CHAPTER 7
DISCUSSION

7.1 INTRODUCTION

In today’s world, ‘Petroleum’ is a magic word. There is hardly a nation that does not seek this indispensable resource. A country that already possesses oil wants more. They struggle to explore it at almost any cost. The common man does not know much about this strange ‘mineral’, although in almost every country he bears the burden of the cost of exploration for oil or its import. One of the basic requirements of human society is energy. The growth of human civilization has dependent upon the availability of cheap and abundant resources of energy. The oil industry constitutes a broad spectrum of human endeavor in modern society.

Gandhar, a major oil field was discovered in November 1983 and situated on the western rising flank of Broach depression of Cambay Basin. It is located 40 km. NW of Broach town and spreading over 800 sq. km. It is connected by all weather black topped road of State and National Highways and is approachable from Ankleshwar. It has a flat topography with an elevation of 50m above mean sea level (MSL) and covered by alluvial plains comprises of thick pile of unconsolidated sediments. River Dadhar flows in the north and River Narmada flows in the south both run east to west are ultimately falls in Arabian Sea. The climate of the area is warm and humid and having subtropical climate.

Tectonically, The Cambay Tertiary basin is an intracratonic graben covered on both sides by basin margin faults. All the six large depressions of graben are separated by basement controlled uplifts and faults. This suggested five tectonic blocks in the basin i.e. I- Sanchor-Patan Block, II- Mehsana-Ahmedabad Block, III- Tarapur-Cambay Block, IV- Jambusar-Broach Block and V- Narmada-Tapti Block.
Gandhar Oilfield falls in Area no. 3 of Ankleshwar project as identified by Oil and Natural Gas Corporation Limited and is situated in Jambusar-Broach block lies between Mahi and Narmada Rivers. In this block, lineaments trend in NS direction and central part of this block is a deep syncline where Tertiary sediments is more than 5.7 km in thickness. Trap is rarely encountered in Gandhar area.

7.2 STRATIGRAPHY, STRUCTURAL SET-UP AND PALAEODEPOSITIONAL ENVIRONMENT OF THE AREA

The lithostratigraphy of the Cambay basin comprises of two distinct broad lithounits. The basement is made up of Deccan basalts which are unconformably overlain by Tertiary group of rocks. Stratigraphically, the Cambay basin is divided into Deccan Trap, Vagadkhol Formation, Cambay Shale, Ankleshwar / Vaso / Kalol Formation, Tarapur Shale / Dadhar Formation, Tadkeshwar Formation, Babaguru Formation, Kand Formation, Jhagadia Formation, Broach Formation, Jambusar Formation and on top Gujarat Alluvium.

The *Traps* form the basement of the Tertiary rocks is hard and compact, dark greenish to dark grey in colors. It is unfossiliferous and intertrappeans are also devoid of fauna belongs to *Upper Cretaceous* age.

The Deccan Trap is unconformably overlain by the *Olpad formation* which is consisted of conglomerate, sand, sandstone, silt, siltstone and clay derived from the Deccan basalts. It is poorly fossiliferous with gastropod, bivalve shells along with palynofossils and belongs to *Paleocene to Lower Eocene* age.

The *Cambay Shale* present throughout in the Cambay basin, unconformably overlies the Olpad formation, comprises of grey to massive black, silty, sideritic and pyritic carbonaceous shales with thin coal and silt bands. This shale is known to be the *Source rock* of hydrocarbons (Mehrotra et. al. 1980) within the Ankleshwar
formation and has generated huge quantities of hydrocarbons which after vertical migration get trapped in the overlying Hazad member of Ankleshwar formation. Cambay Shale is mostly devoid of fauna except a few fossiliferous bands. Datta and Mehrotra (1974) have reported Paleocene planktonic foraminifera from the base of Cambay Shale and belong to Lower Eocene age but in some literature the age of Older Cambay Shale formation has been reported **Upper Paleocene** and Younger Cambay Shale formation as **Lower to Middle Eocene** age.

The Cambay formation is succeeded by **Ankleshwar formation** which has been divided into four members from bottom to top as **Hazad member**, **Kanwa shale**, **Ardol member** and **Telwa shale**. The age of Ankleshwar formation is **Middle Eocene to Upper Eocene**.

The **Hazad member** is the basal member of the formation and contains a lot of hydrocarbons accumulation in Ankleshwar, Gandhar and Nada areas. It is consisted of alternating bands of sandstone and shale. Hazad member is characterized by arenaceous foraminifera.

**Kanwa shale member** occurs between Hazad and Ardol member and it is laminated, fossiliferous and some time calcareous and works as cap rock. Kanwa shale member is characterized by thin marine incursions.

**Ardol member** represents a sequence of sandstone and shale and the consisting laminated sandstones have hydrocarbon accumulation similar to those of Hazad member. Ardol member is poorly fossiliferous and is characterized by few Gastropod and Pteropod assemblages.

**Telwa shale member** is consisted of grey to greenish grey, laminated and poorly fossiliferous shale and also works as cap rock.
In Gandhar area the pay sands in Hazad member has been informally identified from bottom to top as $GS-0$ to $GS-12$ and in Ardol member only $GS-13$.

The Ankleshwar formation is overlain by *Dadhar formation* and is consisted of alternations of coarse to medium grained friable sandstone and moderately hard dark grey shale with a bioclastic limestone in the upper part. It is poor in faunal content while the floral assemblage is moderately rich and ranges in age from *Upper Eocene to Early Oligocene*.

The Dadhar formation is overlain by *Tarkeshwar formation* and consisted of variegated claystone and occasional bands of coarse to medium grained sandstone. It is poorly fossiliferous with non-diagnostic faunal elements and belongs to *Upper Oligocene to Lower Miocene age*.

The Tarkeshwar formation is overlain by *Babaguru formation* which is represented by ferruginous, current bedded sandstones, conglomerates and grey clays. The sand grains and pebbles are mostly of quartz, agate and chalcedony. It is mostly devoid of fauna and age assigned to this formation is *Lower Miocene*.

The Babaguru formation is overlain by *Kand formation* which is consisted dominantly of grey clay and claystone with occasional sandstone and conglomerate while in subsurface formation comprises dominantly of alternation of grey to brown, soft clays and claystones and thin bands of white to dirty white coarse grained sandstones. It is rich in faunal assemblage and age assigned to this formation is *Lower Miocene to Middle Miocene*.

The Kand formation is overlain by *Jhagadia formation*, composed of semi to unconsolidated, current bedded, white & greyish, calcareous and micaceous sandstones, laminated, grey, shaly sandstones and loose sands, occasionally with pebbles of agate, sandstone and marl. The formation is poorly fossiliferous in the
subsurface while non-fossiliferous in the outcrops and age assigned to this formation is *Middle to Upper Miocene*.

The Jhagadia formation is overlies by *Broach formation* which is consisted of alternations of chocolate brown to reddish brown claystone, sandy claystone and sandstone. It is rich in faunal assemblage and age assigned to this formation is *Pliocene*.

The Broach formation is overlain by *Jambusar formation* which is composed mainly of yellow and grey clays, coarse sand and kankar and age assigned to this formation is *Pleistocene to Sub-Recent*.

The thick alluvium overlies the Jambusar Formation and it extends throughout the Cambay basin in the subsurface and also in the outcrops. It is composed of coarse and pebbly sands, gravel and kankar etc. which is known as *Gujarat Alluvium*. The formation is devoid of microfauna and age assigned to this formation is *Sub-Recent to Recent*.

Structurally, it is an intracratonic rift graben located on the western coast of India. The studied area is a part of Jambusar-Broach block of Cambay basin. According to the Kund (1996), the Broach block is demarcated by Mahi-Gogha fault in the north and Narmada fault in the south. Listric and Planar faults orient in NS to NNE-SSW direction where the transform faults trends in NE-SW to EW direction. Pakhajan horst separates Tankari and Broach depression. According to Kund (1996), there are two major half grabens (Broach and Tankari) and nine minor grabens in the block. The half grabens are bounded by opposite clipping listric faults and are separated by Pakhajan horst. The overall slope throughout evolution of the basin has been formed NE to SW.
Gandhar is a structural nose on the western flank of Broach syncline. The Gandhar accumulation occurs in multiple pay sands in a combination trap where up-dip pinch-out of sands forms a **structural cum stratigraphic trap**.

The Cambay basin has witnessed different environmental condition and sedimentation from its origin. In present study, the depositional environment of *Cambay (Source Rocks), Ankleshwar (Reservoir Rocks) and Dadhar formations (Cap Rocks)* in Cambay basin has been adopted as suggested by Pandey et al., (1993).

Sudhakar and Basu (1973) have suggested that the frequent occurrence of plant remains, laminated nature of shale and absence of fossils, shows that these sediments were deposited in **lagoons and paludal swamps**.

According to Pandey et al., (1989) the initiation of deposition of Ankleshwar formation (Reservoir Rocks) in the axial part of the Broach depression started in the later phase of Middle Eocene time resulting in the deposition of **Hazad member as delta front and distributary channels environment**. This deltaic sequence is overlain by marine shale (Kanwa shale) and presence of planktonic foraminifera in these shales indicates a transgressive activity during Late-Middle Eocene times. The latest Middle Eocene and earliest Late Eocene sequence (Ardol Member) exhibit reduction in foraminifera and becomes increasingly sandy upwards suggesting a renewed **deltaic progradation**. This sand unit is in turn, overlain by a marine Late Eocene shale (Telwa Shale) characterized by presence of *Globorotalia-Lenticulina* biofacies indicating an upper marine influence and another destructive phase in deltaic progradation.

The lower part of **Dadhar formation (Cap rocks) represents a wide transgressive phase** characterized by *Nummulites-Discocyclina* assemblage indicating inner-middle shelf environment with warm water conditions in the South Cambay basin. In this
area the large input of coarser clastics brought in by the Proto Narmada river system was reworked by marine agencies and was deposited as widespread sheet sandstones.

Thus, the major part of Dadhar formation represents the sediments deposited during the destructive phase of Proto-Narmada delta system. The upper part of this formation characterized by the Reticulate Nummulites assemblage represents a short regressive span of minor sea encroachment in this regime.

7.3 RESERVOIR AND CAP-ROCKS

In Cambay basin, sandstones and siltstones are the main hydrocarbon reservoirs. Fractured coals, fractured shales, and sideritic marls are also served as a subsidiary reservoir. The reservoirs in different stratigraphic levels are:

**Paleocene**- Siltstones in Olpad formation

**Lower Eocene**- Lenticular sands in Cambay shale, and sands and silts in Kadi clastic wedge in Mehsana block.

**Middle Eocene**- Sandstones in Ankleshwar formation and siltstones, fractured coals and sandstones in Kalol formation

**Upper Eocene-Oligocene**- Lenticular sands in Tarapur shales and sandstones-sands in Dadhar formation

Of these, the sandstones and siltstones in Ankleshwar, Kalol and Kadi formations are the main reservoirs. The sandstones of Ankleshwar and Dadhar Formations deposited in Narmada-Tapti and Jambusar-Broach blocks are the reservoirs in Ankleshwar, Kosamba, Gandhar, Nada, Dabka, Motwan-Sisodara and Elao fields. These sandstones, deposited in a deltaic to shallow marine environment, were fed into the basin during Middle Eocene-Oligocene period along Palaeo-Narmada River and were widely distributed to cover Broach and Narmada blocks. These sands in general have good porosities and permeabilities and make very good reservoirs.
The Tarapur shales of Upper Eocene-Oligocene age are the principal cap rocks in northern Cambay basin. In the southern Cambay basin, the *Telwa and Kanwa shales of Middle Eocene to Oligocene age* and the shales intercalated with sandstones in Dadhar Formation *form the principal cap rocks*.

**Reservoir Rock Properties**

Porosity and permeability of Gandhar sediments are *0.10 to 0.30 range (ϕ) in P.U.* and *10 to 2000 (k) range in md (weighted mean value)* respectively.

### 7.4 Physical and Chemical Properties of the Area

According to Levorsen (1958), the organic matter found in sedimentary rocks consists largely of complex, resistant hydrocarbon compounds which have the unique composition in percentages by weight as compared to the composition of petroleum. This composition is shown in table 7.1:

**Table 7.1: Chemical Composition of Organic Material and Petroleum. (After Levorsen, 1958)**

<table>
<thead>
<tr>
<th></th>
<th>Organic Material</th>
<th>Petroleum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>52-71 Percent</td>
<td>83-87 Percent</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>7-10 Percent</td>
<td>11-15 Percent</td>
</tr>
<tr>
<td>Oxygen</td>
<td>15-35 Percent</td>
<td>Trace to 4 Percent</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>4-6 Percent</td>
<td>Trace to 4 Percent</td>
</tr>
<tr>
<td>Sulphur</td>
<td>Traceable</td>
<td>Trace to 4 Percent</td>
</tr>
</tbody>
</table>

In studied Gandhar oils, carbon content varies between 63.53% and 73.80% (average: 67.68%), hydrogen content varies between 10.54% and 12.83% (average: 11.93%), oxygen compound varies between Nil and 5.15% (average: 1.81%), nitrogen compound is absent in all the oil samples, sulphur compound varies between Nil and
0.724% (Average: 0.05%) and metallic constituents varies between 10.03% and 24.18% (Average: 18.59%). The composition of crude oil is almost similar as suggested by Levorsen but the carbon % is different. Because Levorsen has not taken the metallic contents and in present study the metallic content has been taken separately.

The organic matter found widely disseminated in the sediments consist largely complex, resistant, solid or semi-solid mixture of carbon compounds, insoluble in petroleum solvents, and is a pyrobitumen. The organic material is finally transformed into petroleum cover a wide range of physical, chemical, and geological processes which involves- (i) heat and pressure (ii) bacterial action (iii) radioactive bombardment, (iv) catalytic reactions. In a highly reducing environment bacteria tend to convert the organic remains of plants and animals into substances that are more petroleum-like. The trend of these reactions is illustrated in table 7.2. The table shows the effect of the oxidizing zone in the high oxygen content of marine sapropel, which supports the aerobic bacteria, and a loss of oxygen with burial, which suggests that, as the source of air and free oxygen is shut off, there is a change from aerobic to anaerobic bacteria.

**Table 7.2: Trend of various reactions on compositions of various type of materials.** *(After Levorsen, 1958)*

<table>
<thead>
<tr>
<th>Type of Material</th>
<th>Carbon%</th>
<th>Hydrogen%</th>
<th>Oxygen%</th>
<th>Nitrogen%</th>
<th>Sulphur%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Sapropel</td>
<td>52</td>
<td>6</td>
<td>30</td>
<td>11</td>
<td>0.8</td>
</tr>
<tr>
<td>Recent Sediments</td>
<td>58</td>
<td>7</td>
<td>24</td>
<td>9</td>
<td>0.6</td>
</tr>
<tr>
<td>Ancient Sediments</td>
<td>73</td>
<td>9</td>
<td>14</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>85</td>
<td>13</td>
<td>0.5</td>
<td>0.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>
In present study average carbon is 67.68%, hydrogen 11.93%, oxygen 1.81%, nitrogen absent and sulphur 0.05% and suggest the source rock content falls in ancient sediments of Levorsen (1958). Very less oxygen (Nil to 5.15%) suggests that the _anaerobic bacteria are involved in the formation of crude oil and the source is ancient sediments_. Thus many anaerobic organisms, both plant and animal, synthesize hydrocarbon compounds in their normal metabolism, and the progressive concentration and preservation of this material seems a most logical source of petroleum.

The colour of crude oils varies from light yellow to red in transmitted light. Some very dark or black oils are opaque. The color of oils depends on specific gravity i.e. higher the specific gravity (or lower the API gravity), the darker the oil. The specific gravity ranges from 0.8 gram per cubic centimeter (45.3º API) for the lighter crude oil to over 1.0 gram per cubic centimeter (10º API) for the asphaltic crude oils. In present study, _colour of all the oil samples is brown to dark brown which is due to low API gravity and it also suggests that it is lighter crude oil._

The agreeable gasoline-like odour of some oils is due to paraffins and naphthenes, pleasant odour is imparted due to large percentage of aromatics and disagreeable odor is imparted due to unsaturated hydrocarbons, sulphur and certain nitrogenous compounds. In present study, _odour of all the oil samples is agreeable due to lighter hydrocarbons._

Specific gravity and API gravity are inversely proportional to each other i.e. high values of API gravity correspond to low specific gravity, and low values of API gravity to high specific gravity. API gravity and Specific gravity are directly affected by temperature, which is shown in table 7.3.
Table 7.3: Effect of Temperature on Specific gravity and API gravity. (After Levorsen, 1958)

<table>
<thead>
<tr>
<th>Gravity at Average Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>60° F</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>SG</td>
</tr>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>0.9</td>
</tr>
<tr>
<td>0.8</td>
</tr>
<tr>
<td>0.7</td>
</tr>
</tbody>
</table>

In present study, specific gravity of crude oils varies between 0.8009 and 0.8338 gram per cubic centimeter whereas API gravity varies between 40.70° and 46.80° that are similar to specific gravity and API gravity as suggested by Levorsen at 60° F and also shows the lighter nature of crude oils.

The viscosity of a crude oil is generally dependent chiefly on the amount of gas dissolved in it and temperature (the more gas in solution and the higher the temperature, the lower the viscosity) and varies only slightly with changing pressure. The reason of viscosity of a liquid decreases with an increase in temperature is that heating increases the molecular agitation (or velocity), which, in the absence of confining pressure maintaining a fixed volume, increases the intermolecular distances and the volume (expansion). An increase in intermediate distance reduces both the inter-molecular attraction and the friction caused by collisions of molecules. Viscosity also varies directly with the densities of oils and the density varies with the composition. Thus, the greater the number of carbon atoms in a member of a hydrocarbon series, the greater will be its viscosity as well as its density. In present study, viscosity of crude oils falls between 0.0690 and 0.2770P, which suggest a less number of carbon atoms in a member of a hydrocarbon series.
Optical activity is the power to rotate the plane of polarization of polarized light. Optical rotary power is confined to organic materials and is caused by the presence of a cholesterin-like substance. Cholestrine (cholesterol), which is an alcohol found in both vegetable and animal matter and is a constituent of initial milk produced from mother cattle. Optical activity is mainly used to know the origin of petroleum from plant or animal remains, because optically active substances cannot be synthesized inorganically. In present study, plane polarized light rotate to right (1-35) in oil samples A, B, D, E, G, H, I, J & L and show dextrorotatory activity whereas plane polarized light rotate to left (0.4-0.5) in oil samples C, F1, F2 & K and show levorotatory activity. Hence all the samples of oils show optical activity and confirm the organic origin of oils.

Boiling point of crude oils are known as a measure of the hazard involved in handling and storing petroleum products and their limits are generally fixed by state law. In present study, boiling point of crude oil varies between 82 and 91$^\circ$C and suggests that it is easy to handle between 82 and 91$^\circ$C and is hazardous before and after these temperature.

Cloud and Pour point tests are essential to determine the influence of low temperatures on crude oils and also to know the presence of solid paraffin waxes. The cloud point is the temperature at which the first cloud appears in the oil. It is due to settling out of the solid paraffin waxes. Wax free naphthenic oils show no cloud point. The temperature attained at the Pour point from 2 to 5 degrees lower than the cloud point is the temperature at which the oil is last fluid and will not flow. If an oil’s pour point is above the surface temperature, as it may be during the winter months, it can freeze during flow through the pipe lines or caused problem to use in vehicles. On the other hand the oil will throw down its paraffins as it approaches the surface and ceases to flow until it is heated. Such oils are frequently expensive to handle, as much time and effort are required to keep the wells producing. In present
study, cloud point is in between 25 and 35\(^{0}\)C and pour point is in between 21 and 33\(^{0}\)C, which is very high and do not create above problems.

Isoprenoid distribution is most commonly measured by gas chromatography (Pristane /Phytane ratio) which is mainly related to diagenetic history. According to Illich (1983) Pristane/Phytane ratios (Pr/Ph) are useful correlation parameters, because they are believed to be sensitive to diagenetic conditions. Very high Pr/Ph ratios are associated with terrestrially influenced sediments, including coals. Pr/Ph ratios substantially below 1.0 are taken as indicators of highly reducing depositional environments (Table. 7.4).

**Table 7.4: Pristane / Phytane ratios as indicators of depositional environment.**
*(After Waples, 1945)*

<table>
<thead>
<tr>
<th>Sediment Type</th>
<th>Pristane/Phytane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoxic marine sediments</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Oxic marine sediments</td>
<td>1-3</td>
</tr>
<tr>
<td>Coals</td>
<td>&gt;3</td>
</tr>
</tbody>
</table>

In present study, Pr/Ph ratios are 0.21 (S. No. J), 0.48 (S. No. D), 1.2 (S. No. I) and 1.6 (S. No. C), which suggests anoxic to oxic marine sediments.

### 7.5 Oil Well Correlation

Gandhar oilfield consists of thirteen reservoir sands, GS-1 to GS-13, which is found between 2700 -3500m depths (GS-13 being shallowest). Sands GS-1 to GS-12 represent the Hazad member of Ankleshwar formation which belongs to Middle Eocene age, whereas Sand GS-13 represent the Ardol Member of Ankleshwar Formation of Upper Eocene age. These reservoirs are separated by extensive shale units.
Gandhar has total reserves of 100mmt (733mmb) in-place oil and 94bcm (3.32tcf) in-place gas, of which about 35mmt (256.55mmb) oil is recoverable. Mostly oil accumulated in GS-1, GS-4, GS-5C, GS-8, GS-9 and GS-11 sands. All the sands have different oil-water contacts and sands in GS-1, GS-4 and GS-5C have gas caps.

In studied oil wells Sand GS-1 occur between 2944 and 3037.5m, Sand GS-2 occur between 2941.5 and 3025.5m, Sand GS-3 occur between 2939 and 3015m, Sand GS-4 occur between 2934 and 3005m, Sand GS-5 occur between 2907 and 2985m, Sand GS-6 occur between 2884 and 2978m, Sand GS-7 occur between 2855 and 2937.5m, Sand GS-8 occur between 2840 and 2927m, Sand GS-9 occur between 2825 and 2913m, Sand GS-10 occur between 2816 and 2899m, Sand GS-11 occur between 2806.5 and 2886m, Sand GS-12 occur between 2795 and 2879m and Sand GS-13 occur between 2781 and 2859m.

In well number A, Source rock (Cambay shale) lies between 3059+ and 3037.5m, Reservoir rock (Ankleshwar Formation) lies between 3037.5 and 2536m (Hazad member sands GS-1 to GS-12 occurs between 3037.5 and 2869m and Ardol member sand GS-13 occurs between 2853 and 2840m) and Cap rock (Dadhar Formation) lies between 2536 and 2302m. Based on preliminary log evaluation and correlation with nearby wells, Sand GS-12, GS-9 and GS-4 are interpreted as oil bearing whereas GS-5C is of marginal interest from hydrocarbon point of view. The sand GS-4 was recommended for testing in the interval 2990-2995m and on testing it produced oil and gas @ 74m3/d and 18287m3/d respectively. Finally the well was completed as oil producer from Sand GS-4.

In well number B, Source rock (Cambay shale) lies between 3055+ and 3035m, Reservoir rock (Ankleshwar Formation) lies between 3035 and 2556m (Hazad member sands GS-1 to GS-12 occurs between 3035 and 2865m and Ardol member sand GS-13 occurs between 2848 and 2845m) and Cap rock (Dadhar Formation) lies between 2556 and 2315m. In these well, Sand GS-12 is oil producer.
In well number C, Source rock (Cambay shale) lies between 3040+ and 3009m, Reservoir rock (Ankleshwar Formation) lies between 3009 and 2539m (Hazad member sands GS-1 to GS-12 occurs between 3009 and 2875m and Ardol member sand GS-13 occurs between 2859 and 2843m) and Cap rock (Dadhar Formation) lies between 2539 and 2310m. In these well sand GS-4 is the only oil producer.

In well number D, Source rock (Cambay shale) lies between 3052+ and 2991m, Reservoir rock (Ankleshwar Formation) lies between 2991 and 2470m (Hazad member sands GS-1 to GS-12 occurs between 2991 and 2821m and Ardol member sand GS-13 occurs between 2744 and 2739m) and Cap rock (Dadhar Formation) lies between 2470 and 2265m. In this well GS-12 sand is oil producer.

In well number E, Source rock (Cambay shale) lies between 3094+ and 3028m, Reservoir rock (Ankleshwar Formation) lies between 3028 and 2500m (Hazad member sands GS-1 to GS-12 occurs between 3028 and 2849m and Ardol member sand GS-13 occurs between 2834 and 2831m) and Cap rock (Dadhar Formation) lies between 2500 and 2307m. In these wells sand GS-4 and GS-12 are oil producer.

In well number F, Source rock (Cambay shale) lies between 3050+ and 2994m, Reservoir rock (Ankleshwar Formation) lies between 2994 and 2425m (Hazad member sands GS-1 to GS-12 occurs between 2994 and 2797m and Ardol member sand GS-13 occurs between 2797 and 2794.5m) and Cap rock (Dadhar Formation) lies between 2425 and 2274m. Well no. F was released as a development well, for dual completion in GS-5C and GS-9B for oil production. Total two objects were tested, Object-I 2925-2930 and 2920-2922m in GS-5C and Object-II 2853.5-2858m in GS-9B, both produced oil@43m3/day and 198m3/day respectively.

In well number G, Source rock (Cambay shale) lies between 3059+ and 2982m, Reservoir rock (Ankleshwar Formation) lies between 2982 and 2458m (Hazad member sands GS-1 to GS-12 occurs between 2982 and 2800m and Ardol member
sand GS-13 occurs between 2783 and 2781m) and Cap rock (Dadhar Formation) lies between 2458 and 2250m. Sand GS-9, Sand GS-8, GS-5C and GS-4 are interpreted to be hydrocarbon bearing but Sand GS-5 is more important and produces oil and gas both.

In well number H, Source rock (Cambay shale) lies between 3037+ and 2981m, Reservoir rock (Ankleshwar Formation) lies between 2981 and 2427m (Hazad member sands GS-1 to GS-12 occurs between 2986 and 2795m and Ardol member sand GS-13 is absent) and Cap rock (Dadhar Formation) lies between 2427 and 2265m. The well H was released as a development well with an objective of gas injection in GS-1 and GS-4 (dual). On log evaluation Sand GS-1 (marginal), GS-4, GS-5, GS-8, GS-9A+B and Sand GS-9C appear to be hydrocarbon bearing.

In well number I, Source rock (Cambay shale) lies between 3060+ and 3017m, Reservoir rock (Ankleshwar Formation) lies between 3017 and 2485m (Hazad member sands GS-1 to GS-12 occurs between 3017 and 2805m and Ardol member sand GS-13 occurs between 2795 and 2791m) and Cap rock (Dadhar Formation) lies between 2485 and 2250m. GS-9 is oil & gas producer.

In well number J, Source rock (Cambay shale) lies between 3010+ and 2950m, Reservoir rock (Ankleshwar Formation) lies between 2950 and 2435m (Hazad member sands GS-1 to GS-12 occurs between 2950 and 2805m and Ardol member sand GS-13 occurs between 2788 and 2785m) and Cap rock (Dadhar Formation) lies between 2435 and 2270m. On log evaluation the Sand GS-8 appear to be hydrocarbon bearing.

In well number K, Source rock (Cambay shale) lies between 3056+ and 3007m, Reservoir rock (Ankleshwar Formation) lies between 3007 and 2482m (Hazad member sands GS-1 to GS-12 occurs between 3006 and 2804m and Ardol member sand GS-13 occurs between 2792 and 2788m) and Cap rock (Dadhar Formation) lies
between 2482 and 2256m. Well K was released as a development well with an objective to complete as an oil producer from GS-9 sand.

In well number L, Source rock (Cambay shale) lies between 3057+ and 2995m, Reservoir rock (Ankleshwar Formation) lies between 2995 and 2464.5m (Hazad member sands GS-1 to GS-12 occurs between 2995 and 2809m and Ardol member sand GS-13 occurs between 2799 and 2797m) and Cap rock (Dadhar Formation) lies between 2464.5 and 2279m. Sand GS-9 is well developed; other sands interesting from hydrocarbon point of view are GS-4, GS-8 & GS-11.

![Figure 7.1: Correlation of Oil Wells.](image-url)
All the wells are plotted from west to east direction (Well A is situated in western side whereas Well L is situated in eastern side of oilfield area) for their correlation. After correlation it is found that Well A is situated in deeper side of the basin and Well L is situated in the elevated side of the basin. According to Pandey, Upadhyaya and Minz (1993) the reservoir sands exhibit rapid vertical and lateral heterogeneity within layers. The reservoir units are seen to pinch out up-dip towards the Nada field which is situated in northwest direction (Fig. 7.2). Studied Well log also suggests that the basin is deeper towards North and North-West direction. It is suggested that NW direction of the field is more suitable to search oil in future exploration.

Figure 7.2: Structural correlation of Gandhar and Nada wells showing pinch-out of sands towards Nada field. (After Pandey, Upadhyaya and Minz, 1993)
7.6 Exploration and Exploitation

Interest in oil exploration in Gujarat was revived after independence in 1947 when the Geological Survey of India carried out geophysical surveys, which broadly delineated the sedimentary basin of Cambay. O.N.G.C. Ltd. extensively explored the Cambay basin beginning in 1956 and about 150 prospects have been tested resulting in the discovery of more than 95 fields with about 1,314 million tonnes (mmt) oil. The first field in Cambay basin was discovered in 1958 and followed by discovery of major oil in Ankleshwar field in Narmada–Tapti block in 1960. About 35% of the oil is present in four fields namely Ankleshwar, Santhal-Balol-Lanwa heavy oil belt, Gandhar and Kalol. In Jambusar-Broach block (Gandhar field), hydrocarbons occur in sands of Ankleshwar formation and in Cambay Shale. Exploration status in the Cambay basin, as in 2002 are gravity surveys- 12,726; magnetic surveys- 12,942; seismic surveys 2D, line km onshore- 96,171 and seismic surveys 3D, sq km onshore- 2,478.

*Gandhar Oilfield is an onshore field and all well is drilled by rotary drilling. The complete process involves drilling, well completion, casing and cementation, tubing, surface completion, activation of well, testing, developing of field and finally oil flow to group gathering station, central tank form and gas collecting station.* Drilling oil well is a very tough and dangerous job, so it is necessary to take precautionary measures for safety. In 1950’s a major blow out occurs in Ankleshwar oilfield. Due to blow-out, the total rig was moved down and only crown block is seen presently. Flow of oil and gas from the well is continued till now (Fig. 7.3), named as Bulbula Tank.
The environment of any Oil field area is easily identified with large-scale of air, water and noise pollution. In the residential and sensitive zones near the Gandhar and Wagra area high noise levels have been observed. Sulphur dioxide, oxides of nitrogen, suspended particulate matter and respirable suspended particulate matter concentrations are very less than the suggested National Ambient Air Quality standards of India, however SRP, GGS, CTF, GAIL unit, are the places where air contamination may be easily identified by smelling. The water quality was decided according to the ISI, WHO and ICMR standard. The hydrogen ion concentration for all water samples revealed a range from 6.78 to 7.72 and this is under the permissible limit of WHO, ISI and ICMR. Temperature ranges from 18° to 37° which are less than the permissible limit as suggested by ISI. Sample No. 2, 3, 5, 6, 7 & 8 are colourless whereas Sample No. 1 & 4 is brownish colour. Turbidity ranges from 2.08
to 9.0, which is under the suggested permissible limit of WHO and ICMR. TDS ranges from 250 to 4530mg/lit. Sample No. 1, 2, 3 & 4 have high TDS whereas Sample No. 5, 6, 7 & 8 have under limit TDS as suggested by WHO, ICMR and ISI. TSS ranges from 546 to 1344mg/lit which shows much more concentration of TSS than the suggested permissible limit of WHO. TS of all the samples range from 796 to 5223mg/lit. TS of all the water samples is more than the permissible limit of ISI, except sample no. 8. Total alkalinity ranges from 164-388mg/lit. Total Hardness in the studied water samples ranges from 112 to 1200mg/lit. Sodium concentration ranges from 14 to 121mg/lit, but it is absent in sample no. 1, 3 & 4 and very high (not measurable) in sample no. 2, 5 & 8. Potassium ranges from 02 to 116mg/lit in sample no. 2, 5, 6, 7 & 8 whereas it is totally absent in sample no. 1, 3 & 4. Calcium concentration ranges from 06 to 92mg/lit in sample no. 2, 5, 6, 7 & 8 whereas it is absent in sample no. 1, 3 & 4. Chloride content ranges from 20-596 in sample no. 2, 5 & 8 but it is quite high (not measurable) in sample no. 1, 3, 4, 6 & 7.

Most of the studied parameters for the samples are not in the permissible limit of ISI, ICMR and WHO, it is because of salinity of neighboring sea affecting water. Hence they may shows adverse effect on the health of human beings. **It is recommended to use this water in drinking, domestic, irrigation and industrial purposes after proper chemical treatment and filtration.**

**Environmental Management Plan**

In any oil field area, an environmental management plan may be recommended to prevent environmental impact due to mining namely land degradation, ecological balance, air, water and noise pollution problem.

**Plantation**

When any oilfield was discovered and prepare for exploration, the earth is torn apart resulting in deforestation, which affects the eco-system. To balance the ecosystem in oilfield area, development of new forest or garden is recommended. Gandhar area is a
salt pan area and their climate is not favourable for plantation. So it is recommended to plantation of that plant and trees which can survive in this climate.

Water Management Plan
During the drilling of well, mud is used which carries both formation water and oil. Mud along with water and oil is collected in a pit tank. This water may again go down to the surface and may pollute the underground water. They also mix with rivers, nalas or other water bodies and pollute it. So it is recommended to apply proper water management plan and avoid the water contamination.

Air Quality Management Plan
Study area needs proper investigation with the help of high volume air sampler to maintain the air quality in the oilfield area.

Noise Management Plan
To minimize the noise pollution in mines areas, the following precautions may be recommended: -

1. The entire mining/drilling machines may be maintained regularly in proper manner by automobile /mechanical engineers.
2. Noise level surveys may be carried out from time to time.
3. Colony and villages should be located sufficiently away from the oilfield area.
4. A green belt of trees, shrubs and grass along the both sides of main haulage road may be developed.
5. The workers may be provided ear muffs/plugs.