CHAPTER 1

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1.1. LOCATION OF THE STUDY AREA

Jharkhand is carved out of the southern part of Bihar on 15 November 2000. It lies between latitude 22°00' and 24°3'N and longitude 83°15' and 87°01'E. The state shares its border with the states of Bihar to the north, Uttar Pradesh and Chhattisgarh to the west, Orissa to the south, and West Bengal to the east. It has an area of 28,833 sq mi (74,677 km²). The industrial city of Ranchi is its capital and Dumka is sub capital while Jamshedpur is the largest city of the state. Some of the other major cities and industrial centers are Dhanbad, Bokaro and Hazaribagh. Dumka is one of the districts in the state of Jharkhand situated in the northeastern part of the state. The study area around Dumka falls under the Survey of India Toposheet No. 72P/3, 72P/4, 72P/7 and 72P/8. The investigated area lies between latitude N24°14′32.5″ to N24°18′32.8″ and longitude E87°11′76.2″ to E87°17′09.4″ which was shown in figure 1.1 (GSI, 2006). The area belongs to the ancient gneissic complex, the Chhotanagpur Granite Gneiss Complex (CGGC) which covers an area of about 100,000 km². These outcrops extend in the E-W across the states of Chattisgarh, Jharkhand, Orissa and West Bengal.

1.2. ACCESSIBILITY OF THE STUDY AREA

The study area, Dumka is linked by road transport services from different corners of the state itself. The area can also be accessed either from Bhagalpur in Bihar or from Kolkata in West Bengal. The nearest railway station is Bhagalpur in Bihar on the Guwahati-Delhi track of the Northeast Railway which is 115.06 Km from Dumka and the two towns is being link by SH19 (Figure 1.2).

1.3. PHYSIOGRAPHY

Jharkhand State consists of a series of four distinct plateaus, each occurring at a height which is different from that of the adjoining plateau. Each plateau represents an erosion surface. The highest plateau is formed by the Ranchi plateau or the Pat Region which is 800 to 1100m above mean sea level. It
covers the north-western part of the Ranchi district and the southern end of the Palamau district. The next plateau is known as the Ranchi plateau, which covers the whole of Ranchi, except the Pat region. The plateau is mostly composed of gneisses and granites and is about 600 m above the mean sea level. The topography is roughly undulating, with terraced slopes ending on one hand on the banks of a local stream and on the other, in local upland which may or may not have a low hill or which may or may not consist of solid exposed rocks, devoid of soil. The Ranchi plateau is separated from the other surface of the same elevation by the Damodar trough. It is the upper Hazaribagh plateau and is a continuation of the Ranchi plateau. The third plateau has an elevation of 300 mt. above the mean seal level and may be termed as the lower Chotanagpur plateau. It consists mostly of gneisses and granites but partly of schist and other Dharwar rocks. The fourth plateau is a uniform surface formed by the river valleys, plains and lower parts of the outer plateau lying between 150-300 m above the mean sea level. This again consists of gneisses, granites and the basaltic. Rajmahal hills and the Kaimur plateau belong to this erosion level.

The area around Dumka town were predominantly comprises of augen gneisses, leptynite, two pyroxene granulites/basic granulites and charnockite/enderbite, containing orthopyroxene + clinopyroxene + K-feldspar + plagioclase + garnet + quartz + biotite + hornblende of the Chhotanagpur Granite Gneiss Complex. There were a number of geologists and researchers working on the complex terrain of the CGGC. Various workers have reported the occurrence of high grade metamorphic rocks, pyroxene granulite, hornblende-pyroxene granulite, acid to intermediate charnockites, khondalites, calc granulites and leptynites around the areas of Dumka town (Bhattacharya, 1976; Barman et. al.; 1994, Singh, 1998). Generally the rocks around the study area have undergone metamorphism under amphibolite to granulite facies conditions.

1.4. CLIMATE

The Jharkhand zone may be divided into three micro-climatic sub-zones based on the analysis of temperature, pressure, rainfall, wind direction and relative humidity of the few meteorological stations located in the zone.
i) Plateau region: This region comprises of eastern division of Ranchi district at a 500m above mean sea level. This region is characterized by average annual rainfall of 1400mm to 1500mm and elevated in the western part.

ii) Higher Central Subarnrekha Basin: This basin includes mainly Saranda-Parhat hills and Daliva-Dhanjon Ranges and the surrounding area at an altitude of 400 m above the mean sea level.

iii) Plain Region: This region covers Panch Pargana, Singhbhum plains and the surrounding area. The elevation is about 100 m above the mean sea level. Average annual rainfall is between 1300mm to 1350 mm.

The climate of Jharkhand is dry semi-humid to humid semi-arid types. The average annual rainfall on the plateau and sub-plateau region is 1400 mm. Out of this, 82.1% rainfall is received between June to September and the remaining 17.9 percent during the rest of the months. The annual rainfall received by the state is 1400mm. Precipitation during winter is scanty and highly variable.

The State has three agro climatic sub zones, namely - Central and North Eastern Plateau Sub-zone (Zone IV), Western Plateau Sub-zone (Zone V) and South Eastern Plateau Sub-zone (Zone VI). All of these fall under agro-climatic Zone 7. The study area, Dumka falls under Sub-zone IV which is characterized by low precipitation ranging from 1050-1300 mm annual rainfall.

1.5. REVIEW OF PREVIOUS LITERATURES

Ball (1881) and others considered the CGGC as the “Fundamental Gneiss” over which the “Transition Series” and related metamorphic rocks were laid. The first generalized geological information on the proposed area have been provided by Dunn (1929) and Dunn and Dey (1942). Bhattacharya (1976) and Barman et. al., (1994) have given preliminary report on the occurrence of high grade metamorphic rocks. Bhattacharya et. al., (1990) have inferred that the granite gneisses represented the basement and the schistose rocks the supracrustals and both containing mafic enclaves were deformed and metamorphosed together, generally under amphibolite to locally granulite facies conditions. Early regional studies on the CGGC were by Ghose (1983), Mazumder (1979, 1988), Banerji (1991) and Singh (1998).
In the CGGC metamorphism reached middle to upper amphibolite facies. The P-T conditions have been deduced to be above 680°C (Bhattacharya, 1988). Under these high-grade conditions the pelitic rocks might have undergone partial melting to give rise to migmatites and anatectic granites. The sporadic occurrence of andalusite and cordierite may be the outcome of low-pressure metamorphism associated with granite intrusions in some areas of the CGGC. Bhattacharya (1988) indicated that the granites of the BMB originated at depth and were emplaced as structurally controlled plutons.

The CGGC includes high grade metasediments, gneisses, migmatites, khondalite, leptynite, granulites and metaigneous rocks, which have been intruded by mafic-ultramafic rocks, gabbro-anorthosite, granite, rapakivi granite, syenite, pegmatite, aplite and dolerite, tholeiitic basalts (Rajmahal Traps) at different geological periods (Mukherjee and Ghose, 1992, 1999; Ghose and Mukherjee, 2000; and Ghose et al., 2005). The granulites and high-grade gneisses were reported from metamorphic belts located on the north and south of the median Gondwana outcrops that were deposited in intracratonic rifts of the CGGC during Upper Palaeozoic time. There were three broad centres of the granulite pods: (i) the Palamau district in west (Ghose, 1965); (ii) the Purulia-Bankura region in the SE (Sen, 1967); and (iii) the Dumka-Mayurakhsh Valley in the NE (Bhattacharya, 1976; Barman et al., 1994). Of these, only the granulites from Purulia-Bankura were located in the southern belt of Mahadevan. Other minor occurrences of granulitic rocks in the CGGC were to the east of Ranchi (Sarkar and Jha, 1985), between Parasnath and Madhupur.

The metasedimentary rocks, occurring inside and outside the granitic gneisses, show varying degree of metamorphism, ranging from greenschist (mostly in SE part of the CGGC terrain) to granulite facies (central and eastern part of the terrain). The occurrence of 762 Cratons of the Indian Shield of metasedimentary and other rocks inside the gneisses of the CGGC suggested that the gneisses were the basement and that both these rock-units were subjected to metamorphism accompanied by profuse granite activities. It was for this reason that the CGGC acquired polymetamorphic character (Sarkar, 1968), like the Archaean gneissic complexes of most cratonic areas. The oldest age of ≥2.3 Ga of the gneisses of the CGGC from Dudhi area, west of Daltanganj
(Mazumder, 1988) suggested that some of the metasedimentary enclaves within the gneisses were formed in Archaean. The enclaves of pelitic granulites, quartzites etc. within the basement gneisses of the CGGC indicated that the CGGC rocks have undergone partial melting in the Precambrian time, generating granitic rocks as intrusive and granulites as melanosome or restite.

The granulite assemblage in the CGGC was commonly represented by khondalite (garnet-sillimanite ± graphite), calc-silicate granulite (scapolite-wollastonite-calcite-garnet±quartz), charnockite (hypersthene-granite), two-pyroxene granulite with or without garnet, hornblende granulite, all occurring as dismembered bands within migmatitic granitic gneisses (Roy, 1977; Sarangi and Mohanty, 1998). Apart from these, there were also enclaves of ultramafic bodies (hypersthene-spinel-hornblende ± olivine), lenticular or elliptical massif of anorthosite and syenite bodies (Mahadevan, 2002). The gneissic layering in granulite enclaves was similarly folded with the surrounding gneisses (Mahadevan, 2002; Mazumder, 1988). Although gneisses, migmatites and high-grade pelitic schists were present in the CGGC, attention has been given mainly on the granulites in the CGGC terrain.

The granulites from the Purulia-Raghunathpur area in the southern domain of the CGGC were reported to have evolved through ITD (isothermal decompression) path at ca. 1000 Ma. This was probably synchronous with the amphibolite grade migmatization. The granite plutonism, which was widespread during 1.0 Ga, was believed to have affected both granulite facies domains of the CGGC (Barman et. al, 1994). The age difference of ca. 100 Ma in the granulites from the north and south of Ranchi shear zone perhaps indicated cooling at different crustal levels rather than to show different evolutionary history (Barman et. al., 1994).

In Saltora area, Bankura district, Manna and Sen (1974) documented a near isobaric cooling in a suite of mafic granulites from 950 to 750°C at 8 kbar. Bhattacharya and Mukherjee (1984), on the other hand, proposed a prograde history involving breakdown of hornblende followed by cooling and retrogression to amphibolite facies conditions at 600°C/6.25 kbar. Again, Sen and Bhattacharya (1993) retrieved highest T (820–840°C at 7.5 kbar) for medium scapolite-calcite-plagioclase equilibria in wollastonite-calcite-
plagioclase-garnet-quartz assemblage in calc-granulites from the same locality. They also obtained lower temperatures (600–680°C) at 6–7 kbar, estimated from Fe–Mg exchange thermometer, which was attributed to retrograde cooling that led to the formation of garnet corona at the interface of hypersthene-plagioclase (Sen and Bhattacharya, 1986). According to these authors, further cooling resulted in the stabilization of mantling pyroxene in mafic granulites. Using different petrological constraints, Sen and Bhattacharya (1993) computed the peak isobaric cooling up to 680°C and 6.8 kbar. Subsequently, infiltration of mixed H2O–CO2 at 500°C/5 kbar developed muscovite, zoisite, and calcite in different proportions in rocks of the area. Sen and 78 2 Cratons of the Indian Shield his coworkers (Sen and Bhattacharya, 1986) also reported anorthosites that were emplaced during second phase of deformation along the core of doubly plunging folds.

In granulites around Dumka, a near isobaric cooling path was deduced by Barman et. al. (1994), based on coronal garnet at the hypersthene-plagioclase interface, similar to that described by Sen and his coworkers from Bankura area in the SE. Barman et. al. (1994) also documented a short decompress phase wherein garnet had developed symplectites of hypersthene + plagioclase. These authors also noted the occurrence of hypersthene-sillimanite in the enclaves of granulites from south of Ranchi and Daltonganj area in North belt, which was interpreted by them to be a product of ultra high temperature (UHT) metamorphism. Thus, the granulites from both belts, on either side of the Gondwana Formations, show similar tectonothermal history. However, relationship of the granulite facies assemblages and migmatization in the rocks of the N-belt were poorly known. Barman et. al. (1994) considered the isothermal decompressive path at 1.0 Ga for Purulia granulites whereas an isobaric cooling path at 1.5 Ga for Dumka granulites.

The CGGC was also characterized by more than one generation of mafic intrusives, mostly dolerite and gabbros to norites in which corona structure was often noticed at several places, especially in Daltonganj, Dumka and Purulia districts. These metaigneous rocks were generally concordant with the foliation of the host gneisses. Age-wise these metaigneous bodies might be older than 1600 Ma. Geochemically, these metabasics were different, tholeiitic in granulitic
rocks while ORB (ocean ridge basalt) in non-granulitic rocks. According to Murthy (1958), the presence of these large-scale coronets in the CGGC implies a major thermal episode in the evolution of the CGGC terrain. These coronites were believed to have been emplaced at midcrustal levels during a distensional stage (Mahadevan, 2002).

In complexly deformed and metamorphosed rocks of the CGGC, one cannot ascertain geological relationship amongst different lithounits, especially when the complex was overprinted by more than one tectono-thermal event. Geochronological data on the rocks of the CGGC were meager and the three age clusters of K–Ar dates have been taken to indicate three cycles of orogenies. A “Simultala orogeny” was proposed to cover ages in the range of 1246–1416 Ma, obtained in the NE part of the CGGC; the time band of 850–1086 Ma from Ranchi-Gaya areas was assigned to the Satpura orogeny; and ages of 358–420 Ma obtained in the extreme NE part of the CGGC were assigned to Monghyr orogeny (Mahadevan, 2002). Newer dates by Rb-Sr systematics on granitic rocks form Bihar Mica belt and charnockitic rocks from Dumka (belt III of Mahadevan, 2002) gave ages in the range 1000–1600 Ma, pointing to the impact of Satpura orogeny. However, age data based on Rb–Sr methods were susceptible to resetting at lower grades and by post-magmatic alteration, hence they tend to record younger ages. Also, a weak Pan-African thermal event (ca. 590–595 Ma) was recorded in the fission-track dating of mica from the Bihar Mica belt (Nand Lal et. al., 1976). The U–Pb data on zircons 2.5 Chhotanagpur Granite-Gneiss Complex 79 from massive charnockite yielded 1625 and 1515 Ma (Mesoproterozoic) while its recrystallization ages were at 1071–1178 Ma, indicating Grenville orogeny. Acharyya (2003) and Barman et. al. (1994) tentatively correlated the near isobaric cooling event at ca. 1500 Ma and the near-isothermal decompression at ca. 1000 Ma. This time span was recorded in the granitic rocks that were characterized by high initial Sr ratios (Barman et. al., 1994).

The charnockites were intrusive into the basement rocks, namely the khondalite, basic granulite, calc-granulite etc. (Mahadevan, 2002). The intrusive granulites with igneous texture have acquired foliation due to deformation imposed on them subsequent to their emplacement. Alternatively, it was also
possible that the scattered charnockites occurring amidst high-grade gneisses and migmatites owe their origin to in-situ charnockitization brought about by dehydration melting or by influx of carbon dioxide in the pre-existing gneisses and metasediments. This means that the granulite facies rocks could be as old as the associated gneisses of the CGGC and hence Mesoproterozoic or perhaps older (Late Archaean). However, no information was available about the precursor material either of the Mesoproterozoic charnockite or of granite that intruded the basement. Ghose (1983) and Banerji (1991) suggested that the charnockite-khondalite-granulite and associated tonalitic gneisses represented the basement complex of Archaean age. Supracrustals to this basement complex were pelitic schists, paragneissess, calc-silicates and marbles—all grouped by the stated authors under Older metasediments (equivalent to Singhbhum Group of 2600 Ma age). According to these authors, both basement and cover were metamorphosed up to granulite facies with emplacement of plutonic rocks, such as anorthosites, gabbros, and granitoids and also pegmatites, most probably during Grenville orogeny. Later, igneous activities included intrusion of basic and granitic rocks and extrusion of Rajmahal basalts.

1.6. STATEMENT OF THE PROBLEMS

The various rock types - two pyroxene granulite/basic granulite, charnockite/enderbite, leptynite, gneiss and augen gneisses that were encountered in the study areas around Dumka are interesting from several aspects:

i) The granulites are high pressure rocks which are uncommon at the earth’s surface (Heier and Adams, 1965; Heier, 1965; Lambert and Heier, 1968).

ii) The charnockite/enderbite and two pyroxene granulite/basic granulite occurred as domal shaped outcrops surrounded by gneisses and migmatites of the CGGC.

If the basic garnet granulites and the charnockite/enderbite rocks were genetically related, they could be correlated with the basic division of the charnockite series of Holland (1900) in southern India or the pyroxene granulites of Subramanian (1959). However, unlike the basic charnockite from the type area in Pallavaram, Madras, the Dumka and surrounding granulites are
characterized by the presence of garnet. In this respect, it becomes interesting to investigate if the granulites and charnockite of Dumka represent a differentiated igneous rock series. Of course, the mineral assemblages of the rocks at Dumka favor metamorphic origins of the granulites, yet igneous origins cannot be rejected when the larger size of the granulites, the high temperature mineralogy and the possible convergence of metamorphic and magmatic at deeper levels were taken into consideration (Howie, 1955).

There was a possibility for such a proposition when garnet was not uncommonly reported in igneous rocks (Green and Ringwood, 1968; Hamer and Moyes, 1982) and when initial experimental studies indicated that almandine-rich garnet could be an important liquidus phase and can even crystallize from a silicic magma at pressures of 5–7Kb (Green, 1976; Keesman et al., 1971). A possibility for garnet to crystallize from basic magma exists when the garnet stability in quartz tholeiitic, determined by Green and Ringwood (1967) and its intersection with the liquidus for dry gabbro is considered.

From Figure 1.3, it was obvious that if the gabbro solidifies on the high pressure side of this boundary, then pyroxene–garnet–plagioclase will be formed more or less simultaneously from the melt, resulting in granoblastic textures. On the other hand, if the gabbro solidifies on the low-pressure side of the boundary only pyroxene-plagioclase will crystallize from the melt. During further cooling, the garnet stability boundary might or might not be intersected for these basic rocks at much lower temperature. In order to develop garnet the rock has got to be "sent" to high pressure. In that case the garnet formation would be restricted at pyroxene-plagioclase contact, most probably in the form of coronitic texture.

The granulites (charnockite/enderbite) were characterized by reaction rims of garnet + clinopyroxene – quartz at hypersthene-plagioclase interfaces. The mineral assemblage was one of these in which the results of experimental petrology have a direct application to natural assemblages. The mineralogy of the rim is expressed by the reaction:

Orthopyroxene + Anorthite = Garnet + Quartz + Clinopyroxene
Figure 1.3: P-T diagram showing dry gabbro liquidus and oceanic geotherm (after Heier, 1965). The garnet stability in Quartz tholeiite (Green & Ringwood, 1967) intersects the crystallization field of basalts at 17kb. Obviously garnet developments depend on whether the gabbro solidified on the low pressure or pressure side of the boundary.

The above reaction has demarcated the boundary between medium pressure and high pressure granulite facies. Green and Ringwood (1967) investigated the transformations of basic granulite assemblages into medium and high pressure types. Olivine–plagioclase was the stable pair in the low-pressure basic granulites; while orthopyroxene–plagioclase was a stable pair in the medium–pressure granulites; the high–pressure granulite was characterized by the incompatibility of Orthopyroxene – plagioclase pair and by the compatibility of garnet + clinopyroxene ± quartz assemblage. The reaction \( \text{Opx} + \text{An} = \text{Gt} + \text{Cpx} + \text{Qz} \) was found sensitive to rock chemistry and is controlled by Fe/Mg, Ca/Na ratios and presence or absence of silica (Green and Ringwood, 1967; Ito and Kennedy, 1970, 1971; Kennedy and Ito, 1972; Wood, 1975; Hansen, 1981).
The presence of ±hornblende in these granulites of Dumka was interesting from two aspects: whether the hornblende was primary or was a product of recrystallization formed by reaction such as:

\[ 3\text{Orthopyroxene} + \text{Clinopyroxene} + 5\text{H}_2\text{O} = \text{Hornblende} + 5\text{Quartz} \]

1.7. OBJECTIVES OF THE RESEARCH

The main objectives of the present research are listed as follows:

1. To do geological field work and detailed rock sampling in the area in order to prepare Geological Map of the study area.
2. To do detailed petrographic studies of the rocks with reference to reaction textures, coronas, symplectites, *etc.* in addition to identify syngenetic &/or post-genetic porphyroblasts.
3. To do geochemical analysis of the rocks with respect to the major, minor & trace elements and REE to enhance the basic geochemical data on granulites.
4. To understand complex petrological problems pertaining to the petrogenesis of Granulites in general and of proposed area in particular based on the field, laboratory and, thus interpretative data.

1.8. SCOPE OF THE PRESENT RESEARCH

Granulites are the representative rocks of the lower crust and exposed on the surface of the earth due to exhumation. The study of granulites throws light on the crustal evolution and enhances our knowledge about the mineralological and bulk composition of the lower crust. The preparation of a geological map of Dumka would bring out the distributions and relations of different rock units in the study area. The petrography, with a special emphasis on grain to grain relationships, was largely relied upon for the paragenesis and tackling the problem of petrogenesis of the different rock types of the gneissic complex in the Dumka town. The geochemical analyses on major and minor oxides, trace elements and REE will enhance the geochemical information in the proposed area. The petrochemical data will tell the story of petrogenesis of the various litho-types as well. Moreover, an attempt on the comparison of the petrographic and chemical data will throw light on the protolith of the different rock types.
Figure 1.1: Geological Map of India showing the geographical location of the study area, Dumka (Geological Survey of India, 2006).
(a) Political map of India.

(b) A map of Jharkhand state showing road links of the various districts.

(c) A map of Dumka district, Jharkhand

Figure 1.2: Location map of the study area, District Dumka, Jharkhand.