CHAPTER I
INTRODUCTION

The Proterozoic Eon of the earth's history was a period of accelerated crustal growth (Taylor and McLennan, 1985) during which mobile belts, sedimentary basins and the first stable cratons developed (Windley, 1984). The Proterozoic Eon represents the period of the earth's history that began 2.5 billion years ago and ended at ~ 542 million years ago. Abundant microscopic life, mostly bacteria and cyanobacteria flourished during this time. The first evidence of oxygen buildup in the atmosphere came with the beginning of Mesoproterozoic Era. This global catastrophe brought extinction of many bacterial groups, but made possible explosion of many. A large part of the Peninsular Indian shield is occupied by Meso-Proterozoic and Neo-Proterozoic platform covers. These vast sedimentary provinces (Figure 1) designated as the Puranas are the (1) Vindhyan Basin (2) Cuddapah-Kurnool Basin (3) Bhima Basin (4) Kaladgi Basin (5) Pranhita-Godavari Valley Basin (6) Chhattisgarh Basin (7) Indravati Basin (8) Khariar Basin (9) Abujhmar Basin (10) Bijawar Basin (11) Gwalior Basin and (12) Sukma or Sabari Basin. Although, in terms of their preservation geometry they appear to be discrete basins, it is hard to say whether, they represent separate basins or multiple depocentre within a large depositional area of sub-continental dimensions (Chakraborty, 2006).

Amongst the aforementioned basins, the Vindhyan basin, situated in the central part of India is one of the largest Meso-Neoproterozoic basins of the Indian Peninsula. It is arcuate in shape with large expanse of shallow marine sedimentary rocks of calcareous, argillaceous and arenaceous sediments. It covers an area of about 1,62,000km². The Vindhyan basin is bordered by the Aravalli-Delhi orogenic belt (2500-900Ma) (Roy, 1988) in the west, Son-Narmada lineament in the southwest and the Satpura orogenic belt (1600-850Ma) (Verma, 1991) in the southeast. The Bundelkhand Massif occupies the north-central part and is fringed by Paleoproterozoic Bijawar rocks along the
Figure 1. The Meso-Neoproterozoic Sedimentary Basins of Peninsular Indian Shield.
eastern edge and their equivalent Gwalior rocks. The basin shows geometry of a half graben (Ram et al., 1996) and is deepest towards the southwest in the proximity of Son-Narmada lineament. It gradually shallows up to the northwest towards Bundelkhand Massif. The northern extension of the basin in the Ganga Valley beneath the Gangetic alluvium is postulated based on geophysical and drilling data of Oil and Natural Gas Corporation of India. However, recently, the absence of Vindhyan sediments in the subsurface sequence of Ganga Valley has been reported based on acritarch studies (Prasad et al., 2005).

Although the rocks of Vindhyan Supergroup are generally flat resting unconformably over the Bundelkhand Granite at the northern margin of the basin, the southern and western margins of this sickle-shaped basin are folded and faulted showing tectonic contact with Pre-Vindhyan basement (Srivastava and Sahay, 2003). This basin is limited within two major faults, i.e., the Great Boundary Fault marking the northwestern margin and Central Indian Suture demarcating the southeastern margin. The maximum stratigraphic thickness of sedimentary fill exceeds about 4500m (Gokaran et al., 1995). The rocks, except near margins of the basin are predominantly undeformed, unmetamorphosed successions of sandstones, shales, carbonates, minor conglomerates and mafic volcanic products. The basin is spread over the states of Rajasthan, Madhya Pradesh, Uttar Pradesh and Bihar and divided into two sub-basins - Chambal Valley in the west and Son valley in the east. In the Chambal Valley, thick Neoproterozoic sediments corresponding to Rewa and Bhander groups of Vindhyan Supergroup are present and expose mainly calcareous and argillaceous facies in the northern part with rich algal mats (stromatolites). However, the southern part of Chambal Valley is covered by the Deccan Traps.

The geological investigation and studies in the Vindhyan basin were initiated from the mid 19th century. It attracted the attention of explorationists because of its large expanse of shallow marine sedimentary rocks and huge thickness. The Son Valley sector strikes ENE-WSW and its depositional axis runs close to Son-Narmada Lineament and swerves to the northwest in the Chambal Valley.
sector. Recently this basin has been taken up for oil and gas exploration and a wealth of subsurface information are available through bore hole logs (Sinha et al., 2002).

Vindhyan Basin comprises of about 6000+m of calcareous, argillaceous and arenaceous sediments deposited in shallow marine environment. Latest organic-walled microfossils (acritarch) evidences suggest the age range of Vindhyan Supergroup from 1500-550Ma with presence of major unconformities between the various subgroups (Prasad et al, 2005). While radiometric dates suggest the Vindhyan base at 1721±90Ma (Sarangi et al, 2004), Rohtas Group as 1550±40Ma (Sarangi et al, 2004) and Kaimur Group as 1140-900Ma (Vinogradov et al, 1964). Age of Rewa and Bhandar groups are well constrained by Vendian marker organic walled microfossils (Prasad, 2007) and Ediacaran soft bodied fossils (De, 2006) broadly suggesting a Neoproterozoic age. The entire basinal sequence of the Basin belongs to two distinct depositional cycles. The first one dominantly calcareous and argillaceous and is characteristically developed in the Lower Part (Lower Vindhyan). The second, arenaceous and argillaceous sequence, developed in the Upper Part (Upper Vindhyan).

The lithological assemblage of the Vindhyan Supergroup is further divided into Semri, Kaimur, Rewa and Bhandar groups (Table 1). Taking into account litho component variants, Bhandar, Rewa, Kaimur and Semri are the type areas of these consanguineous litho components. Vindhyan sediments are considered to have deposited in environments ranging from fluvial to deep marine (Bhattacharya and Morad, 1993; Bose and Chakraborty, 1994; Chakraborty, 1993; Chakraborty and Bhattacharya, 1996). According to Chanda and Bhattacharya (1982), the Vindhyan basin developed in an intracratonic embayment with conditions fluctuating from beach environment through tidal flat lagoon complex to tidal shelf along with barrier beach – dune complexes. Storm dominated sedimentation has been reported by Bose et al., (1988) and Chaudhari et al., (1999). Bose et al., (2001) suggested that Vindhyan
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<td><strong>Dhanda</strong>ul Quartzite&lt;br&gt;Scarp Sandstone &amp;&lt;br&gt;Conglomerate&lt;br&gt;<strong>Bijaigarh</strong> Shale&lt;br&gt;Upper Quartzite&lt;br&gt;Silicified Shale /<strong>Susnai</strong> Breccia&lt;br&gt;Lower Quartzite</td>
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**Semri**

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sedimentary rocks are mostly marine possibly deposited in an E-W elongated Epeiric Sea opening westward. Singh (1973) interpreted the depositional environment of the Vindhyan Basin which includes high gradient rivers to a complex interrelated with shallow marine environment. Srivastava and Sahay, (2003) suggested that the Vindhyan sediments were deposited by means of tidal and turbidity currents operating side by side near the continental platform region to give rise to quiet (stable) and agitated (unstable) depositional cycles. Gupta et al., (2003) postulated that the Vindhyan sediments were deposited under recurrent fluctuating sea level conditions. Sarkar et al., (2006) suggested that the deposition of Chorhat Sandstone of Semri Group ranges from shallow shelf to coastal margin with aeolian sand-sheets. Banerjee and Jeevankumar (2007), have suggested that the Rohtas Limestone of Semri Group was deposited in shallow agitated shelf environment. Sarkar et al., (2008) suggested that Sonia Sandstone of Bhander Group was laid down over a wider range of coastal environment, from the upper neritic transition to the supralittoral zone, shallow sublittoral- littoral-supralittoral transition.

**GEOLOGICAL SETTING**

The 4500m thick Vindhyan Supergroup is subdivided in two successions on the basis of their distinct tectonic settings. The Lower Vindhyan developed in an intracratonic rift basin (Bose et al., 1997), the Upper Vindhyan formed in an intracratonic sag basin (Sarkar et al., 2002) with a compressional interlude in between. The Upper Vindhyan comprises three formations, the Kaimur, Rewa and Bhandar in ascending order. The formations underlying the Bhander Group are entirely siliciclastic and inferred as fluvio-marine-eolian products (Bose and Chakraborty, 1994; Chakraborty, 1995; Bose et al., 2001). Their constituent beds are sub-horizontal and show evidence of mild deformation. The Bhander Formation comprises five members, the Ganurgarh shale, Bhandar Limestone, Lower Bhandar Sandstone, Sirbu Shale and Upper Bhandar Sandstone, from the base upwards; these units succeed fluvio-eolian deposits of the underlying
Rewa Formation (Bose and Chakraborty, 1994; Chakraborty, 1995) and maximum flooding is recorded above the base of the Sirbu Shale (Sarkar et al., 2002; Bose et al., 2001). An extensive carbonate sea developed at an early phase of the transgression (Ray et al., 2002). The Upper Bhandar Sandstone is the topmost unit of the Bhandar Group of the Vindhyan Supergroup and is well exposed, along with the younger members of the Bhandar Group in the central India (Sarkar et al., 2004). The Upper Bhandar Sandstone is, however, mainly terrestrial and of overall progradational affinity. The regional geological setting of the Vindhyan Basin is shown in (Figure 2).

**CHOICE AND LOCATION OF INVESTIGATED AREA**

The huge crystalline massif (Bundelkhand Granite) located in the northern part of the central sector of the Vindhyan Basin divides it into two blocks, a western and an eastern one. The rather inaccessible western block has received far less attention of the workers than the eastern one. In view of this the Upper Bhandar Sandstone formation of Bhandar Group has been chosen in this study which may help to partly unravel geological riddles about western block. Furthermore, the Upper Bhandar Sandstone occurring in the form of parallel ridges is the only exposed formation along Agra-Fatehpur Sikri tract and thus provides excellent opportunity to study the sedimentary attributes of the formation of Vindhyan Supergroup in this region (Figure 3).

The investigation area is spread over 70 square kilometers and is delimited by latitude 26°50' and 26°56'30" N and longitude 77° 25' and 77° 37' E within the Survey of India topographical sheets number 54F/5 and 54 F/9 and forms the northerly extension of great Vindhyan Basin. The area lies in the south-west of Agra-Fatehpur Sikri tract and represents small part of long belt of the Upper Bhandar Sandstone Formation which extends for about >100 km up to Karauli. The studied area has a dry climate with hot summers and cold winters intervened by a short monsoon season. Average rainfall is 657.8 mm. The land
Fig 2. Regional geological map of the Vindhyan Basin (modified after Soni et al. 1987)
Figure 3: Geological map of the study area in parts of Uttar Pradesh-Rajasthan States.
of this region is generally fertile and flat. The general strike of the area is approximately NE-SW. The amount of dip ranges between 3° to 35°.

**PREVIOUS WORK**

The European geographers who studied the area applied the name Vindhyan to the scarp “range” along the northern side of the Narmada Valley. In 1854, the Vindhyan Group of rocks attracted the attention of Geological Survey of India and Oldham (1859) used this name to designate the great sandstone formation of Bundelkhand and Malwa capitals. He also studied these rocks in Central India and proposed the name Vindhyan for the whole gamut of formations and classified them into three sub groups viz., Kaimur, Rewa and Bundair in ascending order. Medlicott (1859) surveyed the region north of Narmada Valley including Bundelkhand area and upheld Oldham’s classification. Mallet (1869) made a regional study of the Vindhyan rocks in northwestern and central part of the Vindhyan range. He retained the earlier classification but concluded that the “sub-Kymore” series of the Son-Valley and Semri series of Bundelkhand were one and the same. He subdivided the Vindhyan into Upper and Lower. The Kaimur and Rewa were placed in Upper Vindhyan, the Semri and Sub-Kaimur series in Lower Vindhyan. Later Hacket (1881) studied the present area, in the central and eastern Aravalli region. He described that the area lies on the long line of hills forming the northern edge of the Vindhyan plateau and extends from Fatehpur Sikri to southwestern direction through Rintumbour near Chittorgarh. Coulson (1927) mapped the Bundi state in Rajasthan and studied the Upper Vindhyan rocks in detail. Fox (1928) tried to solve the dispute of boundary between Upper and Lower Vindhyan. The break in sedimentation is proved by the presence of Sushi breccia and porcellanite which are proved to be most suitable horizons for placing the boundary between Upper and Lower Vindhyan. But Fox (1928) was unable to find this breccia insitu.

Auden (1933) surveyed the Vindhyan rocks in Son Valley (Mirzapur) originally surveyed by Mallet (1869) and later on by Vredenburg and Dutta
(1901). Vredenburg and Dutta (1901) divided the system into four more or less equipartite series, the Semri, Kaimur, Rewa, and Bhandar in ascending order. They discarded the term Lower and Upper Vindhyan.

Heron (1936) carried out detailed mapping of the entire region describing the stratigraphic sequence, lithology and structural feature of the Vindhyan rocks. Ahmad (1962) reconstructed the paleogeography of the Vindhyan basin, after studying the geology of Vindhyan system. He mainly discussed the source of Vindhyan sediments which in his opinion owed their origin to Aravalli craton. He also gave an idea that Aravallis were almost peneplained at the time of Vindhyan sedimentation and the western Rajputana basin was connected with the main eastern basin. Large part of the Vindhyan basin went to form a craton during Gondwana period and a great thickness of Bhandar and post- Bhandar beds have been removed. Ahmad (1962) concluded that post-Vindhyan but pre-Gondwana rocks were deposited in this area.

Basumallick (1961) discussed sedimentological features of the Bhandar Sandstone of Maihar, U.P. His studies were mainly based on directional elements; i.e., ripple marks, cross-stratifications and grain orientation noted in the Bhandar Sandstone and suggested a tidal flat environment for this rock.

Jafar et al., (1966) on the basis of palaeocurrent studies suggested that the Vindhyan sedimentation took place in two phases, i.e., in a restricted basin in Semri times and in an extended basin across Aravalli craton.

Akhtar (1978) studied the paleogeography and sediment dispersal pattern of the Vindhyan basin. He mainly discussed the shoreline, palaeoslope and dispersal pattern of the Proterozoic sediments comprising the Bhandar Group in Mandalgarh-Singoli area of southeastern Rajasthan and adjoining Madhya Pradesh. Earlier workers postulated a NW regional palaeoslope of the Vindhyan Basin on the assumption that the predominant palaeocurrent pattern reflected the palaeoslope. The study of Akhtar (1978) however, suggests that the predominant palaeocurrent pattern is independent of the palaeoslope and represents the longshore sediment dispersal. Singh (1980) worked on the
depositional environment of Bijaigarh Shale in Son valley are. His study revealed that the sediments were deposited in a transgressive phase which culminated in the development of extensive coastal sand deposits, overlying the Bijaigarh Shale.

*A number of workers give the geotectonic aspects of the Vindhyan basin e.g., Narian and Kaila, 1982 worked on the seismic data analysis of the Vindhyan basin along the Son Valley revealing several deep fractures within the crust underlying the Vindhyan and Mahakoshal belts of Son Valley as revealed by DSS profiling. Radhakrishna and Naqvi, 1986 stated that the two episode of collision in the north Indian Shield corresponding to the Paleoproterozoic Aravalli-Sakoli orogeny and Mesoproterozoic/Neoproterozoic Delhi-Sausar orogeny have been evolved probably as a curvilinear mobile belt (MPMB) following the boundary of Bundelkhand craton. Yedekar et al., 1990 has identified the Narmada-Son Lineament as the Central Indian Suture Zone (CISZ). Gravity and magnetic surveys in the Son Valley have revealed that the Mahakoshal are present under the Vindhyan occurring in successive, narrow, east-west trending zones (Das, 1988). Geophysical and deep drill-core studies have revealed the existence of the Vindhyan sediments under the Gangetic alluvium (Das, 1988; Kaila et al., 1989; Verma, 1991). Raza et al, 2009 stated that the lower Vindhyan volcano sedimentary succession was deformed and exposed to erosion before deposition of the upper Vindhyan rocks. The orogenic forces were active intermittently throughout the Vindhyan sedimentation. Chakraborty and Battacharya, 1996 delineated that the coarser Siliciclastic facies of the Vindhyan basin fluctuated among alluvial fan, braidplain, fan delta, eolian, shallow marine and lacustrine environment. The carbonates are interpreted to represent deposition in different parts of ramp setting varying from intertidal to deep offshore (Banerjee, 1997). Since then number of workers have made significant contributions on sedimentation history, depositional environment and age correlation of Vindhyan basin (Venkata Chala et al., 1996; Sarkar et al., 1998; Chakraborty et al., 1998; Bose et al., 1999, 2001; Gupta et al., 2003; Sarkar et al., 2004a; Sarangi et al., 2004; Banerjee and Kumar, 2007; Prasad, B. 2007; Sarkar et al., 2008),
suggesting depositional environment ranging from fluvio-deltaic to shallow marine environment, particularly in the eastern and central part of the Vindhyan basin. In contrast the western part of the Vindhyan basin has received little attention by the researchers. A few authors such as Coulson (1927), Heron (1936), Nazish (1972), Prasad (1984) and Mathur (1985) are confined to deciphering petrography and depositional environments of the youngest members of the Vindhyan basin outcropped in southwestern parts of the Uttar Pradesh and Rajasthan states. Nazish 1972, suggest that the upper Bhandar sandstone of Fatehpur Sikri area is highly mature and fall within orthoquartzite field. Prasad, 1984 and Mathur, 1985 suggested that the Fatehpur Sikri sandstone is deposited under barrier beach environment.

The western part of the basins to which the present study is virtually virgin for geological investigations in general and the sedimentological studies in particular. Therefore, there exists a gap in knowledge about the depositional environment, sediment dispersal and diagenetic aspects of the sedimentary succession in this part of the Vindhyan basin. The present study is an attempt to fill up this knowledge gap by taking up a detailed facies analysis, sediment dispersal patterns, provenance and diagenetic history of the Upper Bhandar sandstone of the basin in order to reconstruct the depositional model for the chosen area.

**AIM AND SCOPE OF INVESTIGATION**

The present study mainly aims at reconstructing the sedimentation and history of the Upper Bhandar Sandstone in western Vindhyan basin. For this purpose two field sessions were devoted during the month of December and January, 2006 and November, 2007 for detailed lithofacies studies, measurements of the sections, collection of paleocurrent data, and collection of samples for the follow up laboratory investigations. Thirteen well exposed lithostratigraphic sections were measured from different localities. Special attention was paid to study the nature of sedimentary structures like cross bedding, lamination, ripple marks etc. Lithologs were prepared on the basis of field data and litho facies were identified.
The 105 thin sections of the Bhander sandstone were used for petrographic analysis. Data were generated on textural attributes such as size, roundness and sphericity to interpret the provenance. Bivariant plots were used to find out the interrelationship of various textural attributes with the depositional setup of Upper Bhander Sandstone units. Cumulative frequency curves were plotted and statistical parameters of grain size were computed according to the method of Folk (1980).

Detrital mineralogy of the sandstone including lighter and heavy mineral fraction were studied for the purpose of the petrographic classification of the sandstones and their provenance interpretation. The classification scheme of Folk (1980) based on composition of the detrital constituents and classification scheme of Dickinson (1985) emphasizing the tectonic setting of provenance were used for the studied sandstones.

Palaeocurrent data was employed to interpret the dispersal pattern of the sediments. For this purpose azimuthal data collected on large scale planar and trough cross bedding was used. Study of palaeocurrent included construction of palaeocurrent maps at different levels of sampling and determination of statistical parameters of azimuthal variability at each level.

Diagenesis is an important aspect of sedimentological investigation but published studies dealing with this aspect are scarce, especially those made on Vindhyan sediments in parts of Uttar Pradesh and Rajasthan. In the present study an attempt is made to study the diagenetic history of the sediments. These sandstones were studied for compaction and cementation history. These data sets were analysed for the evolution of the types of grain contacts and porosity reduction.