CHAPTER 1
INTRODUCTION
1.1. Introduction

Sedimentary rocks contain a wealth of information about the composition of source rock, tectonic setting of basin and evolution of crust through geological times (Taylor and McLennan, 1985; Gibbs et al., 1986; Condie, 1993; McLennan et al., 1995). Barring few exceptions, the studies on sedimentary rocks particularly clastic rocks remained focused on facies modeling and detrital mode estimation till late seventies (Pettijohn et al., 1987; and references therein). Such studies have an inherent bias for coarse grained clastics. Thereby, standard petrographical approaches employed investigation of undulosity and polycrystallinity of quartz grains (Basu et al., 1975), types of feldspar present and rock fragments (Pettijohn et al., 1987), for the identification of source rock, grain roundness and average degree of feldspar alteration to constrain relief and climate of the source area (Folk, 1980), estimation of relative proportion of quartz, feldspar and rock fragments to interpret tectonic setting (Dickinson, 1985) and examination of roundness and sphericity of grain, textural and mineralogical maturity to infer transport history (mechanism, agency, intensity etc.) (Pettijohn et al., 1987). And therefore, because of comparatively straight forward application of this technique which requires only a petrographical microscope, provenance information in majority of cases has been extracted from sandstones. On the other hand, petrographic examination of shales being much more time consuming and far less illuminating, due to their fine grained nature and diagenetic modification of clay minerals, got less favor of sedimentologists. Consequently, petrographic studies on shales were conducted in those sequences where sandstones are rare or absent.

However, since the pioneer works of Wildmen and Condie (1973), Nance and Taylor (1977), Taylor et al., (1983), Taylor and McLennan (1985), there has been a great deal of interest in the geochemical studies of clastic rocks of all the geological ages, across the globe (Mongelli et al., 2006; Nyakairu and Koeberl, 2001). These geochemical studies are now widely used as a tool to constrain changes in the crust building and crust evolution processes across Archean-Proterozoic boundary.

It is now well established fact that the chemical and mineralogical compositions of clastic sedimentary rocks is the manifestation of composite interaction of various variables including source rock composition, weathering, erosion, transportation and
sedimentation processes such as mechanical sorting, decomposition and diagenesis (McLennan et al., 1993). In view of these, geochemical composition of clastic rock has been widely used to decipher the composition of source area (Wronkiewicz and Condie, 1987, 1990; Naqvi et al., 1988, 2002; McLennan et al., 1995; Cullers, 2000; Cullers and Podkovyrov 2000; Condie et al., 2001), to evaluate weathering processes and paleoclimate (Nesbitt and Young, 1982; Sreenivas and Srinivasan, 1994; Fedo et al., 1995, 1996), to reconstruct the tectonic setting of depositional basin (Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986, 1988; McLennan et al., 1990), to quantify secondary processes, like post depositional metasomatism (Fedo et al., 1995, 1997) and to evaluate the composition and evolution of continental crust (Taylor and McLennan, 1985, 1995; McLennan and Taylor, 1991; Condie, 1993; Lahtinen R., 2000) particularly the Precambrian crust, where either the source rock has been destroyed by erosion or exhumed by subduction process (Feng and Kerrich, 1990; Hofmann, 2005; Hofmann et al., 2003; Holland, 1984; Johnsson, 1993). In addition to above, the clastic geochemistry is found quite helpful in constraining 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 and ultimately in quantifying and defining the geochemistry of the average composition of the upper crust and global crustal evolution models through geological times.

There has been considerable debate about the application of geochemical data of coarser clastics in interpreting factors controlling sediment generation and their deposition. Several workers are of the opinion, that fine grained clastic sedimentary rocks are more useful in geochemical studies than the coarser ones (Taylor and McLennan, 1985). As they are thoroughly homogenized before deposition and acquire debris from wide area thus, provide crustal scale sample, enabling study of crustal scale processes (Taylor and McLennan, 1985). Furthermore, due to the fact that their mineralogy is rarely affected during diagenesis and metamorphism (Weaver, 1989), they are more suitable for geochemical studies. Studies of the influence of grain size and transportation distance in a given tectonic environment on the chemical composition of sediments show that some major elements and trace elements concentrations and ratios, including REE patterns and negative Eu-anomaly size are similar to the source rock in fine grained sedimentary rocks.
compared with the more variable chemical composition of coarse grained sediments in the same sedimentary sequences (Cullers et al., 1975; Cullers, 1988, 1994; Mongelli et al., 1996). The coarse grained sediments may show sorting effects (Taylor and McLennan, 1985; Sugitani et al., 2006) and the $\sum$REE content decrease steadily with an increase in grain size (Cullers and Stone, 1991).

Though, it is preferable to use fine grained sedimentary rocks for geochemical studies in general, as they are homogenized representatives of source(s), the geochemical approaches are also found equally applicable to coarse and medium grained sedimentary rocks. McLennan et al. (1990) observed that it is compositional variability and not the grains size that leads to insights about provenance and the sedimentary processes. And that fine grained sediments formed in confined basin and from more restricted source rocks are not globally homogenized, as many workers have shown that the composition of mud rocks from volcanic arc setting bear little resemblance to average shale compositions (Bhatia and Taylor, 1981; Bhatia, 1985). It should also be noted that intimately associated sands and muds may be derived from quite different sources with different sedimentary histories and so both require independent evaluation (McLennan et al., 1990). Recent studies by several workers (Crichton and Condie, 1993; Yamashita et al., 2000), have shown that in some cases, even diamictites and conglomerates can yield valid trace and rare earth element provenance information.

Nowadays there is another emerging trend where petrography of clastic rocks is integrated with their geochemical data, in order to get more realistic and accurate information about their provenances, paleoclimate and the tectonic processes which control their deposition (McLennan et al., 1993; Zimmerman and Bahlburg, 2003; Raza et al., 2011). And thus, such studies are giving more accurate picture of crustal evolution in complex geological terrains.

The Indian shield is broadly constituted by two major cratons, designated as North and South Indian cratons according to their current directional positions. Each of these craton is a mosaic of several small tectonic domains of discrete lithological makeup which were accreted together to form single crustal block along tectonic boundaries (Radhakrishna, 1989). The South Indian Craton is composed of the Tamil Nadu-Kerala block, the Karnataka block, the Bastar block and the Singhbhum block. These blocks are
considered to be separate entities during Archean, which got welded together to form a single South Indian Craton (SIC). Similarly, North Indian Craton is formed by two tectonic domains viz. Bundelkhand block and Aravalli block (Fig.1.1).

Figure-1.1: Map of India showing tectonic architecture of the Indian shield. Note that the northern and southern parts of the shield are separated by a major tectonic zone referred to as Central Indian Tectonic Zone. NIC=North Indian Craton, SIC=South Indian Craton, SMB=Satpura Mobile Belt, EGMB=Eastern Ghat Mobile Belt, SGT=Southern Granulite Terrain, CHB=Chhotanagpur Belt and GBFZ=Great Boundary Fault Zone (After Radhakrishna, 1989)

It is suggested that early Proterozoic successions in India were formed by extensional tectonics around the margins of these two cratons. The two cratons came
together during Mid-Proterozoic and got welded along a lineament referred to as Narmada-Son-Brahmaputra lineament or the Central Indian Tectonic Zone (Biswas, 1987). Consequently, the epicratonic cover as well as the Archean basement were subjected to intense folding, faulting and deformation which resulted into the formation of a large intercratonic mobile belt referred to as Middle Proterozoic Mobile Belt by Radhakrishna and Naqvi (1986).

Another view regarding the formation of present shield has been put forward by Qureshy and Iqbaluddin (1992). According to them the Indian shield has been constituted by three geotectonically exotic blocks viz. the South Indian Craton SIC, the Bundelkhand Block (BB) and the Trans Aravalli block (TAB). They proposed that TAB represents a fragment of the Arabian-Nubian Shield (ANS). The BB represents a rifted block from the Siberian continent. Following an Andean type convergence, the BB sutured with the SIC at about 919±21 Ma (Balasubramaniyam et al., 1978). The BB moved towards the SIC along a bounding western margin transform, and was juxtaposed and later sutured with ANS along the Aravalli-Delhi orographic axis. The TAB, along with rest of the Indian shield, apparently separated from the Arabian plate during the mid Tertiary (Moicene?) and moved northward along the Owen Fracture Zone-Chaman Fault System, finally colliding with the Eurasian plate.

Nevertheless, irrespective of the mechanism or the process involved in the formation of Indian Precambrian shield, the geologists are by and large in close agreement that they are discrete blocks/mini cratons of distinct lithological assemblages having their own evolutionary histories, which constitute present day Indian shield.

The Aravalli craton is the NW extension of the Indian shield. The rocks of this craton are exposed over 80,000 kms$^2$ in the states of Delhi, Haryana, Rajasthan and northern Gujarat. The litho package of Aravalli craton consists of a variety of rocks ranging in age from Archean to Phanerozoic (Heron, 1953; Gupta et al., 1997).

The principal physiographic feature of the Aravalli craton is the Aravalli Mountain Range (AMR) which strikes northeast-southwest from Delhi to part of Gujarat. AMR extends for about 700 kms from Palanpur in northeast Gujarat in the south to Delhi in the north and varies in width between 30 kms to 200 kms. But the best preservation of all the rocks is mainly in Rajasthan and Gujarat states.
The AMR is bounded by GBF in the east and western Marginal Fault in the west. To the east of AMR there occurs the generally undeformed Mesoproterozoic Vindhyan Supergroup rocks (Rasmussen et al., 2002) and on the western side the rocks of large Malani Igneous Province are exposed. Apart from these, there are several other crustal scale mega lineaments in this part of western Indian shield. For example, the Delwara lineament occurring between the BGC and the Aravallis, Rakhabdev lineament that acts as a suture between the deep water Jharol and shallow water sediments of the Aravalli Supergroup. Similarly, the Delhi and the Pre-Delhi rocks are separated by the Kaliguman lineament. Phulad Lineament Zone (PLZ) acts as a major boundary, that separates orogenic and anorogenic crustal segments. Pali and Banas lineaments are also examples of other such mega lineaments occurring in the AMR (Fig. 1.2).

Because of the unique character of AMR, preserving complete record of Precambrian with excellent exposures which is lacking in southern Indian craton it has been a cynosure of geological studies for both national and international geologists. Unfortunately, studies in Aravalli block were either directed towards resolving stratigraphic riddles through mapping (Heron, 1953; Sen, 1981; Roy, 1988; Gupta et al., 1980; 1997), structure and metamorphism (Naha and Halyburton, 1974; Sharma, 1988) or crustal evolution envisaged by magmatic components (Raza and Khan, 1993; Volpe and MacDougall, 1990; Raza et al., 2010). Whereas, the sedimentary rocks of Aravalli block got little attention. Of late, Raza and his coworkers have published some papers on Mesoarchean-Paleoproterozoic sediments of Aravalli block (Raza, 2010, 2011). On the other hand, despite their less volume and exposure in Dharwar block, of southern Indian craton, its sedimentary lithopackage has been extensively studied (Naqvi et al.1988, 2002; Tripathy and Rajamani, 1999; Hegde and Chavadi, 2009; etc ).
In India there are few suspect ophiolite sequences viz. Tal ophiolite, Mahakoshal belt (Mathur and Mani, 1978; Qureshy and Iqbaluddin, 1992), Dalma ophiolite, Singhbhum block (Sarkar, 1982), Phulad ophiolite, South Delhi Fold Belt (Gupta et al., 1980; Khan et al., 2005). Phulad ophiolite has been extensively debated among geoscientists about its tectonic environment of formation. Advocates of formation of crust during Neoarchean–Paleoproterozoic by the operation of Wilson Cycle consider Phulad sequence as a dismembered ophiolite (Volpe and MacDougall, 1990; Khan et al., 2005), as a mélangé (Sinha Roy, 1988) representing the remnants of arc whereas, some other consider it as a late magmatic intrusive phase in an extensional rift (Singh, 1988; Roy et al., 1988; Roy and Jakhar, 2002). Moores (1982), proposed that studies of pre-emplacement sedimentary rocks and post-emplacement deposits can be a useful guide in constraining the tectonic setting of an ophiolitic sequence than the components of ophiolite itself. Even then, the huge pile of sedimentary rocks of Phulad ophiolite belt remained ignored till date and inferences/interpretation about processes and mechanism of crust building processes in this region are exclusively derived from magmatic rocks.

In the light of the above, the present study is undertaken using whole gamut of clastic rocks which include phyllites, fine to coarse grained quartzites, pelitic schists, greywackes, pelitic gneisses and calcareous pelitic gneisses (calc gneisses), to get an idea about the initial sediment detritus of the basin. Selected sedimentary rocks of underlying lithosequence of Phulad ophiolite belt have also been analyzed. Furthermore, in order to investigate secular changes in the chemistry of upper continental crust from Archean to Proterozoic, published geochemical data is used.

1.2. Aims and Objectives

The present study incorporates petrographic and geochemical investigation of clastic sedimentary rocks of Kumbalgarh Group associated with Phulad ophiolite (1800–Ma) and those of underlying Gogunda Group forming South Delhi Fold Belt of Aravalli Mountain Range, with the following aim and objectives:

1. A classical whole rock geochemical study of Kumbalgarh Group of Mesoproterozoic South Delhi Fold Belt.
2. To identify and delineate the provenance of the sediments of SDFB using Dickinson Scheme.

3. To unravel weathering and paleoclimatic conditions during sedimentation.

4. To understand tectonic setting of the sedimentary basin.

5. To investigate secular changes in the composition of continental crust from Archean to Proterozoic by comparing the present data with published data of older and younger ages.

6. To assess the implications of these data for evolutionary trends of early crust in the north western Indian shield and a comment on the changing climatic condition through geological times.

Present work is the maiden attempt to carry out a detailed geochemical investigation of sedimentary litho package of Phulad ophiolite belt. Although, there is enough literature available on geology, geochronology, mineralization and geochemistry of magmatic rocks of the area (Sen, 1980,1981; Gupta et al., 1980, 1997; Volpe and MacDougall, 1990; Sudgen et al., 1990; Bose et al., 1990; Fareeduddin and Bhattacharjee, 2000; Sinha Roy et al., 1995; Golani et al., 1998; Kirmani and Fareeduddin, 2000; Roy and Jakhar, 2002; Deb and Thorpe, 2004; Khan et al., 2005), but there is not a single published reference either on the petrography or on the geochemistry of these sediments.
Organization of the thesis

Chapter 1: Introduction and aims and objectives of present study.

Chapter 2: Deals with the general geological set-up of Aravalli cratonic block and stratigraphy of Kumbalgarh group.

Chapter 3: Contains details of petrographical study carried out on quartzites of Kumbalgarh Group.

Chapter 4: Describes the procedure adopted in sampling, sample preparation and techniques used for geochemical analysis of different sedimentary sequences.

Chapter 5: Contains results of geochemical analyses and detailed discussion on geochemical characteristics of Kumbalgarh clastic rocks in terms of major, trace and rare earth elements.

Chapter 6: Presents discussion regarding paleoweathering and paleoclimatic conditions.

Chapter 7: Deals with provenance characterization including source modeling and tectonic setting of Kumbalgarh sedimentary sequence using geochemical data. Investigation of secular changes in the composition of continental crust from Archean to Proterozoic.

Chapter 8: The summary and conclusion.