CHAPTER - IV

Geology
GEOLOGY

General Statement

The geology of Bharatpur district has been studied in detail (Heron 1917, 1922; Fermor, 1930; Pascoe, 1965; Iqbaluddin et al., 1978; Parsad, 1984; Singh, 1982, 1985, 1991). Geological information of Aligarh and Mathura districts is rudimentary, Bajpai and Gokhale (1986); Khan & Joshi (1985); Khan et al. (1987); Anon (1993) and Iqbaluddin (1996b) provided brief account of geology, but no published geological map is available for Aligarh and Mathura districts. The geological map of Bharatpur district has been published by Geological Survey of India (Anon, 1978).

The study area presents highly diverse rock types ranging from Precambrian metasediments to recent alluvial cover. The part of study area in Bharatpur district is tectonically, structurally and lithologically very complex and had attracted many workers (Heron, 1917, 1922; Fermor, 1930; Pascoe, 1965; Iqbaluddin et al., 1978; Parsad, 1984; Singh, 1982, 1985, 1991). It comprises rocks of Delhi Supergroup, Vindhyan Supergroup and Recent Quaternary sediments. The Vindhyan rocks are exposed in the eastern part of the Bharatpur district. The Great Boundary fault strikes NE-SW and passes through Bayana and Rupbas tahsils. The Delhi rocks are wide spread in the Bharatpur district and the best exposures are found near Bayana town in the Bayana basin. Bayana basin extends as an isolated sequence of outcrops from Bayana in the southeast to Nithar in the northwest over a strike length of about 31 kms. The rock belonging to the Delhi Supergroup are also exposed
in the northern part of the district in Kaman, Parahi and Deeg tahsils. The Aligarh, Mathura and central part of Bharatpur district presents almost a uniform alluvial plain. The depth to bed rock has been reported at >30 m in Bharatpur (Aggarwal, 1982), and 340 meters at Aligarh (Anon, 1977).

The stratigraphic sequence of the study area in Bharatpur district was established by Heron (1917). He used the term "Purana Group" and "Delhi System" and described the Bayana Basin under Alwar Series and divided it into five distinct stages namely, Nithar stage, Badalgarh stage, Bayana stage, Damdama stage and Weir stage, in descending order of antiquity. Pascoe (1965) adopted the classification proposed by Heron (1917). Singh (1982; 1985; 1991) carried out detailed mapping in the Bayana Basin and proposed a new stratigraphic succession. According to him basement rocks comprise Pre-Delhi metasediments and metabasites and are overlain by Railo Group, the oldest lithologic unit of Delhis in the area is the Railo Group, it is overlain by Alwar Group and the Ajabgarh Group, which are separated by unconformities, in Bharatpur district.

The rocks belonging to Vindhyan Supergroup have also been reported from Bharatpur district in the south-eastern part. The exposures correspond to the Rewa and Bhandar groups represented by Lower Rewa Sandstone, Gannurgarh Shales and Upper Bhandar Sandstone. The Delhi Supergroup and Vindhyan Supergroup in Bharatpur district are separated by Great Boundary Fault striking NE-SW. The rocks of Delhi Supergroup lie to the northwest of the fault and those of Vindhyan Supergroup to southeast of it.
The deposition of terrigenous clastics in the negative tectonic topography during the Quaternary period is represented by the Older Alluvium Group, Newer Alluvium Group and Recent Alluvium Group. The clastics were supplied from the newly risen mountains of Himalayas in the north and Vindhyan Plateau in the south.

Table - 15 presents the generalized stratigraphic succession of the study area and Table - 16 presents the lithostratigraphic sequence of the Bayana Basin. For purpose of Land System Studies the stratigraphy is presented under two subheads, namely basement rocks and Quaternary Cover sediments.
Table - 15 Stratigraphic sequence of the study area covering Aligarh, Mathura and Bharatpur districts

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<td>Vindhyan Super Group</td>
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<td>Delhi Super Group</td>
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**Basement Rocks**

**Pre-Delhi Rocks**

The basement rocks corresponding to Pre-Delhi's are exposed all along the southern margin of the Bayana basin over which Delhi rocks lie unconformably (Singh, 1982). The Pre-Delhi rock include schists, phyllites, minor quartzite's and highly altered basic rocks (probably volcanics) which have been cut by basic dyke e.g. near Madpur (Singh, 1982). The metasediments which have been described as Pre-Delhi by Singh (1982) possibly represents the Delhi metamorphics (?) older than Bayana sequence. Basement rocks are exposed in the areas, north of Bareja, south of Mangrain, south of Tharhi Bat, north of Ballabgarh, near Ghatri, Nithar and Aund.

**Delhi Supergroup**

The metasedimentary sequence referable to the middle Proterozoic, resting over the Pre-Aravallis in the northeastern Rajasthan has been referred to as Delhi Supergroup. The rocks of the Delhi Supergroup have been divided into Railo, Alwar and Ajabgarh Groups in the Bharatpur district of Rajasthan (Singh, 1977, 1982a, 1982b).

The quartzite interbedded with phyllite and schists have been mapped as Ajabgarh Group which are exposed in the Lalsot hills and continues northwards as isolated hills around Kaman and Pahari areas of Bharatpur.
district. These represent the northern most extension of Delhi Supergroup, the distal exposures are seen around Barasana-Nandgaon in Mathura district and around Dungrawan in Gurgaon district of Haryana, which continues northwards into the Union Territory of Delhi.

The volcano-sedimentary sequence exposed in the Bayana basin which has been correlated with the Railo and the Alwar groups by Singh (1982, 1988) deserve younger stratigraphic status than Ajabgarh Group. However the stratigraphic nomenclature adopted by GSI (Anon, 1978) for the rocks of the Mathura quadrangle (54 E) have been retained in the present write-up.

Lalsot Basin

The Lalsot basin extended from Lalsot in the south to Barsana-Nandgaon and Pahari in the north-east. The rocks of the Lalsot basin represent Ajabgarh sedimentation of the Delhi Supergroup. The beginning of the Ajabgarh was characterized by regional down warping and eliminating interbasin barriers as a result of which vast basin developed which extended upto Bharatpur in the east and Barsana-Goverdhan and Pahari in the north-east, it continued northwards through Haryana into the State of Delhi. This basin received sediments in multi-lagoonal tidal flats. In the Lalsot basin the rocks referable to Pratapgarh Formation of Alwar Group and Bharkol Formation of Ajabgarh Group are exposed in Lalsot hills, around Kaman and west of Pahari. Isolated outcrops are seen west of Sewar in Bharatpur District.
Alwar Group

An assemblage of quartzite, arkose, schists and conglomerate metamorphosed to green schist facies, resting over Railo Group in the type area was assigned to Alwar Group by Sant et al., (1980). The Alwar Group of rocks based on lithological inhomogeniety between lower coarse elastics and upper orthoquartzite sequence and the middle argillaceous metasediments in the type area was divided into Rajgarh, Kakarawali and Partabgarh formations by Sant et al., (1980).

In Bharatpur a domal outcrop of feldspathic sandstone and orthoquartzite exposed between Kaman and Pahari has been assigned Partapgarh Formation of Alwar Group (Anon,1978). The rocks of Partapgarh Formation are developed into northwesterly elongated dome. The outcrop is smooth, rounded extending over a length of about 10 km, from west of Kaman towards Pahari. The beds are having moderate to steep dips in a doubly plunging anticline, which is plunging 45° towards south-east and 40° towards north-west. The quartzite is dark gray, medium to coarse grained, moderately sorted, comprising quartz, feldspar and magnetite grains, which are cemented by siliceous and carbonaceous cement.

In thin sections the rock shows well rounded to very well rounded grains of quartz, which are inequigranular and are cemented with carbonaceous cement, the presence of chert in thin sections is reported in significant amount. The quartz grain show symmetrical extinction in cross section. The other minor constituents include feldspars, micas, opaque and tourmaline.
Intercalated with the feldspathic sandstone are orthoquartzite and dark green bands. The rock which is dark in color comprise quartz, feldspars, micas and iron oxide which are floating in a salt and pepper matrix of sericite and quartz. The sericite flakes appear to be alternating along two well defined cleavage sets of feldspar. The dark green rock occur as 1 - 2 meter thick bands intercalated with feldspathic sandstone.

In the Bayana basin Singh (1982b) has considered the Nithar Formation and Jahaz-Govindpura volcanics as representative of Railo Group and the overlying rocks of Damdama, Budgaon, Jogipura formations as representative of the Alwar Group in the Bharatpur District of Rajasthan. However in the present write-up, the rocks of the Bayana basin are considered younger in stratigraphy to the Railo, Alwar and Ajabgarh Groups and hence they have been dealt with as separate unit under Bayana Basin.

**Ajabgarh Group**

The dominantly argillaceous sequence with the subordinate calcareous and arenaceous silici-clastics developed around Ajabgarh in the Alwar district and regionally metamorphosed to green schist facies was mapped as Ajabgarh Series (Heron, 1935). Following norms of stratigraphic classification (Anon, 1971) the Ajabgarh Series was redesignated as Ajabgarh Group (Sant et al., 1980). The Ajabgarh Group has been divided into Kushalgarh Formation, Thana Ghazi Formation, Ajabgarh Formation, Arauli Formation and Bharkol Formation by Sant et al. (1980) in the type area of Alwar district.
In the Lalsot hills and further north in Kaman and Pahari areas of the Bharatpur district, the quartzite interbedded with phyllite and schist have been assigned to Bharkol Formation of Ajabgarh Group. The deposition of Alwar Group which took place in isolated basins was followed by Ajabgarh sedimentation which was herald by wide spread downwarping resulting in submergence of interbasinal barriers of Alwar times and the unified single basin developed (Singh, 1988), which was possibly transgressive and resulted in the deposition of a thick sequence of argillites interbedded with arenites and minor carbonates. The sedimentation took place in multilagoonal tidal flats which was at places interrupted by sub-aqueous/ sub-aerial volcanism (Heron, 1917; Singh, 1988).

In the Bharatpur district the quartzites interbedded with phyllites have been mapped as Bharkol Formation, isolated outcrops have been reported from west of Bharatpur at Sindholi, further north the outcrops are seen around Kaman and Pahari. The most interesting and instructive outcrop of Ajabgarh Group is seen north of Aund which extends as narrow ridge connecting the Bayana sub-basin with Lalsot Hills. The stratigraphic position of the ridge which extends from Morra in Sawai Madhopur district to Aund in Bharatpur district has been a subject of debate. Hacket (1881) referred it to the Weir stage of the Bayana Basin and Heron (1917) was inclined to consider it part of Nithar stage, Singh (1988) assigned these rocks to Ajabgarh Group which extended from Aund to Morra as a steeply dipping ridge punctuated at places by gaps which possibly represent wrench fault tectonics. West of Morra these rocks form gently dipping plateau overlooking the rocks of Lalsot hills.
On examination of rocks of the Bayana sub-basin and Ajabgarh Group of Lalsot hills it was found that there is no similarity of the Morra ridge with the volcano-sedimentary assemblage of the Bayana sub-basin. The dark gray and purple quartzite with argillaceous band of the Morra ridge are lithologically and structurally different from the pale colored and purely siliceous Weir quartzite and with Nithar quartzite with which they exhibit discordance of dips. The rocks of Nithar and Weir formations are characterized by moderate dips of 30° to 40° towards NNE to North, whereas the Ajabgarh quartzite of Morra ridge which continues upto Aund (with local gaps caused by wrench faults) is having a general NE-SW trends dipping sub-vertically to steeply towards NW. Local overturning due to wrench fault tectonics has been recorded in the Morra ridge quartzite.

Along the base of Ajabgarh quartzite in the area a pre-Delhi unconformity is concealed, which is locally exposed at places between Morra and Aund. At Khondra the schists and phyllite dipping 50° towards ESE possibly represents the pre-Delhi rocks which were earlier referred to as Aravalli System (Heron, 1917) and pre-Delhi (Singh, 1988). It appears logical to refer the pre-Delhi rocks to the Bhilwara Supergroup of Rajasthan. The exposures are so few and so much discontinuous that it is not possible at this stage of our work to suggest group or formational status for these pre-Delhi rocks within the Bhilwara Supergroup. From my earlier experience with the Aravalli rocks of Rajasthan, I am convinced that metasedimentary sequence at Kondra is not Aravalli.
The unconformity between the Pre-Delhi and the Ajabgarh Group between Morra and Aund is defined by paleosols which are developed as pure hardened pipe clay slightly mottled pale purple and pink. West of Morra the Ajabgarh rocks are folded into anticlines and synclines, north of Kamalpur near Dhawain the paleosols have developed into talcose bands which provide steatite deposit of Morra and Dhawain. Thus, it will be seen that the paleosols which are present as clay at Kondra have been metamorphosed as talcose schist at the base of the Ajabgarh quartzite. These paleosols define the unconformity between the Ajabgarh and the Pre-Delhi. From the nature of the unconformity it can be seen that the Delhi sediments were deposited over the peneplained basement in the Bharatpur district, whereas the rocks of Bayana basin were deposited in a tectonically active and geomorphologically inhomogenous environments. It is therefore considered desirable in the present write-up to separate the rocks of the Bayana basin from the older sequence of the Ajabgarh Group of Lalsot hills and their northern extension in Pahari and Kaman in Bharatpur district and at Barsana in Mathura district.

Bharkol Formation

The quartzite's of the Lalsot hills continued north-eastward through Govindgarh to Pahari and between east of Nagar to Barsana and Goverdhan in Mathura district, whence from northwards the rocks of Delhi Supergroup pass under the cover of the Indo-Gangetic alluvium. These quartzites have been mapped under Bharkol Formation of Ajabgarh Group (Anon, 1978). The quartzite occur as NE-SW trending ridges around Kaman and the ranges west
of Pahari. The quartzite is dark gray to light gray in color, thinly bedded with intercalation's of phyllite and graphitic mica schist. The quartzite is medium to coarse grained comprising dominantly of quartz; micas and magnetite occur as minor accessories. The quartz grains are equant in thin sections, the grains are devoid of any preferred orientation. The grain contacts are sutured which at many places have undergone pressure solution resulting in development of straight elongated contacts characterized by triple point junctions. A characteristic feature of this triple point contacts is development of seams along the contacts of the material which has escaped solution action. The removal of material is clearly brought out by seams of silica and insoluble residues which occur with optical discontinuity with the adjacent grains of quartz. The general paucity of undulose extinction in the quartz grains point that lithostatic stresses were dominant during the recrystallization history of the Bharkol Formation in Kaman area.

Intercalated with the quartzite, a meter and less thick partings of carbonaceous phyllite, phyllite and graphite mica schist are seen in the area around Kaman-Pahari road (Fig. 5). The schist has three prominent set of planar tectonic anisotropy. The bedding is defined by Q and M bands. The foliation is defined by preferred orientation of the micaceous minerals, sericite and graphite and elongation of quartz grains. This foliation is the regional foliation and is sub-parallel to stratification. Besides, a crenulation foliation is developed in which the earlier formed foliation has been puckered and the crenulation cleavage has developed at high angle to the $S_1$ planes in rock. It is defined by rotation of quartz grains and development of incipient planar tectonic anisotropy which is cutting across $S_0$ and M and Q domains ($S_1$), this
later foliation in thin section is present as $S_2$ planes. The development of snow ball structure in garnet is also seen in thin sections which indicate its syntectonic nature.

**Bayana Basin**

Bayana basin extends as an isolated sequence of outcrops from Bayana in the southeast to Nithar in the northwest over a strike length of about 31 Km. It represents a volcano-sedimentary assemblage which is separated from Delhis by a narrow gap of about 2 km alluvial cover in the northwest and from the Vindhyans by the Great Boundary Fault in the southeast. Structurally the Bayana rocks are different from the Delhi's and follow a general NW-SE strike in contrast to the north easterly trends of Delhis. The dip of Bayana sedimentary sequence is low to moderate, the average dip being $20^\circ$ in contrast to the moderate to steep dips of Delhi metasediments as seen in Lalsot hills. The Bayana rocks differ from the adjacent Vindhyans which are sub-horizontally to gently dipping.

The Bayana basin is lithologically, structurally and morphotectonically different from the Vindhyans in the south and Delhis in the west, possibly it is a younger rifted basin than the Delhis. The importance of Bayana basin lies in its volcano-sedimentary assemblage which may provide an opportunity to understand the crustal evolution of the Gondwanic Crust during the waning phase of the Proterozoic. The gray areas of the Bayana basin are its geochemistary and geochronology.
The igneous episodes that took place in the Vindhyan basin have been recorded from Jungel (Son Valley, U.P.), Majhgawan (M.P.) and Khairmalia volcanics (Rajasthan). It is likely that the volcano-sedimentary sequence of Bayana might represent an extended phase of the igneous episodes of the Vindhyan basin in Bharatpur district, Rajasthan (?)..

The three major paleo-volcanic centers represented by Jungel volcanics in the Son Valley, Khairmalia volcanics in Chittorgarh and Bayana volcanics in Bharatpur, Rajasthan show peribasinal association with Vindhyan rocks. The structural trends of the rocks of Delhi and Vindhyan Supergroups represent NE-SW trend but the rocks of Bayana basin show a NW-SE trend.

Heron's regional mapping of the Vindhyan basin was constrained by the concept that the Great Boundary Fault was the limit of Vindhyan sedimentation. Any rock to the north of the Great Boundary Fault was not included in the Vindhyans and in the regional context was assigned a pre-Vindhyan in the stratigraphy of Rajasthan. Revised mapping of Vindhyans in Rajasthan by Geological Survey of India in 1963-64 indicated the presence of Vindhyan rocks to the north of Great Boundary Fault in Chittorgarh district, it was suggested that the Great Boundary Fault was not the limit of deposition (Iqbaluddin, 1964). Later Balmiki Prasad and others substantiated that Vindhyan sedimentation extends to the north of Great Boundary Fault (see Iqbaluddin et. al., 1978; Prasad, 1984). If the Bayana rocks are seen in the context that Vindhyan sedimentation extended north of the Great Boundary Fault, perhaps flexibility in modeling the volcano-sedimentary assemblage of
the Bayana basin will be available and their lithological, metamorphic and
tectonic inhomogeniety with Delhi Supergroup can be understood.

The rocks of Bayana basin were deposited in a rifted basin whose boundaries
were defined by the Great Boundary Fault in the southeast and Barsana
lineament in the northwest. The volcano-sedimentary assemblage of the
Bayana basin was initially conceived to be restricted from Bayana in the east
and Nithar and Aund in the west. In the present write-up the carbonaceous
shale which are gently to sub-horizontally dipping and have been folded along
NW-SE trending axis, mapped as Arauli Formation in the area south-west of
Kunher and west of Deeg (Anon, 1978) have been included in the Bayana
basin. The lithostratigraphic nomenclature proposed by Singh (1982) has been
followed in the present write-up and the nomenclature proposed by Anon
(1978) for the sediments of Kumher and Deeg has been adopted and Arauli
Formation has been given the youngest stratigraphic position in the rocks of
Bayana Basin. It is proposed that the rocks of Bayana basin be included as
Bayana Group which has been tentatively accommodated as a youngest
Group in the Delhi Supergroup of Rajasthan to facilitate description of
lithotypes.

Bayana Group

The volcano-sedimentary assemblage deposited in the rifted basin bounded
by Great Boundary Fault in the southeast and Barsana lineament in the
northwest has been assigned to as Bayana Group. The sequence which was
mapped as Delhi Supergroup in the Bayana basin extending from Bayana to Aund and Arauli Formation in the Kumher and Deeg areas of Bharatpur have been included in the Bayana Group. The Bayana Group comprise in ascending order of antiquity:

Arauli Formation,
Weir Formation,
Damdama Formation,
Bayana Formation,
Badalgarh Formation, Bayana Group
Jogipura Formation,
Jahaz-Govindpura Formation,
Nithar Formation.

**Nithar Formation**

The basal sequence of the Bayana Group has been designated as Nithar Formation following Singh (1985). The Nithar Formation comprise conglomerate and quartzite. The rocks of Nithar Formation are exposed as isolated hills from Khankhera to katariapura and Aund, from the south of Nagla Gothia to Ghatri and around Rewalpura and Khareri in the Bayana tahsil of Bharatpur district. The maximum thickness of Nithar Formation is estimated to be around 200 m (Singh, 1985). The discordance of the Bayana Group with the underlying sequence of Ajabgarh Group is clearly brought out by the quartzite of the Nithar Formation at Aund, which exhibit structural
discordance with the pebbly quartzites of the Bharkol Formation of the Ajabgarh Group.

The conglomerates of Nithar Formation are best developed at Nithar and Aund. The phenoclasts are rounded, comprise gray and white quartzite, range in size from 5 - 40 cms and show moderate sphericity. The phenoclasts are coarser in the west and finer in the east. The framework is disrupted and there is no preferred fabric in the clastics. The interspaces are filled with coarse sand and quartz gravel. The sorting is poor and conglomerate appear to have been deposited by sudden loss in the energy of the transporting currents. The bedding in the conglomerate is defined by alternation of conglomerate and quartzite bands and at places by grain size variation in the phenoclasts population.

The basal conglomerate of the Nithar Formation is overlain by quartzite. The quartzite is gritty, at places pebbly and conglomeratic. Locally feldspathic bands are prominent within the quartzite sequence, It is white to gray in color, fine to coarse grained, moderately sorted to well sorted. The rounding of the clasts is highly variable from angular to sub-angular, some grains are sub-rounded to well rounded, which suggest bimodal source for clastics. At Ghatri the most illustrative section of quartzite of Nithar Formation is exposed where it exhibit a thickness of 20 m.

The quartzite comprises dominantly of quartz and minor amount of K-feldspar, sericite and muscovite occur as accessory minerals. The quartzite show well developed bedding, the beds are characterized by internal
organization, exhibited as planar and trough cross bedding. Convolute bedding and ripple marks are common in the quartzite.

Jahaz-Govindpura Formation

The volcanosedimentary assemblage conformably overlying the quartzite of Nithar Formation has been mapped as Jahaz-Govindpura Formation (Singh, 1982). The volcanics and volcani-clastics occur as interstratified sequence in the Jahaz-Govindpura area of the Bayana basin which represent one of the most illustrative section of continental rifting in the Bayana basin. The volcanics are divisible into three units (Banerjee and Singh, 1976, 1977). The lower unit of Jahaz-Govindpura Volcanics is characterized by quite eruption, the middle member represent highly explosive phase and the upper member again represent a quite phase. The formation has attained considerable thickness in Govindpura-Hathori anticline. The rocks of the Jahaz-Govindpura Volcanics Formation comprise basaltic flows, pyroclastics, flow breccia and inter beds of quartzite. The volcanics are intermittently seen from Nithar in the west, Govindpura, Jogipura, Khankhera and Rewalpura in the east. The most extensive and illustrative section of the volcanics is seen along the road from Ballabgarh to Hathori. Excellent development of the volcanic sequence is seen in the valley extending from Jahaz to Ghotia surrounded by the quartzite ridges which form a natural fortification for the volcanic outcrops around Jahaz. West of Hathori the volcanics are ubiquitously seen upto north of Ghatri where the quartzites of the Weir Formation forms an enveloping boundary for Jahaz-Govindpura Volcanics.
A total of 18 flows from Jahaz-Govindpura volcanics have been reported (Singh, 1982; Banarjee and Singh, 1976, 1977). Based on eruptive tectonics the Jahaz-Govindpura Volcanics have been separated into three units namely, lower, middle and upper. The lower unit is reported to have seven flows characterized by quite eruption, comprising basalts which are amygdoloidal and vesicular, fine grained, dark gray to green in color, the basalt is intercalated with volcani-clastics which are ferruginous at places. The middle unit is reported to have three to five flows with intercalation of agglomerate characterized with spatter pyroclastics, breccia, tuff which are bedded and silicified by chert. Intercalations of shale and quartzite are common in the middle unit. The agglomerate comprise bombs and lapillies of variable shape and sizes. Peals tear are seen beside bombs and blocks. The bombs are at places showing accretionary characteristics indicated by presence of concentric rings of tuffs around the bombs as seen in Hathori section.

The upper most member indicate eruption in quite phase. Singh (1982) has reported eight flows comprising massive vesicular and amygdoloidal basalt. Flow breccia and tuff which are welded and silicified with intercalation of chert and quartzite are recorded from the Jahaz area. The flows are both of "Pahoehoe" and "Aa" type. The Pahoehoe type are characterized by smooth rolling surfaces, showing exfoliation and spheroidal weathering, the Aa type occur associated with volcanic breccia exhibit rough surfaces and are generally associated with big irregular vesicles. The Aa type flows are common in Govindpura, Jogipura section and northeast of Jahaz.
The mineralogical constituents include plagioclase, pyroxene, hornblende, olivine and iron oxide. Epidote, chlorite, sericite, secondary cryptocrystalline quartz and calcite are present in the groundmass, devitrified glass is seen in chilled basalt and tuffs. Texturally, these rocks are microgranular, hypidiomorphic, intergranular, porphyritic and sub-ophitic to ophitic in nature.

The volcanism seen in the Govindpura-Jogipura section in time sequence has been equated with the Jahaz-Hathori volcanism (Singh, 1982). It has eventually led to the erroneous interpretation for the stratigraphy; these are possibly representing two different episodes of volcanism. The Govindpura-Jogipura paleo-volcanic center contributed volcanics at the top of the Nithar Formation and the Jahaz-Hathori paleo-volcanic center contributed volcanics above the Ballabgarh Formation. The stratigraphic assignment of the rocks by Singh (1982) above the volcanics to Jogipura Formation from Khagri to north of Hathori appears to be erroneous. However in the present image interpretation, the stratigraphy proposed in the geological map of the Geological Survey of India (Singh, 1982) in respect of Bayana basin has been accepted for land system study.

**Jogipura Formation**

The sedimentary sequence comprising quartzite and conglomerate resting with an unconformity over the Jahaz-Govindpura volcanics has been assigned to Jogipura Formation (Singh, 1982). The quartzite extending from south of
Bagrain to northeast of Govindpura resting over the volcanics in the Govindpura-Jogipura area and northwest of Nithar and the conglomerate horizon which overlie the volcanics in the area north of Hathori have been assigned as members of Jogipura Formation. The conglomerate horizon continues from Sita Kund towards southeast and shows facies change to quartzite which continues upto north of Khagleri as a continuos band trending northwest-southeast. East of Khagleri the continuity of the Jogipura Formation is punctuated by a fault. The rocks of Jogipura Formation have been mapped near Marpur and south of Alapuri in the Bayana syncline (Singh, 1982). Beyond the railway line the continuity of the outcrops is lost under the alluvial cover of Gambhir river in Bayana Tahsil.

**a. Quartzite**

The quartzite of the Jogipura Formation is at places arkosic and feldspathic with intercalation’s of the micaceous sandstone. Locally ferrugenous staining has given pink color to the quartzite. It is well bedded, locally pebbly, the pebbles comprise white quartz, jasper, slates, tuff and basic lava. The size of phenoclasts vary from few mm to 15 cm, these are rounded. The framework of the quartzite comprise quartz, feldspar, mica and opaques. Feldspars are generally pink, the quartz grains are rounded to sub-angular and are set in a matrix of fine feldspar, sericite and muscovite. Feldspars are generally altered, blue tourmaline and minor zircon are accessory, beside grains of iron oxide and iron coating along grain boundaries are common. The intercalation’s of conglomerates are seen within the quartzite. The bedding with internal organization is common, cross beds are well preserved, bedding
plane inhomogeneities such as ripple marks, shrinkage cracks and foam impressions are seen at some places in the quartzite of Jogipura Formation.

**b. Sita Conglomerate**

West of Sita Kund the Jogipura Formation is represented by conglomerate horizon which is persistent and rests over the volcanics north of Hathori. The conglomerate occurs above the pink quartzite of the Jogipura Formation. The pebbles of the conglomerate are well rounded, the phenoclasts comprise gray and pink quartzite with white quartz, jasper, basalt, tuff, slates. Near Maria insitu accumulation of mica schist derived from underlying Pre-Delhi rocks (Bhilwara Supergroup ?) have been reported by Singh (1982). The phenoclasts range in size from 2 cm to 10 cm, some of which are as large as 1 m. The average size is around 10 cms. The phenoclasts are set in a coarse gravelly matrix of quartz, the interspaces are filled with ferrigenous and siliceous cement. In stratigraphy the Sita Conglomerate and its eastern extension, developed as Jogipura quartzite, might represent a younger event in the sedimentary evolution of the Bayana basin than the Jogipura quartzite mapped south of Bagrain and around Madhopur and south of Alapuri.

**Badalgarh Formation**

A sequence of variegated arenites resting over the Jogipura Formation has been mapped as Badalgarh Formation. It comprise thinly bedded feldspathic quartzite, ferrigenous sandstone, arkose, pink quartzite and intercalation’s of schist. The rocks of the Badalgarh Formation are divisible into two units
namely Bagrain Sandstone and Alapuri Quartzite. The lower Bagrain Sandstone is characterized by dominance of metastable and labile components in the clastic population. The upper, Alapuri Quartzite is characteristically orthoquartzite and conglomeratic in nature.

a. Bagrain Sandstone

The type area of Bagrain Sandstone is the section exposed in the Bagrain village. The arenites comprise tuffaceous, micaceous and feldspathic sandstone, arkose, feldspathic quartzite and shale. The Bagrain Sandstone is medium grain, well bedded, comprising of well rounded equant grains of quartz and sub-rounded grains of feldspar; jasper, muscovite, magnetite, etc. are common accessories; tourmaline in several varieties of blue, olive, lemon, yellow, brown, etc. are present. Quartz grains constitute about 50% of clastic population and are set in a fine grained matrix of sericite and quartz. Micro-cross bedding is seen in the sandstone, ripple marks are rare, sparsely distributed shale discs have been reported from Bagrain Sandstone of the Badalgarh Formation by Singh (1982).

b. Alapuri Quartzite

Alapuri Quartzite overlies the Bagrain Sandstone, the contact between the two is conformable, and lithologically sharp. The Alapuri quartzite is coarse grain, gray in color comprising quartz; jasper and magnetite occur as common accessories. The quartzite is massive, bedding is generally well developed, ripple marked and cross bedded. Mineralogically, it is composed of inequigranular, perfectly rounded to sub-rounded grains of quartz and few rock fragments set in a matrix of quartz and fine flakes of sericite. The
phenoclasts of jasper, quartzite and chert are seen in some bands which occur as intercalation’s. This unit shows sharp contact with the overlying Mortalab Quartzite in the western part and gradational contact in the eastern part.

Bayana Formation

The thick sequence of orthoquartzite overlain by alternating beds of petromictic conglomerate and quartz arenite resting conformably over the Alapuri quartzite of Badalgarh Formation have been included in the Bayana Formation of the Bayana Group. The lower quartzite unit has been given the status of a member as Mortalab Quartzite and the upper sequence of conglomerate alternating with quartz arenite has been designated as Mahloni Conglomerate (Singh, 1982).

a. Mortalab Quartzite

It is essentially an orthoquartzite sequence which is prominently developed in the Bayana syncline and attain a maximum thickness of about 450 meters in the hinge zone of the Bayana syncline. The quartzite extends more or less as a continuos sequence from Shergarh in the east to 5 Km southeast of Sita. Locally the continuity is punctuated by faults across the strike. The Mortalab Quartzite gradually pinches westwards, till its outcrops are lost 5 Km southeast of Sita under the cover of overlying Mahloni Conglomerate-Quartzite sequence. The quartzite is pink in eastern part and changes from light pink to white towards the west. The quartzite is medium to fine grain, well sorted, well bedded, cherty looking. The grains are rounded to well
rounded, in textural composition it varies from sublithic arenite to quartz arenite. Mineralogically, quartz is the dominant mineral (monocrystalline and polycrystalline quartz) followed by chert, metasedimentary lithics and volcanic lithics in the framework. Muscovite, chlorite/biotite are distributed randomly as accessory within the quartzite. At places in the quartzite buff colored feldspar grains are also seen. Heavy minerals include tourmaline, opaques, rutile and zircon. The sorting is generally good, labile components constitute 5-10% of the rock. The weathered outcrops have rusty brown coatings generally associated with ferrugenous staining, on the bedding surface. The leached outcrops have brownish coating of dolomitic material (calc-tufa ?). The quartzite beds are relatively thin at the base and thicken upwards. Current bedding in the Mortalab Quartzite is seen only at places but generally the beds are devoid of any internal organization. The quartzite is highly jointed, the sub-horizontal joint sets are predominantly developed in the escarpment face overlooking Shergarh. The fractures are tensile, the sub-horizontal fracturing is generally associated with slight crushing and brecciation along the fractured surface suggesting minor adjustments. The Mortalab Quartzite strikes N70°W - S70°E and dips 33° N20E. The fault zone trending N40°E - S40°W and dips 43° N50W is also reported near Shergarh suggesting brittle failure.

**b. Mahloni Conglomerate**

Mortalab Quartzite is overlain by Mahloni Conglomerate, which occupies significant area around Mahloni and comprise of interstratified sequence of fanglomerate and ortho-quartzite. The fanglomerate occurs as polymict conglomerate in which the framework is intact. The sorting is extremely poor,
the large phenoclasts as big as 1 m occur in association with gravel of size of the peanut. The phenoclasts are generally large, 80% of phenoclasts are larger than 15 cms and 40% of phenoclasts are larger than 30 cms. Dominantly the conglomerate has phenoclasts of ortho-quartzite which are well bedded and at places cross bedded. The phenoclasts are equant to oblate in shape, sub-rounded to well rounded. Few pebbles of dark green color of volcanic origin are also seen in the matrix. The matrix comprises coarse sandy to gritty admixture of quartz and feldspar. A few fragments of feldspar, chert and jasper have also been noticed in the phenoclasts population. The isotropy in the fabric of the phenoclasts is significant. The outcrop of the conglomerate from a distance exhibit spectacular color banding of dark gray conglomeratic bands and earthy brown quartzite bands. The Mahloni conglomerate strikes N60°E - S60°W and dip varies from 45° to 49° N30W.

Lithologically quartz arenite of this member is very similar to Vindhyan sandstone (Bhandar Sandstone) seen at Fatehpur Sikri and adjacent areas south east of Bayana.

On the basis of distinct lithocharacters the Bayana Formation can easily be distinguished from upper and lower formations of Bayana Group.

The intercalated quartzite in the Maloni conglomerate are pink coarse grain and pebbly and becomes gritty in the upper stratigraphic levels. Locally feldspar becomes dominant and the arenite approximate an arkose. The conglomerate extends as a continuous horizon from Bayana in the east upto 1
Km east of Sitakund, whence from westwards the outcrop pinches out and is overlain by Kanawar quartzite of the Damdama Formation.

The conglomerate sequence which is developed north of Bagrain and south of Ghotia, juxtaposed with the volcanics, has been assigned to Mahloni conglomerate by Singh (1982).

**Damdama Formation**

A sequence of conglomerate, orthoquartzite, feldspathic arenites with intercalatory shales has been mapped as Damdama Formation after the village Damdama. The lower unit is conglomerate, middle is quartz arenite and upper is feldspathic sandstone, which have been given status of Umraind conglomerate, Kanawar Quartzite and Lakhanpur sandstone by Singh (1982).

*a. Umraind Conglomerate*

The conglomerate horizon developed from west of Bayana to WSW of Kherora as a wedge shaped outcrop resting over the Mahloni conglomerate has been assigned as Umraind Conglomerate. The outcrop is seen from Bayana to Imlia Biskhori, whence from upto Mahloni, the continuity of outcrop is punctuated by faulting. North of Mahloni the outcrops are intermittently seen upto Umraind (whence from the name for the conglomerate member has been given) thereafter west of Umraind, the conglomerate horizon is fault bounded and continues as a wedge between the underlying Mahloni Conglomerate and overlying Kanawar Quartzite.
The separation of the Umraind Conglomerate from the underlying Mahloni Conglomerate of Bayana Formation to an uninitiated geologist will appear arbitrary.

The Umraind Conglomerate is poorly sorted, at places bedding is defined by size variation of the phenoclasts which occur as pebble conglomerate, boulder conglomerate and cobble conglomerate beds in vertical section. The conglomerate predominantly has phenoclasts composed of quartzite and white vein quartz, besides, its framework constituents have basic rocks, jasper, shale, re-worked conglomerate, mica and tourmaline. The phenoclasts population points to pre-Delhi and Jahaz-Govindpura Volcanics as possible source rocks for Umraind Conglomerate. The matrix is variable in texture and composition from place to place. It is quartzofeldspathic sand and granules with admixture of micaceous constituents. The matrix is moderately rounded and sorted, beds exhibit internal organization as co-set, cross beds which suggest wave dominated environment. The thickness of the Umraind Conglomerate is maximum in the eastern part which progressively wedge out 2 Km east of Sitakund.

b. Kanawar Quartzite
The quartzite sequence developed west of Kanawar, northwest of Bayana and as a more or less continuos band from Bhagora to 1.5 Km east of Sita has been mapped as Kanawar Quartzite. This unit is indistinguishable from the Mortalab Quartzite of the underlying Bayana Formation. Singh (1982) assigned it status of a member in the Damdama Formation because of its younger position in the stratigraphy of the Bayana sub-basin. It comprise sub-
angular grains of quartz, which are coarse and are set in a matrix of quartz, sericite, muscovite and feldspar. Feldspars are generally sericitized, rounded and spherical clasts of tourmaline are common which occur in shade of blue, orange and yellow. The quartzite is separated by sandstone which Singh (1982) mapped as Lathanpur Sandstone on the basis of its quartzo-feldspathic nature, and separated from Kanawar Quartzite. The Kanawar Quartzite is well bedded, showing ripple marks and cross bedding, the thickness of the cross bedded unit vary from few centimeters to over 1 meter; at places it exhibits foresets and backset in the cross-bedded units.

c. **Lakhanpur Sandstone**

It represents the youngest member of the Damdama Formation. It comprise feldspathic sandstone, which has intercalation's of quartz arenite and brown shale. The sandstone being feldspathic is prone to easy weathering and erosion, as a result the outcrop density of Lakhanpur Sandstone is low, the member occurs as isolated outcrops between Baghora and 5 Km east of Sita. The sandstone is thinly bedded, the bedding is defined by alternating layers of feldspathic and micaceous bands. It is cross bedded and has ripple marks which are developed as bedding plane inhomogenities. The Lakhanpur Sandstone at places is overlain by shales and carbonaceous phyllites which have been locally mapped north of Sita and northwest of Khairora. These outcrops have been given status of Kushalgarh Formation by Singh (1982). However author is inclined to include them as part of Lakhanpur Sandstone which is reported to have inter bands of laminated brown shale near Khairora, (Singh, 1982). The Kushalgarh Formation of Ajabgarh Group reported by Singh (1982) has no validity in the stratigraphy of the Bayana Group.
Weir Formation

The rocks of Damdama Formation are overlain by quartzite which is white, locally rusty brown due to ferrugenous staining. The quartzite is prominently developed south of Weir, whence from the formation derives its name. It forms sinuous ridge from Bhajuli in the east to east of Randhargarh. The continuity of the outcrop is punctuated by transverse faults which are geomorphologically expressed as wind gaps and saddles.

The quartzite is medium to coarse grained, moderately well sorted to well sorted in nature, at places due to leaching the quartzite exhibit rough and spongy surface which has deceptive appearance of trace fossils. The quartzite exhibit bedding plane inhomogeneities as ripple marks which are both asymmetrical and symmetrical. The ripple index varies from 3 to 5. The bedding is defined by color banding and grain size variation within the quartzite. Generally the quartzite is having internal organization exhibited as planar cross beds, locally it is massive, white and crystalline and can be used as glass sand. Its use as ornamental stone has remained unexplored, in some of the sections examined north of Hathori it shows excellent development and can provide material which may be useful as building stone. Its ability to take polish need to be explored.

The Weir Formation apparently appears to be end of Bayana basin but in the present write-up the carbonaceous shale outcrops developed intermittently between Weir and Deeg have been considered part of the Bayana basin
whose limits are defined by Great Boundary Fault in the south and Barsana lineament in the north.

**Arauli Formation**

The rocks referred to as Arauli Formation (Anon, 1978) have been included as younger sequence of the Bayana Group. Earlier the carbonaceous phyllite, shales and slates exposed around Deeg, southwest of Kumher and west of Kathena were assigned to Arauli Formation of Ajabgarh Group. The inclusion of Arauli Formation in Bayana Group has been prompted by gentle to moderate dips with little deformation in contrast to the pervasive and penetrative north-easterly steeply dipping trends of the planar tectonic anisotropy characteristic of Ajabgarh Group of the Delhi Supergroup. The rocks of Arauli Formation in Bharatpur district are recorded from Hindupura, southwest of Kumher and Deeg. The carbonaceous phyllite occur as isolated hillocks, medium to dark gray in color, thinly bedded and exhibit fine parallel lamination. Southwest of Deeg town the Carbonaceous shales have interbeds of sandstone (Fig. 5). Sandstone is occurring as 1 meter and less thick intercalation’s with several joint sets, cross bedding and convolute lamination are characteristically present within sandstone layer.
**Vindhyan Supergroup**

The rocks of Vindhyan Basin represents the northwestern extension of the Karauli sequence in the district which has been studied in some detail (Heron, 1917). The Vindhyans in Bharatpur district are represented by the Rewa and Bhandar groups.

**Rewa Group**

The Rewa Group in Bharatpur district is represented by a sandstone which forms low strike ridges from Nagal upto Baretha lake whence from northwards the continuity of the outcrops has been punctuated by wrench fault. The outcrops of the Rewa sandstone extend through Jatrauli along a NE - SW strike upto right bank of Banganga river, whence from northeastwards the Vindhyans go under alluvial cover. The sandstone developed in the Bharatpur district as first bed of Vindhyan possibly represents the Upper Rewa Sandstone. It occurs as northeast-southwest trending strike ridge. The north western abutment of the Baretha lake represents the Rewa Sandstone which is rusty brown in color well bedded arkose. The quartz grains are medium to coarse grain, the feldspar is white to slightly pinkish which constitutes 10-20% of the rock. The arkose is cemented by ferruginous cement. The development of the arkose possibly as the first bed of Vindhyan in Bharatpur district reflects a mixed metamorphic and igneous provenance, for the Vindhyan basement in Bharatpur.
In the sections the quartz grains are of two types namely, the metamorphic quartz which is represented by grains having sutured boundaries with the clastics, the other quartz is having clear grain boundaries with small inclusions. The feldspars are generally sericitised. A few grains exhibit faintly developed cross hatch twinning indicating the presence of microcline, within the feldspar population, plagioclase grains are significantly absent in the clasts of the Rewa sandstone. The cement is chert impregnated with hematite. Ferrugeneous coatings along grain boundary outline are characteristically present along the quartz grains.

**Bhander Group**

The Bhander Group is most conspicuously developed in the Rupbas Tahsil of Bharatpur district, forming the plateau along the southeastern boundary of the Bharatpur district. It occurs as natural fortification overlooking the plains of Ghambhir river. The Bhander Group is represented by Ganurgarh Shale and Upper Bhander Sandstone. The carbonate horizons associated with the Bhander Group have not been recorded from the area. Though the subsurface drilling carried out in the Banganga basin by Central Ground Water Board has reported occurrence of a limestone horizon north of the Great Boundary Fault in Bharatpur and adjoining areas (Mehta and Dhiman, 1980).
**Ganurgarh Shale Formation**

The outcrops of Ganurgarh Shale are not exposed. The sub-crops of shales between the Rewa Sandstone and the Upper Bhandar Sandstone are referable to Ganurgarh Shale Formation, which are seen in well sections.

The Ganurgarh shales are sandy, bright and greenish in color, the thin partings of sandstone are common in the Ganurgarh shale. The bedding being dominant plane of fissibility in the Ganurgarh shales has given rise to flaggy strata, which provides good aquifer zones in the villages located above the Ganurgarh Shale horizon.

**Upper Bhandar Sandstone Formation**

The Upper Bhandar Sandstone form the surface of the plateau south of the Gambhir river. It comprise medium to coarse grain, thin to thick bedded sandstone, the sandstone is characteristically dark red with spots and splashes of fawn. At places white to buff color sandstone beds are seen without any staining. The sandstone is hard, compact, well bedded and come out in slabs of suitable thickness and dimension.

As a result the red spotted Upper Bhandar Sandstone is one of the most extensively used building material in northern India. The architectural work of Fatehpur Sikri, Agra, Delhi and former princely state of Bharatpur are excellent examples of the full utilization of the Upper Bhandar Sandstone as a
building resource. The Upper Bhandar Sandstone is unimodal, fine grain, well rounded and well sorted, comprising mostly of quartz as coarse clastics. The paucity of the micaceous and sheet minerals has made this sandstone suitable as building material. The red color is due to ferruginous cement which has prevaded the rock.

The amenability of the Upper Bhandar Sandstone to fine carving has open up new opportunities to export it as a value added product. The local artisans of Bharatpur district need to be encouraged under microlevel developmental planning to exploit Upper Bhandar Sandstone for export market.

**Quaternary Supergroup**

**General Statement**

The Quaternary sediments of the study area forms part of the Indo-Gangetic plain. These sediments were deposited over a basement formed by Proterozoics of the Indian Shield in the southern part and the thrustsed Tertiary sediments in the northern part of the basin (Sastri et al., 1971; Rao, 1973). The Quaternary sediments comprising admixture of sand, silt and clay were deposited in negative tectonic topography, which received sediments from the rivers debouching both from the Vindhyan Upland in the south and newly risen mountains of Himalaya in the north. The alluvium sand and gravel, that filled the negative tectonic topography during the Quaternary period
constitute the vast alluvial plain. In the present study the Quaternary sediments have been separated into three groups namely, Older Alluvium Group, Newer Alluvium Group and Recent Alluvium Group in descending order of antiquity based on transgressive spatial relationship and superposition.

**Older Alluvium Group**

In the present study the Older Alluvium has been divided into two formations namely, Varanasi Older Alluvial Formation (VOA) (Joshi & Bhartiya, 1991; Gupta & Gupta, 1992) which is Older Alluvium sensu-stricto (Krishnan, 1982) and Aligarh Older Alluvial Formation (AOA) (Iqbaluddin, 1992). Aligarh Older Alluvial Formation has been delineated as outliers within the Varanasi Older Alluvial Formation (VOA). For the purpose of stratigraphic description the Aligarh Older Alluvial Formation (AOA) and Varanasi Older Alluvial Formation (VOA) have been grouped in the Older Alluvium Group.

**Varanasi Older Alluvial Formation (VOA)**

Varanasi Older Alluvial Formation is the base of Quaternary sediments in the study area deposited over the eroded basement of Vindhyans and Delhi Supergroup. The Varanasi Older Alluvial Formation has a thickness of about 276 m as indicated by sub-surface borehole logs (Anon, 1994).
The elastics of this formation were deposited over the Delhi metasediments and Upper Vindhyan rocks with a first order unconformity. This formation is dominated by very fine sand clastics averaging 67.36% of the clastic population. The examination of the available vertical sections indicate that the upper most few meters thick mass of sediments are oxidized and show khaki to brown color while the lower sediments are of gray color.

The sediments are characterized by lateral persistence uniformity of bedding and unimodal as well as bimodal distribution of the clastics. The upper part of the Varanasi Older Alluvial Formation is deficient in finer clastics. Fig. 2 shows the average percent of clastics in Varanasi Older Alluvial Formation.

The basal sediments of the VOA have been mostly derived from Vindhyan uplands and represent a clastogenic assemblage of the southern provenance. The quartz grains are subangular to well rounded and have high sphericity. Synsedimentary washout, breaks in deposition and occurrence of sandy sediments indicate deposition in closed shallow inland basin. The Caspian sea is possibly the present day analog of the Quartenary sea of Varanasi Older Alluvial Formation which received clastics from northern and southern provenance’s. The northern shore were encircled by high mountains of Himalaya and the southern shore encompassed a low coast platformal characters, where relief difference between the provenance and the depositional areas was not of a very high order.

The sediment samples of Varanasi Older Alluvial Formation collected from field were analyzed for their mineral composition. Quartz occur in abundance
(84.34%), feldspar, garnet and rock fragments are common. The rock
fragments are of siltstone, chert and phyllites. The other accessory minerals
are tremolite/actinolite, muscovite, biotite, hornblende, tourmaline, zircon,
rutile, opaques, sillimanite, apatite, kyanite, epidote and staurolite. Fig. 6
represents the mineralogenic population of VOA Formation.

The textural, granulometric analysis of sediments indicates that the sediments
in general are fine textured, the mean size (Mz) ranges from 5.26 \( \phi \) to 3.4 \( \phi \). The standard deviation (\( \sigma_1 \)) values range between 1.31\( \phi \) to 2.54 \( \phi \) indicating poorly sorted to very poorly sorted sediments, the skewness values are 0.52 to 0.70 suggesting strongly fine skewed and kurtosis values are 0.59 to 1.97 corresponding to very platykurtic to very leptokurtic clastics.

The VOA shows wide range of mean size which suggests variation in the
intensity of depositing currents, which is reflected in bimodal distribution of
the clastics (Visher,1969; Singh and Bhardwaj,1991). Poorly to very poorly
sorted nature of the sediments indicate variable depositing currents. The
skewness measures the degree of asymmetry as well as the "sign". The
granulometric results show positive skewness which indicates excess fine
material. Symmetrical distribution of sediments has Skewness value 0. All the
samples show asymmetrical distribution of sediments. Kurtosis is the
quantitative measure used to describe departure from normality. Few samples
show better sorting in the central part which are said to be leptokurtic while
the others show better sorting at tails which are said to be platykurtic.
The sand of Varanasi Older Alluvial Formation fall under the sub-litharenite class (Folk's, 1980). The heavy mineral assemblage like kyanite, sillimanite, staurolite, garnet, rutile, zircon, tourmaline, hornblende indicates possibly mixed Himalayan and Indian Shield provenance’s for Varanasi Older Alluvial Formation (Khan and Rawat, 1992; Gupta and Gupta, 1992).

Fig. 6. Histogram showing mineral population in Varanasi Older Alluvial Formation
Aligarh Older Alluvial Formation (AOA)

The Varanasi Older Alluvial Formation is overlain by channel fills and flood plain deposits of north flowing palaeodrainage which emerged from Vindhyan uplands and debouched in central depression around Meerut (Iqbaluddin, 1997). The deposits of the north flowing paleo-drainage represent Aligarh Older Alluvial Formation (AOA), which were first recognized in Aligarh District (Samdani, 1990; Iqbaluddin, 1992). The AOA lies as outlier within the Varanasi Older Alluvial Formation (Fig. 5). The clastics of the AOA rests with disconformity over the VOA. The AOA comprise clay, silt and sand deposits in various proportions (Fig. 4) and vary in thickness from few meters to over 20 meters. The unit of stratification varies from thin bedding to fine laminations (McKee and Weir, 1953). The beds have lateral persistence and are characterized by compositional homogeneity over large tracts. Paucity of coarse clastics in the AOA, distinguish it from the underlying sandy horizons of VOA.

The mineralogic constituents of AOA comprise quartz in abundance (88.75%), feldspar, opaques and rock fragments are common. The accessory minerals are muscovite, tourmaline, zircon, rutile and kaoline the mineral species of AOA are less in number than VOA. Fig. 7 presents the mineralogical composition of AOA.

The textural, granulometric analysis of (AOA) formation shows that the mean size (Mz) range from 5.63 $\phi$ to 4.63 $\phi$, standard deviation ($\sigma_1$) varies from 2.34 $\phi$ to 1.83 $\phi$ indicating very poorly sorted to poorly sorted sediments,
skewness values are 0.73 to 0.28 corresponding to strongly fine skewed to fine skewed and kurtosis values range from 0.99 to 0.48 which suggest mesokurtic to very platykurtic clastics. The mean size of AOA is within narrow size range suggesting that during the process of deposition, the combined hydraulic factors (discharge, density, depth and velocity) attained by the depositing current system and bed roughness were more or less alike (Moss, 1963; Visher, 1969). Positive values of skewness show asymmetrical distribution of sediments. The kurtosis values show that the sediments are better sorted in the tails. Fig. 4 shows the distribution of clastics in AOA.
Fig. 5. Histogram showing mineral population in Aligarh Older Alluvial Formation
Newer Alluvium Group

The term Newer Alluvium has been used in its original sense for the sediments which occur along Yamuna river and its tributaries as Khadar deposits (Krishnan, 1982; Khan and Rawat, 1992). This Newer Alluvium has been assigned group status in the stratigraphy and has been included under Newer Alluvium Group. The Newer Alluvium Group comprise terrace deposits of the paleo-flood plain of Yamuna, which have been mapped as Yamuna Terrace Alluvial Formation.

After deposition of AOA a new drainage system evolved leading to the entrenchment the river Yamuna in the VOA (Joshi and Bhartiya, 1991; Khan and Rawat, 1992). The Newer Alluvium is the third cycle of fluvial sediments deposited in Ganga-Yamuna-Doab. The term Newer Alluvium was introduced to describe the sediments of the paleo-flood plain of Ganga and its tributary rivers. The flood plain deposits have been locally described as khadar and consists of light colored mud, clay, silt and sand which geomorphologically form terraces (Gupta and Gupta, 1992; Thussu et al., 1992) For the purpose of stratigraphic description the Newer Alluvium is described as Yamuna Terrace Alluvial Formation in the study area.
Yamuna Terrace Alluvial Formation (YTA)

The paleo flood plain deposit of Yamuna which occur as linear stretch between VOA and Recent flood plain of Yamuna have been mapped as YTA. The development of YTA represents a period of rejuvenation when the river possibly due to lowering of sea level cut through the earlier flood plain and later started depositing silt and clay with admixture of sand. The sediments of YTA are unoxidized, gray in color, varying in thickness from 4 to 10 m. The bedding is defined by parallel laminations and climbing ripple laminations. Kankar is developed in clay beds. Some lensoid fine sand bodies occur in clay beds. These lensiod sand bodies occuring in clay have been described as crevass splay deposits. These deposits resulted due to sudden fluctuation in the current velocity eroding the clayey deposits and depositing fine sand in lensoid shape.

The mineral assemblage occuring in the YTA is quartz in abundance (81.87%), rock fragments, felspars and garnet are common and tremolite/actinolite, mica, hornblende, tourmaline, opaques, sillimanite, kyanite, epidote, titanite occur as accessory minerals in YTA (Fig. 9). The mineral species occuring in this formation are derived from Himalayan provenance.

The granulometric results of YTA are Mean size (Mz) ranges from 4.66 $\phi$ to 4.88 $\phi$ standard deviation ($\sigma$) from 1.74 $\phi$ to 1.94 $\phi$, skewness from 0.56 to 0.75 and kurtosis from 0.9 to 1.15. The mean size range of this formation is very low and suggest uniform velocity of depositing current, which is
reflected in unimodal distribution of clastics. The skewness value show asymmetrical distribution of clasts. The kurtosis values show better sorting both in central part and in tails. Fig. 8 presents the average percent of the clastics in YTA.

Figure - 8 : Clastic Population of Yamuna Terrace Alluvial Formation
Recent Alluvium Group

The youngest sedimentary cycle has been mapped as Recent Alluvium Group which comprise sand, silt and clay admixture developed along recent flood plain of Yamuna and its tributaries.
The deposit of sand and silt with admixture of clay and mud seen along the recent flood plain of Yamuna have been assigned as Recent Alluvium Group. It represents sediments of post Glacial period roughly corresponding to Mesolithic to present day. The sediments comprise loose unconsolidated sand, silt and clay admixture deposited along the active flood plain of Yamuna and its tributaries. The sediments of Recent Alluvium Group comprise recent flood plain deposits which have been described as Yamuna Recent Alluvial Formation in Aligarh and Mathura districts, Banganga Recent Alluvial Formation and Bharatpur Loam Formation in Bharatpur district.

**Yamuna Recent Alluvial Formation (YRA)**

The active alluvium of the recent flood plain and associated T₀ terrace along the Yamuna river together with the channel deposit of sand, silt and clay have been mapped as Yamuna Recent Alluvial Formation (YRA). The sediments of the YRA formation exhibit transgressive relationship with the underlying VOA sediments. Sand fraction is maximum followed by clay and silt in YRA (Fig. 10). The river Yamuna passing through the Mathura and Aligarh districts has sinuous course representing typical point bar deposits. The point bar deposits at the base represent large scale trough cross beds followed by large scale climbing ripples, parallel laminations and massive clay at the top (Fig. 5). The clay beds are impregnated with kankar. On remotely sensed data of LANDSAT TM FCC this lithological unit is recognized by its medium to dark tone, indicating high moisture content in the soil, extensive agricultural practice and association with present day drainage channels.
Mineralogical study of YRA shows that quartz occurs in abundance (81.09%) and rock fragments, mica, feldspar, garnet, opaques are common while hornblende, zircon, rutile, sillimanite are accessory minerals. Fig. 11 presents the mineral population of YRA. Petrographically the sediments of YRA are sublithic arenite like the Ganga Recent Alluvium (Singh et al., 1993).

The textural characters of YRA represents that Mean size (Mz) is 3.53 $\phi$, standard deviation ($\sigma_t$) is 1.02 $\phi$, skewness is 0.45 and kurtosis 0.29. The poorly sorted and bimodal distribution reveals variable depositing currents. Kurtosis value indicate that sediments are well sorted in the tails.

Figure - 10: Clastic Population of Yamuna Recent Alluvial Formation
Bharatpur Loam Formation

This formation is characterized by mixture of aeolian and alluvial sediments and is separated by a disconformity with Aligarh Older Alluvial Formation. The sediments of Bharatpur Loam Formation have been derived from adjacent Alwar district in the west and the provenence limit of this deposit is possibly the Aravalli Orographic axis. This lithological unit is well developed in Bharatpur district it pinches out and terminate west of Bharatpur town making a lithological contact with Aligarh Older Alluvial Formation. The
Bharatpur Loam Formation exhibit overlap on Aligarh Older Alluvial sediments. Its stratigraphic position is uncertain within Recent Alluvium Group, for purpose of description it has been tentatively placed above Yamuna Recent Alluvial Formation (YRA).

The sediments of this unit are predominantly sandy in nature, sub-angular to sub-rounded. Granometrically these comprise 68% sand, 28% silt and 4% clay (Fig. 12).

This lithological unit is identified on TM FCC data by its light to medium tone, irregular lithological boundary outline, association with erosional and structural hills belonging to Delhi and Vindhyan Supergroups, scanty vegetation and low locked up moisture. This unit occupies a major part of the Bharatpur district and extend from north to south adjacent to Aravalli hills and Vindhyan plateau in the district.

The mineralogical constituents of Bharatpur Loam Formation include quartz in abundance, micas and feldspars are common. The other accessory minerals include rutile, tourmaline, zircon, epidote, garnet, opaques, etc. Fig. 13 presents the mineralogical population of this formation. The textural parameters of this formation indicate that their mean size (Mz) range from 6.64 φ to 3.63 φ, standard deviation range from 3.15 φ to 0.64 φ. The values for kurtosis (KG) range from 3.92 to 1.46 and Skewness (SK₁) values range from 0.71 to -1.03. These parameters indicate that the sediments of Bharatpur Loam Formation are medium to coarse grained, moderately well sorted to
poorly sorted, fine skewed to strongly coarse skewed and leptokurtic to extremely leptokurtic in nature.

The geotechnical parameters have also been determined for the Quaternary sediments of Bharatpur Loam Formation, its Liquid limit range from 10.0 to 23.75, Plastic limit vary from 12.04 to 32.70 and Flow index from 9.25 to 17.50.

![Figure - 12: Clastic Population of Bharatpur Loam Formation](image)
Banganga Recent Alluvial Formation

It is the youngest stratigraphic unit in the study area which comprise flood plain deposits of Banganga river which enters into the district from Alwar district in the west. Banganga river is a typical example of the entrenched river which is cutting across the earlier Quaternary deposits and depositing the fresh sand, silt and clay in its flood plain, which extends across 2 to 3 kilometers on its right and left banks. Due to the low channel depth, the river
causes frequent sheet flooding in the district during the monsoon season. The Banganga Recent Alluvial Formation is referable to Recent Alluvial Group in the Quaternary Stratigraphy of Indo-Gangetic plain.

The formation is recognized on the TM FCC by its light tone, first order drainage channels joining the main Banganga river, abandoned/dry channels, scars, low settlement density and scanty vegetation. This formation stretches in a linear pattern from west to east along the course of river Banganga.

The mineralogical constituents of this formation include quartz in abundance, micas and feldspars are common. The accessory minerals include tourmaline, zircon, epidote, garnet, staurolite, spinel, opaques and rock fragments. Fig. 14 presents the mineralogical population of Banganga Recent Alluvial Formation.

Granometrically these comprise 66% sand, 30% silt and 4% clay (Fig. 15). The textural parameters of this formation indicate that their mean size (Mz) range from $3.56 \phi$ to $5.06 \phi$, standard deviation range from $0.50 \phi$ to $1.34 \phi$. The values for kurtosis (KG) range from 0.83 to 4.81 and Skewness (SK$_1$) values range from 0.25 to -0.02. These parameters indicate medium to fine grained sand, moderately well sorted to poorly sorted, fine skewed to near symmetrical and platykurtic to extremely leptokurtic nature of clastics in the flood plain deposits of the river.
Figure 14: Mineralogic Polysparion of Banana Creek Alluvial Formation
The geotechnical parameters have also been determined. Liquid limit range from 9.25 to 13.25, Plastic limit vary from 15.34 to 22.65 and Flow index from 11.5 to 21.00.
Table - 15 Stratigraphic sequence of study area covering parts of Yamuna basin in Aligarh, Mathura and Bharatpur districts.

<table>
<thead>
<tr>
<th>Super Group</th>
<th>Group</th>
<th>Formation</th>
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</table>
| Quaternary  | Recent Alluvium Group | - Banganga Recent Alluvium Formation  
|             |       | - Bharatpur Loam Deposit  
|             |       | - Yamuna Recent Alluvial Formation (YRA) |
|             | Newer Alluvium Group | - Yamuna Terrace Alluvial Formation (YTA) |
|             | Older Alluvium Group | - Aligarh Older Alluvial Formation (AOA)  
|             |       | - Varanasi Older Alluvial Formation (AOA) |
| Vindhyan Super Group | Bhandar Group | - Upper Bhandar Sandstone  
|                     |       | - Gannurgarh Shales |
| Rewa Group |       | - Lower Rewa Sandstone |
| Delhi Super Group | Ajabgarh Group | - Arauli Formation  
|                 |       | - Bhakrol Formation  
|                 |       | - Weir Formation  
|                 |       | - Kushalgarh Formation |
| Alwar Group |       | - Damdama Formation  
|             |       | - Bayana Formation  
|             |       | - Badalgarh Formation  
|             |       | - Jogipura Formation |
| Railo Group |       | - Jahaz-Govindpura Volcanics  
|             |       | - Nithar Formation |
| Pre Delhi |       | |

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Table - 16 Lithostratigraphic Sequence of the Bayana Basin

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<th>Group</th>
<th>System</th>
<th>Series</th>
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