Chapter 1

Introduction

1.1. Introduction

Precambrian sedimentary deposits are believed to record the history of development of Earth's early crustal composition, eustatic controls, nature of tectonics and early atmosphere (Taylor and McLennan 1985). Of particular interest is the nature of sediment depositional systems and combined effects of eustasy and tectonics on the development of basin-fills. Eo-Paleoarchean sedimentary records are mostly components of greenstone belts preserved in the granite-greenstone cores of early crust spread over different continents (Fig. 1.1). The greenstone belts dominantly comprise of deep-marine graywacke-mudstone-volcaniclastics and BIF interbedded with metavolcanics. Such volcano-sedimentary stratigraphy dominated the rock record till the Mesoarchean. In contrast the shallow-marine/continental arenaceous sedimentary systems started appearing since later part of Mesoarchean, e.g., the Moodies Group and the Witwatersrand Supergroup in the Kaapvaal craton, South Africa, Bababudan Group in the Dharwar craton, India. These successions record the emergence of continental crust in significant proportion. Oldest such record comes from the ~3.2 Ga Moodies Group (Heubeck and Lowe 1994).

Peninsular India is constituted by five major Archean cratonic nuclei, namely, Dharwar craton, Bastar craton, Singhbhum craton, Bundelkhand craton and the Aravalli craton. (Fig. 1.2) (Ramakrishnan and Vaidyanadhan 2008). In the eastern part of peninsular India the cratonic block of the Singhbhum-Odisha region is mainly

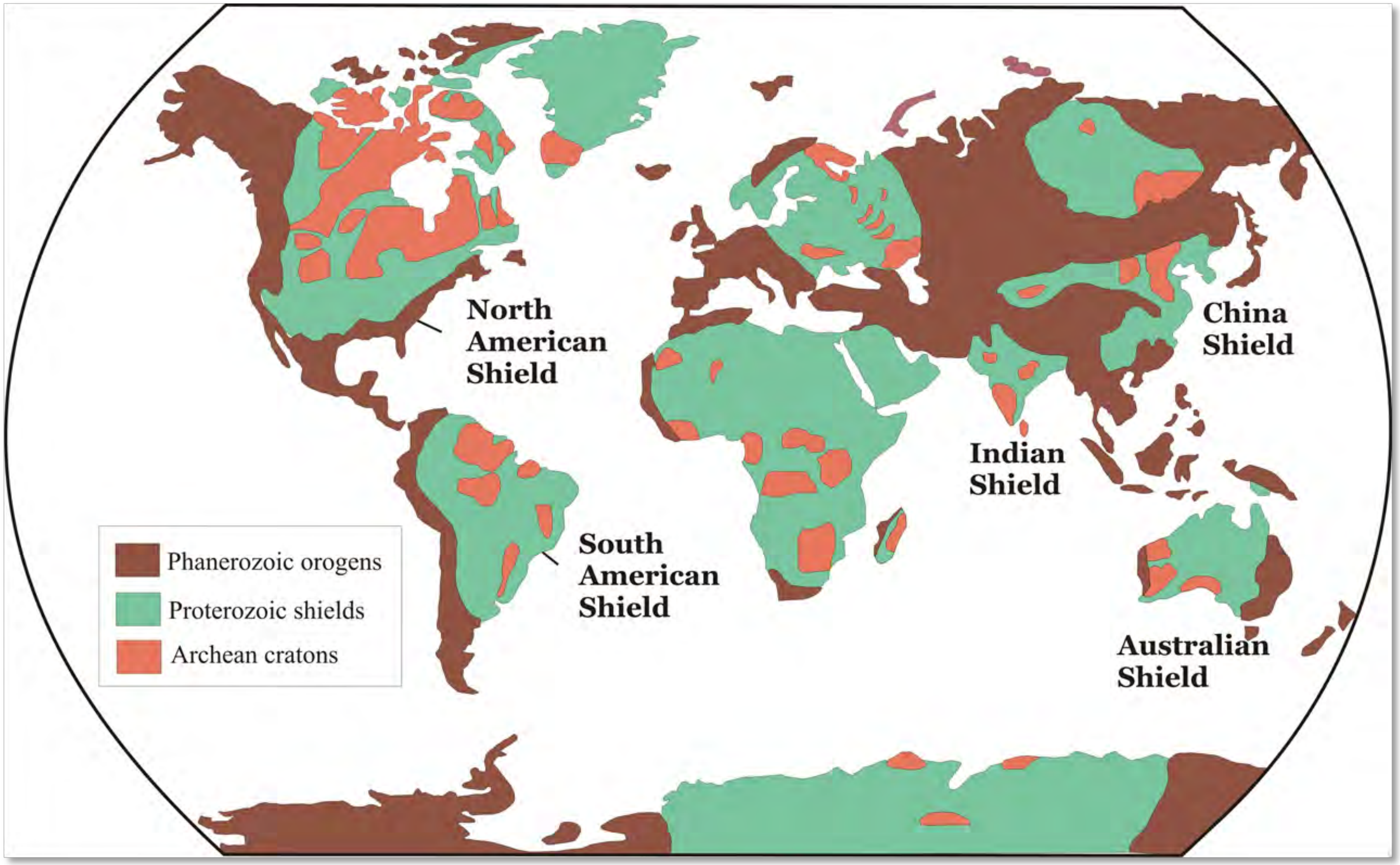

Fig. 1.1. Generalized world distribution map of the Archean basins.

constituted by Precambrian rocks ranging in age from Paleoarchean- Mesoproterozoic (Saha 1994) (Fig. 1.2). The core of the craton is mainly comprised by the multicomponent Singhbhum Granite batholith (Mishra et al. 1999; Mukhopadhyay 2001; Acharyya et al. 2010a, 2010b; Tait et al. 2011; Nelson et al. 2014; Upadhyay et al. 2014). The batholith includes enclaves of Paleo-Mesoarchean BIF-bearing greenstone belts (Acharyya 1993) collectively known as the Iron Ore Group (Saha 1994). The granitoid-greenstone core of the craton is unconformably overlain by Meso-to-Neoarchean siliciclastic rocks exposed in several detached outcrop belts bordering the core that include the Phuljhari Formation in the lower parts of the Dhanjori succession in the north, and in the Keonjhar, Daitari and Pallahara areas in the south and west of the block (Mukhopadhyay et al. 2014).

The aim of the thesis is to primarily attempt to throw light on the Mesoarchean arenite depositional system and nature of Mesoarchean upper crust from a collective study of internal stratigraphic development, interpretation of depositional settings and provenance analysis of the hitherto unclassified siliciclastic succession around Keonjhar Town in the Singhbhum craton, Odisha. The dissertation also explores the stratigraphic controls on the detrital iron ore deposits present in this succession and potential for radioactive placer mineral deposition as reported from stratigraphically comparable successions from Mahagiri Hills and Mankaharchua area of the southern parts of the Singhbhum craton (Mukhopadhyay et al. 2014; 2016). The dissertation has also explored the age of detrital iron ore deposits present in this succession and potential for radioactive placer mineral deposition.

Fig. 1.2. Google map of distribution of Archean cratons of India.

1.2. Geological setting of the Keonjhar siliciclastics

The Singhbhum craton in eastern India is constituted by a granite-greenstone core, Mesoarchean to Mesoproterozoic supracrustal cover sequences and peripheral mobile belts along northern and southern margins (Fig. 2.2; *for review* Saha 1994). The granite-greenstone core records granite emplacement at three phases ranging in age between 3.4 Ga to 3.1 Ga (the Singhbum Granite Phases I, II and III). The granitoids are essentially Archean TTG components, oldest of which is referred to as Older

Metamorphic Tonalite Gneiss (OMTG) and which is considered equivalent to the Singhbhum Granite phase I (3.44 Ga) (Mukhopadhyay 2001; Misra 2006). The greenstones with thick metabasalt-BIF-shale/volcaniclastics either occur as narrow linear enclaves of synformal keels in the western, eastern and southern peripheries of the granitoid core traditionally known as the Iron Ore Group (IOG) or as numerous small metasedimentary-metavolcanic enclaves of relatively higher metamorphic grade within the granitoids, collectively referred to as Older Metamorphic Group (OMG). The three prominent synformal keels with thick BIF-hosted iron ore deposits in each are referred to as Eastern, Western and Southern Iron Ore Group (IOG) (Saha 1994; Beukes et al. 2008). U-Pb zircon ages from the metalavas from southern IOG suggest a Paleoarchean (3.51 Ga) age (Mukhopadhyay et al. 2008a) for the oldest greenstone component in the craton so far.

Subsequent stratigraphic development is recorded in the siliciclastics dominated successions of the Dhanjori Group in the northern (ranging in age from >2.8 Ga to 2.2 Ga; Acharyya et al. 2010b; Mazumder et al. 2012) and Mahagiri Quartzite and the siliciclastic succession around Keonjhar and Mankaharchua (Mukhopadhyay et al. 2016) along the southern and western peripheries of the craton. The Mesoarchean to Paleoproterozoic successions are followed upwards by the carbonate-siliciclastics succession of the Mesoproterozoic Kolhan Group. The mobile belt in the north is referred to as North Singhbhum Mobile Belt (NSMB) between the Singbhum craton and the Chhotanagpur Granite Gneissic Complex. The NSMB includes siliciclastics of the Singhbhum Group and the metavolcanics dominated Dalma Volcanics and is separated from the Singhbhum craton by the Singhbhum Shear Zone. The southern margin of the craton is in tectonic contact with the high-grade Eastern Ghats and the Rengali Mobile Belts.

The siliciclastic succession under study is ~715-m thick and unconformably overlies the Singhbhum Granite (3.1 Ga to 3.4 Ga; Upadhyay et al. 2014) and the Western IOG around Keonjhar Town (Fig.1.2) with locally developed *Keonjhar Paleosol* along the unconformity (Mukhopadhyay et al. 2014). The succession is dominated by low-dipping mature sandstone with conglomerate interbeds in its lower parts.

1.3. Scope of the work

The succession north of Keonjhar Town studied here was considered to be equivalent to Proterozoic Kolhan succession (Ghosh and Chatterjee 1990, 1994; Saha 1994). Recently, Keonjhar siliciclastics were radiometrically dated to be ~3.0 Ga from U-Pb detrital zircons and have been interpreted as one of the best preserved among such Mesoarchean successions that records sedimentation from 3.1 Ga (Mukhopadhyay et al. 2013, 2014). Ghosh and Chatterjee (1990) suggested largely fluvial depositional facies from this succession. However, preliminary studies reveal that the ~715 m thick arenite-dominated succession offers a scope to study the sedimentation in a Mesoarchean transgressive shelf depositional system (cf. Mukhopadhyay et al. 2014). Such succession provides opportunity to understand nature of source terrain and composition of Mesoarchean upper crust (Ghosh et al. 2016). The geochemical proxies used in conjunction with the petrographic analyses provide important information about the nature of the source terrain, climate as well as tectonics of the source terrain from sedimentary rock record (e.g., Bhatia 1983; Bhatia and Crook 1986; Taylor and McLennan 2009). The study of the sediments that are sourced from such old crustal blocks remains very effective in understanding the poorly constrained composition of early continents and the appearance of differentiated upper crust (Taylor and McLennan 1985; Veizer and Mackenzie 2005).

The succession also includes uraniferous paleoplacer at the basal parts and detrital iron ore deposits near the upper parts. The present dissertation also attempts detailed analyses of the radioactive paleoplacer potential and the age of formation of iron ore from the detrital iron ore bearing.

1.4. Objectives

The above discussed scope of research in the Keonjhar siliciclastic succession necessitated the following objectives of this research programme as outlined here:

1. Study in detail the depositional history of the siliciclastic succession around Keonjhar.
2. Internal stratigraphy and U-Pb detrital zircon geochronology for constraining maximum depositional age.
3. Composition and condition of the upper continental crust at Mesoarchean time from petrography and geochemistry of the siliciclastic succession.
4. Lu-Hf isotopic analysis from detrital zircon to understand the nature of upper crust.
5. Detrital U-Pb deposition age of detrital iron ore deposits and study of mineralogy and geochemistry of uraniferous QPCs for potential source from upper crust and assessing geochemical tracers for the U-Th paleoplacer exploration.

1.5. Methodology

To get adequate information to fulfil the objectives of this research programme, the following methodologies were planned and can be divided into two parts: a. *Field* and b. *Analytical*.

Under the *field parts* following methodology have been followed:

1. Detail internal stratigraphy of the hitherto unclassified siliciclastic succession in the proposed area was carried out through preparation of geological map (1:50,000 scale) of the study area and by working out the lithostratigraphy and mappability of the succession. The siliciclastic succession studied here is exposed for a stretch of about 20 km to the north of Keonjhar Town between the Singhbhum Granite and the western Iron Ore Group. The study area cover almost 200 sq Km.

2. Detail sedimentary facies analysis was carried out in order to reconstruct depositional environment, sequence stratigraphy and paleocurrent analysis. To reconstruct depositional environment here I measured twenty nine major litholog sections on the basis of different lithofacies characteristics (detail description in chapter 4). Paleocurrent analysis has been carried out on the basis of about 300 paleocurrent data.

Among the *Analytical parts* the following broad methodologies were adopted:

1. To understand the composition and geodynamic condition of the upper continental crust at Mesoarchean time routine petrographic analyses, Scanning electron microscope with Cathodoluminescence (SEM-CL) analyses and the bulk geochemical analyses (XRF and ICPMS) have been carried out. Petrographic and SEM-CL analysis of the Keonjhar sandstone have been performed on the basis

sixty six thin sections. Total fifty three major oxides and thirty eight trace and REE analysis of the Keonjhar sandstone have been carried out.

2. LA-ICPMS U-Pb detrital zircon geochronology for constraining maximum depositional age for this siliciclastic succession. Total seventy nine detrital zircon grains from Keonjhar siliciclastics were analyzed.

3. LA-ICPMS Lu-Hf detrital zircon was obtained for understanding the nature of early crust. Total seventy nine detrital same zircon grains from Keonjhar siliciclastics were analyzed for Lu-Hf study.

1.6. Area of Investigation

The Keonjhar siliciclastics cover about 400 sq km area in the low lying hill ranges on north/north-west/west of Keonjhar Town. The study area stretches from Nayagarh in the south to Chamakpur in the north. The siliciclastics and is ~715 m thick and unconformably overlies the Singhbhum Granite phase II and are bordered to the west by western IOG assemblage and to the east by Singhbhum Granite and phases of OMTG. The area covers the parts of the Survey of India toposheet nos. 73G/5, 73G/9, 73F/8 and 73F/12. The area is accessible by rail from Jamshedpur as well as from Bhubaneswar and is well connected by national highways.

1.7. Instruments used for present studies

Various instruments were used at different stages of present research work. However, the following list provides a brief description of all the instruments:

a. *Petrological (Optical) Microscope:* Fresh medium-grained quartz arenite samples were collected from the study area covering the range of the stratigraphy. Polished thin-sections were prepared for petrographic studies. The petrographic study was carried out with a Nikon POl200 petrological microscope at Presidency University, Kolkata.

b. *Modal counting machine:* Standard petrographic thin-sections of twenty-eight medium to coarse-grained sandstone samples were used for point counting methods. The counts are varied from 500 to 600 data points as matrix and cement were also recorded. Modal compositional data of the framework grains in the sandstones are obtained by the Gazzi-Dickinson method (Ingersoll et al. 1984). This instrument used at Presidency University, Kolkata.

c. *Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-ray Spectroscope (EDS):* Polished thin sections were carbon-coated in a carbon-sputtering instrument to maintain electrical conductivity and were placed in the sample dispenser of the SEM. The model of the SEM used is TESCAN VEGA LSU make attached with OXFORD EDS spectroscope at the UGC-CAS Laboratory of Presidency University, Kolkata, to identify and characterize radioactive mineral phases.

d. *Wavelength Dispersive X-Ray Fluorescence (WDXRF) Analysis:* The samples were powdered to −200 mesh using a chromium free tool steel mill (Pulverisette 9 Fritz-GMBH). Major element analyses were carried out by using X-ray fluorescence spectrometry (XRF Model Panalytical Axios WD-XRF) at the Department of Geology, Presidency University. Total fifty-three XRF analysis of the Keonjhar sandstone have been carried out. The pressed powder pellets were analyzed on the XRF with matrix correction procedure at 60 kV, 170 mA with nominal analysis time was 300s for all major oxides. Overall precision for major and minor oxides is <5%. The precision and accuracy are based on multiple analyses of international rock standards [JG-2 (granite), NIM G (granite)].

e. *Induction coupled plasma mass spectrometer (ICPMS):* Analyses of trace element concentrations including rare earth elements (REE) were carried out using a Perkin-Elmer SCIEX Model ELAN DRC II ICP-Mass Spectrometer at the ACME Lab Canada Vancouver. Total thirty eight trace and REE analysis of the Keonjhar sandstone have been carried out. For each sample 2 to 3 replicate analyses were carried out in order to check that precision and accuracy were within acceptable limits. The precision was <5% RSD with comparable levels of accuracy (Balaram and Rao 2003). The precision and accuracy are based on multiple analyses of international rock standards [JG-2 (granite), GSR-5 (shale)].

f. *Scanning Electron Microscope (SEM) attached with Cathodoluminescence:* SEM-CL fabric analyses of more than 1500 quartz grains from different locations and mounted in polished, carbon-coated thin sections were carried out by a JSM 6510 scanning electron microscope with an attached cathodoluminescence detector (SEM-CL) at the Institute of Geoscience, Federal University of Minas Gerais, Belo Horizonte, Brazil. This instrument was commonly operated at 30 kV and a beam current of 10 nA. CL images were recorded in 18-19 working distance.

g. *Laser ablation sector field induction coupled plasma mass spectrometer (SF-ICP-MS) U-Pb dating:* To constrain the maximum depositional age of the unclassified Keonjhar siliciclastic succession U-Pb dating method were carried out (for seventy nine detrital zircon) by Laser ablation sector field induction coupled plasma mass spectrometer (LA-SF-ICP-MS) at the Federal University of Ouro Preto, Brazil. Laser spot size of 20 µm was used. The typical depth of the ablation crater was 15 - 20 µm. Data were acquired in peak jumping mode during 20s background measurement followed by 20s sample ablation. There are three secondary standards were used before and during runs: Plešovice zircon (337 ± 1 Ma; Sláma et al. 2008), M127 zircon (524 ± 1 Ma; Klötzli et al. 2009) and 91500 zircon (1065.4 ±0.6 Ma; Wiedenbeck et al. 1995).

h. *Laser ablation multicollector inductively coupled plasma mass spectrometer (MC-ICP-MS) Hf analyses:* These analyses were performed on the same detrital zircon grains (for seventy nine detrital zircon) as U-Pb dated by Laser ablation sector field induction coupled plasma mass spectrometer (LA-SF-ICP-MS), using a Thermo-Finnigan Neptune multicollector ICP-MS coupled to a Resonetics M50 193 nm Excimer laser system, at JWG, and a Photon-Machines 193 nm laser system, at the Federal University of Ouro Preto, Brazil. (e.g., Gerdes and Zeh 2006, Moreira et al. 2016). At UFOP, three reference materials were used before and during runs: GJ1, Temora and Plešovice ($^{176}Hf/^{177}Hf$ = 0.282482 ± 0.000013; Sláma et al. 2008).

1.8. Organization of the thesis

Chapter 1 of the thesis deals with an introduction on the distribution of Eo-Paleoarchean sedimentary succession. This chapter also includes the brief description on the statement of the present work, geological setting of the study area, scope of the work, detail objectives and methodology obtained, instrument used for the present studies and significance of the present work.

Chapter 2 gives brief overview on the previous works on the Singhbhum stratigraphy.

Chapter 3 includes the internal stratigraphy of the Keonjhar siliciclastics based on distinctive lithology and mappability carried out during the present study.

Chapter 4 deals with the facies analysis and depositional environment of the siliciclastics. Based on the identification of facies associations, facies sequence, and paleoslope / paleocurrent direction of the Keonjhar siliciclastics the depositional environment and base level chages have been interpreted.

Chapter 5 of the thesis basically deals with the source and geodynamic condition of the upper crustal constitution during the Mesoarchean time. This chapter attempt petrographic and SEM-CL studies of the Keonjhar siliciclastics for the provenance determination from collective analyses of petrography and SEM-CL.

Chapter 6 reports the detrital zircon U-Pb-Lu-Hf compositions from the Keonjhar siliciclastics in order to understand the source of early continental crust and its bearing on the geodynamics of Mesoarchean continental growth.

Chapter 7 gives the idea about the radioactive mineralization from surface QPCs samples. This chapter describes the geochemical and mineralogical aspects to assess the possible proxy indicators of uranium-thorium mineralization from surface Keonjhar samples in absence of drill core samples. The geochemical composition of the siliciclastics is presented in order to understand nature of the source terrain and Mesoarchean upper crust.

Chapter 8 deals with the sedimentological controls, description of ore clasts and U-Pb detrial zircon geochronology in order to understand the deposition of the iron ore conglomerate body and the age of primary orebody from which the ore clasts were derived.

A summary of outcome of the present research is included in discussion and concluding chapter.