Chapter-1

INTRODUCTION

1.1 Introduction:

The true nature of Archaean tectonics, crustal growth and metallogeny remains a matter of great conjecture despite intense research efforts by geoscientists for the last few decades (Taylor and McLennan, 1985; Maruyama *et al*., 1996, De Wit, 1998, Hamilton, 1998, Rudnick and Gao, 2003; Rollinson, 2008; Stampfli and Hochard, 2009; Isozaki *et al*., 2010). The main reason behind this hindrance lies in the fact that most of the preserved tracts of Archaean crust present globally are small, highly fragmented, intensely deformed and metamorphosed, thus posing unsurmountable difficulties for any straight forward interpretation of early crust forming processes from them. In spite of these difficulties, the fragmentary and complex Archaean crustal records continue to serve as the only available proxies for unveiling the early Earth dynamics and crust forming processes (Campbell and Allen, 2008; Naeraa *et al*., 2012). As a result, these are increasingly being subjected to intense scientific scrutiny by geoscientists for extracting key information leading to disentanglement of the early Earth processes. Some of the major questions around which the debate mainly centres involve the nature of early crust formation, crustal growth through time, genesis of the metalliferous deposits and dynamics of early Earth processes.

The ancient models for the continental growth were based predominantly on the geographic distribution of isotopic ages in the continents (Hurley and Rand, 1969). Isotopic age data suggest that continental growth was not continuous throughout the geological period. Rather, it occurred in an episodic manner (Taylor and McLennan, 1985; Condie, 2005) with major crust forming pulses marked at *ca*. 2.7 Ga, *ca*. 1.9 Ga and *ca*. 1.2 Ga. Some of these early models demonstrates that continents grew slowly in the Archean time and rapidly grows after *ca.* 2 Ga. On the contrary, there are alternative models that suggest the rapid growth early in the Earth's history, followed by extensive recycling of continental crust into the mantle (Fyfe 1978; Reymer and Schubert, 1984). These models proposed that the volume of continental crust in the Proterozoic actually exceeded than that present today on the Earth's surface. Most of the models, however, indicate that the continents developed by repeated collision, lateral accretion and intraplate magmatism over the last *ca*. 3.0 Ga period of the Earth's history (Polat *et al*., 1998; Kerrich and Polat, 2006; Santosh *et al*., 2015). Utmost models for the development of new continental crust involve the formation of basalt and its subsequent differentiation by fractional crystallization and/or partial melting to more silica rich felsic compositions (Rudnick 1995; Kemp and Hawkesworth, 2003; Zandt *et al*., 2004; Plank, 2005; Hawkesworth *et. al*., 2010). Identification of such crustal segments with distinctive geological history and understanding the exact nature of their amalgamation are fundamental to the understanding of the tectonic processes involved in the growth and construction of protocontinents during the Archaean time.

The exact nature of tectonic processes during the Archean also continues to be a matter of great debate (Maruyama *et al*., 1996; Stampfli and Hochard, 2009; Isozaki *et al*., 2010). It has been suggested that horizontal plate motions driven by subduction-accretion process started very early in the Archean era resulting formation of thin juvenile felsic crust which were frequently recycled back to the mantle. On the other hand, alternative models propose that stagnant-lid convection dominant at early Archean later changed into horizontal plate motions during the late Archean era (Debaille *et al*., 2013). The exact timing of onset of modern-style plate tectonics remains to be a topic marred with controversy. Stern (2005) demonstrated that the modern-style plate tectonics started at around 1.0 Ga. In an alternative way, Brown (2006) and Cawood (2006) suggested the timing of the modern style plate tectonics to be Neoarchean (3.1-2.8 Ga) depending on the presence of accretionary orogens, paired metamorphic belt and subduction-related ore deposits. Now a days thermal modeling also suggests that the modern-style plate tectonics vis-à-vis crustal recycling was started during the Neoarchean-Paleoproterozoic time (Chowdhury *et al*., 2017). Hopkins (2010) stated that the horizontal plate tectonics was well in place during the Hadean era (> 4.0 Ga), with the presence of continental crust and hydrosphere on the basis of detrital zircon geochemistry. Hastie *et al*. (2016) recently suggested that the first and foremost continent could have been generated by subduction and partial melting of Eoarchean oceanic crust (*ca*. 4.0 Ga), which also points towards an early onset of plate tectonics on Earth.

The Archean cratons along with the later developed Proterozoic basins all over the world have also gained much significance in the light of occurrence of high-grade uranium deposits within them (Sinha *et al*., 1995; Verma *et al*., 2008). Uranium mineralization is believed to be controlled by older basement structures that were reactivated and acted as channel ways for fluid circulation (Tourigny, 2002; Alexandre *et al*., 2003; Polito *et al*., 2004). Oxidizing, saline basinal fluids carrying U^{6+} interacted with reducing basement rock types (basement-hosted,) or reducing fluids from the basement (sediment-hosted) resulting precipitation of U^{4+} at or near the unconformity surfaces (Hoeve and Quirt, 1984; Kotzer and Kyser, 1995; Cuney *et al*., 2005). Uranium deposits associated with Paleoproterozoic successor basins were investigated using structural, petrographic, geochronological relationships to understand the character and timing of ore-forming fluids and the structural control on uranium mineralization.

The Indian crustal block comprises of several Archean crustal nuclei (Fig. 1.1) most of which have been under thorough scientific scrutiny for decades not only for evaluating the early Earth processes but also for a better understanding of the genesis of rich metalliferous deposits that these contain. Of these Archean nuclei, the well-studied Dharwar craton forms a major portion of the southern Indian block and represents an advanced stage of cratonization characterized by complex tectonic and structural controls (Naqvi *et al*., 1981; Swami Nath and Ramakrishnan 1981; Divakar Rao and Rama Rao 1982; Naqvi and Rogers 1983, 1987; Radhakrishna 1983, 1984; Pichamuthu and Srinivasan 1984; Radhakrishna and Naqvi 1986; Rogers 1986; Chadwick et al. 1988; Chardon *et al*. 1988; Naha *et al*. 1993; Dey *et al*., 2012, 2014, 2017; Jayananda *et al*., 2000, 2006, 2008, 2014). The Neoarchean time represents a key period of crustal growth with major tectonic assembly and stabilization in the Dharwar Craton (Condie, 2000; Kroner *et al*., 2005). The basement gneisses and granites of the Dharwar Craton underwent a late Archaean transpression (Chadwick *et al*., 2000) followed by extension and opening up of the Proterozoic Cuddapah basin in phases. The Cuddapah Basin formed along the eastern periphery of the Dharwar Craton exposes highly favourable lithostructural setup for uranium mineralization, especially in the northern part. This is evident from medium-grade and small- to medium-tonnage uranium deposits established at Lambapur, Peddagattu and Chitrial in the Srisailam Sub-basin and Koppunuru in the Palnad Sub-basin (Shrivastava *et al*., 1992; Dwivedy, 1995; Sinha *et al*., 1995, 1996; Jeyagopal *et al*., 1996, 2011; Banerjee, 2005; Nageswara Rao *et al*., 2005; Verma *et al*., 2008, 2009, 2012; Umamaheswar *et al*., 2009; Gupta *et al*., 2010, 2012) in recent times. These deposits are spatially confined at the juncture between the older granitoid basement and sedimentary cover rocks of Mesoproterozoic Srisailam sub-basin. Amongst these deposits, the Chitrial outlier forms the focus of the present study. It is located along the NW fringe of the Cuddapah basin and is made up of the rocks of the Mesoproterozoic Srisailam Formation unconformably overlying the 2.2-2.4 Ga Palaeoproterozoic biotite rich basement granitoids of the East Dharwar Craton (Pandey *et al*., 1988; Ramam and Murty 1997). The present research mainly reflects results of a study on the mode of occurrence, nature and distribution of the uraniferous mineralized zones with respect to the faults and fracture zones developed in the basement rocks of the Chitrial outlier. The ultimate aim is to understand the control and timing of mineralization from the study area with the help of a multipronged approach that involves structural analysis, geochemistry and geochronological studies.

1.2 Statement of the present work:

The present research work intends to carry out stratigraphic, petrological, geochemical and geochronological studies of the rocks of the Chitrial outlier situated in the north-eastern fringe of Eastern Dharwar Craton. As discussed in the preceding paragraphs, among a few well established uranium provinces identified in India, the uranium prospects in the Cuddapah basin, especially those occurring in its north-western part, are very unique and little studied. Recent exploration programme by Atomic Minerals Directorate (AMD) has led to the discovery of a number of potential radioactive mineralized zones in the northwestern part of the Cuddapah basin such as around the Chitrial area. Barring the preliminary investigation by AMD geologists reporting the potential for radioactive mineralization in the Chitrial area, the nature and controls on such mineralization is not yet fully known. The stratigraphic status, timing of uranium mineralization as well as its relationship with surrounding country rock is also largely lacking till date.

While the major part of the Eastern Dharwar Craton (EDC) and the Cuddapah Basin (CB) has been studied in detail by several workers for more than a century, a few areas like the Chitrial outlier and its adjoining parts in the EDC-CB boundary did not attract much attention of the geoscientists till date. Recent discovery of uranium together with the significantly high concentration of sulphide ore mineralization in the Chitrial outlier brought the area in the lime light. Under the present investigation, systematic geological and structural analyses have been carried out. As the geological information remained very scanty so far, the present work on stratigraphy, geochemistry, mineralogy and geochronology of the outlier helped to develop a comprehensive picture of the geology and metallogeny of this area. An attempt has been made to identify the discrete geological events to frame a chronostratigraphic succession of the rocks of the outlier with the assumption that it would ultimately provide a basis for studying similar unclassified uraniferous zones in future.

1.3 Objectives:

1. Identifying the extent of development of the uraniferous zones and their relationships with the overlying and underlying lithounits in the study area.

2 Detailed petrographic studies for classification, characterization and identification of potential uraniferous zones and assessing their post-formational modifications, if any.

3 Geochemical analyses for characterizing tectonic set up and basement anomalies.

4 Geochronological studies for ascertaining chronostratigraphic evolutionary history of the terrain with special emphasis on timing of uranium mineralization and crustal growth.

1.4 Methodology:

The methodology followed can be broadly divided into two categories:

1. Field investigations and 2. Laboratory investigations

1. Under field investigations, following course of study was planned:

1.1 Detail study of lithostratigraphy and association of rock types on the outcrop scale of the study area.

1.2 Delineation of the radioactive mineralization zones by way of surface radiometric surveys with the help of the hand-held gamma-ray detecting scintillometer counter.

1.3 Collected samples of granite and sandstone systematically within the study area in order to carry out petrological analysis for understanding the depositional settings and provenance respectively.

2. Among the laboratory investigations the following broad methodologies were adopted:

2.1 Mineralogical, petrographic, geochemical and geochronological studies have been done using petrological (Optical) microscope, Scanning Electron Microscope (SEM), Electron Probe Micro Analyzer (EPMA), X- Ray fluorescence (XRF) and Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS) techniques for understanding the mineralogical and compositional characteristics as well as the mode of occurrence of the radioactive and other ore minerals.

2.2 Preparation of lineament map of the study area with the help of LISS-III satellite imagery data in Arc-GIS platform.

1.5 Organization of the Thesis

The entire thesis has been divided into eight chapters. The first Chapter includes a brief introduction, statement and objectives of the present study and brief outline of the procedures followed and significance of this thesis.

Chapter 2 deals with the geology of the Dharwar craton, its stratigraphic overview, geochemistry and geodynamic modelling of the Eastern Dharwar Craton (EDC) followed by a short overview of the Cuddapah Basin (CB) and Srisailam sub-basin.

A detailed description of the study area has been attempted at the first part of the following Chapter 3. The latter half of the Chapter 2 deals with description of the lithology and rock types of Chitrial Outlier and the economic importance of the area followed by a short overview of stratigraphic description.

The first part of Chapter 4 includes a description of the structural elements. It portrays a lineament mapping of the study area through GIS technique. The latter half of this chapter includes description of structural synthesis of the study area.

The 5th Chapter has been devoted to petrography and geochemical analyses from the rocks of the overlying and underlying sequence which includes details of the methods followed, results of the analyses and conclusions made thereof.

The nature and mineralogical association of ore mineralization has been discussed in the 6th chapter. This chapter includes the petrography, textural evolution, and mineral chemistry of the uranium bearing rocks.

The 7th chapter includes geochronological study of the zircon grains from the basement rocks as well as cover sediments of the Chitrial area. It includes description of the basic method and analysis of the results obtained from such studies. Chronologies of the mineralizing events have been attempted at the end.

The 8th and the final chapter deals with assimilation of the results obtained so far and discussions made from the earlier chapters. It starts with the nature of the basement granites and is followed by comments on the timing of magmatism, cover sediments deposition and its provenance, evaluation of the different tectonic pulses suffered by the study area and growth of the study area within a protracted time frame.

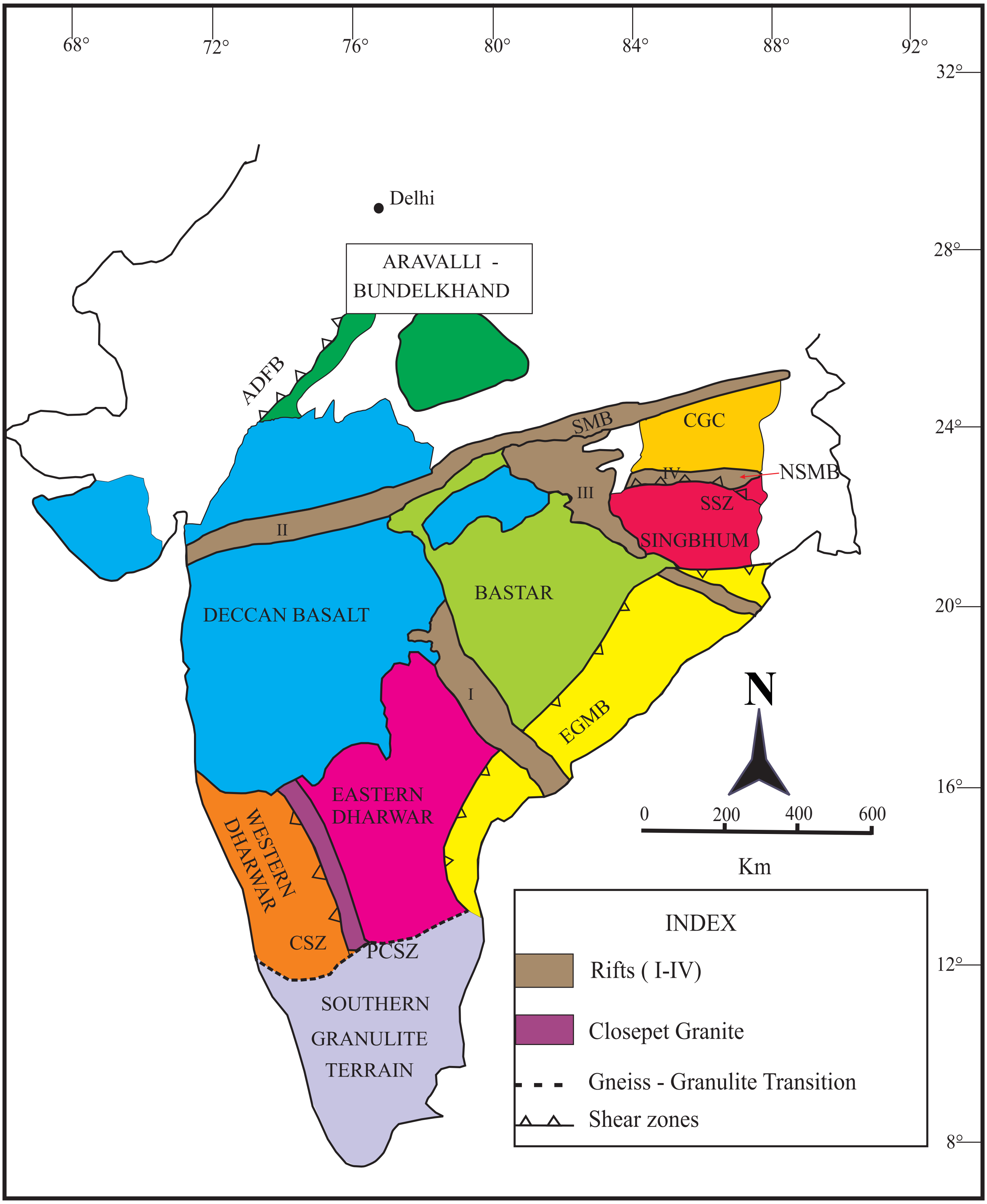

Figure. 1.1: Simplified geological map of India (Modified after Rogers, 1986, and Mishra 2015) showing Archean Cratons, rift valleys and Proterozoic Mobile Belts. Rift Valleys are: I- Godavari; II- Narmada-Son; III- Mahanadi; IV- Damodar. ADFB - Aravalli Delhi Fold Belt; SMB - Satpura Mobile Belt; CGC - Chotanagpur Gneissic Complex; NSMB - North Singbhum Mobile Belt; SSZ - Singbhum Shear Zone; EGMB - Eastern Ghat Mobile Belt; CSZ - Chitradurga Shear Zone; PCSZ - Palghat Cauvery Shear Zone

CHAPTER 2

2.1 GEOLOGY OF THE DHARWAR CRATON

2.2.1 OVERVIEW OF THE WESTERN DHARWAR CRATON

2.2.2 OVERVIEW OF THE EASTERN DHARWAR CRATON

2.2 CUDDAPAH BASIN

2.2.1 SRISAILAM SUB – BASIN