SUMMARY AND CONCLUSION

The Vindhyan basin, situated in the central part of India is one of the largest Meso-Neoproterozoic basins of the Indian Peninsula. It extends over a strike length of more than 1,62,000 km in NE-SW direction. 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 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 Upper Bhandar Sandstone Formation which defines northerly extension of the great Vindhyan Basin is a fossil graben with over 4500m thick metasedimentary successions. The present investigation area spreads over 70 Square kilometers confining between latitude 26°50' and 26°56'30" north and longitude 77° 25' and 77° 37' east. The area lies in the south-west of Agra-Fatehpur Sikri tract and represents small part of the long belt of Upper Bhandar Sandstone Formation which extends for about >100km up to Karauli. The infillings of the Upper Bhandar Sandstones are composed of shale and thin bedded, fine to medium grained sandstone. The sandstone is hard and compact, dark red to brick red with white spots. Stratigraphically, the 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) and the Upper Vindhyan formed in an intracratonic sag basin (Sarkar et al., 2002) with a compression interlude in between. Each of this succession has been further sub-divided into formations and members in conformity with the 'code of stratigraphic nomenclature of India'.

In the present work, an attempt has been made to interpret the sedimentation and history of the Upper Bhander Sandstone in western Vindhyan basin by taking up a detailed analysis of lithofacies, sediment dispersal patterns, provenance and diagenetic history using sandstone petrography and diagenetic aspects as tools of the Upper Bhander sandstone in order to reconstruct the depositional model for the chosen area.

The study area of Upper Bhander Sandstone of Vindhyan Supergroup rocks is constituted by a heterogeneous assemblage of sandstones and shale which occur as scattered outcrops. Generally the Upper Bhander Sandstones exhibit variable colors of pink, red, brownish yellow, yellow and white etc. Most of the sandstones are hard and compact, massive and occasionally friable. Their is vertical variations in the primary sedimentary structures. These structures include tabular and trough cross-bedding, herring-bone cross-bedding, ripple marks, channel sandstone body, laminations etc. In the present work, thirteen lithostratigraphic sections are described. These sections were measured, analyzed in the field and (200) representative sandstone samples were collected for their petrographic examination. Amongst which 105 samples were finally chosen for the study. The sandstone samples were cut into standard
petrographic thin-sections. They were stained with cobaltinitrate for potassium feldspar recognition. 250 to 300 grains were counted per thin section. The traditional methods (Ingersoll et al., 1984) were used to classify and tabulation of grain types. Standard petrological techniques using a polarizing microscope were employed to describe the thin sections. Authigenic components (cement and matrix replacement constituents) were counted separately. The heavy mineral separation was done following Carver (1971), and identification was undertaken following Krumbein and Pettijohn (1938) as well as Milner (1962). Taylor (1950) method was applied for the study of the nature of detrital grain contacts and for computation of contact index; the method of Pettijohn et al., (1987) was used. The diagenetic process of sandstones was taken into account to check the modification of original detrital composition while attempting interpretation of provenance. Detrital mineralogy of the sandstones including lighter and heavy minerals were studied for the purpose of petrographic classification of the sandstones and interpretation of their provenance. Classification scheme of Folk (1980) based on composition of detrital constituents and Dickinson (1985) scheme based on the tectonic setting of the provenance were used.

Nine lithofacies are defined on the bases of lithology, sedimentary structures, geometry and palaeocurrent directions. The lithofacies are named and coded individually following Miall’s (1977) scheme. These are tabular cross-bedded sandstone facies, trough cross-bedded sandstone facies, massive sandstone facies, interbedded shale and fine grained sandstone facies, parallel laminated
sandstone facies, ripple laminated sandstone facies, shale facies, channel sandstone facies, and herringbone cross-bedded sandstone facies.

The statistical parameters of grain size analysis show that the sandstones are medium to fine grained, moderately to moderately well sorted, strongly fine skewed and mesokurtic to leptokurtic. Most of the grains are subangular to subrounded and have low sphericity. Bivariant plots of various parameters show no systematic relationship between mean size versus sorting, mean size versus roundness, mean size versus sphericity, roundness versus sorting and sphericity versus sorting. Overall textural maturity of the Upper Bhandar Sandstone can be considered as mature to supermature. The studied sandstones show bimodality in term of coarser and finer layers.

The depositional processes and environment have been employed to categorize three main genetic lithofacies assemblages. Facies association I (FAI) is constituted of lithofacies like tabular/trough cross-bedded sandstones, herringbone cross-bedded sandstones, wave ripple-bedded sandstone, parallel laminated sandstone along with interbedded shaly-thinly bedded fine grained sandstone and represents prograding high energy estuarine deposits. Facies association II (FAII) consists of a tabular package of tabular cross-bedded sandstones, trough cross-bedded sandstones, parallel laminated sandstone, massive sandstone and channel sandstone body and it represents tidal and ebb channel deposits. Facies association III (FAIII) represents foreshore-offshore deposits and is characterized by the presence of five lithofacies; large scale
tabular cross-bedded sandstones, symmetrical and asymmetrical ripple, interference ripples and laminated sandstone. These contrasting palaeoenvironmental settings suggest deposition at the basin margin, through several episodes of transgression and consecutive regression, evidence of which are well-documented in the study area. The polymodal to bimodal-bipolar pattern of tabular and trough cross-beds, lower value of vector magnitude (47%) and higher values of variance (7548) indicate large azimuthal dispersion perhaps due to diverse current system of coastal environment including tidal and longshore currents. The diagonally/opposite oriented modal classes of the two types of cross beddings at various sections of the study area are genetically significant and may correspond to ebb tidal/foreshore currents directed towards east or southeast and backshore/flood tidal currents parallel to or across the shoreline towards west or northwest.

According to Folk (1980) classification, the Upper Bhander Sandstone are mainly quartzarenite. The framework grains are mainly quartz followed by feldspar, rock fragments, micas and heavy minerals. Most of the quartz grains are monocrystalline, rest being polycrystalline. The monocrystalline quartz generally shows undulatory extinction. Polycrystalline quartz grains possess both sharp and sutured intercrystalline boundaries. Feldspars include plagioclase and microcline, both fresh and altered varieties. Biotite as well as large flakes of muscovite mica are observed. Rock fragments include chert, shale, schist, phyllite etc. Average detrital mineralogy includes monocrystalline quartz (90.98 %), polycrystalline recrystallised metamorphic
quartz (1.82 %), stretched metamorphic quartz (1.76 %), feldspar (2.10 %), rock fragments (2.42 %), mica and heavy minerals (0.92%). The detrital grains of the Upper Bhandar Sandstone are in the sand size range. Due to presence of small amount of feldspar and rock fragments in the studied sandstone, prolonged reworking and presence of high gradient stream is quite likely within the basin.

Occurrence of zircon, tourmaline, and rutile suggest an origin from igneous (plutonic) source rocks. Presence of epidote, garnet and staurolite indicate a source of metamorphic rocks (Wanas et al. 2006). Thus the suite of heavy minerals suggests various sources probably Precambrian metasediments, Bundelkhand massifs and granite-gneiss of Aravalli–Delhi Supergroup. These probable sources contributed the sediments to the basin from SW, NE and NW direction of the study area. The data on the types of quartz in diamond diagram yields consistent result that indicates a source area containing largely of plutonic and upper metamorphic rocks, which represent the exposed roots of magmatic cores or older crystalline basement in the area (Dickinson and Suczek, 1979).

To understand the tectonic settings of the Upper Bhandar Sandstone, all the petrofacies were plotted in the Qt-F-L, Qm-F-Lt, Qp-Lv-Ls, Qm-P-K standard diagram, given by Dickinson (1985). The Qt-F-L diagram which emphasizes factors controlled by provenance, relief, weathering and transport mechanism is based on total quartzose, feldspars and lithic content. Most of the samples lie in
continental block provenance field suggesting contribution from the craton interior with basement uplift. Rest of the samples fall in the recycled orogen provenance which suggest their derivation from metasedimentary and sedimentary rocks that were originally deposited along former passive continental margins (Dickinson, 1985). The Qm-F-Lt plot showed that the samples fall in continental block provenance with little contribution from the recycled orogen provenance. In the Qm-P-K diagram, the data lie in the continental block provenance reflecting maturity of sediments and stability of source area. In Qp-Lv-Ls plot, the sample data mostly fall in the intracratonic rift basin. Analysis of data from the plotting of triangular diagram doesn’t exactly suggest the same interpretation which is due to the weathering and post-diagenetic modification of the unstable minerals. Considering the analysis of data plotted on different triangular diagram, a tectonic collage can be suggested as tectonic setting. This interpretation is also supported by the evolutionary history of the Vindhyan Basin. The tectonic setting of the Vindhyan basin is seemingly akin to that of the Indus Ganga and Alpine basins, both located on underthrust plate and cited as example of peripheral foreland (Dickinson, 1974; Reading, 1986), foredeep (Miall, 1984, 2000) basin. The sedimentary fill and stable setting of the Vindhyan Basin are ‘however’, unlike those of the aforesaid foreland basins overlooking the rising fold belts of high relief, in which thick terrigenous sediments mainly comprising polymictic coarse clastics are deposited at a rapid rate. Moreover, paucity of coarse and polymict clasts and dominance of quartzarenite and good textural maturity in
the basal part of Vindhyan Supergroup (i.e., Semri Group) suggest that the highlands providing the sediment debris to the peripheral basin were reduced to low relief due to protracted erosion of the uplifted fold belt. This discrepancy in the post orogenic Vindhyan basin is inexplicable, pending relevant data in respect of the original deposition and abundance of sandstone and conglomerate facies and basement deepening (flexuring) in the basal/proximal parts. Dominance of quartzarenite and good textural maturity in the Upper Bhandar Sandstone suggest that the highlands formed by upliftment fold belts provided sediment debris to low relief area through their protracted erosion.

The studied sandstones are divided into two groups on the basis of diagenetic features, one group that was subjected to more compaction than cementation i.e., the lower part of the studied sandstone section which shows low porosity values leading to more compaction than cementation and other group that was subjected to more cementation than compaction i.e., the Upper part of the studied sandstone section where the original porosity value is comparably high leading to very little compaction before cementation. The sandstones consist of silty and clayey matrix. The matrix compositionally represents fine-grained monocrystalline quartz, muscovite and feldspar grains. The framework constituents of the Upper Bhandar Sandstone exhibit mainly long contacts (50%) followed by point contacts, which explains the high value of average contact index in the studied samples. Porosity of the sandstones is studied in terms of existing optical porosity (EOP) and minus cement porosity (MCP). Average percentage of EOP is 4 and average MCP percentage is 18. The
primary porosity of the rock is reduced by compaction and cementation through mechanical processes in the early stage of diagenesis, and through chemical processes in the later stage, which finally results in the generation of secondary porosity. Compaction, largely influenced by roundness of detrital particles was possible in the absence of an early major cementation phase that could have stabilized the detrital framework. Major diagenetic event was alteration and dissolution of feldspars. The feldspar grains show different stages of alteration. At places, complete dissolution of feldspar grains resulted in oversize pores. Dissolution and loss of feldspar can take place in the shallow weathering zone or in the deep surface (McBride, 1985). The shallow depth of burial and lack of illitization suggest that the feldspar in the studied sandstones were destroyed in the shallow weathering zone.