Chapter-1

Introduction
Chapter – I

INTRODUCTION

1.1 Introduction

The Indian Proterozoic basins formed part of the northern rim of Gondwanaland prior to its dismemberment along six major radial fractures. In Peninsular India, the Proterozoic basins (Bikaner–Nagaur, Vindhyan, Cuddapah, Chhattisgarh, Bastar, Bhima and Kaladgi) cover a total area of 327830 km$^2$. They contain unmetamorphosed and relatively undeformed sediments resting unconformably on metamorphosed and deformed basement successions are commonly designated as the Purana successions in the Indian stratigraphy (Holland, 1907; Radhakrishna, 1987). The Purana Formations occur in a number of detached belts, presumably representing fills of different basins that developed on different Archaean/early Proterozoic cratonic blocks, encircled or separated by mobile belts (Fig. 1.1). The search for hydrocarbons in these Proterozoic basins is driven by the rapidly increasing energy demand in India, which already has highest annual rate of hydrocarbon consumption in the world. The information available from the limited Neoproterozoic–Cambrian outcrops is, however, inadequate for assessing the petroleum prospectivity of these basins, and most have not been fully explored for hydrocarbons.

The favorable tectonics indicating discrete episode of subsidence necessary for accumulation of organic rich sediments and entrapment conditions with numerous step faults corroborate further to the hydrocarbon potential of Vindhyan Basin, making it a geologically prospective Category III sedimentary basin of India (DGH, 2012). The Vindhyan are considered analogous in terms of their petroleum geology with the other Proterozoic sedimentary basins of the world which have shown commercial discovery of hydrocarbons (Jokhan Ram et al., 1996; Jokhan Ram, 2012; Vardhan et al., 2007; Cozzi et al., 2012). Therefore, the Vindhyan Basin is important as the sedimentological point of view.
Fig. 1.1: Distribution of Meso-Neoproterozoic sedimentary basins of Indian peninsular shield.
Vindhyan Basin is the largest Proterozoic basin that developed in the central part of the Indian shield. It covers an area of 1, 62,000 km² over the states of Rajasthan, Madhya Pradesh, Uttar Pradesh and Bihar (Fig. 1.2). It began as an intracratonic rift basin during Palaeoproterozoic times in extensional settings and subsequently converted to a passive margin set-up during the post-Neoproterozoic Era (Auden, 1933; Santosh, 2012). The Vindhyan sequence overlies a range of Precambrian basement rocks that form the basin floor. It is bounded by the Narmada-Son lineament towards south and extends northwards under the Indo-Gangetic plains (Jokhan Ram et al., 1996; Chakraborti, 2006). The Bundelkhand Granitic Complex lies in the center. The western part of Vindhyan Basin is mostly covered by the Deccan Traps. It consists of unmetamorphosed, tectonically less disturbed and well preserved Palaeo-Neoproterozoic sedimentary sequence in India (Auden, 1933; Srivastava et al., 1983). The Vindhyan succession is divided into the Lower Vindhyan (Semri Group) which is overlain unconformably by the Upper Vindhyan (Kaimur, Rewa, and Bhander Groups) (Sastri and Moitra, 1984; Prasad et al., 2005; Sharma and Shukla, 2012). The principal rock types include the quartzite, sandstone, shale and limestone. Radiometric dates bracket the age of the Vindhyan Supergroup between 1700 and 900 Ma (Rasmussen et al., 2002; Ray et al., 2003; Bengston et al., 2009; Gopalan et al., 2013). The basin is divided in two sub-basins, the Son Valley in the east and the Chambal Valley in the west (Fig. 1.2). Substantially thick Vindhyan rocks have also been recognized under the Gangetic alluvium. The duration of sedimentation, if continuous, is certainly among the longest in the world. The Vindhyan Basin parabolically encloses the Archean domain of Bundelkhand massif and lies in front of Aravalli and Satpura Orogenic Belts. The margins of the basin are demarcated by an arcuate thrust belt comprising the Mesoproterozoic Aravalli-Delhi Fold Belt (ADFB) and the Satpura Orogenic Belts (SB) referred to as the Mid-Proterozoic Mobile Belt (MPMB) of Radhakrishna and Naqvi (1986). It is believed that the basin was formed as a consequence of the collision of the Bundelkhand Craton with the Deccan, Protocontinent in the south and Mewar Craton in the north during the Early Mesoproterozoic period (Yedekar et al., 1990; Raza et al., 1993; Raza et al., 2009). The Proterozoic Vindhyan Supergroup of India has attracted the attention of geologists since 1856 owing to the presence of diverse rock types (Oldham, 1856). The entire basinal sequence belongs to two distinct depositional cycles.
Fig. 1.2: Generalized stratigraphy and correlations of the Vindhyan Supergroup for the Son Valley and Rajasthan sections. Age determinations from Gregory et al. (2006), Sarangi et al. (2004), Ray et al. (2003, 2002) and De (2006).
The first is dominantly calcareous and argillaceous and is characteristically developed in the lower part (Lower Vindhyan). The second is arenaceous and argillaceous nature of rocks is developed in the upper part (Upper Vindhyan). The Lower Vindhyan comprising Semri Group and the Upper Vindhyan comprising Kaimur, Rewa and Bhander Groups each separated by conglomerate units (Auden, 1933). These two depositional successions are separated by a well marked erosional unconformity (Jokhan Ram, 2012). Being exposed at the margins of the basin, the Semri Group is folded (Chakraborty, 1996), whereas Upper Vindhyan are known to be structurally undisturbed. The Vindhyan Basin (Fig. 1.3) is the largest of the Precambrian intracratonic sedimentary basins in India (Sastry and Moitra, 1984; Bhattacharya, 1996; Chaudhri et al., 1999; Bose et al., 2001; Ray and Chakraborty, 2006). It comprises of nearly 6000m thick sequence of largely undeformed- shales, sandstones, limestones, dolostones with subordinate felsic volcanics, which lies on top of the deformed metasediments of either Bijawar/Mahakoshal Group or Archaean gneissic basement. The Vindhyan Supergroup is divided into two sequences separated by an unconformity and a laterally correlatable conformity (Bose et al., 2001). The Lower Vindhyan (Semri Group) constitutes dominant carbonate deposit and the overlying Kaimur Group of siliciclastic deposit. A sharp upward transition from carbonates to siliciclastics across this surface reflects a basin-wide regression of the sea (Bose et al., 2001).

Sedimentation in the Vindhyan started before 1.7Ga until shortly after 1Ga (Sarangi et al., 2004; Gregory et al., 2006; Chakraborty, 2006; Malone et al., 2008). Kajrahat limestone and Deonar/Porcellanite Formation yielded a Pb–Pb age of 1721±90Ma and U–Pb ages of 1630–1631Ma, respectively (Rasmussen et al., 2002; Ray et al., 2002; Sarangi et al., 2004). Thus, the sedimentation in the Son Valley basin started sometime prior to 1721Ma and continued till ~650Ma. However, the upper limit of Vindhyan sedimentation has been bracketed down to 1Ma (Malone et al., 2008).

In a major turmoil in the Vindhyan chronostratigraphy and paleobiology, two startling fossil discoveries were published: firstly the trace fossils of ‘triploblastic animals’ (Seilacher et al., 1998) from the Chorhat Sandstone of the Lower Vindhyan with assigned age of more than 1.1 billion year, and secondly the small shelly fossils
Fig. 1.3: A part of the regional geological map of the Vindhyan Basin, Son Valley (modified after Soni et al., 1987).
of earliest Cambrian age (Precambrian-Cambrian boundary markers ~542Ma; Azmi, 1998a) from the Rohtasgarh Limestone that conformably lay little above the trace fossils-bearing Chorhat strata, suggesting far younger age than the traditional age of the Vindhyan Supergroup. But the record of the earliest Cambrian small shelly fossils indicating a major upward age revision of the Vindhyan Supergroup made claim of ‘deep’ metazoan origin in the Vindhyan succession a debatable issue (Azmi, 1998a, b; Brasier, 1998; Kerr, 1998a).

An evaluation between conflicting radiometric dates and evolutionary consistency in the Vindhyan fossil records, latter indicating Vendian - Early Cambrian age for the Vindhyan Supergroup (Azmi et al., 2007) is shown in (Fig. 1.4). However the age constraints for the Kaimur Group, derive from the Rb/Sr dating of a kimberlite pipe that intrudes the Kaimur Group at Majhgawan: Crawford and Compston (1970) reported 1140±247Ma. Kumar et al. (1993) reported 1067±31Ma, and Gregory et al. (2006) reported 1073.5±13.7Ma from the $^{40}\text{Ar}/^{39}\text{Ar}$ from the phologopite in the kimberlite pipe.

The Kaimur Group (400m) lies unconformably over a tilted, somewhat deformed and partially eroded Rohtasgarh Limestone of the Semri Group. The outcrops of the Semri and Kaimur Groups of the Son Valley bounded by Bundelkhand Gneissic Complex (BGC) to the north and Mahakoshal Group and Chhotanagpur Gneissic Complex (CGC) in the south. The Kaimur Group has been divided into Lower Kaimur Group and Upper Kaimur Group. The Lower Kaimur Group is further divided into the Sasaram Formation, the Ghurma Shale and the Markundi Sandstone. The Upper Kaimur Group comprises three lithounits (Fig. 1.5)- Bijaigarh Shale being the lowermost followed by the Scarp Sandstone and the Dhandraul Sandstone (Auden, 1933; Prakash and Dalela, 1982).

1.2 Stratigraphy of the Study Area

For the present study, four traverses were taken along Markundi Ghat section, Churk Markundi Road section, Barkacha Ghat section and Lakhania dari section in Sonbhadra and Mirzapur districts, respectively (Fig. 1.5). In these sections the Upper Kaimur Group (Dhandraul Sandstone, Scarp Sandstone and Bijaigarh Shale) is well exposed whereas Lower Kaimur Group is dislocated by the Markundi-Jamwal Fault (Prakash and Dalela, 1982).
Fig. 1.4: Conflicting radiometric dates and evolutionary consistency in the Vindhyan fossils records (modified after Azmi et al., 2007)
Fig 1.5: Detailed geological map of Vindhyan Supergroup in and around Sonbhadra and Mirzapur district, UP, India (modified after Auden, 1933; Sastry and Moitra, 1984).
Consequently, Bijaigarh Formation directly rests over the Semri Group. The relevant details pertaining the stratigraphy, lithology and structure of the Upper Kaimur Group are summarized in Table 1.1 and brief description of the these major lithounits are as follows-

**Dhandraul Sandstone** is characterized by mostly tabular and laterally persistent (for tens to hundreds of meters) white, coarse-grained quartzose sandstone beds with sharp boundaries. It also exhibits sedimentary structures such as large scale cross-bedding with long, low-angle foresets alternate with co-sets of parallel laminated sandstone, trough cross-bedding and ripple marks.

**Scarp Sandstone** is characterized by trough and planar cross bedded variegated medium-grained sandstone. It shows planar, laterally impersistent erosion surfaces, invariably carpeted by lensoid bodies of conglomerates, consisting of flattened and angular red shale pebbles of intraformational origin.

**Bijaigarh Shale** consists of 55-60m thick black splintery carbonaceous shale having millimeter thick lamination and meter to centimeter thick bands (locally) of pyrite. Further it is characterized by intercalated with thin beds of fine to very fine grained sandstones with cross-bedding, wave ripples, parallel bedding, wrinkle marks, rill marks mud cracks. Locally at some places it is marked as a capped by volcaniclastics (Chakraborty et al., 1996).

### 1.3 Geological Setting

In the Son Valley section, the Vindhyan Supergroup unconformably overlies the metamorphites of ~ 2500 Ma old (Rb-Sr) Bijawar Group of rocks (Crawford and Compston, 1970). The Vindhyan Basin is bordered by the Aravalli–Delhi orogenic belt (2500–900 Ma) (Roy, 1988) in the west while the Satpura Orogenic Belt (1600–850 Ma) (Verma, 1991) occurs to the south and east. The Bundelkhand granite massif (3.3–2.5 Ga) (Crawford and Compston, 1970; Mondal et al., 2002) occurring at the center of the basin divides it into two sub-basins—the Son Valley Vindhyan to the east and the Aravalli–Vindhyan to the west. Much of the northern part of the Vindhyan Basin along with the Aravalli–Delhi Fold Belt (ADFB) and the Bundelkhand granite-gneiss is overlain by recent alluvium of the Gangetic plain while
the southern part of the Vindhyan Basin is covered by the Deccan Trap lava (Cretaceous to Oligocene) (Krishnan, 1968). Along the southern edge of the Vindhyan Basin and along the eastern edge of the Bundelkhand granite-gneiss complex occurs a low-grade metamorphic group of volcano-sedimentary rocks, known as the Mahakoshal Group (2400 Ma) and the Bijawar Group (2100 Ma), respectively (Das et al., 1990; Roy and Bandyopadhyay, 1990).

The southern edge of the Vindhyan Basin is also marked by a major structural feature called the Narmada-Son lineament which is considered to have formed along Archean structural trends and remained active throughout its geologic history up to the present day (Naqvi and Rogers, 1987; Kaila et al., 1989). South of this lineament, a southerly dipping reverse fault separates the Vindhyan Supergroup rocks from the Satpura Belt in the Son Valley (Tewari, 1968). This faulting caused deformation of the Vindhyan sedimentary rocks exposed immediately to the north but cannot be traced farther west, as it is possibly covered by younger structures (Rogers, 1986).

The western margin of the Vindhyan Basin is marked by the Great Boundary Fault, another major lineament, characterized by westerly dipping faults, which separates the Vindhyan sedimentary rocks from the Aravalli-Delhi Fold Belt (ADFB) rocks. Major part of the basin consists of unmetamorphosed sediments providing suitable environment for the deposition of hydrocarbons.

The Vindhyan Basin consists of a thick pile of rocks occupying a large area extending from Sasaram (Bihar) in the east to Chittorgarh (Rajasthan) in the west and Dholpur (Rajasthan) in the north to Hoshanabad (Madhya Pradesh) in southwest comprising sandstones, shales and limestone. Outcrops of the Vindhyan Supergroup cover vast areas in the Son Valley, Central India. The Vindhyan sedimentary rocks are marine, possibly deposited in an E-W elongated epeiric sea opening westward (Chanda and Bhattacharya, 1982; Bose et al., 2001). The lower Vindhyan is considered to have been developed in an intracratonic rift basin (Bose et al., 1997), on the other hand, the Upper Vindhyan formed in an intracratonic sag basin (Sarkar et al., 2002) with a compressional interlude in between.
Table 1.1: Stratigraphy of Vindhyan Supergroup showing details of the Upper Kaimur Group (after Prakash and Dalela, 1982) with special reference to lithology and sedimentary structures.

<table>
<thead>
<tr>
<th>Group</th>
<th>Formation</th>
<th>Lithology</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhandari</td>
<td>Dhandraul Sandstone (120m)</td>
<td>Dominantly arenaceous (medium-to coarse-grained) texturally coarsening upward sequence, milky white and compact</td>
<td>Large scale cross bedding, through bedding ripple marks, tabular and lenticular beds</td>
</tr>
<tr>
<td>Bighthari</td>
<td>Scarp Sandstone (150m)</td>
<td>Medium-grained multicolored sandstone (pink to gray) sublitharenite, micaceous siltstone and sandstone</td>
<td>Cross bedding, fault gouge and breccia, water seepages, seepages, drag fold, ripple marks, clay galls</td>
</tr>
<tr>
<td>Kaimur</td>
<td>Bijaigarh Shale (25m)</td>
<td>Heterogeneous lithology, reddish brown to buff color shale ranging from siltstone to mudstone</td>
<td>Wavy laminations, Wavy pyritiferous laminae, microbial mats, mud cracks, ripple and wrinkle marks, flute casts, rain prints, adhesion marks</td>
</tr>
<tr>
<td>Lower Kaimur</td>
<td>Markundi Sandstone</td>
<td>Lower Kaimur formations are dislocated by Markundi-Jamwal fault (Prakash and Dalela, 1982)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ghurma Shale</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sasaram Sandstone</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Faulted/Normal contact

Lower Vindhyan/ Semri Group (760-3055m)
1.4 Location of the Study Area

The Upper Kaimur Group of Vindhyan Supergroup is exposed as a linear belt along the Son River in parts of the Sonbhadra and Mirzapur districts between latitude (24° 31′ to 25° 10′) and longitude (82° 45′ to 83° 10′). The area enjoys a typical tropical climate with distinct summer, rainy and winter seasons. Summers are hot and winters are cold with mean maximum and minimum temperatures of about 43ºC and 11ºC, respectively. The area is easily accessible by rail and road from all the major cities of India.

The Upper Kaimur Group of rocks can be studied by staying at Varanasi or Robertsganj or Mirzapur. However, if the section is covered from Varanasi via Robertsganj the following outcrops will be noticed: The Older Alluvium of the Quaternary Period covers the area around Varanasi. First outcrop of the Vindhyan Supergroup is exposed near Adalhat, about 24 km from Varanasi. Close to south of Ahraura (about 32 km from Varanasi) the regular ENE-WSW trending escarpments can be seen which are formed by the rocks of the Kaimur Group. The Dhandraul Sandstone comprising dirty white and buff, medium to fine grained sandstones exhibit profuse development of tabular and trough megacross-bedding. It is underlain by brownish red massive sandstone belonging to the Scarp Sandstone (the Mangesar Formation; Sastry and Moitra, 1984). The Dhandraul Sandstone occupies the plateau area of Robertsganj, the district headquarters of Sonbhadra. Thick soil and laterites cover large areas of the plateau. Further south, the excellent sections of both the Kaimur and Semri Groups are exposed along the Son River bank by cutting the Kaimur plateau. About 150 m thick Dhandraul Sandstone is exposed in the section, as one descends from the top of the scarp. It is underlain by the Scarp Sandstone (Mangesar Formation). The uppermost part of the Bijaigarh Shale is exposed at the base of the Scarp at Markundi Ghat. Samples were collected from different locations.

1.5 Previous Work

The Vindhyan Basin occupies a large area in Central India and attains a huge thickness of more than 5 km. The rocks are unmetamorphosed and undisturbed to moderately disturbed with low angle dips. Oldham (1856) was the first to use the term ‘Vindhyan’ for the entire group of rocks forming a prominent feature along the
northern bank of Narmada River known as Vindhya Parbat or Vindhyananchal. Oldham (1856) studied Vindhyan rocks of Central India and proposed the name for all the formations seen in the scarps of Vindhyan range and classified them into three subgroups, “Kymore”, “Rewah” and “Bundar” in ascending order. Medlicott (1859) in his report on the Vindhyan rocks of Bundelkhand agreed with the classification given by Oldham. However, he observed a group of rocks comprising limestone, shale and sandstone between the Vindhyan rocks and the crystalline basement and termed it Semri Group. Williams was the first geologist who studied the Vindhyan rocks of “Keymore” range in the west of the Son River in the early part of 1848. Auden (1933) made a detailed study of the stratigraphy and sedimentation of the Vindhyan rocks of the Son-Valley (Mirzapur District) and divided the system into four series namely Semeri, Kaimur, Rewa and Bhandar, but discarded the use of the terms "Lower" and "Upper" Vindhyan. He was the first worker to study the lithology of the rock types, origin and the physiographical conditions prevailed during the Vindhyan times.

Mallet (1869), after a regional study of Vindhyan rocks in northwestern and Central India finally correlated the “Semri Series” with “the Sub-Kymore Series” and included them in the Vindhyan System. He also introduced the term “Lower Vindhyan” for the “Semris” and “sub-kymores and grouped the other three sub units (“Kymores, Rewah, and Bundair”) into what he called the “Upper Vindh yans”. It is unfortunate that the “terms” “Upper” and “Lower” Vindhyan have persisted in literature despite the very valid objections raised by Auden (1933) and Ahmad (1971). Thus after the addition of a fourth sub-unit (Semri) to its base Oldham’s original lithostratigraphic classification became well established in Vindhyan stratigraphy and continues to be in use till date.

Much of our knowledge of Vindhyan stratigraphy is based on the early investigations of various parts of the Great Vindhyan Basin by the Geological Survey of India (Oldham, 1859; Medlicott, 1859; Mallet, 1869; Oldham et al., 1901; Heron, 1922, 1936; Coulson, 1927; Auden, 1933). Later, much valuable work has also been done by some universities of India, notably those of Lucknow, Calcutta, Banaras, Jadavpur and Aligarh. Excellent historical reviews of the Vindhyan literature have been presented by Ahmad (1962, 1971) and Misra (1969).
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 the Vindhyan system. He gave an idea that large part of the Vindhyan
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 Bhander and
post-Bhander beds have been removed. He concluded that post-Vindhyan but pre-
Gondwana rocks were deposited in this area. Basumalick (1962) concluded that
Bharder Sandstone deposited under tidal flat environment. 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 extended basin across
Aravalli Craton.

During last five decades, a great deal of work has been carried out on various
aspects of Vindhyan rocks such as stratigraphy and primary sedimentary structure
(Mishra and Awasthi, 1962; Prasad, 1976, 1984; Banerjee and Sinha, 1981; Valdiya,
1982; Soni et al., 1987; Prasad and Verma, 1991), Paleogeography and sedimentation
Ghosh, 1981; Chanda and Bhattacharya, 1982; Srivastava et al., 1983; Bhardwaj and
Mathur, 1989; Banerjee et al., 2006; Chakraborty, 2006), depositional environments
(Auden, 1933; Morad et al., 1991; Chakraborty and Bose, 1992; Bhattacharya and
Morad, 1993; Chakraborty, 1993, 1996; Bose et al., 2001; Paikaray et al., 2008;
Mishra and Sen, 2008, 2010; Aabiroo, 2010; Aabiroo et al., 2012; Quasim et al.,
2017), micro-and mega fossils (Kumar and Srivastava, 1992, 1995; Anbarasu, 2001;
Kumar, 1999, 2001, 2009; Kumar and Pandey, 2008, etc.), stromatolites (Kumar,
1976, 1980; Raha and Shastry, 1982; Valdiya, 1989), isotopic studies (Kumar et al.,
2002, 2005; Chakrabarty et al., 2007; Gopalan et al., 2013), few studies on the bulk
and molecular organic matter have been reported (Krishnamurthy et al., 1987;
Banerjee et al., 1992, 2006; Dutta et al., 2006).

Number of workers gave the geotectonic aspects of the Vindhyan Basin e.g.
Narain 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-Saucer 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 Bhattacharya (1996) delineated that the coarser siliciclastic facies of the Vindhyan Basin fluctuated among alluvial fan braid plain, 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., 1990, 2001; Gupta et al., 2003; Sarkar et al., 2004; Sarangi et al., 2004; Banerjee and Kumar, 2007; Prasad, 2007; Sarkar et al., 2008; Aabiroo, 2010; Aabiroo et al., 2012; Ahmad et al., 2012; Quasim et al., 2017) suggesting depositional environment ranging from fluvial-deltaic to shallow marine environment.

A few authors like Awasthi (1961, 1964), Mathur and Srivastava (1962) and Misra and Awasthi (1962) have studied the Vindhyan of Son Valley from sedimentological point of view, and suggested a shallow water environment for their deposition. Later workers (Banerjee, 1964, 1974; Singh, 1973, 1976) have interpreted depositional environments as varying from beach to barrier bar or shoal through tidal flat (sub-, inter-, and supra-tidal) and lagoon. The Kaimur Group in Rajasthan, India has been reported as a prograding storm and tide dominated (Bose et al., 1988; Chakraborty and Bose, 1990; Ruchi, 2013). Despite such important studies, the Upper
Kaimur Group remained the focus of discussion for its depositional environment mainly because of its sandy character, lacking fine-grained muddy facies and any diagnostic fossil or trace fossils present in them, 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 geochemistry, petrography and diagenetic history of the Upper Kaimur Group in order to reconstruct the depositional model, tectonic setting and diagenetic features of the study area.

1.6 Aim and Scope of Investigation

Despite deep longing of geologist in this area for professed cause, scanty attempts have been made for systematic sedimentological studies. Thus, the purpose of the present study is to carry out the lithofacies analysis, petrography, heavy mineral analysis, fluid inclusion studies, diagenesis and geochemistry of the Upper Kaimur Group rocks to interpret its depositional environment which is still in vague. It is further aimed to interpret the provenance, tectonic setting and diagenetic history of the Upper Kaimur Group of rocks. For this purpose two field sessions were devoted during the month of February 2014 and March 2015 for detailed lithofacies studies, measurement of sections, collection of palaeocurrent data and rock samples for the follow up laboratory investigations. The traverses were taken along Markundi-Ghat, Churk-Markundi Road, Barkachha Ghat and Lakhania Dari sections in Sonbhadra and Mirzapur districts. Four well exposed lithostratigraphic sections were measured from Markundi Ghat, Churk Markundi road, Barkachha Ghat and Lakhania Dari localities is based mainly on regional field work and augmented by laboratory techniques. During fieldwork, special attention was paid to study the nature of sedimentary structures, like cross-bedding, lamination, ripple marks etc. Lithosections were prepared on the basis of field data and lithofacies were identified and collection of representative samples from the measured sections of the Upper Kaimur Group of rocks in Son Valley was done. Lithofacies analysis was carried out to interpret the depositional environment of the Upper Kaimur Group of rocks that is based on field data.
Introduction

Thin section of sandstone samples were prepared and used for the petrographic study. The textural attributes of the sandstones, such as size, sorting, skewness, kurtosis, roundness and sphericity were studied with a view to interpret the depositional environment and to estimate the influence of texture on the detrital modes. Statistical parameters of grain size were computed according to the method of Folk (1980). Statistical measure for average grain size, sorting, skewness and kurtosis proposed by Folk and Ward (1957) were then obtained from values intersected at specific percentiles on these curves. Other grain size parameters determined includes maximum size, medium size, and “C” the first percentile in the grain size distribution (Passega, 1957). The grain size parameter were then plotted on the various bivariant diagrams or substituted into multivariate linear discriminant functions to find out interrelationship of various textural attributes.

Petrographic studies have shown that siliciclastic rocks can be used to identify the source area (provenance) as well as related geological processes responsible for deposition. The main purpose of this study is to interpret the sandstone petrography so as to characterize the detrital sediments of the Upper Kaimur Group and to infer its provenance. This will serve as a foundation in developing a depositional model of the Upper Kaimur Group of rocks in Son Valley. Detrital mineralogy of the sandstones, including light and heavy minerals fractions, were studied for the purpose of description and petrographic classification of the studied sandstones and interpretation of their provenance. Classification scheme of Folk (1980), based on composition of common detrital framework constituents and Dickinson’s (1985) classification, based on tectonic setting of provenance were employed in the present study. The factors of climate and transport that influence the framework composition of sandstones were studied to evaluate their effects on the detrital modes of sandstones.

An attempt has been made to study the diagenetic history of the sediments of Upper Kaimur Group of rocks. The study is based on thin-section petrography, scanning electron microscopy (SEM) and X-ray diffractometry (XRD). Samples selected for thin-section petrographic studies were impregnated with colored epoxy to facilitate the recognition of porosity. A modal analysis only for the interstitial component, counting 100 points per thin section, was performed by using detailed distinctions of several types of detrital and recrystalized matrix and authigenic
components (the latter as pore-filling cements or pore-lining clays and overgrowths of quartz and feldspars). The diagenetic history includes compaction, porosity reduction and cementation. The examination of thin sections includes various diagenetic aspects, such as types of grain contacts, porosity reduction and types of cement. A JEOL JSM-5800 LV scanning electron microscope (SEM) equipped with an EDAX energy dispersive X-ray spectrometer was used to observe the cement morphology, pore geometry, paragenetic relationships, textural relationships and porosity of the sandstone samples. Bulk and clay mineralogy was confirmed, and determined by X-ray diffraction (XRD).

The fluid inclusion study is also performed to know the P–T emplacement history of the fluids in the study area. The fluid inclusion study covers the fluid inclusion petrography, fluid chronology and microthermometry. The fluid chronology helps to explain the entrapment of various generation of fluid with time. The microthermometric measurements of fluid inclusions provide the temperature of initial melting/eutectic temperature ($T_{im}$), final melting temperature ($T_{fm}$) and homogenization temperature ($T_h$). These measurements will help understand the fluid composition, salinity, density and exhumation/upliftment history of the study area.

Nowadays there is a new emerging trend where sedimentological studies of clastic rocks are integrated with their geochemical data. Chemical compositions of clastic rocks are a powerful indicator for determination of their provenance, palaeoclimate and tectonic setting of sedimentary basins. Chemical variations of clastic sediments may yield useful information about sedimentary evaluation, and thus, the relationship between source area and sedimentary basin can be extracted through geochemistry. In accordance of this perspective geochemical analysis, including major and trace elements on both coarse and fine clastic rocks of the Upper Kaimur Group have been performed to evaluate the source rock composition and tectonic setting, and to infer the palaeo-weathering and climatic conditions which prevailed during the deposition of the Upper Kaimur Group of rocks.