CHAPTER 1

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Introduction

Continental crust covers nearly one-third of the total Earth's surface area and makes up 70% of the total volume of the Earth's crust. Its formation during the early phases of Earth's history greatly modified the coupling of lithosphere-asthenosphere, biosphere and atmosphere (Lowe and Tice, 2004). Its composition is intermediate in contrast to the upper mantle which is ultramafic in nature. Most models for the generation of new continental crust involve the generation of basalt and subsequent differentiation by fractional crystallization and/or re-melting, to higher silica compositions (Rudnick 1995; Kemp and Hawkesworth, 2003; Zandt et al., 2004; Plank, 2005; Hawkesworth et. al., 2010). The exact mechanism is, however, debatable and several models have been proposed. Though there are a number of evidences of modern style plate tectonics in the Phanerozoic era (Maruyama et al., 1996; Stampfli and Hochard, 2009; Isozaki et al., 2010), the exact nature of tectonics during the Precambrian times is a matter of debate. It was suggested that horizontal plate tectonics driven by subduction-accretion process resulted in the formation of thin juvenile crust in the Archean era. On the other hand, an alternative model proposed that stagnant-lid convection (vertical tectonics) at an early stage changed into horizontal tectonics during the late Archean era (Debaille et al., 2013).

The timing of onset of modern-style horizontal plate tectonics is another topic of controversy. There is hardly any evidence of ultra-high pressure (UHP) metamorphism and ophiolite sequence, considered to be prima facie evidence of modern style tectonics involving subduction, older than ca. 1 Ga. Stern (2005) suggested that onset of modern-style plate tectonics must be around 1.0 Ga. On the other hand, Cawood (2006) and Brown (2006) suggested the timing to be Neoarchean (3.1-2.8 Ga) on the basis of presence of paired metamorphic belt, accretionary orogens, subduction-related ore deposits. Recent thermal modelling also supports that the modern-style plate tectonics vis-à-vis crustal recycling was initiated during the Neoarchean-Paleoproterozoic time (Chowdhury et al., 2017). Hopkins (2010) suggested that horizontal component of plate tectonics was well in place during the Hadean era (> 4.0 Ga), along with the presence of hydrosphere and continental crust on the basis of detrital zircon geochemistry. Hastie et al. (2016) recently demonstrated that the first 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.

Though post-Archean continental arcs are produced at subduction zone, their exact production mechanism is not well-understood. Many workers consider oceanic arcs and plateaus as the fundamental building blocks of continental crust in the Archean time which eventually accreted during the growth of continents (Condie and Kröner, 2013). However, accretion of these mafic blocks/terranes to form continent, which is essentially felsic in nature is enigmatic. Several processes can attribute to the growth of continents: (i) mafic underplating (ii) accretion of oceanic plateaus (iii) accretion of oceanic arc. The oldest known continental crusts are compositionally tonalite-trondhjemite-gneiss (TTG) with fragments of komatiite and basalt. It may be possible that the earliest TTG crust was developed from melting of the base of the primitive basaltic crust of oceanic plateaus in a stagnant-lid regime. This TTG crust was essentially submarine in nature, underlain by a pyroxenite-amphibolite-garnet root. Rise of a mantle plume head resulted in komatiite and basalt and rise of this mantle plume resulted in partial melting of the root of TTG crust. Partial melting of the root results in generation of felsic magma that ultimately produced the granitoid plutons and felsic volcanics. Some of the basalts and komatiites are preserved today in greenstone belts (Campbell and Davies, 2017).

There are several lines of arguments regarding the growth pattern of continental crust. The earliest models for continental growth were based chiefly on the geographic distribution of isotopic ages in the continents (Hurley and Rand, 1969). These models suggest that continents grew slowly in the Archean and rapidly after 2 Ga. On the contrary, there are models that suggest rapid growth early in Earth's history, followed by extensive recycling of continental sediment into the mantle (Reymer and Schubert, 1984). In the model proposed by Fyfe (1978), the volume of continental crust in the Proterozoic actually exceeded that of the present today. The most accepted model suggests that continental growth was not continuous, rather an episodic phenomenon (Taylor and McLennan, 1985; Condie, 2005). Isotopic data suggests continental crust formed in episodic pulses at ca. 2.7 Ga, ca. 1.9 Ga and ca. 1.2 Ga (Fig. 1.1). Most of the workers agree that continents grew by repeated collision, accretion and intraplate magmatism over the last 3.0 Ga of Earth's history (Kerrich and Polat, 2006; Polat et al., 1998; Santosh et al., 2015). Though a craton can be considered as the nucleus of a continent, the entire evolutionary history of the continent is hardly preserved in such cratonic nuclei due to repeated phases of metamorphism and deformation. Factors, like post-orogenic thermal activity, ductile and brittle deformation further complicate the growth history of the continents. The most suitable places to study the growth history of a continent are the craton-margin orogenic belts. Growth of continent in an orogenic belt involves several phases of metamorphism, deformation and magmatic intrusions. Convincing evidence of such processes came from Phanerozoic as well as Proterozoic orogenic belts (Rivers, 2009; Dong et al., 2012). Many workers are in the opinion that continents formed and grew through tectonic processes since the Neoarchean time (Cawood et al., 2006; Smithies et al. 2007; Condie and Kröner 2008; Polat et al., 2011). But Archean orogenic belts, especially those exposing deep crustal sections, have complex geological histories due to multiple reasons. Problems emerge due to the paucity of exposed deep crustal orogenic sections, hightemperature metamorphism that obliterates crucial geological relationships and phases of deformation that these orogenic belts suffered. It is also important to note that only 7% of the preserved continental crust is older than 2.5 Ga. During the Precambrian era, two types of orogeny were functional: (i) collisional orogen, associated with little or no crustal growth and (ii) accretional orogen, which involves amalgamation of several juvenile continental crusts to form cratonic blocks (Windley, 1992; Cawood et al., 2009). These accretionary orogens present at the craton margin are the suitable regions for understanding the continental growth history. There are several Neoarchean-Paleoproterozoic craton-margin orogenic belts throughout the world that provide significant inputs regarding the exact nature of growth of continental crust (Condie, 2005). High-grade gneisses and granulites from these belts provide information regarding the behaviour of middle and lower crust in response to the tectonic processes. Albany-Fraser orogen at the southern margin of Yilgarn Craton, Trans-Hudson orogen of the Canadian Shield, Northern Limpopo Belt of Zimbabwe craton, and Svecofenian orogen of the Baltic shield are some examples of such craton-margin orogenic belts. The Limpopo belt, in particular, has been considered as a prime example of Precambrian accretionary orogen, where complex assembly of terranes took place along shear zones through processes involving compression, extension, and transpression (Barton et. al., 2006). These are blocks with different geological histories evident from isotopic signatures and P-T-t path history. The rocks of this belt were subjected to granulite or higher amphibolite facies metamorphism. Another example of continental growth through terrane accretion is the Western Superior craton, where the craton was created by a sequence of five orogenic events that assembled continental and oceanic terranes into a coherent unit, part of the supercraton Sclavia (Bleeker, 2003), during the Mesoarchean and Neoarchean eras (Percival et al. 2006).

Supercontinents are unique features of the Earth which bear testimony to the onset of plate tectonics (Murphy and Nance, 1989; Unrug, 1996; Rogers and Santosh, 2002, 2004).

The concept of the supercontinent cycle has revolutionized the idea of crustal evolution involving lithosphere, asthenosphere, biosphere, hydrosphere and atmosphere (Santosh et al., 2009). From the studied accretionary orogenic belts around the world, it is apparent that orogenic belts stitched smaller blocks to cratons, cratons to continents and continents to supercontinents (Santosh et al., 2009) and provide important clues about the configurations of widely dispersed supercontinents that formed over geological time.

Peninsular India is composed of several cratonic fragments and nuclei of Archean age (Fig. 1.2) that attained tectonic stability by ca. 2.5 Ga (Saha et. al., 2016 and references therein). All the cratons, namely the Dharwar, Singhbhum, Bastar, Bundelkhand and Aravalli occupy a large part of the Indian shield and are surrounded by several craton-margin orogenic belts. Most of these belts evolved during the Proterozoic era (Saha et al., 2016), though few Archean-age craton-margin mobile belts have been identified from Indian shield (Santosh et al., 2015; Bose et al., 2016a). All these major orogenic belts, namely the Delhi-Aravalli fold belt, Eastern Ghats Belt, Central Indian Tectonic Zone, North Singhbhum Mobile Belt, Nallamalai Fold Belt etc. have recorded histories of multiple episodes of deformation, magmatism and metamorphism. All these mobile belts are present surrounding the above mentioned cratonic nuclei and were formed either by accretion or collisional process. Based on geochronological data, these orogenic belts have been proved to be black boxes of ancient supercontinents. The Aravalli-Delhi Mobile Belt, the Central Indian Tectonic Zone and the Eastern Ghats Belt thus bear evidences of supercontinents Columbia and Rodinia (Bhowmik et al., 2012; 2014; Dasgupta et al., 2017). Evidence of the earliest conceived supercontinent “Ur” (Rogers and Santosh, 2002) is, however, very cryptic in Peninsular India. Traces of metamorphic and magmatic events during the late Archean time have been recorded from the Dharwar and Singhbhum cratons (Saha et al., 2016), but a complete record of tectonic buildup is still missing. These orogenic belts expose the deep crustal section consisting of complexly deformed Archean to Neoproterozoic high grade metamorphic and magmatic assemblages. It is also important that the crustal blocks within an orogenic belt are separated by regional-scale shear zones. Thus, the crustal blocks of the Southern Granulite Terrain were accreted by many crustal-scale shear zones (Chetty et al., 2006 and references therein). Crustal growth during various orogenic cycles has been recognized in this region, with one model proposing that the dominant event was at around ca. 2500 Ma (Rajesh, 2012). Presence of Neoarchean granulite facies rocks from the region suggests continental growth through magmatic underplating in a continental arc environment (Bohlen, 1987; Peucat et al., 1989; Rajesh and Santosh, 2004). Nilgiri Block in southern India exposes exhumed Neoarchean lower crust and provides one of the best examples of continental growth through vertical stacking and lateral accretion in a subduction environment during the Neoarchean. Volcanism and plutonism associated to granite-greenstone belts (Hutti, Kolar, Kadiri belt) at the margin of Western Dharwar Craton is another example where continental growth corresponding to Eastern Dharwar Craton occurred through crustal accretionary process during the Archean era (Jayananda et. al., 2000, 2013). Here a two-stage accretionary process led to the growth of a 2.7–2.6 Ga juvenile province of mafic volcanics and felsic plutons along the eastern margin of the Western Dharwar craton and induced reworking of that margin formed the Eastern Dharwar Craton. This is followed by another accretion (2.58-2.52 Ga) where emplacement of TTG and calc-alkaline plutons and felsic volcanics took place throughout the Eastern Dharwar craton (Dey, 2013; Dey et al., 2014; Mukherjee et al., 2017).

Until now, history of the crustal growth from the southern part of the eastern Indian shield is poorly recorded and a systematic study of the deformation, magmatism and metamorphism in combination with geochronological and geochemical histories is the need of the hour. The present study will attempt to bridge this gap in knowledge. The studied crustal block, which is known as the Rengali Province (Crowe et al., 2001) is a longitudinal belt, squeezed between the northerly lying Singhbhum craton and southerly lying Eastern Ghats Belt. Geochronological data, although sparse, indicate that a vestige of the Singhbhum craton could be traced in the Rengali Province (Misra et al., 2000, Crowe et al., 2001; Mahapatro et al., 2012).

The main objectives of the present study are:

1. To unravel the tectono-metamorphic history of the rocks of the Rengali Province from the Riamal-Rengali-Khamar sector and to explain the lithological and structural heterogeneity of the province.
2. To build a geochronological evolutionary history of the Rengali Province and ascertain specific events of orogenesis and crustal growth. This will also help to evaluate its possible genetic linkage with the Eastern Ghats Belt or the Singhbhum craton.
3. To propose a possible tectonic model for the evolution of the Rengali Province.
4. On a larger perspective, the role of the Rengali Province during the Precambrian supercontinent cycle(s) would also be attempted.

To fulfil these objectives, a small segment of the central part of the Rengali Province has been selected for detailed geological investigation in this study. The Riamal-Rengali-Khamar sector surrounding the Rengali reservoir has been chosen for this purpose as it provides a complete transect through the terrane depicting the lithological and structural heterogeneity as well as its boundary relations with the adjoining Singhbhum craton and the Eastern Ghats Belt.

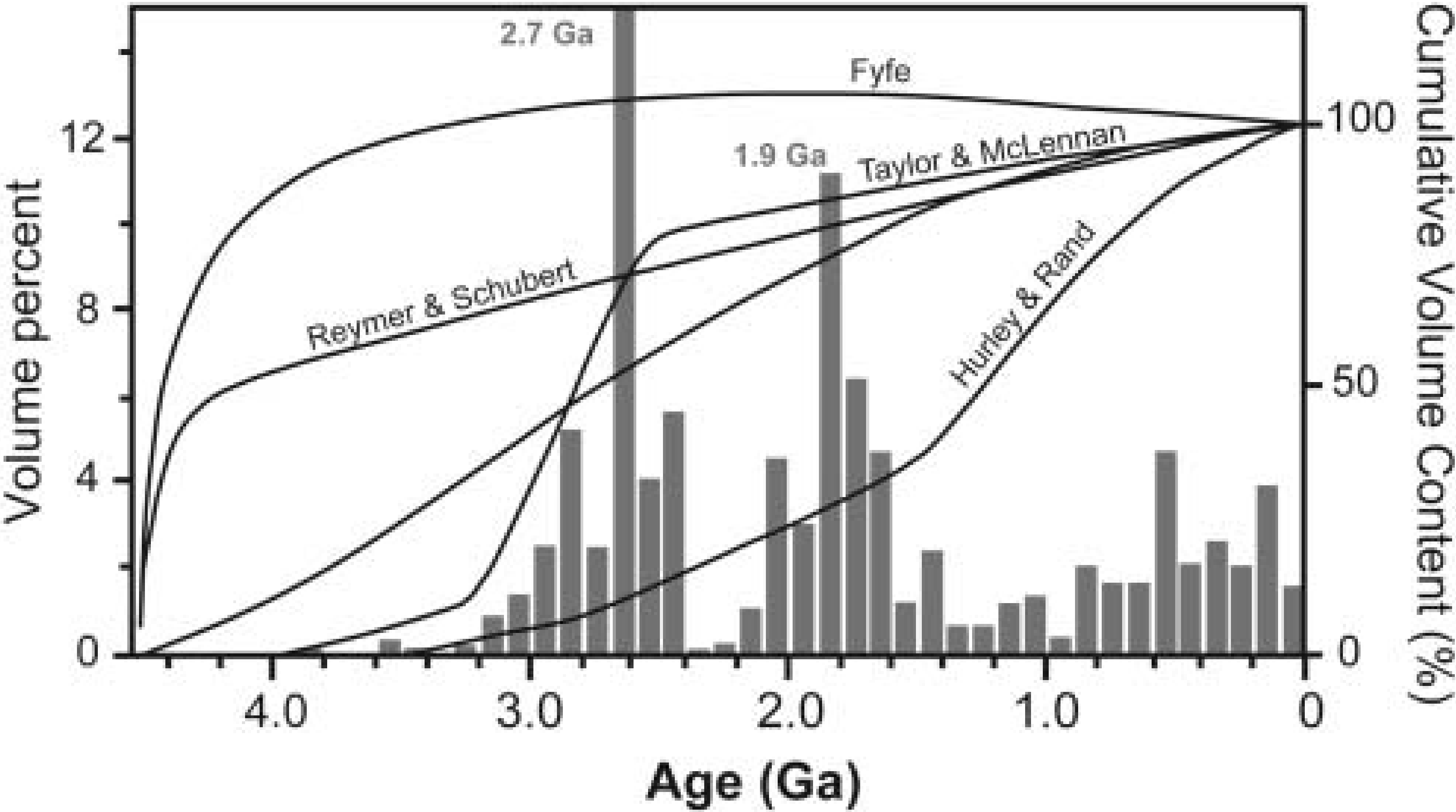

Fig. 1.1: Different models proposed by workers for continental growth through time. Also a histogram of the volume distribution of juvenile continental crust based on a compilation of U–Pb zircon ages integrated with Nd isotope ratios and lithological association. (Hawkesworth et. al., 2010)