CHAPTER - 2

LITERATURE REVIEW

2.1 General

A literature review is an evaluation of the intellectual component of a topic. It summarises existing data, helping us to discover existing study methodologies, concepts, and gaps. We have provided an assessment of much research and explored controversial features in the granulite formation and study area in this chapter, which aids in classifying the critical gaps that must be addressed. A review of the literature is an essential component of every research project. It offers a solution to the problem based on the prior work of numerous scientists and experts. The following is a list of available literature relating to the study of the research area.

2.2 Introduction

The study of granulites during the last few years has gained new attention due to their unique role as a component of the lithosphere from the crust to the upper mantle. Granulites provide profound information about heat exchange between the lithosphere and asthenosphere during orogenesis (Carter and Tsenn, 1987; Rudnick and Fountain, 1995; Zi et al., 2004; Wang et al., 2018). The Granulitge birge in Saxony, eastern Germany, is the type locality for granulite. The term "granulite" first emerges in the literature because of this locality (Weiss, 1803). Nonetheless, the term "granulite" is older; it was coined in 1785 by Johann Wolfgang von Goethe, a German writer, from the Latin granulum. Geologists are usually curious about the compositional characteristics of the deep continental crust and how it operates. Xenoliths and exposed high-grade rocks are the two most common types of deep crustal rocks. Xenoliths are necessary but less valuable than crust since they are smaller. As a result, high-grade metamorphic terrains are an essential source of knowledge about the lower crust. Granulites are high-grade metamorphic rocks mostly made of anhydrous Fe-Mg-silicates, feldspar, and a significant percentage of quartz. Granulites are high-grade metamorphic rocks dominated by garnet, pyroxene, and plagioclase with no hydroxyl group in the silicates. Cordierite is also possible, although the micas are not present. Granulites are of pelitic, mafic, or quartzo-feldspathic nature. Mafic granulites are rocks that contain more than 30% mafic minerals (ideally pyroxene), while felsic granulites include less than 30% mafic minerals. Granulites have a granoblastic texture defined by the parallel arrangement of felsic and mafic minerals, and they originated under high *P–T* conditions.

Granulite rocks, which are generated under regional metamorphic conditions, are one of the primary divisions of the metamorphic facies classification. A granulite facies can reach temperatures up to 800°C and pressures up to 13 kbar, which is a relatively high state of *P–T***.** The formation of granulite facies rocks was thought to be in a paired metamorphic belt, resulting in an island arc or continental margin overriding the oceanic plate (Ernst, 1971; Uyeda and Miyashiro, 1974), with the heat source derived from sub-crustal magmatism and thought to have formed in situ. These granulites facies rocks, which represent middle to lower crustal rocks, provide insight into geological processes, tectonic evolution, metamorphic history, nature and composition of the lower crust, crust building processes, and magmatic processes responsible for the evolution of the lower crust (Harley, 1989; Brown, 2010). According to Harley (1989, 1992), the radiometric age of the granulites ranges from 3.9-3.0 Ga (lower to middle Archean) to 0.04 Ga. (tertiary). As a result, a thorough examination of the petrology, metamorphic processes, and geochronology of any granulite rock can aid in deciphering the geodynamic history and chemical dynamics during subduction tectonism.

2.3 Previous work done in the Bundelkhand Craton

The Bundelkhand Craton (BuC) is mostly covered by 3.5–2.6 Ga granitoid, but it also has small enclaves of metapelites, gneisses, quartzites, meta-ultrabasic rocks, BIFs, carbonates, and calc-silicates (Mondal et al. 2002; Pati, 2020). Tonalite-Trondhjemite-

Granodiorite Gneisses (TTGs) and Neoarchean potassic granite intruded into TTGs, and supracrustal lithounits are the dominant lithologies of the Bundelkhand craton. The BuC primarily comprises two east-west trending belts: the Central Bundelkhand Greenstone Belt (CBGB), stretching from Mahoba in the east to Babina in the west, via Mauranipur and Kuraicha; and the Southern Bundelkhand Greenstone Belt (SBGB), extending from Madaura to Girar. (Ramakrishnan and Vaidyanathan, 2008; Saha et al., 2011; Singh and Slabunov, 2015; Singh et al., 2021). TTGs exposed as patches in the Mauranipur area are generally associated with high-grade rocks. Many geochemical analyses of these rocks have been conducted, drawing attention of geologists to BuC. Amphibolites, BIF, basalts (pillow and komatiitic), metavolcanics, mafic-ultramafics, white schists, calc-silicate rocks, quartzites, and metapelite (garnet-cordierite-sillimanite-biotite gneiss) are among the other rocks exposed in the BuC (Singh and Dwivedi, 2009, 2015; Singh et al., 2018, 2019; Nasipuri et al., 2019). These high-grade terrains are Archean or younger in age, and they exhibit distinct geochemical behaviour when compared to lower-grade rocks.Many researchers have studied the geochemical, deformational, and geochronological aspects of the BuC's TTGs, BIFs, and amphibolites (Chauhan et al., 2018; Raza et al., 2021; Singh et al., 2021), but the metamorphic evolution of the BuC's pelitic and mafic rock assemblages remains unknown. Several studies have revealed greenschist to eclogite facies metamorphisms with the textural association and mineralogical aspects from the BuC. Medium to high-grade metapelites and metabasalts from the Mauranipur area have clockwise *P–T* paths, with *P–T* values of 6.2 kbar/730°C and 5.44 kbar/720°C, respectively, indicating collisional tectonics (Singh and Dwivedi, 2009, 2015). However, high-grade metamorphism of 6.48–8.52 kbar/630–725°C has been recorded in TTGs of the Sukwan region of Babina (Nasipuri et al., 2019). Instead, ultrahigh-pressure eclogite facies metamorphism in corundum-bearing white schist from the Babina region has been preserved with 20–18 kbar/630°C *P–T* conditions (Saha et al., 2011).

The lowest pressure recorded in garnet-bearing BIF from the Mauranipur is 0.1–0.2 GPa at 500°C, indicating lower amphibolite facies (Raza et al., 2021). High-grade metamorphism has also been identified in the Mauranipur area's amphibolites and garnet-biotite gneisses, with *P–T* estimates of 7.3kbar/578°C and 6.75kbar/780°C, respectively (Pathak et al., 2022a, b).

TTGs ranging from 3.6 to 2.7 Ga are typically found as enclaves inside archean alkali granitoid gneisses (Nasipuri et al., 2019; Singh et al., 2018, 2019). The Bundelkhand gneiss, which is part of the Archean greenstone belt, dates from 3.5 to 3.2 Ga (Kaur et al., 2014; Saha et al., 2016). Banded iron formations (BIFs) are supracrustal rock types that consist of alternating iron-rich and silica-rich layers (Pati, 2020). Amphibolites are typically linked with greenstone components and found as enclaves among granitoids and gneisses along the E-W-trending Bundelkhand Tectonic Zone (BTZ) (Pati et al., 2011). Granitic magmatism occurred in BuC over a 700 million-year period, and the age of distinct granitic variations is estimated to be between 1.9 and 2.58 Ga. (Mondal et al., 2002; Pati et al., 2007; Singh et al., 2019). The granitoids from BuC are classified on the basis of colour (leuco, pink and grey granites), texture (aplite, medium- and coarse-grained granites, porphyritic, rapakivi and orbicular), mineralogy (quartz + feldspar-bearing, biotite granite and hornblende granite), modal types (monzogranite, syeno-granite, granite and granodiorite) and based on major oxide data. The age of pink granite and granodiorite, which intrude the greenstone sequence, has been suggested as ca. 2.500 Ga (Kaur et al., 2016; Joshi et al., 2017).

2.4 Geothermobarometry and Phase equilibria modelling

Estimating pressure-temperature conditions is essential for understanding the granulite formation's metamorphic processes in deeper parts of the Earth's crust. However, metamorphic geology aims to reveal the *P–T* conditions preserved by the rocks and create appropriate *P–T* paths to deduce the tectono-metamorphic events. This is achieved by using geothermobarometers that constitute stable mineral phases. Developing a 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 forms the fundamental and most crucial step to determining P-T-t paths in any area. The maximum pressure and temperature phases are chosen for peak metamorphism. It would be desirable to locate this point using geothermometry and geobarometry models. Models of geothermometry and barometry are advantageous in estimating *P–T* conditions in metamorphic petrology. 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 differences 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 the 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 they act as good geobarometers if the temperature can be derived from some other method (e.g., exchange thermometry). The work on geobarometers began in the 1970s and was successively done by Ghent (1976) using a plagioclase-garnet-Al_2SiO_5-quartz assemblage (Miyashiro, 1973). The *P–T* conditions may also be estimated using the Pav, Tav, and PTav methods of the mineral’s 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

THERMOCALC has overcome the two problems, including inverse modelling to calculate the geothermobarometry using PTav and forward modelling to calculate phase diagrams for different model systems.

With the advancement in science, pseudosection modelling has evolved into a precise and robust method in metamorphic petrology, used to evaluate the *P–T* condition, thereby suggesting the development of metamorphic rocks. (Connolly, 1990, 2005; Holland and Powell, 2011; Powell et al., 1998; Connolly and Petrini, 2002). A pseudosection is also known as a phase equilibria diagram, showing the stable fields of various equilibrium mineral phases for a single-bulk-rock composition. Pseudosection modelling is currently the most potent technique employed to derive *P–T* data from exhumed metamorphic rocks. It is therefore used to interpret mineral paragenesis that can be further represented on the *P–T* diagram. Pseudosections arose from constructing petrogenetic grids, which show all the stable invariant points and univariantequilibria for all phases and bulk compositions in a chemical system (e.g. Hess, 1969; Harte & Hudson, 1979; Spear & Cheney, 1989; Powell & Holland, 1990). Such grids provide information regarding the absolute stability of assemblages. However, they do not provide information regarding the composition and abundance of phases. Pseudosections offer a means by which the system's petrogenetic grid is modified for a specific bulk composition, forming a mineral assemblage map in P–T–X space (Powell et al., 1998). Making 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 programmes such as PERPLE_X, THERMOCALC, THERIACDOMINO, etc., are being used. The internally consistent databases, the crucial part of the software package, are almost similar or even identical in all cases. It constructs a phase diagram using fixed bulkcomposition concerning parameters like pressure, temperature, composition, etc., using internally consistent data sets (e.g., Holland and Powell, 1998). The

P–T pseudosection was constructed using Perple_X 6.9.0 software (Connolly, 2005, 2009) and end-member thermodynamic data from Holland and Powell (2011). They can deliver significant constraints on calculating *P–T* conditions and observing reaction textures. However,it is necessary to investigate whether modelling has been performed in a suitable chemical system because it may be misinterpreted (White et al., 2007). The typical pseudosection shows contour lines, referred to as compositional and modal isopleths. These contour lines are the various stable fields of mineral phases of its bulk-rock composition within the *P–T* condition range. The modal isopleths are lines of a modal abundance of minerals within each assemblage field (e.g., 10% garnet); the compositional isopleths represent a constant value of one compositional variable within a particular phase (e.g., 10% grossularite of garnet).

2.5 Geochemistry

The word geochemistry is created from two words; geo (the Earth) and chemistry (a branch of science that deals with chemical transformation). A petrologist must look for the chemistry of the rock, known as geochemistry, to comprehend and quantify the chemical composition and structural properties of a rock exposed on the Earth's surface. The Earth's crust is primarily composed of igneous rocks, which are primary rocks derived from magmas. The nature of igneous rock suites can be broadly defined by major and trace element chemistry. Silicates are the fundamental unit for most igneous rocks, which are formed from aggregates of one or more minerals, which are naturally occurring inorganic chemical compounds. Geochemistry is the most important tool for distinguishing igneous rock suits, identifying involved magmatic processes, the nature of meltand protolith, and tectonothermal environments based on quantitative measurement and patterns of geochemical variations.

The major elements are petrochemical components such as Si, Al, Fe, Mg, Ca, Na, K, Ti, P, and Mn. These elements show an organized variation trend for volcanic rocks and form the bulk rock chemical composition. Hence, the oxide of these elements plays a vital role in classifying the different rock types. Si, Al, and Ca are crucial to these elements as structural constituents in mafic to ultramafic rocks. Mg and Fe are intermediate elements in mafic rocks because they are present in the end-member of solidsolution and do not occupy a particular site in any mineral. Still, their abundance is stoichiometrically significant (Langmuir and Hanson, 1980). The rest of the five elements, such as Na, K, Ti, P, and Mn, are comparatively low in mafic rocks, and their abundance does not reflect stoichiometric constraints for the mineral phases. For mafic rocks, these elements are considered trace elements (Hanson, 1989). The total alkali versus silica diagram (TAS; Le Maitre et al., 1989) was used to classify volcanic rocks. Major elements have mobile behaviour during metamorphic processes therefore, immobile trace elements have been taken for volcanic rock classification (Zr/TiO_2 vs Nb/Y; Winchester and Floyd 1977).

The term "trace element" is generally assumed to mean those elements available in rocks with a low concentration of up to a few thousand parts per million. Because trace elements are susceptible to crystal fractionation, partial melting processes, and source composition, their availability and comparative ratios are often employed to understand genetic processes. The concentration of trace elements will never change. However, the extent of the melting process is determined by several factors, including the melting process, the remaining solid phases after the melts have been eliminated, any differentiation before final crystallization, and possible interactions with foreign country rocks or melts (Hanson, 1989). The REEs' contents have not changed during the prograde regional metamorphism of metapelites that ranged from greenschist facies to amphibolite facies (Cullers et al., 1974). The oceanic tholeiites and related amphibolites have shown similar REE distribution and suggest the metamorphic process was isochemical (Kay et al., 1970).

The geochemistry of major oxides and trace elements plays an essential role in magma's fractional crystallization and evolution. The relative and absolute amounts of calculated trace elements (especially Zr, Y, Nb, Ga, and Sc) are stable during weathering, metasomatism, and metamorphic processes. The characteristics of immobile elements are generally related to some major elements; the Zr/Ti and Nb/Y ratios are associated with SiO_2 and alkaline elements, respectively (Floyd and Winchester, 1975; Winchester and Floyd, 1977). Immobile elements, such as HFSEs (Zr, Nb, Hf, Ta, and Ti), are suitable for classifying metamorphosed parental rocks (Pearce and Cann, 1973; Pearce and Parkinson, 1993). The parental chemical composition of rock can be assessed even from highly metamorphosed volcanic rocks and altered ash-fall deposits. The LILEs (K, Rb, Sr, and Ba) and the LREEs (especially Ba) are mobile and easily moved by melts. Most REEs reflect variation in the geochemical properties of the major elements, providing specific evidence of magma generation and evolution (Motoki et al., 2015). Geochemical plots of immobile elements are used to estimate the tectonic settings of various volcanic rocks (Pearce et al. 1995). The availability and concentrations of HSFEs are immobile during weathering and metasomatism, and they are generally enriched in high density and high resistance to alteration types of accessory minerals, such as monazite, zircon, and apatite. For rock classification and tectonic differentiation plots of altered igneous rocks, immobile elements can be helpful. The crustal material will increase the K_2O and Na_2O elemental composition in the melt after crustal contamination. 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 in investigating the geodynamic setting in which they were deposited (Mishra and Sen, 2012; Adeigbe and Jimoh, 2013; Madukwe and Bassey, 2015; Madukwe et al., 2016; Grizelj et al., 2017).

2.6 Why to need this study

After a quick look at the existing literature survey, one will decipher that there is no active research on the pelitic granulites within the BuC. Based on the previous literature study described above, it is clear that within the BuC, many high-grade metamorphic rocks have been discovered in the Mauranipur and Babina regions. Afterwards, investigation of the study area revealed that the Mauranipur area contains granulite facies rocks, like; pelitic granulites, high-grade gneisses, and amphibolites. Though various rock types have been identified and mapped in the Mauranipur and Babina regions, there is no systematic study on developingdiverse metamorphic mineral assemblages based on micro-textural studies. A detailed petrographic and microtextural investigation is essential to unravel specific mineral reactions and document any prograde or retrograde metamorphism in high-grade terrane. Such systematic studies have not been conducted in the Mauranipur and Babina regions.

There is only a reconnaissance type of *P–T* estimate available for the Mauranipur and Babina regions by a few early workers. Many thermodynamic models have been formulated to estimate the *P–T* conditions and software to calculate the pseudosection for investigating the stable phase with appropriate *P–T* conditions. For any meaningful interpretation of *P–T* data, specific mineralreactions have to be used based on the petrographic study. A combination of specific mineral reactions and mineral *P–T* estimates will aid in unravelling the exhumation history of high-grade metamorphic rocks, specifically whether they have undergone Isobaric Cooling (IBC) and Isothermal Decompression (ITD) P-T-t path, which has a significant bearing on the tectonic process in the lower continental crust.

If we review the literature, we find that most of the age-dating work has been done on TTGs, BIFs, and felsic granitoids in the BC, but no age-dating has been done on pelitic granulites and amphibolites. Based on geochronological data, the formation of the CBGB started with ultramafic-mafic magmatism around 2.81–2.78 Ga and ended with felsic volcanism around 2.54 Ga (Singh et al., 2019). The felsic volcanic rocks (2.5 Ga) have been reported in the Babina, Maheshpura, Umri, Kararkhera, Nayakhera, Baragaon, and Mahoba regions, whereas SHRIMP data from the Babina and Mauranipur regions indicate ages of 2.81 Ga and 2.54 Ga, respectively (Singh and Slabunov, 2015, 2018; Joshi et al. 2017). These felsic volcanic rocks suggest that the Babina greenstone belt evolved from the subduction-related tectonic environment (Singh & Slabunov, 2015a,b). Felsic magmatic activity in the Babina greenstone belt during 2.54 Ga marks the second stage. Because both magmatic activities result from subduction, the Central Bundelkhand Craton formed in a subduction–accretion setting between 2.8 and 2.54 Ga. However, no research has been conducted on the metamorphism in the BuC. In this study, the first time the Lu-Hf dating method is applied, it emphasizes the age of emplacement and various metamorphic events.

Another major problem that needs to be investigated, is the geochemical analysis of amphibolites, pelitic granulites, and high-grade gneisses. Geochemical characterization of metamorphic rocks is an essential feature of knowing the nature of protolith, the character of magma or tectonic environment for magma generation and petrogenesis of these studied rocks.

A critical evaluation of the above problems needs a careful study of the metamorphic process and evolution of amphibolites, pelitic granulites, and high-grade gneisses. The present research aims to study the lithological and metamorphic mineral assemblages and the *P-T-t* paths of all three metamorphic rocks to unravel the relative metamorphic processes.