INTRODUCTION

The Indian plate is a part of Indo-Australian plate that along with Antarctica, Africa and Madagascar constituted the Gondwanaland of the geological past (Figure1). The continental part of Indian shield consists of several terrains accreted at different times. These terrains contain rocks as old as 3.4 Ga. The northwestern part of Indian shield, referred to as Aravalli craton, is marked by the presence of NE-SW trending Aravalli mountain belt or ADFB (Figure 2). This belt spans for about 800 km from Palanpur in north Gujarat to Delhi and adjoining parts of Rajasthan state. ADFB is a large orogen which contains a complete record of early Proterozoic volcanic-sedimentary sequences preserved in various isolated basins separated by Archaean baseman rocks (Deb and Sarkar, 1990; Roy and Jakhar, 2002) referred to as Banded Gneissic Complex or BGC (Heron, 1953). The geological history of Aravalli craton evolved through a wide span of time ranging from >3000 Ma to about 500 Ma (Gopalan et al. 1990; Roy and Jakhar, 2002 and references therein). In recent years the ADFB has been a focus of numerous studies but its tectonic evolution and role in reconstruction of pre- Rodinia Columbia supercontinent during 2.1 – 1.8 Ga have been matter of debate (e.g. Rogers and Santosh, 2002; Zhao et al., 2002). The mafic volcanic rocks occurring in different Proterozoic basins within the ADFB have been taken as evidence for either arc related, or mantle-Plume or plate- rift models (Raza et al., 2007; Ahmad et al., 2008a; Khan et al., 2005).

In this region the Archaean basement (BGC), is overlain by numerous Pruterozoic cover sequences (Deb and Sarkar, 1990) belonging to Palaeoproterozoic Aravalli and Mesoproterozoic Delhi Supergroups (Figure 2). The southern part of this orogen is broadly constituted by various belts containing metasedimentary sequences of Aravalli and Delhi Supergroups. On the other hand, the northern part

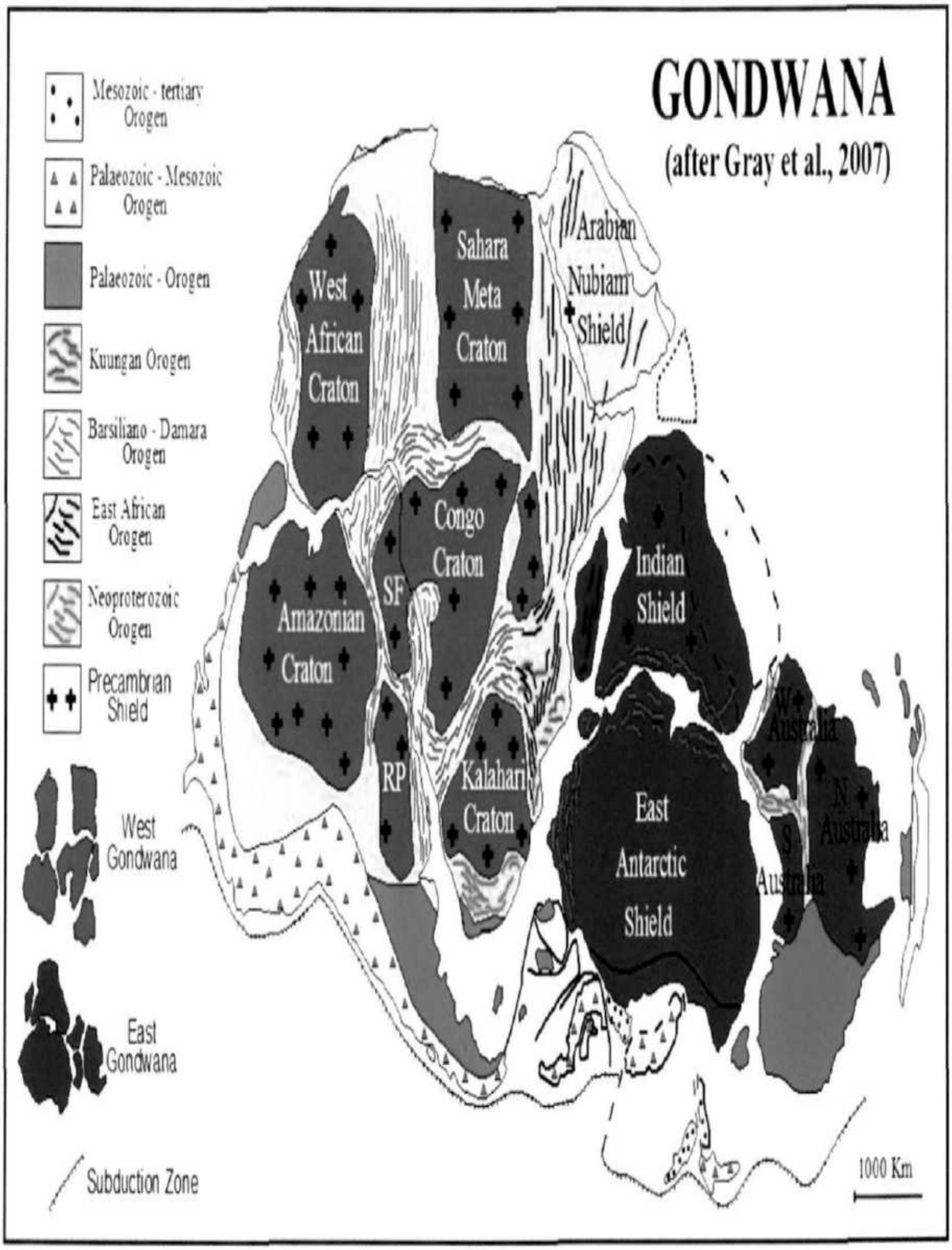

Figure 1 Map showing distribution of continents in Gondwana assembly (Gray et al., 2007; Meert and Lieberman, 2008).

of this mountain belt is considered to be entirely consisting of Delhi Supergroup occurring in three volcano-sedimentary basins. These are from east to west: the Bayana sub-basin, the Alwar sub-basin and the Khetri sub-basin (Singh, 1988). The first two taper towards south whereas the third one appears to extend towards south into SDB. Although mafic volcanic rocks of this orogen have been extensively studied for their geochemistry (Ahmad and Tarney, 1994; Raza and Khan, 1993; Raza et al., 2001a, 2007, 1993; Ahmad et al., 2008a, b), the geochemical data on sedimentary rocks are lacking. In some of these basins, the sedimentary rock sequences are excellently preserved and stratigraphically well defined, thus are most suited for Proterozoic crustal evolution and palaeoclimatic studies. The volcano-sedimentary rocks sequences of ADFB have been previously thought to have formed during the global scale orogenic event, which existed at about 2100-1800 Ma (Zhao, et al., 2002). Recent studies suggest that India was a constituent landmass in the Columbia (e.g. Rogers and Santosh, 2002; Zhao et al., 2002). The provenance characteristics and tectonic environment of the sedimentary sequences of this region may provide important information for resolving the controversies about the tectonic evolution of the Aravalli craton in particular and North Indian shield in general. Among these basins the Alwar Basin crop out in a key area in the central part of NDFB and contains 1800 Ma old variably deformed and metamorphosed sedimentary succession consisting predominantly of siliciclastic sediments, developed in a rift basin (Raza et al., 2007).

Present study involves a geochemical examination of clastic sedimentary rocks constituting the Delhi Supergroup occurring in Alwar basin of NDFB.

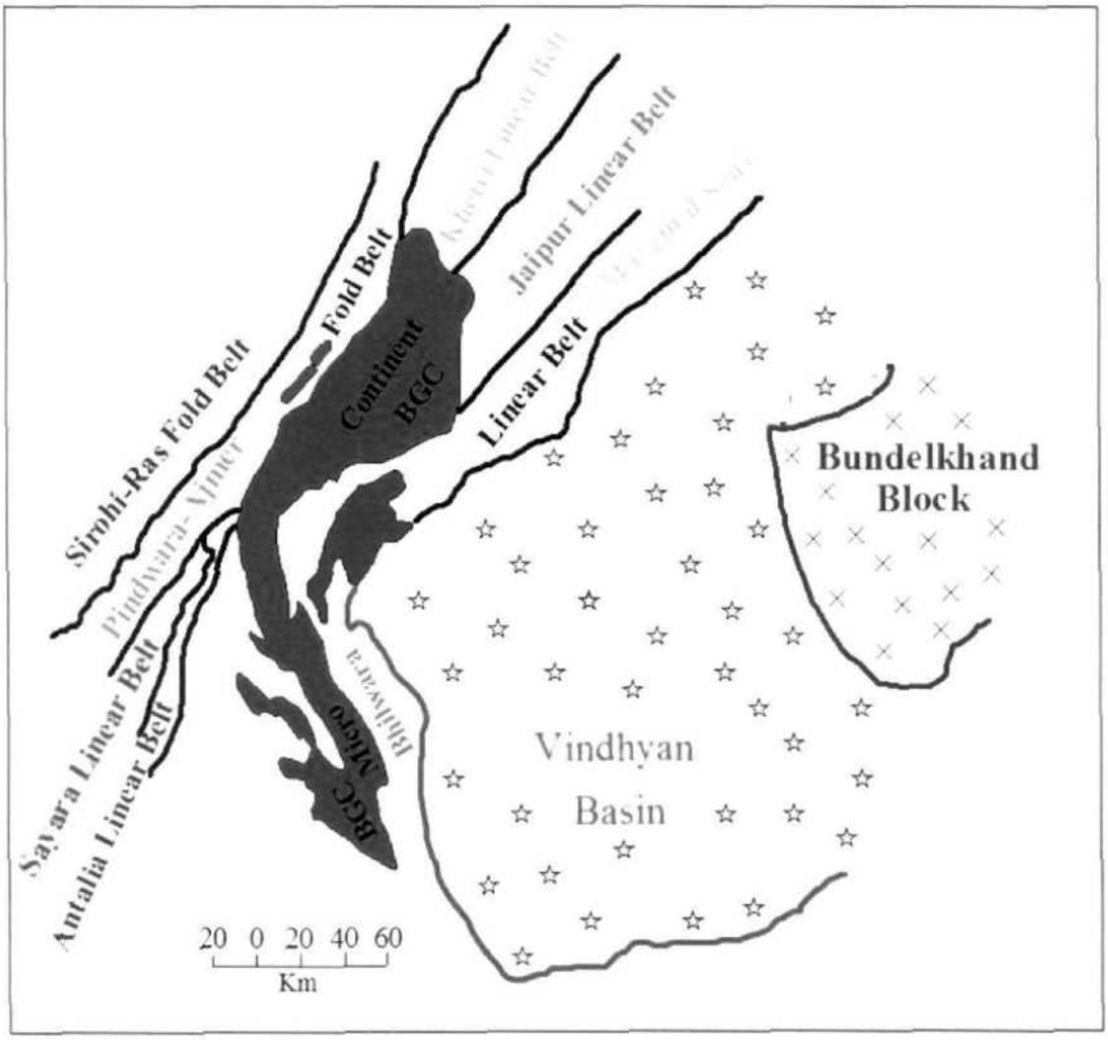

Figure 2 Sketch map showing linear Tectonic Zones in Aravalli-Delhi Orogenic Belt and Proterozoic sedimentary basins of surrounding area (After Sen 1980, 1981).

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The composition of Detarital sediments is a function of complex interplay of various variables including source rock composition, weathering processes operating in source terrain, tectonic setting of depositional basin, and digenesis (McLennan et al., 1993). The Clastic sedimentary rocks are considered to represent the geochemical average of the exposed continental crust from which they were derived (Taylor and McLennan, 1985). Therefore, the geochemical characterization of sedimentary records has been used to constrain provenance composition and depositional setting particularly in the case of Archaean and Proterozoic sequences (Wronkiewicz and Condie 1987; McLennan, 1989; Cullers, 2000; Condie, 2001; Hofmann, 2005; Absar et al., 2009; Raza et al., 2010a, b). However, it is a rather recent trend to use geochemical composition of clastic sediments both as independent field of study as well as an important adjunct to sediment logical studies to constrain the potential source areas (McLennan et al., 1995; Naqvi et al., 1988), to construct the tectonic setting of depositional basin (Bhatia and Crook, 1986) and to reveal possible Palaeoclimatic conditions (Nesbitt and Young, 1982). The geochemistry of clastic sediments is particularly helpful to constrain the evolutionary history of the provenance domain including compositional characteristics, changes in source lithology due to unroofing and addition of juvenile mantle material, and sedimentary recycling. In provenance studies the sedimentary rocks may be of two types i.e. (1) those having derived from local sources and (2) those having remained in river, marine system for a longer time before deposition as well mixed sedimentary debris. The latter types of sediments provide data for crustal scale processes. The importance of sedimentary provenance in constraining tectonic processes that have shaped sedimentary source regions has been recognized by many authors (e.g. Li et al., 2005; Payne et al., 2006).

Most of these studies are based on the assumption that trace elements such as the REE, Cr, Th, Zr, and Sc are transported from source to the site of deposition without significant modification due to sorting, fractionation, diagenesis or post-depositional tectonothermal events. Since these elements are transferred virtually quantitatively from the upper continental crust into clastic sediments, the trace element geochemistry of clastic rocks has been used to determine the composition of source terrain. These elements include high field strength elements (HFSE) such as Th, Zr, Hf, Ti, Nb, V, Cr, Ga, and rare earth elements (REE). In particular Zr and Ti are representatives of the immobile or least mobile elements (Lowe et al., 1999; Polat et al., 2002; Polat and Hoffman, 2003). In this regard the REE are considered to be more reliable and have been used widely in geochemical studies of clastic sedimentary rocks. The degree of differentiation of LREE from HREE is a measure of proportion of felsic to mafic rocks in the provenance and Eu anomalies reflect the processes affecting the source area such as whether the plagioclase has been fractionated from igneous rocks of the source terrain (Taylor and McLennan, 1985). The digenesis appears to have little effect on the abundances of immobile trace elements or on their ratios (Totten and Blatt, 1993; Taylor and McLennan, 1985; Polat and Hoffman, 2003). As a result, the select trace elements and REEs are widely used as a tool in sedimentary provenance studies (Sugitani et al., 2006; Payne et al., 2006; Polteau et al., 2006). Therefore the concentration and ratios of trace elements have been proved very useful for inferences about provenance history, climate attended during weathering and changes in the composition of continental crust at the Archaean – Proterozoic boundary (Taylor and McLennan, 1985). For example, higher Cr/Zr and lower La/Sc and Th/Co ratios in a clastic sediment sample suggest greater contribution from komatiite than granitic terrain. Consequently, any change in their chemical composition should reflect the changes undergone by provenance during the time it supplied debris to a site of sedimentary deposition. Similarly, sediments having low Th/U ratio suggests absence of significant recycling. In case of Archaean fine grained sediments the Th/U ratio reflect less oxygenating atmosphere (Taylor and McLennan, 1985). On a local scale such information together with classical sedimentological data (e.g. Paleocurrent data etc.) provides important constraints in the identification of source terrain and greatly helps to determine changes in climatic and tectonic regimes in the source terrain through geological times. On a regional scale the geochemical data provide useful clues to investigate the secular variation in the composition of continental crust.

Moreover, the geochemistry of sedimentary rocks may greatly help in constraining the average upper crust composition and global crustal evolution models, for example the average composition of upper continental crust changed during Archaean – Proterozoic transition (e.g. Gibbs et al., 1986; Condie and Wronkiewicz, 1990; Taylor and McLennan, 1985; 1995). These authors found abrupt changes in the composition of sedimentary rocks at Archaean–Proterozoic boundary. For example,(1) an increase in the negative Eu - anomaly (2) a decrease in the normalized Gd/Yb ratio from >2.0 to 1.0-2.0 (3) a decrease in Sm/Nd ratio from about 0.21 to 0.19 and (4) an increase in the Th/Sc ratio from about 0.5 to 1.0. The Archaean crust formation was dominated by greenstone tectonics and the crust was predominantly mafic in composition. The Archaean-Proterozoic transition witnessed intrusion of high– k granite. Therefore, the Archaean sedimentary rocks are characterized by flat REE pattern with no Eu- anomaly and high Ni-Cr content in comparison to their Proterozoic counterparts which show fractionated REE patterns with significant Eu-anomaly and low Ni-Cr contents. Large production of high k-granites has been suggested for these changes in expense of Komatiite magmatism of greenstone association of Archaean. Condie (1993, 1997) related upper crustal geochemical changes at APT to four evolutionary changes of earth history. These are: (i) Komatiitic effect (ii) Tonalite-Trodhjemite-Granodiorite (TTG) effect (iii) subduction effect and (iv) weathering effect. Komatiitic effect resulted from large production of komatiitic magma during Archaean. These effects are reflected in the geochemical compositions of sedimentary rock records. For example, high Ni-Cr contents, flat REE patterns and positive Eu-anomaly in Archaean sediments are indicators of komatiite in their source terrain. The sedimentary rocks derived from TTG dominated provinces display highly fractionated REE patterns with high $(La/Yb)_n$ ratios and Y depletion. During late Archaean-early Proterozoic, voluminous amount of granitic magmas were produced due to partial melting of metasomatised mantle wedge. In sedimentary rocks these characteristics are preserved in terms of less fractionated REE patterns and less depleted LILE in comparison to TTG derived sediments. Some geochemical changes across APT seem to be related to paleoweathering effects since intensity of chemical weathering decreased during post Archaean period. Therefore, the geochemical compositions of clastic sedimentary rocks can greatly help to constrain the crustal evolution during Archaean where the source rock will be subjected by erosion (McLennan, et al., 1983; Taylor and McLennan, 1995; Cullers et al., 1988; Condie and Wronkiewicz 1990; Sugitani et al., 1996; Fedo et al., 1997; Naqvi et al., 2002; Raza et al., 2002; Hoffman, 2005; Absar et al., 2009). The geochemistry of sedimentary rocks has also been used to identify the tectonic setting of ancient sedimentary sequences (e.g. Bhatia, 1983; Bhatia and Crooks, 1986).

Previous work

Although enough sedimentary record is available in Indian shield, the application of geochemistry to the sedimentological studies did not catch up widely. Despite early beginning by Naqvi and his co-workers (Naqvi and Hussain, 1972; Naqvi and Rogers, 1983 and references there in) in the field, very few geochemical studies have been carried out on sedimentary rock records (e.g. Srinivasan and Naqvi, 1990; Bose, 1994; Bhushan, 1998; Raza et al., 2010a, b, 2012, 2001; Islam et al., 2002; Tripathi and Rajamani, 2003; Chakrabarti et al., 2007). In India most of the work on the geochemistry of sedimentary rocks has been carried out on the Archaean sequences of Dharwar craton of south Indian shield (Naqvi et al., 1983; Naqvi and Rogers, 1987 and references therein; Naqvi et al., 2002). The present work deals with the major and trace element geochemistry of Proterozoic clastic sedimentary rocks of the Delhi Supergroup occurring in Alwar basin of North Delhi Fold Belt (NDFB). Although the geochemistry of mafic rocks of the Alwar basin has been examined (Raza et al., 2007), geochemical data on associated sedimentary rocks are not available in literature. The Alwar basin thus remains unrepresented in any model proposed for the evolution of the Proterozoic continental crust. The present study is the first, to report major and trace element (including REE) compositions of sedimentary rocks of Lower Proterozoic Delhi Supergroup from the Alwar basin of NDFB.

Aims and Objective

The present study involves geochemical and petrographical examination, particularly of clastic sedimentary rocks of Alwar basin (~1800 Ma) with the following aims and objectives.

1. A classical whole rock geochemical investigation of clastic sedimentary rocks of Alwar Basin by generating geochemical data of advance nature including major and trace elements and REE.

2. To constrain and locate the provenance of the sedimentary sequence of Alwar Basin to distinguish petrofacies as per Dickinson scheme.

3. To reveal the weathering conditions and palaeoclimatic conditions prevailing during sedimentation.

4. To understand the tectonic setting of sedimentary basin.

5. To examine the applicability of geochemical data in interpreting the nature of continental crust particularly during the Proterozoic time.

6. The implications of these data along with available geochemical data of older Archaean and younger middle Proterozoic sedimentary rocks of the Aravalli craton for evolutionary trends of early crust in northern part of Indian shield through geological times.

1.4 Scope and limitation of present study

The present study deals with geochemical and geodynamic aspects of metasedimentary rocks occurring in central part of the Alwar basin of NDFB, covering northeastern parts of Rajasthan state of India. The study area is an important depocentre zone within the northern part of Aravalli mountain belt. New geochemical data of advance nature for quartzites and metapelites of Delhi Supergroup of Alwar basin are generated and reported for the first time. The geochemical data are utilized to obtain new information about provenance, tectonic setting, weathering history and depositional environment of Alwar basin sedimentary fill. The implication for evolution of continental crust at Archaean- Proterozoic boundary and continent assembly are further discussed.

The thesis includes extensive studies carried out to understand the field relations and petrographic study of metasedimentary rocks of different formations of Delhi Supergroup occurring in Alwar Basin. The results have been discussed and concluded in the form of various variation diagram and have been correlated with various petrogenetic models proposed worldwide for metasedimentary rocks of Precambrian shield areas around the globe.

Although, the geochemical approaches to draw interpretations regarding provenance and tectonic setting are helpful, they lack a specific applicable methodology that can be applied. Several geochemical ratios, plots and trends have been proposed, but have either been too broadly applied or too narrowly constrained. It has been generally accepted that geochemical discriminants can identify features not readily recognized by petrography. Therefore, geochemical parameters have been successfully used to constrain the potential source areas and to reconstruct tectonic settings of depositional basins.

Organization of the thesis

The work is presented in nine chapters:

Chapter 1: Deals with the general geological set-up of Aravalli cratonic block and stratigraphy of Alwar basin of North Delhi Fold Belt.

Chapter 2: Contains details of petrographical study carried out on quartzite (meta-arenite) of Alwar basin.

Chapter 3: Describes the procedure adopted in sampling, sample preparation and techniques used for geochemical analysis of different sedimentary formations.

Chapter 4: Contains results of geochemical analyses and detailed discussion on geochemical characteristics of quartzite and metapelites of Delhi Supergroup of Alwar basin in terms of major, trace and Rare Earth Elements.

Chapter 5: Present discussion on geochemical data of clastic sedimentary rocks of Alwar basin and relevant interpretations regarding surface processes such as sorting, quartz dilution, chemical weathering and palaeoclimatic conditions.

Chapter 6: Deals with provenance characterization including source area modeling of Alwar basin sedimentary sequence using geochemical data.

Chapter 7: Presents discussion and relevant interpretation on tectonic environment of sedimentary sequence of Alwar basin and implication for continent assembly using geochemical data.

Chapter 8: Contains discussion on crustal evolution at Archaean-Proterozoic boundary.

Chapter 9: The summary and conclusions are presented in the last chapter.