northern margin of the central Indian tectonic zone**.** A peak pressure condition of 5.24 kbar at 600 °C is obtained from Grt-Cpx-Pl-Qz barometers and the estimated temperature is 675 °C at 7 kbar. The average P–T condition of metamorphism of granulite formation is at 624 ± 97 °C and 5.6 ± 0.8 kbar. The formation of stable mineral assemblages such as (Grt-Cpx-Sph-Cz-Pl) in the NCFMAST-HC model system is suitable within the temperature range of 620-635°C at ($XCO_2$ > 0.4).

**Keywords:** Calc-granulite, Sphene, MKG, Metamorphism, P-T condition and Makrohar.

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## 1. INTRODUCTION

Granulites demonstrate the important mechanism of tectonic activity and geodynamic evolution which was responsible for the formation, growth, and development of the continental mass (Harley, 1989). The study of granulite helps in understanding the nature, composition and geodynamic evolution of the lower crust and upper mantle (Harley, 1989; Bohlen, 1991). In the last few decades, estimation of P-T-t evolution of calc-silicate rocks of granulite facies terrain is important to establish models for the genesis and evolution of the continental crust. (Dasgupta, 1993; Shaw and Arima, 1996). These rocks are of sedimentary protoliths, derived from siliceous limestone or marls and show high-temperature pressure mineral assemblages like grossularite, scapolite and wollastonite (Bucher and Grapes, 2011). They occur as lenses, boudins or blocks and are interbedded with metapelites (Dasgupta, 1993; Shaw and Arima, 1996).

Based on geothermobarometry and textural relations three metamorphic stages of evolution of garnet-metabasic and pelitic granulites rocks were established. These stages are 800°C and 9Kb for Peak metamorphic conditions followed by an isothermal decompression through 740°C at 6.5 Kb and a final re-equilibrium at 685°C (Solanki et al., 2003). However, detailed mineralogical and petrological study of calc-granulite of Makrohar area has not been carried out so far. To fulfil the research gap in the study of calc-granulite, the main aim of the present study is to discuss the petrography, mineral chemistry and geothermobarometry of the calc-granulites of the Makrohar granulite belt.

## 2. GEOLOGICAL SETTING

The study area is situated at the Baradghata village 10 km northeast of the Makrohar area in the Singrauli district of Madhya Pradesh. The Makrohar granulite belt is in the Northwestern part of the Chotanagpur-granite-gneiss complex (CGGC) which lies south of the Son Narmada south fault (Acharya and Roy, 2000). CGGC is an E-W trending Proterozoic supracrustal belt situated between the Mahakoshal mobile belt in the north and the Singhbhum fold belt in the south, Gondwana deposits to the west of the CGGC, whereas the Rajmahal basalt borders the northeastern section (Mahadevan, 2002) as shown in Fig. 1.(a). Three distinct suites of rocks are found in the Makrohar area (a) Metapelitic and Metabasic rocks (b) granite gneiss and migmatites and (c) gabbro, anorthosite and metabasalt where calc-silicate, marble, schist, pelitic and mafic granulite occurs as an enclave in migmatite and granite gneiss as shown in Fig. 1.(b) (Pitchai Muthu, 1990; Solanki et al., 2003). Crystalline limestone is well exposed in the Makrohar area and at places, it grades into banded calc granulite (Pitchai Muthu, 1990). The Makrohar granulite belt consists of a gabbro anorthosite complex with oval-shaped masses, which represent a stratified layered complex undergone metamorphism up to granulite facies condition and assigned gabbro suite as tholeiitic in composition emplaced under island arc setup (Solanki et al., 2003). Based on geothermobarometric and textural analyses two stages of the metamorphic evolution of mafic granulites of the study area were established at a peak of metamorphism 799 ± 40°C/6.3 ± 0.9 kbar followed by post-peak P-T condition of metamorphism 590-693°C/2.1-2.4kbar (Pandey and Dwivedi, 2022). Rb-Sr dating of 1.73 Ga age was deduced for the granitoid of this area that contains enclaves of calcsilicate and metapelite which suggests that these metapelites must have occurred earlier than 1.73 Ga. (Sarkar, 1998). The calc-granulite is medium to coarse-grained and exhibits granoblastic texture. The rock has a layering of dark green colour rich in clinopyroxene and a light pinkish colour layer rich in garnet and white colour plagioclase crystals can be easily seen in the hand specimen as shown in Fig. 2. (c).

**Fig. 1.** (a) The inset shows the proterozoic mobile belts of India, including Chotanagpur granite gneiss complex (CGGC), Central India Tectonic Zone (CITZ), Eastern Ghats Belt (EGB), Aravalli Delhi Mobile Belt (ADMB), Shillong Meghalaya Gneissic Complex (SMGC) and Singhbhum Mobile Belt (SMB). Archean Cratonic nuclei of India, Deccan (DC), Singhbhum craton (SC), Bundelkhand(BuC) and Bastar craton (BC) (modified after Chatterjee et al., 2008).(b) Geological map of the Central granite gneiss complex. The abbreviations used are: DVB -Dalma Volcanic Belt, DL-Daltonganj, NPSZ -North Purulia Shear Zone, SSZ -Singhbhum Shear Zone, P-Purulia, SONA-Son Narmada Lineament zone, M-Munger, SPSZ -South Purulia Shear Zone, R -Rihand-Renusagar Area, RN -Ranchi, An -Anorthosite, B -Bankura, D –Dudhi, DM –Dumka and MGB -Makrohar Granulite belt (modified after Chatterjee and Ghosh, 2011).(c) Geological map of the Piprakurund area, Makrohar granulite belt, Singrauli (Modified after Pichai muthu, 1990).

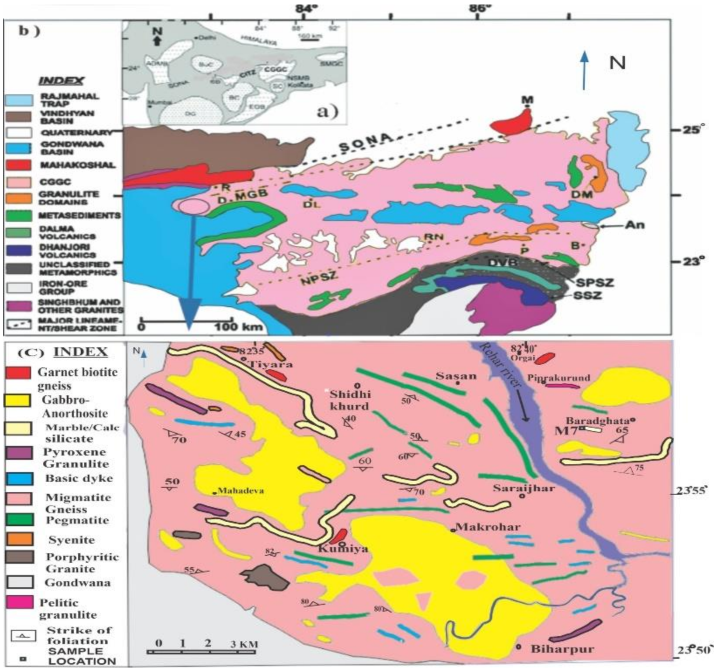


**Fig. 1**

## 3. ANALYTICAL TECHNIQUES

Representative samples of Calc granulites have been collected from Baradghata areas around the Makrohar granulite belt Singrauli district. A detailed petrographic study of Calc-granulite samples has been done with the help of a Leica (DM 2500 P) petrological microscope. Based on petrography we have chosen samples of Calc-granulite (M-7) for electron microprobe analysis, which was carried out by using an EPMA (CAMECA SX 5) instrument at DST-SERB National Facility, Centre of Advanced Study, Department of Geology, BHU. By using a LEICA EM ACE 200 carbon coating device, a layer of carbon of thickness 20 nm was applied to the polished thin section for electron microprobe analysis. The operation was carried out by CAMECA SX 5 instrument at an accelerated voltage of 15 kV and beam current of 10 nA and the electron beam was generated in the electron gun using a LaB6 source. The following X-ray lines were used in the analyses:, Si– Kα,Al– Kα, Na– Kα, Cl– Kα,K– Kα, Mg– Kα, Ca– Kα, Mn– Kα, F– Kα,P– Kα, Cr– Kα, Ti– Kα, Ni– Kα , Fe– Kα and Ba– Lα.The standards provided by CAMECA-AMETEK used for quantification and routine calibration are halite for Cl apatite for P, rhodonite for Mn, periclase for Mg, corundum for Al, wollastonite for Si and Ca, rutile for Ti, hematite for Fe, chromite for Cr, orthoclase for K, and Pure metals of V and Ni.

XRF analysis of the calc-granulite sample (M7) for the phase equilibria calculations, was carried out at the Birbal Sahni Institute of Palaeosciences (BSIP) Lucknow, India. The EPMA data along with the structural formula of different mineral phases are shown in Tables 1-4.

**Table1.** EPMA and structural formula of garnet, from the calc granulite (sample no. M-7) of the study area on 12 Oxygen basis.

| Domain | Core1/23 | Rim1/24 | Core1/25 | Rim1/26 | Core1/27 | Rim1/28 |
|---|---|---|---|---|---|---|
| Oxides | Grt | Grt | Grt | Grt | Grt | Grt |
| $SiO_2$ | 37.12 | 36.96 | 37.85 | 37.57 | 38.46 | 37.38 |
| $TiO_2$ | 0.24 | 0.16 | 0.16 | 0.18 | 0.19 | 0.07 |
| $Al_2O_3$ | 18.89 | 18.39 | 17.8 | 18.06 | 19.05 | 20.67 |
| $Cr_2O_3$ | 0.09 | 0.09 | 0.05 | 0.11 | 0.05 | 0.05 |
| FeO | 12.53 | 13.66 | 13.34 | 13.45 | 12.16 | 12.68 |
| MnO | 0.78 | 1.31 | 1.36 | 1.11 | 1.26 | 1.33 |
| MgO | 0.19 | 0.15 | 0.18 | 0.2 | 0.17 | 0.00 |
| CaO | 29.2 | 28.91 | 28.93 | 28.59 | 28.75 | 28.57 |
| TOTAL | 99.04 | 99.63 | 99.67 | 99.27 | 100.09 | 100.74 |
| Si | 2.95 | 2.95 | 3.01 | 2.99 | 3.01 | 2.92 |
| $Al^{IV}$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ∑Z | 2.95 | 2.95 | 3.01 | 2.99 | 3.01 | 2.92 |
| $Al^{VI}$ | 1.77 | 1.73 | 1.67 | 1.70 | 1.76 | 1.90 |
| Ti | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| Cr | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 |
| $Fe^{3+}$ | 0.25 | 0.31 | 0.31 | 0.29 | 0.22 | 0.18 |
| ∑Y | 2.04 | 2.06 | 1.99 | 2.01 | 1.99 | 2.08 |
| $Fe^{2+}$ | 0.58 | 0.60 | 0.57 | 0.60 | 0.58 | 0.65 |
| Mn | 0.05 | 0.09 | 0.09 | 0.07 | 0.08 | 0.09 |
| Mg | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.00 |
| Ca | 2.49 | 2.47 | 2.46 | 2.44 | 2.41 | 2.39 |
| ∑X | 3.14 | 3.18 | 3.15 | 3.13 | 3.09 | 3.13 |
| $X_{Mg}$ | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 |
| Pyrope | 0.7 | 0.6 | 0.7 | 0.8 | 0.6 | 0.00 |
| Almandine | 18.4 | 18.9 | 18.2 | 19.2 | 18.8 | 20.8 |
| Grossularite | 66.4 | 62.8 | 62.7 | 63.1 | 66.8 | 67.9 |
| Spessartne | 1.70 | 2.80 | 2.90 | 2.40 | 2.70 | 2.80 |
| Andradite | 12.8 | 14.9 | 15.5 | 14.5 | 11.10 | 8.40 |

$X_{Mg}$ = Mg/(Mg + Fe).

**Table 2.** EPMA and structural formula of clinopyroxene, from the calc granulite (sample no. M-7) of the study area on 6 Oxygen basis.

| Domain | Core1/7 | Rim1/8 | Core1/9 | Rim1/10 | Core1/11 | Rim1/15 |
|---|---|---|---|---|---|---|
| Oxides | Cpx | Cpx | Cpx | Cpx | Cpx | Cpx |
| $SiO_2$ | 48.93 | 48.24 | 48.85 | 48.52 | 48.66 | 47.87 |
| $TiO_2$ | 0.09 | 0.15 | 0.12 | 0.14 | 0.1 | 0.11 |
| $Al_2O_3$ | 0.87 | 0.9 | 0.8 | 0.86 | 0.92 | 0.75 |
| $Cr_2O_3$ | 0.07 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 |
| FeO | 19.95 | 21.09 | 20.57 | 20.45 | 20.65 | 21.68 |
| MnO | 0.31 | 0.38 | 0.45 | 0.18 | 0.39 | 0.15 |
| MgO | 5.33 | 5.15 | 5.1 | 5.23 | 5.06 | 4.94 |
| CaO | 24.45 | 24.47 | 24.13 | 24.59 | 24.64 | 24.44 |
| $Na_2O$ | 0 | 0 | 0 | 0 | 0 | 0 |
| $K_2O$ | 0 | 0.02 | 0.04 | 0.02 | 0.04 | 0.06 |
| Total | 100 | 100.47 | 100.13 | 100.06 | 100.54 | 100.08 |
| Si | 1.95 | 1.93 | 1.95 | 1.94 | 1.94 | 1.92 |
| Ti | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Al | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Cr | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $Fe^{+2}$ | 0.66 | 0.70 | 0.69 | 0.68 | 0.69 | 0.73 |
| Mn | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Mg | 0.32 | 0.31 | 0.30 | 0.31 | 0.30 | 0.30 |
| Ca | 1.04 | 1.05 | 1.03 | 1.05 | 1.05 | 1.05 |
| Na | 0 | 0 | 0 | 0 | 0 | 0 |
| K | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 4.03 | 4.05 | 4.03 | 4.04 | 4.04 | 4.05 |
| Wo | 51.39 | 50.76 | 50.78 | 51.42 | 51.38 | 50.78 |
| En | 15.59 | 14.87 | 14.93 | 15.22 | 14.68 | 14.28 |
| Fs | 33.02 | 34.37 | 34.29 | 33.36 | 33.93 | 34.94 |
| $X_{Mg}$ | 0.33 | 0.31 | 0.3 | 0.31 | 0.31 | 0.29 |

$X_{Mg}$ = Mg/(Mg + Fe).

**Table 3.** EPMA and structural formula of plagioclase, from the calc granulite (sample no. M-7) of the study area on 8 Oxygen basis.

| Domain | Core1/12 | Rim1/13 | Core1/14 | Rim1/16 |
|---|---|---|---|---|
| Oxides | Pl | Pl | Pl | Pl |
| $SiO_2$ | 44.05 | 44.07 | 44.39 | 44.56 |
| $TiO_2$ | 0.02 | 0.01 | 0 | 0.01 |
| $Al_2O_3$ | 34.92 | 35.15 | 35.65 | 35.29 |
| CaO | 20.45 | 20.56 | 19.8 | 19.75 |
| $Na_2O$ | 0.24 | 0.15 | 0.11 | 0.15 |
| $K_2O$ | 0.03 | 0 | 0.02 | 0.01 |
| Total | 99.71 | 99.94 | 99.97 | 99.77 |
| Si | 2.05 | 2.04 | 2.05 | 2.06 |
| Ti | 0 | 0 | 0 | 0 |
| Al | 1.91 | 1.92 | 1.94 | 1.93 |
| $Fe^{+2}$ | 0 | 0 | 0 | 0 |
| Ca | 1.02 | 1.02 | 0.98 | 0.98 |
| Na | 0.02 | 0.01 | 0.01 | 0.01 |
| K | 0 | 0 | 0 | 0 |
| Total | 5.01 | 5 | 4.98 | 4.98 |
| An | 97.75 | 98.7 | 98.89 | 98.59 |
| Ab | 2.08 | 1.3 | 0.99 | 1.35 |
| Or | 0.17 | 0 | 0.12 | 0.06 |
| $X_{Ca}$ | 0.98 | 0.99 | 0.99 | 0.99 |

**Table 4.** EPMA and structural formula of sphene and clinozoisite from the calc granulite (sample no. M-7) of the study area.

| Domain | Core1/18 | Rim1/19 | Core1/20 | Rim1/21 | Core1/22 |
|---|---|---|---|---|---|
| Oxides | Sp | Sp | Sp | Sp | Cz |
| $SiO_2$ | 29.22 | 28.94 | 30.14 | 30.17 | 38.51 |
| $TiO_2$ | 36.51 | 35.71 | 35.96 | 35.57 | 0.15 |
| $Al_2O_3$ | 2.2 | 2.33 | 2.38 | 2.23 | 27.62 |
| $Cr_2O_3$ | 0.07 | 0.01 | 0.01 | 0.01 | 0.04 |
| FeO | 0.58 | 0.5 | 0.7 | 0.28 | 8.64 |
| MnO | 0.03 | 0 | 0.12 | 0.18 | 0.03 |
| MgO | 0.03 | 0 | 0 | 0 | 0 |
| CaO | 29.84 | 29.65 | 29.52 | 28.7 | 23.3 |
| $Na_2O$ | 0 | 0 | 0 | 0 | 0 |
| $K_2O$ | 0.01 | 0.02 | 0.05 | 0.06 | 0 |
| Total | 98.49 | 97.16 | 98.88 | 97.2 | 98.29 |
| Based | on | Oxygens | 5 | | 12.5 |
| Si | 0.97 | 0.98 | 1 | 1.01 | 2.97 |
| Ti | 0.92 | 0.91 | 0.9 | 0.9 | 0.01 |
| Al | 0.09 | 0.09 | 0.09 | 0.09 | 2.51 |
| Cr | 0 | 0 | 0 | 0 | 0 |
| $Fe^{+2}$ | 0.02 | 0.01 | 0.02 | 0.01 | 0.56 |
| Mn | 0 | 0 | 0 | 0.01 | 0 |
| Mg | 0 | 0 | 0 | 0 | 0 |
| Ca | 1.07 | 1.07 | 1.05 | 1.03 | 1.92 |
| Na | 0 | 0 | 0 | 0 | 0.04 |
| K | 0 | 0 | 0 | 0 | 0 |
| Total | 3.06 | 3.07 | 3.06 | 3.05 | 8.01 |

## 4. PETROGRAPHY AND MINERAL CHEMISTRY

In Calc-granulite rock (M-7) garnet, clinopyroxene and plagioclase occur as dominant minerals and sphene and clinozoisite as accessory minerals. Garnet crystals occur as hypidiomorphic porphyroblasts characterized by their isotropic optical properties. They occur as a medium to coarse-grained and mostly subhedral to euhedral and in equilibrium with medium to coarse -grained clinopyroxene, plagioclase and sphene as shown in Fig. 2. (d). Garnet grains of calc-granulite have a characteristic solid solution between grossular (62.7 –67.9 mol%), almandine (18.20- 20.8 mol%), andradite (8.4 –15.5 mol%) and spessartine (1.70–2.90 mol%)(Table 1). Clinopyroxene occurs as a matrix phase as well as inclusion in garnet as shown in Fig. 2. (e) & (f). Clinopyroxene is light to dark green and shows inclined extinction. Various symplectites were seen rimming of garnet mineral around clinopyroxene. The EPMA data of clinopyroxenes shows the clinopyroxenes belong to the ferrosalite and wollastonite composition. The $X_{Mg}$ value of clinopyroxene ranges between 0.29 and 0.33 (Table 2). Plagioclase occurs as anhedral to subhedral grains and shows lamellar twinning. It occurs as a matrix phase and inclusion within Garnet (Fig. 2e&f). Plagioclase occurs as a medium to coarse-grained, idioblastic to sub-idioblastic aggregate as shown in Fig. 2 (d) & (e). The plagioclase is anorthite in nature and compositional variation is $Or_{0-0.17}$ $Ab_{0.99-2.08}$ $An_{97.75-98.89}$. The $X_{Ca}$= (Ca/Ca+Na+K) ratio of plagioclase ranges from 0.98 to 0.99(Table 3). Sphene occur as accessory mineral either as tiny grains within intracrystalline clinopyroxene grain boundary or as rhomb-shaped crystals in plagioclase coexisting with garnet as shown in Fig. 2. (d) & (f). $TiO_2$ content of Sphene ranges between 35.57 wt%-36.51 wt% (Table 4). Clinozoisite is greenish brown coloured and massive form occurs as inclusion within clinopyroxene and in matrix phase.

**Fig. 2.** (a) & (b) Field photograph of calc-granulite. (c) Hand specimen photograph of calc-granulite (d) Photomicrograph shows garnet coexisting with cpx, plagioclase, sphene and clinozoisite under PPL. (e) Photomicrograph shows inclusions of clinopyroxene and plagioclase in garnet under PPL. (f) Photomicrograph shows that garnet partially rimming around clinopyroxene and sphene occurs as inclusion in clinopyroxene coexisting with quartz and plagioclase. Where, Cpx = Clinopyroxene Pl = plagioclase, Sph = Sphene, Grt =Garnet, Cz = Clinozoisite and Qz = quartz (Whitney and Evans, 2010).

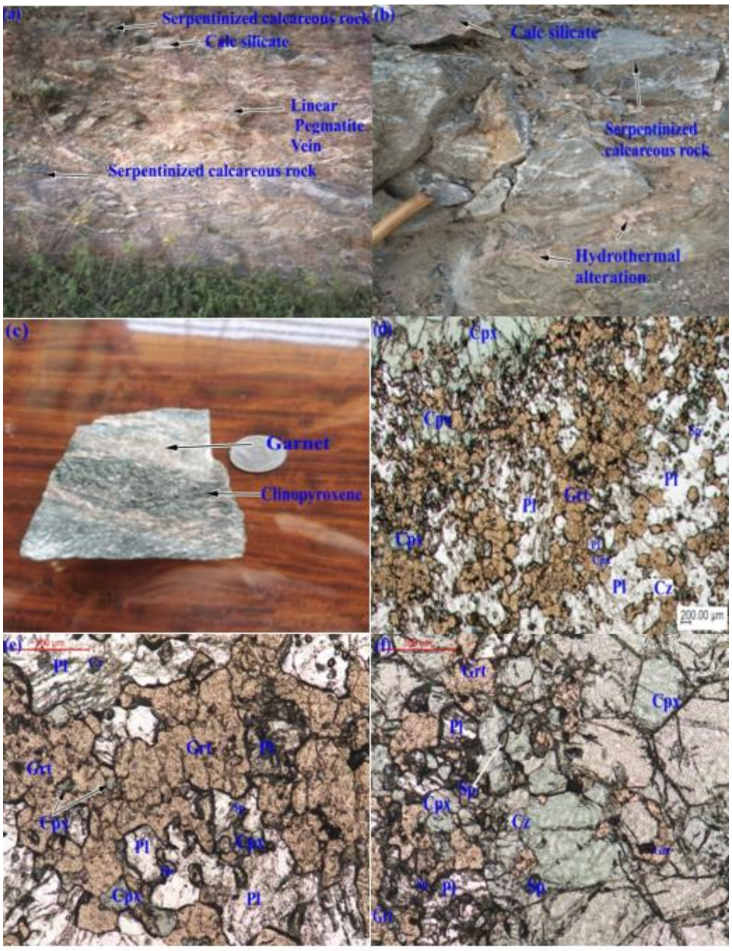


**Fig. 2**

## 5. GEOTHERMOBAROMETRY

The Pressure-Temperature conditions are the most necessary parameters for understanding the thermal situation of the crust and lithospheric mantle (Tam et al., 2012). Thermobarometric conditions of the Calc granulite were calculated using conventional exchange geothermobarometer -rs as well as the internally consistent dataset of (Holland and

Powell, 2011) with the help of THERMOCALC software 3.21 (Holland and Powell, 1998). The temperature and pressure conditions of their formation have been estimated with the help of conventional garnet–clinopyroxene exchange geothermometers and garnet–clinopyroxene–plagioclase–quartz geobarometers. The temperature estimate through garnet-clinopyroxene exchange thermometer of the calc-granulites of the study area varies in the range of 553 °C to 833 °C and the average temperature is 675 ± 89°C at 7 kbar. The pressure calculated for the calc-granulites ranges from 3.71 to 6.98 kbar and the average pressure is 5.24 ± 0.93 kbar at 600°C is given in Table 5. The average P–T condition of metamorphism is evaluated by the intersection of the different sets of metamorphic phases involving clinopyroxene, garnet, plagioclase and clinozoisite is 624 ± 97 °C/5.6 ± 0.8 kbar. The Isobaric T–X ($CO_2$) pseudosection in the NCFMAST-HC model system were estimated based on bulk composition to constrain the mole fraction of $CO_2$ and temperature condition equilibrium mineral assemblage (Grt-Cpx-Sph-Cz-Pl) of the Calc granulite (M-7). The PerpleX software (version. 6.8.2; Connolly, 2005) was used with the solid solution models such as Clinopyroxene (HP: Holland & Powell, 1998); Garnet (HP: Holland & Powell, 1998); melt (W: White et al., 2014); feldspar (feldspar: Fuhrman and Lindsley, 1988), as well as some pure end-member phases of sphene, clinozoisite, chlorite, quartz $CO_2$ and $H_2O$. The average chemical composition of the Calc granulite sample in mol% is: $SiO_2$ = 47.28, $Al_2O_3$ = 11.19, CaO = 20.93, FeO = 11.33, MgO = 4.95, $Na_2O$ =1.02, TiO2 = 1.46. MnO, $K_2O$ and $P_2O_5$ contents are very low, hence it is neglected in pseudosection construction, whereas $P_2O_5$ is used in a recalculation of CaO. The mole fraction of $CO_2$ ranges from ($XCO_2$ = 0) to ($XCO_2$ = 1) and is plotted along the X-axis. The Isobaric T–X ($CO_2$) pseudosection is constructed in the range of 300-800 °C and at a fixed pressure of 7kbar. The mole fraction of $CO_2$ ($XCO_2$ > 0.4) is a suitable constituent for the formation of stable mineral assemblage such as (Grt-Cpx-Sph-Cz-Pl) along with a temperature range from 620 -635°C in the NCFMAST-HC model system (Fig. 3).

**Table 5.** P-T estimates of the calc granulite (M-7) of the study area through conventional geothermobarometers and internally consistent data set.

| **Grt-Cpx geothermometers** | **T(°C) at 7 kbar** |
|---|---|
| (Ellis & Green, 1979) | 833 |
| (Dahl, 1980) | 573 |
| (Ganguly, 1979) by (Ganguly et al., 1987) | 721 |
| (Krogh, 1988) | 553 |
| (Ai, 1994) | 694 |
| Average | 675±89 |
| **Grt-Cpx-Pl-Qz geobarometers** | **P(kbar) at 600 °C** |
| (Newton & Perkins, 1982) | 3.71 |
| (Eckert et al., 1991) | 5.95 |
| (Holland & Powell, 1985) by (Eckert et al., 1993) | 4.47 |
| (Holland & Powell, 1990) by (Eckert et al., 1993) | 5.59 |
| (Berman, 1988) by (Eckert et al., 993) | 4.76 |
| (Moecher et al., 1988) | 6.98 |
| Average | 5.24±0.93 |
| Result of internally consistent dataset (Thermocalc v 3.21) | a ($H_2O$) = 0.5 |
| **(P–T) average** | 624 ± 97 °C/5.6 ± 0.8kbar |

Independent set of reactions used to estimate average (P-T average).

1. 2gr + alm + 3q = 3hed + 3an
2. alm + 8cz + 5q = 3hed + 13an + $4H_2O$
3. alm + 2andr + 4cz + 3q = 3hed + 3an + 4ep

Symbols:- gr : Grossular, alm : Almandine, q : Quartz, hed : Hedenbergite, an : Anorthite, cz : Clinozoisite, andr : Andradite, ep : Epidote.

**Fig. 3.** The T–$XCO_2$ pseudosection for calc-granulite from the study area (M-7) was calculated in the NCFMAST-HC model system using the perpleX software.

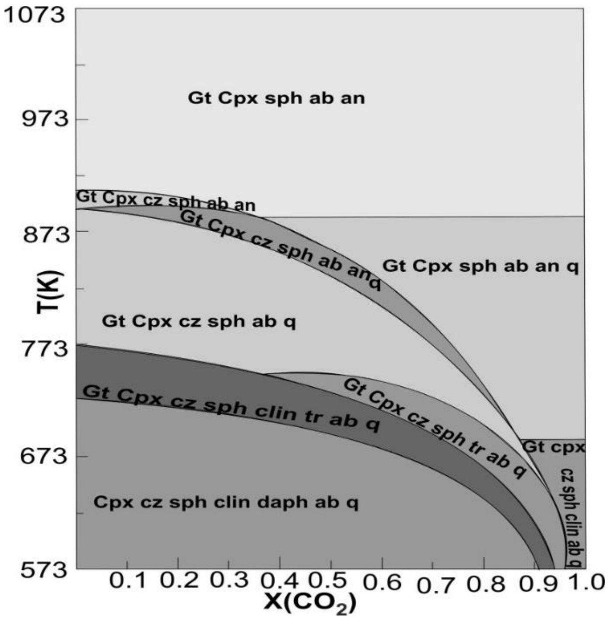


**Fig. 3**

## 6. DISCUSSION AND CONCLUSIONS

We have reported a new potential location of the calc-granulites which are present as small patches around the Baradgatta area of the Makrohar granulite belt.

The samples are studied based on petrography and mineral chemistry and the different mineral phases are identified such as garnet-clinopyroxene-plagioclase-sphene-clinozoisite. Clinopyroxene and plagioclase occur as inclusion in garnet suggesting that calcium rich plagioclase and clinopyroxene underwent metamorphism to form calcium-rich garnet through the following retrograde reaction: anorthite + wollastonite = Grossular + quartz. The presence of grossular and wollastonite in calc-granulites indicates the average P-T condition of granulite formation at 624± 97 °C and 5.6 ± 0.8 kbar which indicates the depth of burial of about (3.5 km/kbar) 20 km of the protolith. The presence of a pegmatite vein close to the calcsilicate granulite enclave increases the possibility that fluid produced from the pegmatites vein may have caused contact metamorphism and metasomatism, leading to the formation of calc granulite as shown in Fig. 2. (a) & (b). Calc silicate rocks are also reported from other locality in CGGC such as in Tatapani area, occurring western part of Chotanagpur Gneissic Complex, Visuvianite bearing calc-silicate occurs as an enclave in quartzofeldspathic gneiss near Tatapani and their metamorphic condition is 590-650°C at a pressure less than 4 kbar (Patel, 2007). The P-T studies by (Sen and Bhattacharya, 1993) for the garnet wollastonite bearing calc granulites from the Saltora area of the north-eastern part of the Chotanagpur Granite Gneiss Complex (CGGC) reveals that the scapolite + calcite + plagioclase equilibria constitute the high-temperature granulite facies conditions 820-840°C at 7.5 kbar pressure. The above data corroborate with the calc-granulite of the study area which has the average P–T condition of metamorphism is 724 ± 117 °C/7.6 ± 0.8kbar.

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