CHAPTER-2

LITERATURE SURVEY

2.1 General

This unit covers previous research works related to granulite formation and compilation of literature studies according to various methodology and rocks from the study area. Review of literature is an indispensable part of any research work. It provides a solution to the problem raised by various scientists and researchers' previous work. Rocks are the most important natural resources of nature, and preserve the evolutionary and geodynamic history of the Earth. The literature related to the study of the research area is presented in the following sections.

2.2 Introduction

The type locality of granulite is Granulitgebirge in Saxony, East Germany. The term "granulite" first appears in the literature [105]. Granulite facies were first observed by [106], which developed during regional metamorphism. The formation of amphibolite for granulite facies was regarded as a paired metamorphic belt, resulting in an island arc or continental margin overriding upon the oceanic plate [107, 108], where the heat source was derived from sub-crustal magmatism and are thought to have formed insitu. Granulites are high-grade metamorphic rocks in which the silicates are free from a hydroxyl group, and these are dominated by garnet, pyroxene and plagioclase, whereas micas are absent, but cordierite may be present. Granulites are characterized by hypersthene + diopside instead of hornblende and other amphiboles or by kyanite and sillimanite + garnet instead of muscovite and biotite. Granulites are coarse granular rocks formed at high P-T condition, which exhibits gneissic structure due to parallel arrangement of grains, and it is known as granoblastic texture. More than 30% of mafic minerals (predominantly pyroxene) in granulites can be identified as mafic granulites, while less than 30% of mafic minerals (mainly pyroxene) can be referred to as felsic granulites.

The granulite facies rocks represent the exhumed portion of the lower section of the Earth's crust; however, their study is necessary to carry out crust-mantle interaction. Younger terrains represent sporadically exposure of the granulites, which may be developed along fault zones during tectonic upliftment, whereas lower continental crust composes abundance of granulite in the Precambrian shield.

2.3 Previous work in the Central Indian Tectonic Zone (CITZ)

The Central Indian region is distinguished by the presence of granulite bands of minor dimensions inside the Central Indian Tectonic Zone (CITZ) and adjacent cratons. The CITZ is a mobile belt that originated during the Proterozoic era. Its regional trend is oriented in the ENE–WSW direction. The region under consideration represents the convergence area of two prominent cratonic blocks, specifically the Bundelkhand craton located in the northern region and the Bastar Craton situated in the southern region. The lithotectonic units observed within the region encompass metamorphosed supracrustal and granulite belts, metamorphosed mafic and ultramafic formations, extensive metacarbonates, iron and manganese deposits, tonalite trondhjemite granodiorite (TTG) gneisses, charnockites, and related arc magmatic assemblages. Furthermore, it is worth noting the existence of exhumed metamorphic bands characterised by high-pressure and ultrahigh-temperature conditions, alongside postcollisional granites enriched in potassium. [16-18, 21, 27]

The Central Indian Tectonic Zone (CITZ) represents the region where the Bundelkhand craton in the northern part and the Bastar Craton in the southern part converged and sutured together. The Central Indian Tectonic Zone (CITZ) is situated in a geographically constrained position, with the Son Narmada North Fault to its north and the Central Indian Shear (CIS) zone to its south. The region under consideration encompasses a minimum of three separate supracrustal belts, specifically the Mahakoshal, Betul, and Sausar belts. These belts consist of supracrustal rocks that have undergone metamorphism of low to medium grade. These rocks are predominantly found inside undifferentiated gneisses and granitoids.

2.4 Monazite and Zircon Geochronology

Electron microprobe dating (EPMA) of monazite is one of the best applications for insitu geochronology in recent decades and is a rapid as well as cost-effective technique. Monazite is the common accessory minerals in supracrustal rocks; monazite has been used extensively to acquire information about tectono-metamorphic evidence and depositional history of sediments ([131, 132] and references therein). Monazite has several essential features that indicate an appropriate mineral for U-Th-Pb dating. These comprise: (a) high content of U [133]; (b) Pb is not incorporated at the time of crystallization [134]; (c) the U-Th-Pb component reveals high closure temperature (>900 °C; [135]; (d) monazite found from the various lithology [136]; (e) amphibolite granulite facies is suitable for the formation of monazite [137-140]. The utilisation of the electron microprobe technology enables the field of geochronology to reconstruct the pressure-temperature-time (P-T-t) route history of metamorphic rocks. Chemical zoning in monazite has correlated with distinct age domains, whereas Y and Th act as characteristic elements [141, 142].

Monazite (Ce, La, Y, Th) [PO_4] is a phosphate of rare earth element that contains substantial amounts of U and Th but contains negligible amounts of Pb. The radiogenic Pb has reorganized the monazite ages by diffusion through the monazite lattice and is unaffected over geological timescales, both experimentally and empirically [135, 143, and 144]. Monazite can also be developed during partial melting, where P and REE are saturated in the melt phase [145, 146]. The monazite grains tend to preserve prograde and retrograde metamorphic events, not necessarily to preserve the peak metamorphic condition [147]. The combined characteristics of monazite such as reactivity and isotopic robustness with silicate minerals make it an ideal contender for recreation of poly-metamorphic events and deformation within metamorphic rocks. Monazite is a widespread phosphate mineral that occurs as an accessory mineral in diverse crystalline rocks. It commonly preserves discrete age-composition domains within a single thin section, individual grains, and specific micro-textural environments in poly deformed rocks. As such, polygenetic monazite occurrences are utilized increasingly for deciphering complex histories of grain growth, recrystallization, dissolution and regrowth [139, 148-151]. The record of such grain-scale processes in monazite can be linked to regional thermotectonic histories when integrated with a full complement of petrofabric, petrologic, and geochronologic data [141, 142, 152-155].

U–Pb zircon dating is the oldest dating method that can be used to analyze the age of rocks that range from 1 million years to 4.5 billion years ago [156, 157]. Zircon (ZrSiO4) has various characteristics that make it very valuable for petrologists and geochronologists. LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) is used for geochronological analysis on zircon grains that is particularly suitable for providing rapid and accurate U-Pb ages [158-160] and is also capable of analyzing the zoning patterns of zircon and other minerals. Zircon is usually used for

U–Pb geochronology, due to their mechanical and chemical stability, and ubiquity in all types of rocks. Both monazite and zircon reveal enormous closure temperature for the U-Th-Pb system and low Pb diffusivity [135, 161], thus are essential for dating the high-grade metamorphic events. Zircon can either grow during partial melting of prograde metamorphism, or crystallize during the solidification of melt [162-164], or develop from the breakdown of Zr-bearing mineral phases like garnet and ilmenite [165, 166]. Single monazite has preserved various zoning patterns due to coupled dissolution and recrystallization processes, and therefore record various apparent ages. Both of these minerals have shown complex behaviour in high-grade metamorphism and can record the past geological events to improve the timing of tectono-magmatic events [163].

2.5 Geothermobarometry and phase equilibria modelling

Metamorphic rocks can be formed under a wide P-T range; the mineral recrystallization occurs due to change in existing P-T condition resulting in the creation of new mineral phases that are stable within the new metamorphic conditions. The development of new mineral phase also depends upon the bulk rock composition. So, the interpretation of micro-textures combined with mineral assemblages and compositions in metamorphic rocks form the fundamental and most crucial step to determine P-T-t paths in any area. Its mineral assemblage can broadly suggest the determination of P-T conditions attained by any metamorphic rock. The other way to estimate P-T condition is by analyzing the chemical composition of minerals that are solutions of various minerals such that their equilibrium relationships among solid solutions serve as geothermometers and geobarometers. It is noted that during the transformation of a particular rock either non-metamorphic or even metamorphic to a newly formed metamorphic rock, various thermodynamic variables occur. These thermodynamic variables such as entropy, enthalpy and free energy form mafic formulation of any geothermometers/geobarometers. The advancement in petrology by use of geothermobarometers developed by the involvement of thermodynamic dataset and improved activity models of minerals has contributed significantly for the better understanding of the evolution of metamorphic rocks.

The geothermobarometric studies have been found to have critical applications in understanding granulites' genesis. Different techniques have been the most significant improvements in metamorphic petrology to quantify the P-T condition of metamorphism and evaluate the processes, which caused granulite metamorphism. Geothermometry of metamorphic rocks is typically based on Fe and Mg exchange of mineral pairs; therefore due to difference in mineral assemblage temperature estimations were done using garnet-biotite, garnet-cordierite, garnet-orthopyroxene, garnet-clinopyroxene, and orthopyroxene-clinopyroxene. However, the use of solvus thermometry began in the 1950s, i.e. before solid solution geothermometry based on Fe-Mg exchange. Since Ti content in biotite is always temperature-dependent, thermometry based on the Ti content of biotite was also used. It is well known that solid-solid reactions are susceptible to pressure and temperature conditions, and it acts as good geobarometers if the temperature can be derived from some other methods (e.g. exchange thermometry). The work on geobarometers began in 1970’s and successively done by [167], using plagioclase-garnet-Al2SiO5-quartz assemblage [168]. In the present study garnet-cordierite-sillimanite-quartz geobarometry has been used for pressure estimation. The estimation of P-T conditions can also be conducted through the utilisation of the P_{av}, T_{av}, and PT_{av} methods, which involve the analysis of mineral probe data and the implementation of the THERMOCALC software version 3.47 [99]. This program employs an internally consistent dataset (tcds62) [80], which has been modified to adhere to the activity models proposed by [169]. The THERMOCALC has overcome the two problems, including inverse modelling, to calculate the geothermobarometry using PT_{av} and forward modelling to calculate phase diagrams for different model systems.

With the advancement in science, pseudosections modelling have evolved as the most robust and accurate techniques in metamorphic petrology that are used to evaluate the P-T condition thereby suggesting the evolution of metamorphic rocks [78-80, 170-172]. A pseudosection is used to interpret mineral paragenesis that can be further represented on the P-T diagram. In present work instead of making petrogenetic grids, pseudosections were made because it displays only those set of fields and reactions that are possibly experienced by the particular bulk composition used. The pseudosection is challenging to calculate by hand since many phases are involved which change composition with a change in P-T. Therefore many phase equilibria modelling programs such as PERPLE_X, THERMOCALC, THERIACDOMINO etc., are being used. It constructs phase diagram using fixed bulk composition concerning varying parameters like pressure, temperature, composition etc.

The dataset has since been refined and developed [99, 173, 174]; the concept of geothermobarometry is well highlighted by [102]. The quality of an internally consistent dataset (tcds78) of [80] updated to comply with activity models of [169], the a–x relationships for silicate minerals and fluid has been drastically changed and improved, particularly in terms of handling multi-component phases that also involve order-disorder models [81, 102, 174, 175]. The PT pseudosection was constructed by using Perple_X 6.9.0 software [78, 79] and end-member thermodynamic data from [80] (filename: hp78ver.dat). They can deliver significant constraints on calculating P-T conditions and observing reaction textures, although care should be taken to investigate whether modelling has been performed in a suitable chemical system because it may misinterpret [104]. According to petrographic analysis, the observed reaction textures exhibit a varied spatial distribution of mineral phases, typically characterised by the presence of layered structures (known as coronas) and small-scale intergrowths of minerals (referred to as symplectites) that partially replace the coarse-grained minerals [176].

The granulite facies of rocks have been well reported and studied by various authors within the supracrustals of Sausar and Mahakoshal belt and tectonic relationships have been established. The Bhandara portion of the BBG belt is quite constrained, consisting of a medium to coarse grained, gabbroic, two-pyroxene granulite body that preserves relic igneous fabric. [25-28].

2.6 Geochemistry

Geochemical parameters such as Si, Al, Mg, Ca, Na, K, Ti, P and Mn are considered major elements. Oxides of these elements show a well-defined variation and act as the major constituent of bulk rock chemistry. Hence, they are used to classify the different rock types. The total alkali vs silica (TAS) diagram [182] was considered nomenclature and volcanic rocks classification. The TAS diagram was intended for common fresh volcanic rocks. Major oxides have a mobile nature during metamorphism [183]; therefore, the classification of diagrams is plotted using immobile trace elements. [184] proposed a diagram based on immobile trace elements such as Th, Zr, Y and La to represent magmatic affinity to rock samples.

The trace elements cannot be rigorously defined, but those elements are usually taken to mean concentrations of less than a few thousand parts per million (ppm) present in rocks. The trace elements are used to comprehend the magmatic emplacement of igneous rocks and provide information about the partial melting, crystal fractionation and source composition. The concentration of trace elements will never change; however, the melting process's extent depends on the various factors such as melting process, the remaining solid phases after elimination of the melts, any differentiation before final crystallization, and potential interactions with foreign country rocks or melts [185]. The change in rare earth elements (REEs) patterns can be used to derive information related to the rocks protolith's genesis. Progressive variations of the REE plots suggest that the protolith may be obtained by crystallization from parent magma [186]. The enrichment of elements can also provide important information on mineral fractionation at variable depth. Enrichment in HREE suggests garnet fractionation as HREE makes high partition co-efficient and is highly compatible in garnet [187]. [188] also suggested clinopyroxene act as a sink of LREE and garnet for HREE. Thus, garnet plays a crucial role in the partitioning of trace element during crystal fractionation of V and Cr [189, 190]. The abundances of LILE (Rb, Ba, U, and Pb) and LREE are deduced due to enrichments by a fluid-rich component [191]. There is no observable variation recorded in REE abundance between metamorphosed rocks and unmetamorphosed rocks [192]. The REEs contents have not changed during the prograde regional metamorphism of metapelites that ranged from greenschist facies to amphibolite facies [193]. The oceanic tholeiites and related amphibolites have shown similar REEs distribution and suggest the metamorphic process was isochemical [194].

Terrigenous sediments are a valuable source of information regarding the composition, geodynamic setting, and development of the primordial continental crust. The geochemical composition of these substances is determined by the intricate interplay of multiple factors, including the origin of the sediment, the process of weathering, the means of movement, and the process of diagenesis ([195] and references therein). Many studies have traditionally shown that geochemistry plays a crucial role as a sensitive indicator in determining the provenance of sedimentary and metasedimentary rocks and also to investigate the geodynamic setting in which they were deposited [196-205]. Numerous studies have emphasized the immobile trace elements and REEs in particular as reliable in studying the origin and depositional environment of metasedimentary rocks particularly in pelitic and semi-pelitic rocks [196, 206, and 207].

2.7 Research Gap

The Betul Group is comprised of supracrustal rocks that exhibit low-to-medium grade metamorphism, which occurred within the amphibolite facies [3]. The presence of Betul supracrustals inside the Central Indian Tectonic Zone (CITZ) [72, 73, 78, 79 and references therein] serves as a significant indicator that the protoliths could have undergone metamorphism up to the granulite facies. The Central Indian Tectonic Zone (CITZ) has been previously studied in the context of its role as a trans-continental boundary separating the northern Bundelkhand Craton from the Southern Bastar Craton [105]. Previous research has extensively shown the presence of granulite bands within the northern Bundelkhand Craton and southern Bastar Craton [106, 107, 108, 109, 110, 111, 112, and 113].

This work is an attempt to provide a metamorphic perspective that granulite facies of metamorphism can exist within the supracrustal rocks of Betul belt as it is an active part of the Central Indian Tectonic zone. The tectonic zone encompasses a number of crustal units that participated in multiple instances of subduction, collision, and accretionary orogenesis during the Proterozoic period. The tectonic zone has undergone a long and complex history involving multiple phases of magmatism, sedimentation, and orogenesis. These processes have resulted in the generation of extreme temperatures and pressures, contributing to the formation of granulite facies metamorphism. As a consequence, the original rock compositions have been transformed into metamorphic equivalents that are stable under the prevailing conditions of pressure and temperature in this zone. Apart from this, the tectonically active characteristic of this Proterozoic mobile belt can cause subsidence and upliftment cycles creating variable range of PT conditions which would cause progradation and retrogression of the mineral facies.

An attempt has been made in order to solve these problems to make out clear picture resulting in the occurrence of granulite facies metamorphism.