CHAPTER–2

LITERATURE REVIEW

2.1 General

An examination of the existing works of literature is an essentialaspect of any research endeavour as it offers insights and resolutions derived from the collective work of numerous scientists and researchers. Rocks are the major naturalresource that serves as invaluable repositories of Earth's evolutionary and geodynamic history. The subsequent section of this chapter presents the relevant literature about the study area. The primary location where granulites were initially identified is the Granulitgebirge in Saxony, East Germany. The term "granulite" made its debut in the scientific literature (C.S. Weiss, 1803). The emergence of granulite facies was first documented by (P. Eskola, 1939). The process of forming amphibolite within the granulite facies was considered as a part of a paired metamorphic belt giving rise to either an island arc or a continental margin overriding an oceanic plate (Srivastava et al., 1984; Uyeda et al., 1974). The heat necessary for this transformation was believed to originate from sub-crustal magmatism and was thought to have formed in situ. Granulites are highly metamorphosed rocks in which silicates lack hydroxyl groups and they are predominantly composed of garnet, pyroxene, and plagioclase with an absence of micas but the possible presence of cordierite. Granulites are characterized by hypersthene + diopside and sillimanite + garnet as opposed to muscovite and biotite (Bucher et al., 2011). These coarse-grained rocks form under high-pressure and high-temperature conditions resulting in a gneissic structure due to the parallel alignment of grains, which is known as granoblastic texture. Granulites can be categorized as mafic granulites when more than 30% of their mineral composition is mafic minerals (primarily pyroxene) or as felsic granulites when less than 30% of their mineral composition is mafic minerals (mainly pyroxene). Granulite facies rocks represent the exposed lower section of the Earth's crust that has undergone exhumation. Their study is crucial for understanding the crust-mantle interactions. These rocks are sporadically exposed in younger terrains, often developed along fault zones during tectonic uplift, while in the Precambrian shield, the lower continental crust contains an abundance of granulites (Rudnick and Fountain,1995).

2.2 Previous work in the Chhotanagpur Granite Gneiss Complex

The Chhotanagpur granite gneiss complex comprises an expansive plateau located in the eastern part of the Indian peninsula shield which links with the eastern extension of the Satpura Mountain Range (Maji et al. 2008; Sanyal and Sengupta 2012). This extensive area underwent multiple phases of migmatization, deformation and metamorphism throughout 2000 Ma from Archean to Proterozoic (Ray Barman and Bishui 1994; Maji et al. 2008; Mukherjee et al. 2017). The primary geological investigation reveals that the region consists mainly of granite gneiss and migmatite (Sarkar et al 1998). Within these gneisses, sub-parallel lenticular enclaves of metasedimentary and metabasic rocks often align with the orientation of the surrounding country rocks (Singh, 2001). In addition, intrusive granites have cut across the entire geological sequence and are thought to have formed after significant tectonic events (Lahri and Das, 1984). India's first anorthosite massif was discovered near Saltora, situated at the eastern edge of the Peninsular Shield (S.C. Chatterjee, 1937). This massive anorthosite formation is found within the Chhotanagpur Granite

Gneiss Complex and is commonly referred to as the 'Bengal Anorthosite' (S.C. Chatterjee, 1937). The lithology, tectonism and grade of metamorphism were influenced by the emplacement of gabbroic- anorthosite in a rift related setting as well as the presence of peraluminous granite plutons within CGGC (Roy and Devrajan, 2000). The granulites and granitoids within the CGGC belt have provided Rb-Sr whole-rock isochron ages of around 1600-1500 Ma for high temperature-pressure events primarily concentrated in the northern region (S.K Acharya, 2003). Additionally, there is an isochron age of approximately 1000 Ma for anatectic events, leading to various types of granite and migmatites with sporadic occurrences of high-temperature and high-pressure granulite in the southern region (R. Sharma, 2010). In some rare cases, a thermal event around 500 million years ago is also indicated by whole- rock-mineral isochron age (Ray Barman et al., 1990). The presence of sillimanite and corundum assemblage in metapelitic rock associated with the Makrohar granulites (Pitchai Muthu, 1990) indicates temperatures near 1200°C and pressure exceeding 10 kb. Radiogenic isotope dating, specifically Rb-Sr dating of granitoids suggests an age of 1.73 billion years for this region, containing enclaves of metapelite and calc-silicate rocks. This finding implies an occurrence of these metapelites before the 1.73 Ga age (Sarkar et al., 1998). Neoproterozoic granite emplacements have been radiometrically dated at 815± 47 Ma for pink granites and 1005 ± 51 Ma for grey granites (Singh and Krishna, 2009).

2.3 Previous work in the Makrohar area

The Makrohar granulite belt encompasses metamorphic rocks ranging from amphibolite to granulite facies (Acharya, 2001). Two pyroxene granulites have been reported from this area (Pascoe, 1973; Pichaimuthu, 1990; Acharya, 2001). Pichaimuthu has indicated the presence of both clino- and ortho-pyroxene in the granulites. Geological mapping revealed that most of the area is occupied by granite gneiss and migmatites (Fig.2.2). Earlier research has proposed a magmatic origin for these granitic rocks (Dunn, 1942). However, subsequent several studies have suggested an anatectic origin for these gneisses based on the presence of migmatite and the occurrence of high-grade metamorphic minerals within the gneisses (Sarkar, 1988). Earlier research has proposed that the older gneisses and migmatites contain inclusions of metasedimentary and metabasic rocks (Sarkar et al., 1998). There are also gabbro and metabasalt with some gabbroic anorthosite (Narayan et al., 1981). The granite gneisses in the study area exhibit alkaline characteristics and are metaluminous in nature originating from the melting of the lower crust, which had been metasomatized by mantle-derived alkali-rich fluids, possibly due to asthenospheric upwelling (Yadav et al., 2022). Zircon U-Pb data from intrusive granite gneiss from the Makrohar area indicates a crystallization age of 1,498 ± 38 Ma and this age represents a significant Mesoproterozoic within-plate magmatic event in the CGGC, occurring concurrently with the breakup of the Columbia Supercontinent (Yadav et al., 2022).

2.4 Monazite dating

In recent years, monazite dating by the Electron Microprobe Analyzer (EPMA) has become a highly effective and efficient method for in-situ geochronology. Monazite, which is a prevalent accessory mineral in supracrustal rocks, has been widely used to gain knowledge about tectonic-metamorphic processes and the depositional history of sediments. This technique offers both speed and cost-effectiveness making it a valuable tool in the geochronological investigation (De Souza et al., 2006; R.R. Parrish, 1990). Monazite is an ideal mineral for U-Th-Pb dating due to its high U content, high closure temperature, and tendency to form in various rock types, especially in the amphibolite- granulite facies (Montel et al., 1996). Monazite (Ce, La, Y, Th) [PO_4] is a phosphate mineral containing substantial amounts of U and Th but negligible amounts of Pb. Radiogenic Pb does not significantly alter the monazite ages over geological timescales, both experimentally and empirically (Cherniak et al., 2004; McFarlane et al., 2006).

Monazite may also be formed during partial melting when P and REE are saturated in the melt phase (Watson et al., 1989; Montel, 1993). Monazite grains tend to preserve prograde and retrograde metamorphic events although not necessarily the peak metamorphic conditions (Fitzsimons, 2005). The combination of monazite reactivity and isotopic stability with silicate minerals makes it an ideal candidate for reconstructing poly-metamorphic events and deformation within metamorphic rocks (Gardes et al., 2007). Monazite is a widespread phosphate mineral present as an accessory mineral in various crystalline rocks. It frequently retains discrete age-composition domains within a single thin section, individual grains, and specific micro-textural settings in poly- deformed rocks (Wing et al. 2003). Consequently, polygenetic monazite occurrences are increasingly employed to decipher complex histories of grain growth, recrystallization, dissolution and regrowth (Vry et al., 1996; Lanzirotti et al., 1996; Ayers et al., 1999; Williams et al., 1999). The insights gained from these grain-scale processes in monazite can be integrated with petrofabric, petrological, and geochronological data to reconstruct regional thermotectonic histories (Montel, 2000; Pyle et al., 2003; Gibson et al., 2004).

2.5 Geothermobarometry

Metamorphic rocks can form under a broad range of pressure-temperature (P-T) conditions. Changes in the existing pressure-temperature (P-T) conditions induce the transformation of minerals through recrystallization, leading to the emergence of new mineral phases that maintain stability within the newly formed metamorphic condition. The emergence of these new mineral phases is also contingent upon the overall bulk rock composition. Consequently, interpreting micro-textural features, mineral assemblage and composition within metamorphic rocks is crucial in elucidating the pressure-temperature- time (P-T-t) paths in any geological region. The mineral assemblage in a metamorphic rock can provide useful information about the temperature and pressure conditions.

Another way to estimate these conditions is by examining the chemical composition of minerals, which can function as geothermometers and geobarometers due to their equilibrium relationships within solid solutions. Throughout the transformation of a rock, whether it was previously non-metamorphic or already metamorphic, numerous thermodynamic variables, such as entropy, enthalpy and free energy, come into play. These variables contribute to the formulation of geothermometers/geobarometers, particularly in the context of mafic rocks. The field of petrology has witnessed remarkable progress through the development of geothermobarometers, which incorporate thermodynamic datasets and enhanced mineral activity models. These geothermobarometric investigations have proven to be invaluable in enhancing our comprehension of the origins of granulites. An array of techniques has been advanced within metamorphic petrology to quantitatively ascertain the P-T conditions of metamorphism and to assess the mechanisms underlying granulite metamorphism. Geothermometry of metamorphic rock commonly relies on the exchange of Fe and Mg in mineral pairs. Consequently, temperature estimation was performed using garnet-biotite, garnet-cordierite, garnet-clinopyroxene, Amphibole-plagioclase and orthopyroxene- clinopyroxene, taking into account the variations in mineral assemblages. Additionally, considering the temperature-dependent nature of the Ti content in biotite, thermometry based on this parameter was also employed. Geobarometric studies, initiated in the 1970s and pioneered by (Ghent, 1976) employ mineral assemblages like garnet-plagioclase-Al_2SiO_5-quartz for this purpose. The *P–T* conditions may also be estimated using the Pav, Tav, and PTav methods of the mineral probe data with the help of THERMOCALC software v.3.47 (Powell and Holland, 1988) with an internally consistent dataset of Holland and Powell (2011) updated to comply with the activity models of White et al. (2014). The construction of pseudo sections has emerged as a robust and precise technique in metamorphic petrology to assess P-T conditions and the history of metamorphic rocks (Holland and Powell, 2011; Connolly and Petrini, 2002). Pseudosections, serving as tools to interpret mineral paragenesis and presented on P-T diagrams are constructed through various phase equilibrium modelling softwareapplications such as PERPLE_X, THERMOCALC, and THERIACDOMINO (Connolly, 1990, 2005; Powell and Holland, 1990; Powell et al., 1998). These pseudosections are developed while considering fixed bulk compositions with varying parameters like temperature, pressure and composition (Holland and Powell, 1998). The P–T pseudosection was constructed using Perple_X 6.8.2 software (Connolly, 2005, 2009) and end-member thermodynamic data from Holland and Powell (2011). They provide essential constraints for calculating P-T conditions and offer insights into reaction textures (White et al., 2007). In summary, the field of metamorphic petrology mainly quantifies the P-T conditions of metamorphism and in comprehending the processes underlying granulite metamorphism. Geothermobarometric investigations, pseudosection modelling, and mineralogical analysis have collectively enhanced our capacity to understand the complex history of metamorphic rocks and the conditions governing their formation.

2.6 Geochemistry

The term "geochemistry" originates from "geo" referring to the Earth and "chemistry" the scientific study of chemical transformations. A petrologist analyzes the rock chemistry known as geochemistry to grasp the chemical composition and structural attributes of a rock found on the earth's surface. The earth's crust mainly comprises igneous rocks, formed primarily from magmas. Understanding the nature of these igneous rocks involves examining major and trace element chemistry. Silicates constituting the building blocks of most igneous rocks are created from aggregates of one or more minerals naturally occurring as inorganic chemical compounds. Geochemistry serves as a significant tool in distinguishing various rocksuits, identifying the involved magmatic processes, the nature of protolith and the tectonothermal environments through quantitative measurements and patterns of chemical variations. Geochemical parameters encompassing Si, Na, K, Al, Ca, Mg, Mn, Ti, and P are regarded as major constituents in geological compositions. These elements combined in oxides exhibit distinct variations and serve as the primary building blocks of bulk rock chemistry. Consequently, they are employed as the basis for categorizing different rock types. The total alkali versus silica (TAS) diagram (Le Maitre, 1989) is a widely utilized nomenclature and classification tool for volcanic rocks. Notably, major oxides exhibit a mobile nature during metamorphic processes (Rollinson, 1992). Hence, for classification purposes, diagrams are constructed based on immobile trace elements like Th, Zr, Y, and La to depict the magmatic affinity of rock samples (Ross and Bedard, 2009). The term "trace element" generally refers to elements found in rocks in relatively low concentrations, typically ranging up to a few thousand parts per million. These elements, due to their low concentrations, are sensitive to crystal fractionation, partial melting processes, and the composition of the source material. Their presence and ratios are often used to understand the processes involved in their formation. While the concentration of trace elements remains constant, the extent of their availability can be influenced by various factors, such as the melting process, the remaining solid phases post-melting, any differentiation before final crystallization, and potential interactions with other rocks or melts (Hanson, 1989). Studies on rare earth elements (REEs) have indicated that their content remains unchanged during the prograde regional metamorphism of metapelites across a range from greenschist facies to amphibolite facies(Cullers et al., 1974). Similarly, oceanic tholeiites and related amphibolites have exhibited comparable REE distributions, suggesting an isochemical metamorphic process (Kay et al., 1970). The chemistry of major oxides and trace elements significantly influences the fractional crystallization and transformation of magma. Certain trace elements like Y, Zr, Sc, Nb, and Ga maintain stable relative and absolute quantities despite weathering, metasomatism, and metamorphic processes. These immobile elements often relate to major elements; for instance, Zr/Ti and Nb/Y ratios have connections with SiO_2 and alkaline elements, respectively (Floyd and Winchester, 1975; Winchester and Floyd, 1977). High field strength elements (HFSE) such as Nb, Zr, Ta, Ti, and Hf are immobile and valuable for categorizing metamorphosed parent rocks (Pearce and Parkinson, 1993). Even in highly metamorphosed volcanic rocks and altered ash-fall deposits, the original chemical composition of the parent rock can be determined. Large ion lithophile elements (LILE) like K, Rb, Sr, and Ba are mobile and readily influenced by melts. REEs often reflect variations in major element geochemistry, providing specific evidence of magma generation and evolution (Motoki et al., 2015). Geochemical diagrams using immobile elements aid in deducing the tectonic origin of different volcanic rocks (Pearce et al., 1995). The HSFEs remain immobile during weathering and metasomatism, often concentrating on durable and resistant accessory minerals like zircon, monazite, and apatite. Immobile elements serve as helpful tools for rock classification and distinguishing tectonic variations in altered igneous rocks. Geochemistry has been crucial, in determining the origin of pelitic and basic rocks and exploring the geological settings in which they were formed (Adeigbe and Jimoh, 2013; Madukwe et al., 2016).

2.7 Research gap

The existing published works reveal that there has not been conducted detailed research work in the Makrohar area. Reviewing the preceding literature as described earlier, it is evident that within the Chhotanagpur Granite Gneiss Complex (CGGC) two areas have been recognized for harbouring granulite grade rocks specifically the Baro-Saltora (Purulia) region and the Dumka-Deoghar region. However, the literature survey indicates the presence of signs pointing to high-grade metamorphic rocks within the Makrohar region. Further exploration of the study area has unveiled the existence of granulite facies rocks including pelitic granulites and two pyroxene granulites in the Makrohar area. However, various rock types have been identified and mapped within the Makrohar region, but there has been a noticeable absence of systematic and detailed studies dedicated to examining the development of various metamorphic mineral assemblages based on micro-textural investigations. A comprehensive analysis through petrographic and microtextural studies is imperative to unravel specific mineral reactions, shedding light on potential prograde or retrograde metamorphism within this high-grade metamorphic terrane. Such methodical investigations have thus far been lacking in the Makrohar granulite belt. It is worth noting that existing data regarding pressure- temperature (P-T) estimates for the Makrohar granulite belt are limited to reconnaissance-type studies conducted by a few early researchers. Although numerous thermodynamic models have been formulated to estimate P-T conditions and software tools have been developed to calculate pseudosection for investigating stable phases under specific P-T conditions, meaningful interpretation of P-T data necessitates the application of specific mineral reactions observed by petrographic investigations. The amalgamation of specific mineral reactions and mineral P-T estimations holds the potential to unveil the exhumation history of high-grade metamorphic rocks shedding light on whether they underwent Isobaric Cooling (IBC) or Isothermal Decompression (ITD) P-T-t paths and which have significant implications for the tectonic processes within the lower continental crust. Despite the vast expanse of the Chhotanagpur Granite Gneiss Complex (CGGC) reported U-Pb ages remain relatively limited in number with the majority stemming from whole-rock age analyses primarily from the eastern part of the CGGC. These ages have been determined through Rb–Sr whole-rock isochron dating, monazite dating, and U-Pb zircon dating revealing the presence of four distinct phases of metamorphism within the CGGC (Sanyal and Sengupta, 2012). Notably, the Makrohar granulite belt has witnessed the emplacement of granitic rock during 1.73 Ga (Rb-Sr dating) which contains enclaves of calc silicate and metapelitic rock. This suggests that the metapelites occurred earlier than 1.73 Ga. (Sarkar et al., 1998). Surprisingly, despite these works, no detailed studies have been carried out in the Makrohar area to investigate the metamorphic processes. The objectives of the present study are to discern the genetic evolution of these rocks with a focus on the geochemical characterization of metamorphic rocks. Such analysis is important in understanding the nature of the protolith, the characteristics of magma or tectonic environments responsible for magma generation, and the petrogenesis of the rocks. Addressing the aforementioned challenges necessitates a meticulous examination of the metamorphic processes and the evolution of pelitic granulites, mafic granulites, amphibolites and garnet-bearing gneisses. The research aims to study the mineral assemblages and metamorphic evolution of granulite facies rocks.