Chapter 3.
Regional Geology
3.1 Geological setup

The great Indo-Gangetic plains with an area of about 85000 km² are regarded as a major unit of geology in the Indian sub continent. These plains often referred as Indo-Gangetic trough are tectonically formed in front of the rising Himalayas in the north and elevated peninsular shield in the south. This plain though appearing to be one vast stretch embraces several sub basins with an uneven floor with hidden ridges. Based on seismic and borehole data, the Indo-Gangetic plains are divisible into five parts (Fig.3.1) (Rao, 1973), from west to east which are as follows:

- The Indus basin in Pakistan.
- The Punjab basin in the Punjab.
- The Ganga basin in U.P. and Bihar.
- The Brahmaputra basin in Assam.
- The Ganga – Brahmaputra basin in west Bengal and Bangladesh.

Each of these basins may be divided into shelf zones and a frontal deep part where the basement lies at a depth of 3000 m or more, there is however no natural dividing line, such as hinge line, between two parts except in the Bengal basin. These basins have been delineated on the basis of sub surface ridges and highs. For details concerning the geophysical limits of these basins and review of the sub surface structures, geology, configuration of Indo-Gangetic plains, reference may be made to the works of Sastri et al., (1971) and Rao (1973).

The brief review of sub-surface features of the Punjab basin of which the study area forms a part is given below:

The Punjab wedge i.e. the Archean basement rocks either outcropping or occurring under moderate thickness of alluvium in the Lahore –Sargodha area, separates the Indus basin in the west from the Punjab depression from the east. An account of aeromagnetic surveys carried out in the basin (Sengupta et al., 1962) has provided indications of basement depths under these plains. The results of
gravity surveys in the Punjab, Ganga valley in Assam (Ratnam et al., 1963), together with the accounts of seismic surveys in the Punjab (Datta et al., 1964) has furnished very useful information on subsurface structures. The tectonic map of India (O.N.G.C., 1968) shows the solid geology and structures of the rock covered by alluvium in these plains. Krishnan (1968) has given a summarized account of subsurface geology of entire Indo-Gangetic plains.

The Punjab basin follows a NW-SE and ESE and almost EW course in conformity with the trend of Siwaliks hills. Following underground ridges/ basement highs bound this basin: -

1. Lahore –Sargodha ridge on the west. This is an Archean basement ridge, which separates the Indus basin from the Punjab depression on the east.
2. Delhi- Jagadhari ridge on the east. This is a basement high which controls the water divide between the Punjab rivers flowing to the west and the Yamuna river (Ganga basin) flowing to the east.
3. Aravali –Delhi ridge on the south. This is NW-SE trending broad and gentler regional high. Its highest part is at about 400m depth passing through Sirsa, Mansa and Faridkot (Datta et al., 1964).
4. On the northern side, the Siwaliks rocks bound the Punjab basin.

Fluvialite sediments were deposited in a subsiding trough adjacent to the rising Himalayan ranges. The alluvial deposits have been laid down by the ancestral and the present rivers since Pleistocene in the “fore-deep” or a down wrap formed in front of the mighty Himalayas and thus represents the younger geological formations.

In the Punjab basin, Quaternary alluvium has been deposited on the semi consolidated Tertiary rocks (Siwalik group), or on the basement of semi consolidated Tertiary rocks or on the basement or igneous rocks of Precambrian age. The alluvium represents the last phase of sedimentation in an environment that had its beginning in Mid Tertiary times. The fluvialite sediments were deposited in the subsiding - a fore deep adjacent to rising Himalayan range (Krishnan, 1968).
FIG. 3.1 MAP OF THE INDO GANGETIC PLAINS SHOWING THE MAIN DIVISIONS

(after Rao, 1973)
FIG. 3.2 BASEMENT STRUCTURE MAP OF PUNJAB-RAJASTHAN PLAINS BASED ON SEISMIC DATA (after Rao, 1973)
According to Rao (1973) no rocks older than Siwaliks have been found over the basement. Seismic surveys by O.N.G.C. (Datta et al., 1964) have indicated that the basement surface as well as the sediments below the alluvium dips gently towards the Himalayan foothills. The basement however becomes deep as the foothills are approached with corresponding increase in the thickness of sediments of Punjab depression. Further the Punjab basin, which is fairly deep and wide in the NE portions, becomes narrower to the SW and SE and basement rises gradually in these directions. The Punjab depression generally follows a NW-SE and almost E-W course in conformity with the trends of the Siwalik hills.

A large basement high occurs in the subsurface corresponding approximately to the present water divide between the Punjab rivers and Yamuna belonging to Ganga drainage system. According to Rao (1973), the two ridges extending from Delhi, one to the north towards Dehradun and other to the north-west towards Lahore and are concealed under the alluvium in the plains (Fig.3.2). The isolated outcrops of Archaean rocks found at Kirana hills and Sargodha extending in W-NW direction from Lahore, gives an idea about the presence of subsurface ridge extending under alluvium from Lahore to Delhi. This basement high often referred to as Delhi- Lahore- Sargodha buried ridge from the inference that it represents the north westerly extension of the Aravali mountain system trends NW-SE. As shown by contours the NE flank of the ridge dips steeply, and depth to bedrock increases sharply in that direction. The contours also indicate that the slopes to the southwest are less steep and the average depth of the bedrock over the crest of the ridge is about 400-500 meters. This Delhi- Lahore- Sargodha ridge is believed by some, to be acting as a barrier for the (burried) free movement of groundwater and hence may be causing the serious problems of water logging and salinity in the Punjab plains.

The Delhi–Aravali ridge is a broad regional basement high separating, Rajasthan platform (of Indus basin) from the Punjab platform (Himalayan basin). On the Rajasthan side, to the southwest
of the basement high, sedimentary formations from Paleozoic, Mesozoic to Tertiary ages occur. On the other hand under the Punjab platform, on the NE side of the basement high, no rocks older than Siwaliks have been found over the basement. While on the Rajasthan side a vast thickness of marine sediments were being deposited from early Paleozoic times, on the Punjab side no marine sediments were laid down except perhaps in the depressions which might have been connected with the sea through a north westerly approach towards Gurdaspur. Marine sediments from Permian times upward may be expected in these depressions depending upon the locations. In the southerly depressions only Siwalik sediments can be expected. However by and large, it seems that till the end of Lower Tertiary times a land mass consisting of crystalline basement extended as far as the Himalayan foothills in the north and north-west. It is only about the Miocene times that the land in this part begins to sink gradually allowing the Siwaliks sediments to accumulate. Between Tusham to Bathinda the basement goes down rapidly (Rao, 1973). Later on it has been established that the basement rocks (Delhi system of rocks) protrudes in the form of subsurface ridge or gentle upward which runs roughly NW-SE direction along Jind – Mansa – Bathinda alignments (Anonymous, 1985).

According to Krishna Brahamam and Kochhar (1989) the Aravali – Delhi strike turns northwest from Tusham (Fig. 3.3.). Further the gravity data shows that Tusham lies on triple gravity junction and considerable portion of gravity low is caused by arcuate granitic intrusion (240 km. long and 6 km. wide). There is trifurcation of gravity trend from Tusham marked by the extension of Aravali basement towards Himalayas in the form of Delhi- Hardwar ridge, Delhi- Moradabad ridge in eastward direction and Delhi- Lahore ridge in northwest direction (Fig 3.4.). The Great Boundary Fault trending northeast-southwest separates the Vindhyan rocks from the Aravali basement rocks appears to be extending as Agra – Shahjahanpur basement ridge which changes its trend from northeast –southwest to east – west under Ganga basin. The change in trend is attributed to
FIG. 3.3 BOUGUER GRAVITY ANOMALY MAP OF TOSHAM AND SURROUNDING AREAS.

(after Krishna Brahman and Kochhar, 1989)
FIG 3.4 BASEMENT TECTONIC ELEMENTS OF WESTERN GANGA BASIN

AS AGRA-SHAHJAHAN PUR RIDGE
DM DELHI-MORADABAD RIDGE
DH DELHI-HARDWAR RIDGE
NW-SE RIDGE SYNONYMOUS WITH THE DELHI-LAHORE RIDGE AND ITS EXTENSION SOUTHWARD

(after Mishra and Laxman, 1997)
the collision of Indian and Eurasian plate (Mishra and Laxman, 1997). The region is also characterized by Sohna fault; the Mathura fault and Muradabad fault (Fig. 3.5.)

Aravali–Delhi ridge is quite shallow in southern side becoming deeper on the northwestern side. This is well revealed by the presence of pre-Cambrian rocks immediately below the alluvium at depths of 242 m and 533 m in the exploratory boreholes drilled at Phulka (Haryana) & Khialiwala (Punjab) respectively. At Khialiwala Delhi quartzite and at Phulka, porphyritic hornblende–biotite granite belonging to the Malani suite of igneous rocks has been encountered (Anonymous, 1985). At Jhande khurd (near the southern boundary of the study area and at Punjab and Haryana border) basement has been met at 380 m (Anonymous, 2003). In the immediate vicinity of the study area near Maujgarh, district Sirsa (Haryana), the drill hole for occurrence of potash indicates the thickness of 305 meters for the Quaternary sediments. A borehole on Adampur ridge (near Jalandhar) reached basement of depth of 2500 m (Agarwal, 1977) and in the test hole drilled at Zira near Ferozepur in the vicinity of the burried ridge granitic basement was met at 700 meters below upper and middle Siwaliks (Agarwal, 1977). The maximum depth to the basement in Punjab plains is about 4-5 kilometers and depth increases to some extent under Siwaliks (Fig. 3.6). An information well drilled east of the Adampur ridge on the Janauri anticline in the foothills (15 km north of Hoshiarpur) to a depth of a little over 5 km passed through thick sections of Siwaliks and Dharamshala (equivalent to Murees) and touched metamorphic rocks. It consisted of marbles which is correlated to the "Rialo" marble of the Aravali system. This marble has been taken as crystalline basement (Rao, 1973, Balakrishna, 1997 and Powers et al., 1998). About 5 km north of Jagadhari near Ambala in Haryana state, the basement which appears to remain fairly flat till the Himalayan foothills, is at a depth of 2800m (Rao, 1973).

Delhi ridge can be traced up to the Gurdaspur fault near Himalayan foothills (Balakrishna, 1997). On the basis of geophysical surveys by O. N. G. C., it has been established that the basement is
sloping in the form of monocline, becoming deeper & deeper towards the hills (Datta et al., 1964). The base of the alluvium, which rests on the rocks belonging to the Jodhpur, Nagour and Palana series, slopes vary gently towards the north-west. A sand stone (pink and fine to coarse grain) resembling the Jodhpur sand stone has been encountered in the borehole at Otto (Haryana, district Sirsa) at a depth of 206 m below ground level (Anonymous, 1985).

In Pakistan area of the buried bedrock ridge, exploratory drilling has revealed that Precambrian rocks are overlain directly by Quaternary alluvium (Greenman et al., 1967). It is well known that Aravali formations outcrop on the Sarghoda ridge. The gravity picture shows that these outcrops constitute the core of the ridge (Balakrishna, 1997). Wilsdon and Boss (1934) based on gravity measurement suggested that Sarghoda–Shahkot ridge is a continuation of deeply eroded Aravali hills. They postulated a direct continuation of the buried Aravali hills northwards to the salt range. According to Farah et al. (1977) and Shams (1995) Kirana outliers are the surface protection of a buried Sargodha ridge extending northwest and from Indian shield. Its southeast extension is believed to join Hisar ridge, west of Delhi. There are some outcrops of Aravali formations at Tusham (west of Delhi) in the southern arm of the Lahore ridge. The Kapurthala syncline lies between Lahore and Adampur ridges. This has been mapped by Agocs (1957) in his aeromagnetic surveys of the Punjab plains.

Seismic surveys show that sediments above the basement in the plain are practically undisturbed indicating homoclinal dips. The basement surface is rather irregular and locally contains hills and valleys. Both longitudinal and transverse faults are present in the basement. In the study area deep seated structures and the nature of hard rocks over which the Quaternary deposits of the area lie have been well revealed by the gravity, magnetic, and seismic surveys carried out by Chatterjee et al. (1984). Investigations revealed a deep faulted structure west of Malaut (northwest of study area) trending north-south. This gravity ‘high’ passes through Kilanwali (In the
FIG. 3.5 TECTONIC FEATURES AROUND DELHI REGION
(after Iyengar, 2000)
FIG. 3.6 BASEMENT DEPTH CONTOUR MAP OF PUNJAB BASIN (INDIA)
(after Karunakaran and Rao 1979)
FIG. 3.7 BOUGUER GRAVITY ANOMALY MAP OF PUNJAB PLAINS
(after Bala Krishnan and Chaudhry, 1979)
FIG. 3.8 LOCATION MAP SHOWING BOUNDARY (APPROX.) OF SUBSURFACE EVAPORITE BASIN IN PARTS OF PUNJAB-HARYANA-RAJASTHAN (after Dey, 1991).
FIG 3$*$- MAP SHOWING CONFIGURATIONAL SET UP OF NAGAUR-BIKANER EVAPORITE BASIN LAHORE DELHI RIDGE & PANJAB SHELF.
(After Kumar 1999)
FIG. 310 MAP SHOWING LOCATION OF BIKANER-NAGAUR BASIN, LAHOR-DELHI RIDGE, KIRANA HILLS, SALT RANGE ETC. IN INDIA-PAKISTAN.

(After Sheikh et al., 2003)
immediate vicinity of the study area). Such gravity cum magnetic 'high' indicates some deep seated structural or intrusive features. A gravity 'low' zone is indicated beyond Raman Mandi (in the western most part of the study area) which is associated with a magnetic 'high' zone (Fig. 3.7.). Granite boundary just in the west of Raman Mandi has been summarized by the study. Another geophysical anomaly passes through Shekhu- Pakka Kalan- Kot Guru Bachak in the study area. The rocks of Aravali- Delhi Supergroup and the Malani igneous suite comprising greywacke, orthoquartzites, carbonate sediments, calcareous shales and slates, and the high heat producing granites and felsites form the basement in the region respectively (Tripathi and Rajamani, 2003; Kochhar 1989, 2000).

Dey (1991) on the basis of multi-disciplinary investigations carried out by different agencies like Geological Survey of India (G.S.I.), Central Ground Water Board (C.G.W.B.) and Oil and Natural Gas Commission (O.N.G.C.) reported that under the thick blanket of Quaternary sediments (305-350m) of southwest Punjab (Faridkot, Ferozepur and parts of Bhatinda district) and northwest Haryana (Sirsa district) a thick sequence of halite and associated evaporite (polyhalite , anhydrite , limestone and dolomite) homotaxial to Hanseran group overlie Jodhpur group.

This large evaporite basin (Fig.3.8) is known as Trans-Aravali-Vindhyan basin (Upper Proterozoic- Early Cambrian age) (Dey, 1991) covers an area of about 50,000 km² in sub surface of western part of India, now represented by the semi-desertic rolling plains of Rajasthan, Haryana and Punjab and extending across the India–Pakistan international border into Salt Range area of Pakistan. The Trans-Aravali-Vindhyan basin(Fig. 3.9)(Kumar, 1999) is bounded by (a) the Aravali range in the east ;(b) Delhi –Lahore/ Sarghodha subsurface high in the north and northwest ;(C) Devikot – Nachna subsurface high in the southwest separating it from the adjoining Jaisalmer basin and (d) the Jodhpur –Pokaran– Chohtan -Malani ridge in the south.
The northwestern part of the Nagaur-Ganganagar Basin continues across the Indo-Pak international border and appears to merge with the Indus Basin. The sub-surface—Delhi—Lahore—Sargodha ridge surfaces in the form of Shahpur, Sangla and Kirana hills in the Salt Range of Pakistan (Fig. 3.10), where older metamorphites and Malani igneous suite of rocks are exposed (Sheikh et al., 2003).

The surface and subsurface information indicates that this basin contains a very thick pile of marine sediments of the Marwar Supergroup (Late Proterozoic to Early Cambrian) lying unconformably over the basement rocks of the Malani igneous suite and/or Delhi metamorphites. The Marwar super group is unconformably overlain by rock formations of different ages at different places.

This rock formation lies successively on a basement, presumably found by the Delhi Super Group and Malani Igneous Suite of rocks. The Jodhpur and Nagaur groups are essentially clastic units whereas the intermediate Bilara group comprises mostly carbonates. But the main evaporite basin which extends under the sand blanket in the districts of Nagaur, Bikaner, Churu and Sri Ganganagar (Rajasthan), Sirsa (Haryana), parts of Bathinda & Mansa districts Faridkot and Ferozepur (Punjab), the evaporites sequence directly overlies the Jodhpurs with near complete absence of Bilara rocks. May be the Bilara rocks and the evaporites are facies equivalents. The basin slopes to west and northwest. The geological succession of evaporite basin in Punjab & Haryana is given in Table 3.1 (Dey, 1991).

The five cycles of evaporites with a cumulative thickness of 130.77 m, occur under Punjab plains whereas only three cycles of evaporites with a cumulative thickness of 50 meters occur under plains of Haryana. The dolomite/ dolomitic limestone is of foetid character which probably represents basin limestone subjected to bacterial reduction in the subphotic zone or was probably deposited in restricted / euxenic environment.
Table 3.1 The geological succession of evaporite basin in Punjab & Haryana

<table>
<thead>
<tr>
<th>Formation with possible stratigraphic equivalent</th>
<th>Rock types encountered</th>
<th>Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUATERNARY</td>
<td>Blown sand, sand and kankar, sand with gravel and clay</td>
<td>305.00-329.70</td>
</tr>
<tr>
<td>Marh-Palana formation (Palaeocene-Miocene)</td>
<td>Clay (light brown, sticky), limestone</td>
<td>38.00</td>
</tr>
<tr>
<td>TERTIARY</td>
<td>Polymitic conglomerate and grit-calcareous, with interbedded buff-coloured, calcareous sandstone</td>
<td>6.80-20.90</td>
</tr>
<tr>
<td>Malout Conglomerate and grit</td>
<td>(Entrapped gas and carbonaceous flakes)</td>
<td></td>
</tr>
<tr>
<td>NAGAUR GROUP</td>
<td>Grey Micaceous and feldspathic, non-calcareous, coarse-grained sandstone</td>
<td>3.10-10.43</td>
</tr>
<tr>
<td>Red beds</td>
<td>Clay (pinkish-white to ash grey and red)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MARWAR SUPER EVAPORITE GROUP SEQUENCE</td>
<td>Collapse breccia (nodular to sub-rounded anhydrite/gypsum and fragments of dolomite and limestone within red marl)</td>
<td>50.00-130.77</td>
</tr>
<tr>
<td>(Uppermost Proterozoic (= HANSERA to Early EVAPORITE Cambrian) GROUP)</td>
<td>Limestone (sachcharoidal), foetid dolomite (dark grey, with gypsum-filled vugs) interbedded with grey calci-lutite and red marl</td>
<td></td>
</tr>
<tr>
<td>JODHPUR GROUP</td>
<td>Anhydrite and halite rhythmtes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Halite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Halite with polyhalite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grey calcareous clay, red clay and silt-Stone, sandy clay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sandstone with shale intercalations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dolomite, grading upwards to shaly Sandstone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dolomite to dolomitic shale</td>
<td></td>
</tr>
</tbody>
</table>

(BASE NOT SEEN) (Possibly Delhi and post-Delhi granites)
Drill cutting samples from seven sites during groundwater studies in the Ghaggar River basin (Anonymous, 1985) were sent to the Institute of Petroleum Exploration of Oil and Natural Gas Commission (O.N.G.C.) for Paleontological study. Of the 18 samples sent from the 315-408-meter-below ground level depth range at the Kamharwala site, only six yielded spores and pollens of Middle to Upper Miocene age.

Table 3.2. The depth ranges and assemblages for these six samples were as follows:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth range</th>
<th>Assemblages (with frequencies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>375.53-378.53</td>
<td>Retemonoletes (1), <em>polypodispores</em> (1), <em>pinus-type</em> (10), <em>retitricoloporties</em> (1), <em>Compositoipollenites</em> (1), <em>bryophyte spore</em> (1)</td>
</tr>
<tr>
<td>3b</td>
<td>378.53-381.63</td>
<td><em>Polypodisporites</em> (2), <em>Schizaceae</em>, <em>Anemia type</em> (1), <em>Pinus type</em> (7)</td>
</tr>
<tr>
<td>3c</td>
<td>381.63-384.63</td>
<td><em>Polypodiaceaesporites</em> (1), <em>Pinus</em> (1)</td>
</tr>
<tr>
<td>3d</td>
<td>384.63-387.68</td>
<td><em>Polypodiaceaesporites</em> (1), <em>Pinus type</em> (3)</td>
</tr>
<tr>
<td>3g</td>
<td>393.31-396.31</td>
<td><em>Retimonoletes</em> (1), <em>Pinus</em> (1)</td>
</tr>
<tr>
<td>3j</td>
<td>402.35-405.12</td>
<td><em>Pinus</em> (1), <em>Retiinapewrturites</em> (2)</td>
</tr>
</tbody>
</table>

(After Anonymous, 1985)

The genera identified in the samples, together with the occurrence of conifer pollen and the general plant association, indicate Middle - to - Upper Miocene age for sample No. 3. The flora further indicates the continental nature of the deposits; it is fairly evident from the prevalence of conifer pollen that an elevated topography existed somewhere in the vicinity of the deposition during Miocene times, after the deposition of the Palana series. These sediments are not differentiated lithologically from the Palanas. During excavation of Satluj –Yamuna Link in Patiala district the presence of uno and bivalve shells were reported (Kumar and Dorka, 1989). Coarse sand also shows current bedding. All these features are indicative if ephemeral lacustrine conditions followed by turbulent conditions.
3.2 Palaeochannels

Palaeochannels / palaeodrainage / lost River / buried River are typical geomorphic features in a location representing drainage streams, streams, rivers, rivulets which were flowing either during the past time and now stands either buried or lost or shifted due to tectonic, geomorphological, anthropogenic process / activities as well as climatic vicissitudes. They appear in plan as linear/ curvilinear signature and shape on Remote Sensing data products. However various definition of palaeochannel has emerged. Some of which are as follows:

1. Palaeochannels are the drainage/rivers/ streams which were flowing either ephemeral or perennial during past time but at present time these are lost due to internal (tectonic activities) and external activities (climatic, geomorphic and anthropogenic).
2. Palaeochannels are the older river courses which were buried due to sedimentation.
3. Palaeochannels are the remnant scars of the shifting of the rivers such as Yamuna, Satluj Rivers.

Palaeochannels due to shifting of rivers in parts of southwest Punjab and western Rajasthan are shown in Fig. 3.11.

3.2.1 Evidences in favour of palaeochannel

Intense investigations during the last thirty years have yielded fruitful data obtained through ground and satellite based techniques as well as from palaeoseismic, and palaeoclimatic records all of which had enabled a good reconstruction of the drainage evolution in northwestern India. In spite of a large volume of such data, the chain of natural events during the Quaternary period has given rise to different interpretations about the former river courses. However the evidences derived from geological, geophysical and remote sensing methods have proved beyond doubt the existence of number of palaeochannels.
FIG. 3.11 MAP SHOWING FORMER COURSES OF RIVER GHAGGAR (SARASWATI) AND SATLUJ

LEGEND

PRESENT STREAM COURSES
"FORMER STREAM COURSES"

major dry valleys

SHIFTING
PROBABLE DIRECTION OF CHANNEL
MAJOR OR VALLEYS
FORMER STREAM COURSES
PRESENT STREAM COURSES

(after Kar, 1999)
3.2.1.1 Hydrogeological evidences

Lunkaransar, Didwana and Sambhar, the Ranns of Jaisalmer, Pachpadra, etc. are a few of the notable lakes, formed as a result of the changes; some of them are highly saline today, the only proof to their freshwater descent being occurrences of gastropod shells in those lake beds. Oldham (1886) accepted that there have been great changes in the hydrography of Punjab and Sindh within the recent period of geology.

3.2.1.2 Archaeological evidences

Most of the archaeological sites of the-then civilization are located on the Saraswati river basin. There are four Harappan and pre-Harappan sites in Punjab, in addition to the sites in Rajasthan and U.P. These sites are located at Rupar (present Ropar), Nihang Khan, Bara and Sirsa valley. Harappan culture flourished in the western part of Punjab around 2500 B.C. It is believed that the Harappans entered through the Indus Valley into Kalibangan valley on the left bank of Ghaggar (erstwhile Saraswati) and spread to Punjab along the Saraswati River. Carbon dating of the material at Kalibangan suggests that Harappan culture flourished around 2500 B.C. in India and existed for 1000 years. So the present day geomorphologic set up did not exist till 1500 B.C. and the Indus, the Satluj and the Beas followed independent courses to the sea.

3.2.1.3 Evidences from geophysical studies

Geophysical surveys carried out by the Geological Survey of India to assess groundwater potential in Bikaner, Ganganagar and Jaisalmer districts in western Rajasthan desert areas have brought out several zones of fresh and less saline water in the form of arcuate shaped aquifers similar to several palaeochannels elsewhere in the state. That these subsurface palaeochannels belong to ancient rivers has been confirmed through studies (Nair, 1999) on hydrogen, oxygen and carbon isotopes (\(\delta^2H, \delta^{18}O, {^{14}C}\)) on shallow and deep groundwater.
samples from these districts. The isotopic work has also indicated that there is no direct headwater connection or recharge to this groundwater from present day Himalayas.

### 3.2.1.4 Evidences from Remote Sensing and GIS

A remote sensing study of the Indian desert reveals numerous signatures of palaeochannels in the form of curvilinear and meandering courses, which is identified by the tonal variations. The Saraswati River could be traced through these palaeochannels as a migratory river. Its initial course flowed close to the Aravali ranges and the successive six stages took west and northwesterly shifts till it coincides with the dry bed of the Ghaggar River.

Yash Pal et al. (1980) found that the course of the river Saraswati in the states of Punjab, Haryana and Rajasthan is clearly highlighted in the landsat imagery by the vegetation cover thriving on the rich residual loamy soil along its earlier course. Another study by Rao (1999) has revealed no palaeochannel link between the Indus and the Saraswati, confirming that the two were independent rivers; also, the three palaeochannels, south of Ambala, seen to swerve westwards to join the ancient bed of the Ghaggar, are inferred to be the tributaries of Saraswati/Ghaggar, and one among them, probably Drishadvati. Digital enhancement techniques, identified two palaeochannels trending NE-SW in Jaisalmer district of Rajasthan, which are presumed to be the lost river Saraswati. One detailed study (Ghose et al., 1979) about Saraswati has identified at least four progressive westward shifts in Rajasthan, due to encroaching sands. Yash Pal et al. (1980) observed a sudden widening of Ghaggar near Patiala which, they argue, can take place only if a major tributary had joined it. According to them, ancient Shatadru or Satluj must have been this tributary and possibly ancient Yamuna (palaeo-Yamuna) also flowed into Ghaggar, a conclusion they claim is strengthened by
archaeological findings of active life that existed at one time on their banks. During a subsequent period, Shatadru (Satluj) swung suddenly westwards near Ropar to join Indus (as also Vipas / Beas and Parasuni/Ravi, its two tributaries), deserting its earlier channel to the sea. This sudden diversion of Satluj as well as depletion of waters from Drishadvati due to loss of its feeding streams (Kar et al., 1984) appears to be major events that heralded the drying up of Saraswati. Several workers attribute this event to tectonism involving rise of Delhi-Hardwar ridge and uplift in the Aravali (Kar et al., 1984, Bakliwal et al., 1988, 1999, Yashpal et al., 1980.). Capture of Shatadru (Satluj) by a tributary of Beas through headward erosion or due to diversion of Shatadru (Satluj) through a fault is also considered as possible reasons (Yashpal et al., 1980). Structural control over the migration of Saraswati River is also evident from studies (Bakliwal et al., 1988) in the Great Indian Desert and adjacent parts of western Rajasthan. This area is dissected by several lineaments, some of which (e.g. Luni-Sukri lineament) were reactivated during Pleistocene-Holocene period bringing about alignment of Saraswati with Ghaggar.

3.3 Alluvial deposits

The Quaternary sediments of the area can be broadly classified into two distinct categories (Singh, G. 1999)
1. Fluvial deposits
2. Aeolian deposits

The provinance of alluvial deposits is the Himalayas whereas Aeolian deposits have been laid down by wind action from the core of the Thar Desert of Rajasthan to southwest. The Older Alluvium surface has been considered as alluvial plain, geomorphologically, which is undergoing denudation and Newer Alluvium as a flood plain which is in the process of formation (Pascoe, 1965). However on ground it is difficult to draw a firm line of demarcation between the two. Geomorphologically the Older Alluvium form slightly elevated terraces
and flood plain and is generally above the present day flood level. Aerially, the Older Alluvium and the Aeolian deposits are extensive whereas Newer Alluvium has limited distribution and restricted with in present day channels.

The Older Alluvium has been considered to be of Middle to Upper Pleistocene age and Newer Alluvium to be of Upper Pleistocene to Recent age (Krishnan, 1968). The Aeolian deposits occur as sand dunes and sand sheets of Holocene to Recent age. In the present day the deposition by the Ghaggar River is continuing and contributing to the Newer Alluvium while the newer dunes are being acted upon by the present day winds. The semi stabilized and older dunes, which occur physically below the newer dunes, have been considered to be older than Newer Alluvium. However, they are younger than the Older Alluvium since they overlie the later.

Old Alluvium is dark coloured and generally rich in concretion and nodules of impure calcium carbonate locally known as *kankar*. The kankar formation has also been found in the raised Newer Alluvium on the valley slopes of the Ghaggar River. The Newer Alluvium is light coloured generally grayish and poor in calcareous contents. Since there is no good outward drainage in the Older Alluvium terrain the soil become water logged leading to efflorescence of alkaline soil and saltpeter. Such a sort is locally known as "kallar".

The Older Alluvium consisting of thick pile of alternating beds of sand silt and clay is overlain by fine clay, sand deposits of Newer Alluvium and /or Aeolian deposits consisting of sand sheets and sand dunes of various shapes and sizes. Since sediments to the Newer Alluvium by the Ghaggar and Newer dunes by Aeolian activity are still being added, these deposits are coeval in time. Thus semi stabilized and Older stabilized dunes which occur physically below the Newer dunes are considered to be older than the Newer Alluvium as well.

3.3.1 Older alluvium (the bhanger)

Deposed as a flat, penny plain terrain, it is represented by buff to brownish fine sand, silt and clay sediments. Lithologically the Older Alluvium comprises of horizontal beds and lenses of fluvial sediments
(sand silt and clay) of polycyclic nature. As per soil classification it could be classified as drift sand to loam. In places, calcareous concentration (kankar) and saline and alkaline efflorescence (known as Reh of Kallar) have formed. During the rains the salts are dissolved and leached towards the deeper horizons, but in the dry period the extensive evaporation exerts capillary pull on the solution in the pore spaces of the soil, which on evaporation at the surface leaves crystallized salts as white encrustation on the ground. These salts are mixture of carbonates, sulphates and chlorides of sodium, calcium and magnesium, which might have been derived from the chemical decomposition of the mountains. The bhangar usually ends in broken chains of sand dunes and cliffs. The origin of cliffs and the bhangar uplands, can be ascribed partly to the tectonic uplift during the Pleistocene and partly to the steep cutting by the rivers. Consequent upon the climate changes at the end of Pleistocene period. Mentionable kankar bearing localities are Guraddi, Khiwa, Burike Kalan, Hodla Kalan, Jassarwal, Hiron Kalan, Hiron Khurd, Borawal, Atla, Khaila, Bhikhi, Bhopal, Kishangarh, Bahadur Pur, Khatri Wala, Bareta, Akbarpur Khudal, Alisher and Chak Naya Gaon (Singh, G.1999).

The facies variation both vertical and lateral is quite common the subsurface sand of Older Alluvium is generally grey coloured and exhibits very little oxidation effects, while the sandy horizons in the upper part of the Older Alluvium are usually brownish to yellowish and show fairly high degree of oxidation. These sands generally consist of 90-95% transparent, translucent quartz of pinkish and white colours, besides micas (biotite and muscovite), and opaque.

The clay occurs as bands of substantial thickness of (2-5m) of yellowish to dark earthy colours. They commonly posses good swelling properties and show kankar association. The silty units are brownish to reddish brown in colour often containing disseminated kankar. These usually occur as occasional sporadic bands or as lenses with in the clay. The impervious clays /sticky clay locally known as Pandoo helps in trapping of water under artesian conditions but also promotes water
logging and consequent formations of kankar, sodium and magnesium salts thus giving rise to kallar thereby rendering the soil infertile. At places the individual grains of soil are cemented together by the infiltrating silica and carbonate of the lime to form impervious layers. The Older Alluvium soils are rich in alkaline and lime although there proportion is variable. These soils by and large are very fertile.

The Older Alluvium is well exposed in the area between Mansa branch and Oddat branch of the Sirhind canal encompassing the villages of Mansa-Ramditte Wala-Makha-Maujia-Khillan. Across the Oddat branch the Older Alluvium is also well exposed in Kuleri-Borawal- Biroke Kalan- Jitgarh forming northern part of the area. In the southeast part around Bahwa-Kulerian and on the western part between Jhunir-Dalwala-Bhame Khurd also the Older Alluvium is exposed. In the central and eastern parts which are chiefly underlain by the Aeolian deposits isolated patches of Older Alluvium can be seen in the interdunal parts. In the eastern parts, the Older Alluvium is highly affected by the alkaline soils where as in the northern parts it is very fertile.

On the basis of some shallow sub surface information, the top thirty meters of the Older Alluvium has been classified into seven units (Table 3.3.)

Horizon no’s. 2, 4 and 5 are in fact transitional horizons and are not developed anywhere. Broadly these can be classified into three horizons.

- Top horizon of red soil
- Intermediate horizon of the sticky clay and kankar
- Lower grayish micaceous sand.

In Maur Mandi-Talwandi Sabo-Sardoolgarh area the red soil is invariably underlain by a horizon of kankar which in turn underlain by either sticky clay or red soil. Medium grained sand invariably occurs at a depth of 5-6m whereas in Mansa –Budhlada- Bareta area grayish micaceous sand occurs at a depth of 3-4 m. In this block kankar is developed at a shallower depth (1.5m to 3m) suggesting that considerable upper part of the red soil horizon has been eroded away.
There is considerable variation in the thickness of sediments within a small stretch as observed in the well section in the adjoining areas. The thickness variation of various sediments indicates the undulation nature of the basin in which these sediments were deposited. This also indicates the irregular supply of the sediments or the frequent changes in the energy of the fluvial agency.

The occurrence of kankar along with the sticky clay at Kanakwal Bhanguan and with mixed soil indicates that prior to the Holocene there was a fairly long dry period during which the sediments were exposed to the surface resulting in the development of kankar in the soil profile. Kanakwal - Bhanguan section also shows the presence of two Older Alluvial plains occurring approximately at 32m and 27m from the present day alluvial surface (Singh, G. 1992).

Finer sediments in the northern part of the area laterally coarsen towards the Ghaggar River indicating the extent of the Older Alluvium deposited by the Ghaggar River.

### 3.3.2 Newer Alluvium (The Khadar)

Newer Alluvium is lighter in colour and fresher looking as compared to Older Alluvium and Aeolian deposits. It comprises mainly greyish sand with minor clay which is generally purplish in colour. From the Older Alluvium it can be distinguished by its colour and less compactness of the sediments. From the aeolian deposits it can be distinguished by its brownish grey colour. Newer Alluvium occupies a very small area along the course of the river Ghaggar.

It occupies the lower levels near the river channels and is liable to flooding almost annually. It has less kankar and reh formation in it, due to a continuous leaching process and seepage of water from the river beds. With age, the rivers have been cutting their bed lower, so that the deposits of the younger age are found at a lower level than the earlier ones. The khadars drive a part of their material from the bhangar uplands due to the erosion of the later.

### 3.3.3 Aeolian deposits

Aeolian deposits occur as sand dunes and sand sheets / aeolian flat. Sand dunes of various shapes and sizes are scattered
almost all over the area. Several dunes often interlink and give rise to a large tract of aeolian sediments. In certain parts, however, the Table 3.3. The classification of the upper part of the Older Alluvium

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Horizon</th>
<th>Lithology</th>
<th>Thickness (in meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Top horizon</td>
<td>Reddish silty soil</td>
<td>1.5 to 2</td>
</tr>
<tr>
<td>6.</td>
<td>Intermediate horizon</td>
<td>Reddish soil+kankar</td>
<td>0.75 o 1.5</td>
</tr>
<tr>
<td>5.</td>
<td>Clayey horizon</td>
<td>Sticky clay locally known as pandoo</td>
<td>1 to 6</td>
</tr>
<tr>
<td>4.</td>
<td>Lower intermediate horizon</td>
<td>Mixed clay, silt, sand and kankar. Locally known as kakka reta or jail.</td>
<td>3 to 9</td>
</tr>
<tr>
<td>3.</td>
<td>Upper sandy horizon</td>
<td>Greyish to bluish fine to medium grained micaceous sand.locally known as bareti.</td>
<td>4 to 20</td>
</tr>
<tr>
<td>2.</td>
<td>Upper clayey horizon</td>
<td>Sticky clay.</td>
<td>1 to 4</td>
</tr>
<tr>
<td>1.</td>
<td>Lower sandy horizon</td>
<td>Grey to bluish medium to coarse grained micaceous sand (bareti).</td>
<td>More than 10</td>
</tr>
</tbody>
</table>


height of the sand dunes is less and certain interdunal parts have thin veneer of wind blown sediments. All these have been demarcated as aeolian deposits, so as to differentiate them from the alluvial sediments. The average height of the dunes increases from north to south.

The aeolian deposits/ sand dunes are linearly arranged in NNE-SSW to NE-SW direction. However, in the southern most part of the area around Sardoolgarh these extend in almost E-W direction which also is the trend of the river Ghaggar in this part of the area.

The Older/ stabilized dunes are rare and their remnants were observed NE of Autanwali, Ramdittewala, west of Mandholi and
Chachhohar. Mostly the dunes have been highly modified even obliterated in shape and size due to intensive, successive biotic and environmental interferences. The dunes are invariably associated and surrounded with sand sheet/ spread around them. The sands of the dunes give golden yellowish tinge on surface but are reddish brown at about one meter depth (Singh, G.1999).

Based on the occurrence, degree of consolidation, type of soil etc., the sand dunes have been classified into three sub categories as detailed below:
1. Older/ stabilized/ consolidated sand dunes ('O' dunes).
2. Semistabilised/ semi-consolidated / intermediate sand dunes ('SC' dunes).

The ‘O’ dunes are black coloured and more or less stabilized. Newer dunes are light coloured and consists of loose sand. They are under active erosion of wind action. The Older dunes also show varying degree of kankar formation. Fairly dense wild bushes, gave grown on ‘O’ dunes, whereas ‘N’ dunes are devoid of any natural vegetation. However, some sporadic crops of grams are raised on ‘N’ dunes. An intermediate division of ‘SC’ dunes could be identified which has attained a fair amount of compactness and some wild vegetation. Invariably the ‘N’ dunes overlie the ‘SC’ and the ‘O’ dunes.

The ‘O’ dunes are highly calcareous and contain kankar at depth and not merely on the surface. Whereas the ‘SC’ dunes are moderately calcareous with or without granules of kankar. ‘N’ dunes have been found to be non-calcareous. However, care has to be taken to establish that this non-calcareous nature is not due to leaching. Even with these diagnostic parameters, it is often difficult to differentiate between ‘O’ dunes and ‘SC’ dunes.

It was uniformly found applicable in Sunam- Mansa area. As compared to the eastern part of the area (Bhikhi- Sunam- Dirba block of the Sangrur district) following contrasting features were observed.
1. Much less content of kankar, almost absent on the surface.
3. Absence of brownish grey alluvial sand with large size kankar at depth.

4. Absence of well-developed slip faces on the 'N' dunes.

Minerologically, these dunes are made of rounded to sub rounded quartz, opaques and heavies. The mica is almost absent. Quartz alone accounts for 95% of the bulk. Its variants include transparent crystalline, white crypto crystalline, pinkish to reddish coloured quartz grains. The remaining 5% comprises reddish garnets, rock fragments of quartzite, hornblende, magnetite and opaques. The sand is well sorted and fine to medium grained. Primary bedding features like large, trough - type cross bedding can be seen in cut sections of the dunes at Ram Thirath and Teona Pujarian (Singh, G. 1999).

The Older /Stabilized dunes are rare and their remnants have been observed NE of Autanwali, Ramdittewala, West of Mandholi and Chhachhohar. The Newer dunes are still active and mobile and are very common. These are generally underlain by the semi-stabilized types of dunes. The Newer dunes in the northwest part of the area have fairly well developed slip faces. The slip faces are both convex and concave thus indicating the presence of both transverse and barchans, of these former are more common. The barchan types of dunes are observed north of Kotli and southwest of Musa.

**Source of aeolian deposits**

The dune sediments are bimodal and have a fair amount of mica and hence support the concept that the reworking of the local fluvial sediments by aeolian agencies contributed in the dune formation. However, the reported occurrence of mica (Wassen et al., 1983) in the eastern Thar Desert lends support to the suggestion of alternative source of these sediments and an extension of the Thar Desert in Punjab. The sand dunes of the western Rajasthan have been formed and shifted by the winds blowing from the southwest (Krishnan, 1968). The palaeowind directions, worked out in the present area, are in conformity as these are predominantly due to southwest winds moving...
in NE direction. This suggests that the Older dunes of Punjab are an extension of the Rajasthan desert. However, the extension of the Rajasthan desert does not mean that the sediments have been derived from the Rajasthan dunes, or it's the shifting of the Rajasthan dunes, or the dunes of Rajasthan and those of Punjab had the same provenance. The local sediments, in addition to the one brought from the Rajasthan side, were reworked and aligned parallel to the dunal trends of Rajasthan by the wind blowing from the Rajasthan side.

The attributes of the Aeolian deposits are:
1. Presence of the micro laminations.
2. Occurrence of wedge-shaped cross bedding.
3. Medium scale cross-bedding.
4. Presence of forest and backset beds.
5. Partially high angles of foreset.
6. Plannar or concave upwards erosional surface.
7. Absence of scour and fill structures.
10. Narrow distribution of local palaeowind direction.
11. Occurrence of small scale bedding and
12. Orange to medium red colour.

Following section at Jatana Khurd near Punjab-Haryana border is a typical section of Newer Alluvium:

00 cm to 14 cm Red coloured laminated sticky clay laminations is spaced at 1 mm to 3 cm and show warping.

14 cm to 30 cm Fine grained micaceous sand.
30 cm to 46 cm Red sticky clay.
46 cm to 61 cm Fine grained micaceous sand.
61 cm to 90 cm Red sticky clay.
90 cm to 150 cm Fine grained micaceous sand.
Table 3.4. Showing geological succession and geomorphic landforms of alluvium.

<table>
<thead>
<tr>
<th>System</th>
<th>Geological Age</th>
<th>Stratigraphic Unit</th>
<th>Lithology</th>
<th>Geomorphic Landforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Present Day</td>
<td>Efflorescence Of Alkaline Soil And Salt peter And Formation Of Kankar.</td>
<td>(B) Top Soil Channel Bars And Flood Plains</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(A) Bluish Grey Micaceous Sand &amp; Silt, Reddish Silt Clay</td>
<td>(A) Newer Edunes O L I A N D Semi-E Stabilised Dunes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recent To Present Day</td>
<td>Newer Alluvium</td>
<td>(B) A Newer Edunes O L I A N D Semi-E Stabilised Dunes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(A) Bluish Grey Micaceous Sand &amp; Silt, Reddish Silt Clay</td>
<td>(B) A Newer Edunes O L I A N D Semi-E Stabilised Dunes</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>Efflorescence Of Alkaline Soil And Salt peter And Formation Of Kankar.</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Efflorescence Of Alkaline Soil And Salt peter And Formation Of Kankar.</td>
<td>(B) A Newer Edunes O L I A N D Semi-E Stabilised Dunes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle To Upper Pleistocene</td>
<td>Older Alluvium</td>
<td>Reddish Coloured Soil, Admixtures Of Clay, Silt, Sand, Black Soil, Sticky Clay, Kankar</td>
<td>Undirected Undulating Flat Surface Of Plantation, Older Terraces, Older Flood Plain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium To Coarse Grained Sand</td>
<td>(B) A Newer Edunes O L I A N D Semi-E Stabilised Dunes</td>
<td></td>
</tr>
</tbody>
</table>

(Reproduced from Singh, G.1992)