CHAPTER – 3
LITHOFACIES

3.1 Introduction

Sedimentary facies is defined as any areally restricted part of a designated stratigraphic unit, which exhibits characters significantly different from those of other parts of the unit (Moore, 1949). The study and interpretation of textures, sedimentary structures, fossils and lithologic association of sedimentary rocks on the scale of an outcrop, well section or small segment of basin comprises the subject of facies analysis (Miall, 1984). As suggested by Miall (1984), the word facies is used in both, a descriptive and an interpretive sense. According to him, descriptive facies include certain observable attributes of sedimentary rock bodies, which can be interpreted in terms of depositional processes. On the basis of distinct lithologic features, composition, grain size, bedding characteristics and sedimentary structures, a rock unit is defined as one particular lithofacies. Each lithofacies represents an individual depositional event, which are characteristic of particular depositional environments. These are commonly cyclic, and form the basis for defining sedimentation models (Miall, 1984). The term is also used in an interpretive sense, for group of rocks that are thought to have been formed under similar conditions. According to Miall (1984) with the help of lithofacies studies, one can understand depositional environments and palaeogeography existing at the time when a rock unit was formed and can be better placed to make predictions and extrapolations about lateral changes in thickness and composition.

The Jurassic – Cretaceous sequence exposed in the study area showing six major lithofacies. The discrimination of the lithofacies is based on area of occurrence, stratigraphic position, distinctive lithologic features such as textures, structures, composition and colour as well as physical and biogenic sedimentary structures. Most of these lithofacies are repeated in their vertical extents and also integrate with each other in their lateral extent. The vertical distribution of facies also varies from outcrop to outcrop and not all the facies are repeated at all localities. Different stratigraphic sections measured at
various localities are shown in Figure - 7 to 33. A list of lithofacies along with subfacies proposed is as follows:

I INTERCALATED SHALE SILTSTONE SANDSTONE FACIES (ISSSF)
   1.1 Intercalated Calcareous Shale Siltstone Subfacies (ICSSS)
   1.2 Ripple Marked Ferruginous Sandstone Siltstone Shale Subfacies (RMFSSSS)

II LIMESTONE FACIES (LF)

III SANDSTONE FACIES (SF)
   III.1 Ferruginous Sandstone Subfacies (FSS)
   III.2 Massive Felspathic Sandstone Subfacies (MFSS)
   III.3 Bedded Sandstone Subfacies (BSS)
   III.4 Cross Bedded Sandstone Subfacies (CBSS)
   III.5 Bioturbated Ferruginous Sandstone Subfacies (BFSS)

IV INTRAFORMATIONAL CONGLOMERATE FACIES (ICF)

V GRAY SHALE FACIES (GSF)

VI DHOSA OOLITE LIMESTONE FACIES (DOLF)

3.2 Description of Lithofacies

3.2.1 Intercalated Shale Siltstone Sandstone Facies (ISSSF)

This facies is predominantly argillaceous in nature. In between the shales, thin intercalations of siltstone and sandstone are common in the sequence. Silt and arenaceous part is less in the lower part and it becomes abundant in the upper part. This facies is well developed in lower part of Jumara Formation particularly in Bharasar Member (BM), Chadwa Dungar Member (CDM) and Piludi Lake Member (PLM). It is also developed in Kandawari Wadi Member (KWM), Rathi Dunger Member (RDM) and Sir Edmund Lake Member (SELM) of Jhuran Formation as well as Godpar Member (GM) of Bhuj Formation.

Two subfacies can be distinguished within this intercalated facies sequence. These are: (1) Intercalated Calcareous Shale Siltstone Subfacies (ICSSS) and (2) Ripple Marked Ferruginous Sandstone Siltstone Shale Subfacies (RMFSSSS).
LITHOFACIES INDEX

LF
GSF
DOLF
BSS
BFSS
RMFSSSS
ICSSS
FSS
MFSS
ICF
CBSS
Figure 7: A composite litholog of Jumara Formation in the study area
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<tr>
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<td>GSF</td>
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Figure 8: A composite litholog of Jhuran Formation in the study area.
Figure 9: A composite litholog of Bhuj Formation in the study area
Figure 10: Stratigraphic section - Bharasar dome
Figure 11: Stratigraphic section - along the stream, Bharasar dome area.
Figure 12: Stratigraphic section - SE of Gurukul, Chadwa Dungar block
**Figure 13: Composite section of Samatiya Dungar**

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Figure 14: Stratigraphic section - northern flank of Samtiya Dungar anticline
Figure 15: Stratigraphic section - Opposite to Wala-Khawas on Bhuj-Mandvi road
Figure 16: Stratigraphic section - SE of Samatra village
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Figure 17: Stratigraphic section - E of Phat Sar lake
Figure 18: Composite section from Wandhaya-Ajapar road

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1 m Figure 19: Stratigraphic section - south of Wala - Khawas on Bhuj - Mandvi road
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**Figure 20:** Stratigraphic section - near Phat Sar lake
Figure 21: Stratigraphic section - along the stream south of Wala-Khawas on Bhuj-Mandvi road
Figure 22: Stratigraphic section - 3 km away from Wadasar on Samatra-Wadasar road.

- **Formation**: JHURAN
  - **Lithofacies**: MFSS
    - **Environment**: Shallow subtidal, moderate to high energy
  - **Lithofacies**: ICSSS
    - **Environment**: Subtidal, low energy
- **Formation**: RDM
  - **Lithofacies**: MFSS
    - **Environment**: Shallow subtidal, moderate to high energy
  - **Lithofacies**: ICSSS
    - **Environment**: Subtidal, low energy
Figure 23: Stratigraphic section - along stream NNW of Sir Edmund Lake
Figure 24: Stratigraphic section - north of Godpar village
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Figure 25: Stratigraphic section - along Wadasar stream
Figure 26: Stratigraphic section - along stream on Wadasar-Jamthara road
Figure 27: Stratigraphic section - along Ajapar stream

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Figure 27: Stratigraphic section - along Ajapar stream
Figure 28: Stratigraphic section - near Sarli village on Rampar Vekra-Dahisara road
Figure 29: Stratigraphic section - E of Samatra village on Samatra-Mankuva road

- **Formation**: BHUJ
- **Lithofacies**: BFSS
  - **Environment**: Barrier beach
- **Lithofacies**: ICSSS
  - **Environment**: Subtidal, low energy
- **Lithofacies**: BFSS
  - **Environment**: Barrier beach
- **Lithofacies**: CBSS
  - **Environment**: Estuarine, high energy

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<tr>
<td>GM</td>
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</tbody>
</table>

Figure 30: Stratigraphic section - south of Lalang college on Bhuj-Mandvi road
Figure 31: Stratigraphic section - before Naranpar on Bhuj-Naranpar road

Formations: BHUJ, RM

Lithofacies: CBSSS

Environment: Estuarine, high energy

1 m
Figure 32: Stratigraphic section - near Samatra village
Figure 33 Stratigraphic section - N to NNW of small dam on Samatra-Munkuva road
3.2.1.1 Intercalated Calcareous Shale Siltstone Subfacies (ICSSS)

Description:

This subfacies is well developed in lower part of Jumara Formation i.e. Bharasar Member (BM), Chadwa Dungar Member (CDM) as well as Piludi Lake Member (PLM) and also developed in Jhuran and Bhuj Formation. In BM, it is found at Bharasar dome area, in CDM at Chadwa Dungar block and Bharasar Dome area, and in PLM at Prag Sar block and Bharsar Dome area. In Jhuran Formation the subfacies developed in each member such as, Kandawari Wadi Member (KWM), Rathi Dungar Member (RDM) and Sir Edmund Lake Member (SELM). In KWM, the rocks are lying above the Dhosa Oolite Member, so they are exposed at many places in study area. Similarly they are developed in RDM again almost everywhere in study area. In SELM, they are typically exposed along the stream, which runs northwest-southeast direction and lying northwest of Sir Edmund Lake. In Bhuj Formation it is developed in Godpar Member (GM), the typical section of which exposed near Sarli village on Dahisara – Rampar Vekra road.

This subfacies is argillaceous in nature and contains thin partings of siltstones at various intervals and as we move towards upper part it becomes more silty in between shale layers. Right from top to bottom in each of the member there are numerous intercalations of calcareous shale and siltstone. The calcareous shale beds are thinly laminated with various colours like yellow, grey, pink, yellowish green and even black. These shales consist of small amount of argillites and gypsum. In addition glauconitic grains are found in the rocks. Usually shales are weathered out forming low ground, but because of alternate layers of siltstones, the sequence is exposed at certain sections. From the colour of the shale is difficult to predict that whether it is derived from the weathering in the source region, through insitu oxidation and reduction at the time of deposition or as a result of diagenetic process after sedimentation. Siltstones – intercalated with shales are cream to reddish or yellowish in colour, contains minute mica flakes and calcareous in nature. Muscovite flakes occur parallel to the bedding planes. In BM and RDM, in
between this sequence, there occur black–carbonaceous shales. In KWM, in the lower part i.e. above Dhosa Oolite Member of Jumara Formation, there occur numerous thin partings, which are highly ferruginous. In this intercalated sequence, at certain intervals reddish brown or claret colour bands with silty nature are commonly found everywhere. This may be due to the sub-aerial exposure and oxidation of particularly finer sediments or to the accumulation of oxidized material.

Thin section study reveals that these are silty and micritic and richer in fragmented fossil contents. Clasts are few and fine grained, composed of silty material. Felspars and unstable grains are less than 5%. Framework grains are matrix supported and rock contains micritic to sparitic cement. Ferruginous matrix is comparatively less. It contains fragments of numerous fossils; brachiopods are dominated, others are bivalves, foraminifers etc.

This sub-facies is almost devoid of sedimentary structures in the lower part of the sequence, i.e. in Jumara Formation, but the upper part particularly in RDM of Jhuran Formation contains ripple marks–linguoid type and parting lineations. Bivalves are most abundant in highly fossiliferous siltstone bands. Among others gastropods, cephalopods, foraminifers and brachiopods are common. Along the shale-siltstone intercalations, bioturbation is abundant. They contain horizontal burrows, trails and biogenic markings, which includes Arenicolites, Calycraterion, Chondrites, Cochlichmus, Diplocraterion, Fustiglyphus, Gyrochorte, Imponoglyphus, Monocraterion, Ophiomorpha, Palaeophycus, Phycodes, Rhizocorallium, Skolithos, Taenidium, Thalassinoides etc.

Interpretation:

Dominance of argillaceous material with thin alternate bands of siltstone in the lower part of sequence indicates deposition under low energy conditions and it could be below normal wave base on a shallow marine shelf. In the upper part of sequence, arenaceous material dominates along with argillaceous material, which indicates deposition in much shallower conditions and it could be above wave base on an open marine shelf. So, this subfacies indicates
transgressive and standstill conditions, which is followed by regressive conditions in the upper part. The overall finer material of the subfacies indicate very slow setting of suspended fine hemipelagic material in a low energy regime marked by the absence of coarse grain sands. Shale-siltstone intercalations are constant and uniform in thickness, which spreads over a larger area indicating the gentle gradient of the basin and wide development of facies. The occurrence of ferruginous bands at certain intervals as well as calcareous material present in the sediments suggests the precipitation of ferruginous and carbonate material. During this stage probably the supply of argillaceous material was limited. In the upper part, the presence of sedimentary structure like ripple marks indicates wave action by the shallow shore migrating currents. Prominent oceanic currents normally are absent in such shallow parts (Elliott, 1978). Interbedded parallel laminated silts and muds, which represent suspension depositions, have periodic bottom currents to form ripples (Johnson, 1978). Insitu colonization of epi and infaunal benthic communities are suggested by highly fossiliferous siltstone bands, which are showing no evidences of bioturbation and undisturbed fossil shells within the siltstone bands. On the other end, reworking and erosional features are also supported by the presence of coating of calcareous and ferruginous material on fossil shells as well as fragmented fossils in the bands. Abundant bioturbation along the interface of shale-siltstone intercalations indicates the prolific development and diversity among the invertebrate fauna during the deposition.

In the lower part of sequence, the absence of ripple marks along with cyclic repetition of siltstones indicates the deposition below normal wave base on a shallow marine shelf. In the upper part of sequence, ripple marked top surfaces indicates deposition in much shallower conditions above normal wave base on an open marine shelf. Overall this subfacies indicates deposition under low energy conditions.
3.2.1.2 Ripple Marked Ferruginous Sandstone Siltstone Shale Subfacies (RMFSSSS)

Description:

This subfacies is developed only in Godpar Member (GM) of Bhuj Formation. This sequence is typically developed near Sir Edmund Lake dam axis. It is also found exposed at Chadwa Dungar block and Samtiya Dungar block, found within GM of Bhuj Formation.

This subfacies is characterized by cyclic repetition of sandstones, siltstones and shale. Most of the beds are typically horizontal. The thickness of the sandstone increases, while the thickness of siltstones and shales decreases and completely vanish in the upper part of the facies sequence. The sandstones are variegated in colours and fine to coarse grained, well sorted, soft and friable. Siltstones are fine grained with gray, white, yellowish to reddish in colour. Red colour is due to the presence of ferruginous material and at times such material is so ample that it becomes hematitic or lateritic with spongy or nodular appearance. Shales are yellow, pink, gray and black in colour with fine grained nature. It is mainly composed of clay material with minute mica flakes. The composition of shales varies from felspathic, ferruginous to carbonaceous. As the colour of the shales varies with ferruginous and argillaceous bands, it indicates reworking and setting from suspension. The subfacies show the uniform thickness of intercalated sequence.

Thin sections of the sandstone shows that these are medium to fine grained sandy to silty, grain supported and moderately sorted to unsorted. Along with quartz, grains of felspars are common, which are subrounded to subangular. Cement is mainly ferruginous. Bivalve fragments and foraminifers are seen in thin sections.

The top surface of these intercalated sequence at Sir Edmund Lake showing beautiful interference wave influenced ripple marks along with parting lineations. In the interference ripples, wave length is more and amplitude is less. The ripple marked top surfaces are covered by thin mud drape layers indicating non-depositiona gaps. In the sandstone bed hummocky cross-
stratification and slump structure is preserved very well. The body fossils of bivalves, gastropods and ammonites are found from few siltstone bands while they are almost nil along remaining components of the intercalations. Plant remains are also found in the beds. Abundant trace fossils are found along the intercalations, particularly on the top of ripple marked surface, which includes Cochlichnus, Didymaulichnus, Gyrochorte, Monocraterion, Oldhamia and Palaeophycus.

**Interpretation:**

Ripple marked surfaces with greater wave length and other features indicating deposition in tidal flat environment. The interference ripples suggests changing directions of water movement during the various stages of tidal cycle. The variation in bioturbation suggests deposition variation; wherein the upper portions of a tidal flat burrowing is less intense than the lower portions of the flat, where the density of infaunal animals is high, as suggested by Miller and Knox (1985). As suggested by Klein (1970), Knight and Dalrymple (1975), the interference ripples along with flat topped symmetrical ripples are the common features of intertidal sand flat environment. Slump structure suggests the rapid deposition of sediment on an unstable slope. Lateral movement may be initiated by earthquakes. This probably indicates the actively subsiding nature of the basin (Selley, 1976 pp. 228). Hummocky cross-stratification is indicating undulating depositional surface and winnowing higher energy conditions as suggested by Lindholm (1987). This bed form can be attributed to have been produced during upper flow regime conditions in unidirectional flow.

3.2.2 Limestone Facies (LF)

**Description:**

This facies is defined on the basis of the presence of calcareous material - bands of dense limestones. Actually these bands are alternating with shales of Jumara Formation. This facies is developed only in Bharasar Member (BM)
and Piludi Lake Member (PLM). In both the members, it is typically developed at Bharasar dome area.

BM and PLM are in general, argillaceous in nature, but limestone bands are present in these two members only. Thickness of limestone is more in case of BM than PLM. Usually the individual bed is 50 cm thick, but as a whole all these bands aggregate to form about 5 m thickness in BM. In PLM there is scarcity of good outcrops of limestone like BM because of thin nature, weathering and concealment by overburden. The facies in BM forms the oldest beds of the study area. Limestones are grey, white to buff red in colour. They are fine to medium in grain size. In the lower part limestone is grey to white in colour but in upper part, it is cherty - white in colour, even red and highly fossiliferous at places. Some of the limestone bands are crystalline - neomorphosed. Limestones are massive, hard and dense in general, but particularly cherty limestone beds are much compact.

Thin section study indicates that these are largely micritic in composition. It contains small sized quartz grains, which are angular to subangular with few feldspar and mica flakes. The clastic grains are well sorted to poorly sorted in different sections. In certain sections sparitic, siliceous and ferruginous cement is also seen along with micrite. Fossil content is usually abundant, which contains bivalves, brachiopods, foraminifers, ostracods and bryozoans.

This facies is almost devoid of any sedimentary structures, but at few places viz. at Chadwa Dungar block, the limestones showing mega ripple marks on the top. Here at least two bands of limestone are present - both are different in colour and showing harmony of top of lower band and bottom of upper band in parallel mega ripple form, due to casting of mega ripples marks on the bottom of the overlying band. In the PLM, the pinkish red limestone bed of the facies contains abundant minute fossil shells of bivalves and brachiopods. The colour of the rock may be due to ferruginous material. Trace fossils include Didymaulichnus, Ophiomorpha, Palaeophycus and Taenidium.
Interpretation:

Limestones are intercalated with shales which indicate the deposition on shelf away from the coastal zone.

On the other hand, the mega ripple marks suggest storm generated origin of the structure under high energy conditions below normal wave base. This kind of development of mega ripple marks is found only in the PLM. From the occurrence of bivalves and brachiopods-particularly Rhynochonellid, it is evident that the depositional environment was restricted only below sub-littoral zone. Lithological and biological features along with mega ripple marks suggest a shallow, open shelf deposition where the sea was slowly transgressed under relatively stable conditions.

3.2.3 Sandstone Facies (SF)

This facies is predominantly arenaceous in nature. This facies is developed in Bharasar Member (BM), Chadva Dungar Member (CDM), Samtiya Dungar Member (SDM) and Piludi Lake Member (PLM) of Jumara Formation. It is also developed in Kandawari Wadi Member (KWM), Rathi Dungar Member (RDM) and Sir Edmund Lake Member (SELM) of Jhuran Formation as well as Godpar Member (GM) and Rukmavati Member (RM) of Bhuj Formation. This is the only facies, which developed in each member of all the three formations.

Sandstones are massive, felspathic, ferruginous, horizontal to cross– stratified as well as bioturbated, so based on these variations the sandstone facies can be divided in to five sub–facies named as,

1. Ferruginous Sandstone Subfacies (FSS)
2. Massive Felspathic Sandstone Subfacies (MFSS)
3. Bedded Sandstone Subfacies (BSS)
4. Cross Bedded Sandstone Subfacies (CBSS)
5. Bioturbated Ferruginous Sandstone Subfices (BFSS)
3.2.3.1 Ferruginous Sandstone Subfacies (FSS)

**Description:**

This subfacies is defined on the basis of highly ferruginous, medium to coarse grained sandstones. It is well developed in BM and PLM of Jumara Formation as well as KWM of Jhuran Formation. It is typically developed at Bharasar dome area, with in BM; as well as at Chadwa Dungar block and Samtiya Dungar block, with in PLM of Jumara Formation. In Jhuran Formation, this subfacies is developed in the top part of KWM and found exposed in the area surrounding Kandwari Wadi village as well as on Wandhaya – Ajapar road.

This subfacies is dominating in sandstone. The sandstones are hard, highly ferruginous – purple to reddish black in colour and medium to coarse grain in size. At places it becomes gritty and thickness of individual bed reaches up to 3 m. The sandstones are commonly coarsening upward. These sandstones are usually forming the top part of BM, PLM and KWM, which are highly ferruginous and the top surfaces are ripple marked or parting lineated or sometimes flat–structureless depicting depositional break or hiatus. Particularly in KWM, these sandstones are forming small pockets – detached outcrops. The overall nature of the sandstones is wedge shaped.

Thin section shows that mineralogically, the grains are mature to immature, containing 5 to 20% felspars. Texturally, the sediments are mature to submature. The grains are subangular to subrounded, moderate to poorly sorted. Most of the quartz grains are plain igneous quartz, but few grains show undulose extinction indicating metamorphic origin or strain effects. Generally the rock is matrix supported. Cement is ferruginous as well as micritic in nature. Among the fossils bivalves, echinoid spines and bryozoans are distinct.

Among the sedimentary structures stratification, cross–stratification, herringbone structure, ripple marks as well as mega ripples are common. Fossil content is comparatively less, but there occur bivalves, small gastropods as well as minute fossils of vertebrates, which are probably teeth and vertebrae of
fish. Trace fossils are rare. Even though, *Arenicolites*, *Thalassinoides* and *Palaeophycus* are found.

**Interpretation:**

Overall this subfacies suggest a marine environment. The topmost part of sandstone is either wedge shaped or in pocket form indicating marginal - marine condition of deposition. These patches might be the offshoots of bird’s foot delta towards sea from distributaries river channels, where deposition of sands becomes possible.

As described by Selley (1970), Johnson (1978), the vertical sequence of increased grain size is typical feature of recent barriers and beaches. Transitional zone between off shore margin and barriers depicted by the intermingled or intermittent massive sandstone along with marine fossils, ripple marks, burrows and association of subfacies ICSSS. Parting lineations as well as ripple marks indicate their development in shallower conditions with subaerial exposures under tidal complex. Ferruginous cementing matrix suggests derivation from nearby terrigenous parts and terrestrial influence. The overall evidences directed to a barrier beach to tidal flat environment for the subfacies.

**3.2.3.2 Massive Felspathic Sandstone Subfacies (MFSS)**

**Description:**

This subfacies is defined on the basis of dominance of arenaceous material in the matrix along with occurrence of 5 to 20% of felspar grains in the rock. This subfacies typically developed in Chadwa Dungar Member (CDM) and Samtiya Dungar Member (SDM) of Jumara Formation. It is also developed in Rathi Dungar Member (RDM) of Jhuran Formation. In CDM these are best developed at Bharasar dome area as well as at northern part of Chadwa Dungar block. In SDM, this subfacies found spread over in central part of study area i.e. Samtiya Dungar block, Chadwa Dungar block as well as Bharasar dome area. In RDM, it is developed at Rathi Dungar area.

This subfacies is dominating in sandstones. Sandstones are hard, medium grained with uniform grain size. The colour ranges from yellow to
red–ferruginous. Grains are more or less floating in the matrix. The sediments are immature, contains matrix more than 5% and the felspar content usually ranges from 15 to 20%. These sandstones are quarried from Bharasar dome area. In SDM the sandstone having larger rounded to subrounded cobbles and boulders of sandy to calcareous material. Cement is normally ferruginous, with certain amount of siliceous – cherty material. Matrix is mainly clayey to silty. The sandstones are underlain and overlain by thick gypseous shale units.

Thin section study reveals that these are matrix supported sandstones, but few sections shows grain supported nature. Grains are subrounded to subangular, moderate to poorly sorted and more or less floated in the matrix. In some cases grains touch each other. Quartz grains are largely plain igneous quartz, but few sections showing undulose extinction suggesting secondary strain effect. Feldspar content ranges from 15 to 20%. They are microcline, orthoclase and plagioclase. Certain sections showing high amount of feldspar content. Muscovite and biotite flakes are common along with opaque grains. Cement is chiefly of ferruginous material, with certain amount of siliceous and micritic material. At places it is sparitic also. Few sections are showing stratification as well as lenses of silty matrix. These are moderate to highly fossiliferous, which contains fragments of bivalves, brachiopods, echinoid spine, foraminifers, bryozoans, ostracods etc.

Many sedimentary structures found from this subfacies. The rocks are horizontally stratified to cross–stratified, massive, flat bedded and locally hummocky cross–stratified. Herringbone structure is also found due to the changing directions of ocean currents. The top parts are ripple marked to parting lineated. The ripples marks are pointed crested straight symmetrical ripples, flat top oscillation ripples to interference ripples. Microripples – rivulrites are also found on the top surfaces of sandstones. This subfacies contains few occurrences of bivalves and brachiopods. On the top of sandstones along with ripple marks trails, burrows are also preserved, which include Chondrites, Monocraterion, Ophiomorpha, Palaeophycus, Phycodes, Rhizocorallium, Skolithos, Taenidium, Thalassinoides, Zoophycos etc.
Interpretation:

Marine influenced environment depicted by physical and biogenic data. The varieties of sedimentary structures like massive, flat bedded, horizontally to cross-stratified, along with pointed, straight crested, symmetrical ripple marks indicating the deposition of sediments in a nearshore – onshore region and most probably in a subtidal – tidal region. This is further supported by the overlying shale sequence. Hummocky cross-stratification structure indicates storm generated origin. Shallow subtidal to tidal conditions of deposition is depicted by herringbone structure.

The sandstones are massive and felspathic, which represents reworked beaches, sand dunes and fluviatile deposits by a transgressive sea. Thickness of sandstones as well as sheet like geometry indicates high rate of sand influx, mainly in an encroaching sea, from coastal and related terrestrial sediments i.e. beach, coastal dunes and fluviatile sediments. The high percentage of felspar grains in sandstones, which are liable to be destroyed in constantly agitating tidal marine environment suggests fast rate of sedimentation. Horizontal stratification occurs in a swash zone (Clifton, Hunter and Phillips, 1971) or back barrier wash over sands (Bridges, 1976, Schwartz, 1975) or lower sand flats in an intertidal zone (Evans, 1965).

Such thick sandstone sequence are repeated in the study area as found in CDM, SDM and RDM, which indicates the development of similar type of conditions in a pulsatory manner, in a eustatic to slowly transgressing sea, under subsiding basin conditions. The rounded to subrounded cobbles and boulders of sandstone as found in SDM can be regarded as relict – remnant from an earlier environment, which are now found as reworked sediments; possessing aspects of both its present and former environments. So, these boulders can be considered as remnants of an underlying bed, which is eroded in a nearshore terrestrial environment and incorporated in the sandstone of SDM by transgressive sea. This is further evidenced by unequal size of boulders, sharp contact with the host sediments, variation in composition as
well as compactness of boulders and cement. Overall this subfacies indicates intertidal - shallow subtidal environment with stormy events.

**3.2.3.3 Bedded Sandstone Subfacies (BSS)**

**Description:**

This subfacies is defined on the basis of thick sandstone bands with thin intercalations of siltstone and shale bands. The rocks of the subfacies are typically developed at many places in the study area, particularly on Bhuj – Mandvi road, in between Godpar and Phat Sar, south of Rathi Dungar area as well as near Ajapar and belongs to Sir Edmund Lake Member (SELM) of Jhuran Formation.

This subfacies consists mainly of arenites and subordinate amount of argillites. Sandstones are yellowish to grayish and red–purple–ferruginous with medium to coarse grain size. The rocks are well compacted to almost loose in nature. The rocks are texturally immature, where angular to subrounded, quartz grains are cemented together in unsorted manner. The cement is red, dark brown–ferruginous to calcareous and of marine origin. It also contains few felspar grains, cherty material and Glauconite nodules. Thin bands of gritty – coarse sand material probably derived from outside the depositional basin, occurs in between. Thickness of the facies is uneven from place to place; it is maximum on Bhuj – Mandvi road. Generally these rocks are matrix supported and moderately sorted to unsorted. The rocks range from quartz and felspathic arenite to quartz and felspathic wacke. Clayey matrix in some cases may have been formed due to decomposition of felspar grains.

Thin sections of BSS are showing dominance of quartz grains with the presence of felspars. Grains are subangular to subrounded and touch each other. Most of the quartz grains are plain igneous type. Sorting is moderate. Cement is mainly ferruginous, but in some cases micritic. All such variations found even from one section also. Fossil content is poor in thin sections.

The sedimentary structures include massive to regular bedding characteristics with low angle stratification and channel structure. Near triple junction of Bhuj – Mandvi – Bharasar road, sand volcanoes having diameter of
3 cm and height of 1 -1.5 cm are beautifully preserved. The fossil content is comparatively less and fragmented. Trace fossils found in this subfacies mainly includes *Didymaulichnus, Gyrochorte, Oldhamia* etc.

**Interpretation:**
This subfacies suggest marine environment. The lithological characters along with fossil content indicates tidal flat environment. The massive to regular bedding with low angle stratification indicates deposition of sediments in bars, barriers and tidal flats. The channel structure at the top of certain sandstones were probably cut by tidal currents flowing between open sea and lagoon, or flowing on tidal flat at the time of spring and receding tides. On the contrary, quartz and felspathic arenite to quartz and felspathic wacke sheets suggests that from time to time the shoreline was static. The angular to subrounded nature and undecomposed felspar grains suggest proximity of source area. Further terrestrial influence is evidenced by ferruginous and cherty cement, which indicates the derivation of clay and silt matrix from nearby terrigenous parts.

Dominance of arenaceous material with thin layers of argillaceous material indicates development of tidal flats and subtidal part along a static shoreline, where most probably the rate of sedimentation and subsidence may be almost equal. This subfacies suggests a barrier beach to tidal flat environment.

### 3.2.3.4 Cross Bedded Sandstone Subfacies (CBSS)

**Description:**
This subfacies is defined on the basis of coarse grained sandstones, which are characterized by cross–stratification. The facies is developed in Godpar Member (GM) and Rukmavati Member (RM) of Bhuj Formation. RM is exhibiting peculiarities of this subfacies extensively. Occurrence of this subfacies is found at many localities, as Bhuj Formation occupies major part of the study area.

This subfacies is arenaceous and the sandstones are white, buff, yellow to pink–red in colour, medium to coarse grained, poorly to moderately sorted, friable, current–bedded and felspathic. At places it becomes gritty and contains
mica flakes. This subfacies occurs in isolated cross-bedded sheet form or linear elongated ridge like form or it produces thick amalgamated sequence of cross-stratified beds. At certain places the sandstones becomes conglomeratic, which is found in form of thin bands or lenses.

Thin section study reveals that the sandstones are texturally moderate to well sorted and in certain cases unsorted. Medium to larger sized quartz grains are subrounded to subangular and few grains showing undulose extinction. Feldspar grains present up to 10% along with few muscovite flakes. The rock is mainly matrix supported and highly ferruginous in nature, which remains isotropic. Few sections are grain supported with micritic cement. Glauconitic material is present in certain sections, which becomes oxidized and converted in to ferruginous matrix. Certain sections are gritty to conglomeratic, where subrounded large quartz grains showing undulose extinction are present with few felspars grains. Few sections are showing the presence of bivalves.

This subfacies is characterized by large scale planar and trough cross-stratification, which is found exposed at most of the places. Varieties of sedimentary structures preserved are torrential bedding, channel structure, slump structure, flame structure, convolute bedding, climbing ripple cross lamination, graded bedding, herringbone structure, honey comb structure etc. Thin bands of siltstones showing ripple marks. As mentioned in previous chapter the upper contact is erosional, so hardly any ripple marks are preserved on the top surfaces of sandstones. The lower contact of the beds is showing reactivation surfaces. Thin bands or lenses of pebbly conglomerate occur in form of toe sets in cross-stratified or torrential bedding. The amalgamated sandstones occur in form of larger channel fill deposits where beds occur in form of sheets or broad lenses tapering against erosional channel contacts. The facies is devoid of any fossil fauna, but silicified coral fragments are found from south of Lalan College on Bhuj – Mandvi road. Fossil wood and plant debris are found from certain bands. Occurrence of trace fossils in the subfacies are few, which are found in form of escape structures or in form of Oldhamia, Skolithos and Trichichnus.
Interpretation:

This subfacies suggests that the thick coarse grained sandstone sequence deposited in an estuarine depositional system. Abundance of physical sedimentary structures – their lateral and vertical variation along with the geometry of the beds depicting an estuarine set up. Flood and ebb tides in an estuarine set up are evidenced by sandstone sequence with herringbone structure. The lower contact of the beds are showing reactivation surfaces and upper contacts are erosional, such features are the characteristics of the flood tides and are associated with normal storm events (Leckie and Singh, 1991; Dalrymple, Zaitlin and Boyd, 1992).

Small asymmetric to linguoid ripple marks on the surfaces of siltstones suggests the deposits are of weaker ebb tide flows or fluviatile flows in between two flood tides. The structures like slumping and convolute bedding suggest high rate of sedimentation. Large scale planar cross–stratification with contortion has been interpreted as flood deposits by Collinson and Thompson (1982). Bioturbation is comparatively less, which might be the result of constantly reworked sediment by high tide and wave energy, so the conditions are not in favour of burrowing organisms. From Albian estuarine deposits of Canada, similar kind of conclusions are made by Leckie and Singh (1991). This subfacies thus suggests estuarine depositional environment with higher energy conditions.

3.2.3.5 Bioturbated Ferruginous Sandstone Subfacies (BFSS)

Description:

This subfacies is defined on the basis of highly ferruginous sandstone with abundant bioturbation, which has obliterated primary sedimentary structures of the rocks. It is found only in Rukmavati Member (RM) of Bhuj Formation. In the study area it is typically developed on Bhuj – Mandvi road near Godpar, Dahisara, Sarli, Rampar Vekra, Naranpar, Bharapar, Samatra etc. The facies occurs in the study area in form of two more or less parallel belts, one on the northern side of Katrol hill fault and other on the northern side of Deccan Trap lava flows.
This subfacies is very easily picked from a distance by its peculiarities like typical dark brown colour, highly bioturbated nature and uniform thickness over distant areas. Thickness of individual beds ranges from 0.5 cm to 2 m and the thickness of amalgamated sequence of identical beds reaches up to 20 m. This subfacies is iron rich and can be referred to as ferruginous bands, concretionary hematitic or limonitic with spongy or nodular weathering (Biswas, 1977). Megascopically the sandstones are coarse grained, moderately sorted, yellow to reddish brown in colour. Towards the top thin bands of selenite (gypsum) or crystal aggregates are observed.

Thin section study depicts that the rocks are coarse grained sandstones. They are moderately sorted, grain supported and grains are rounded to subrounded. Few sections show unsorted nature. Plain quartz and quartz with undulose extinction are almost equal in proportion. Cement is mainly dark brown – ferruginous with small proportion of micrite. Fossils are totally absent.

The primary sedimentary structures are disturbed as well as obliterated by abundant bioturbation, even though traces of horizontal stratification and planar cross–stratification has been observed. Structures produced due to differential erosion under the influence of wind have also been found on the top surface of sandstone at Godpar. The lower junction of the beds normally shows scoured uneven surface or load casts and related structures on thin shale bands, while the upper junction is bioturbated or ripple marked. The ripple marks are much obliterated by bioturbation. The ripple marks are straight crested symmetrical to asymmetrical or in some cases current ripples. This subfacies also devoid of any fossil fauna, but leaf impressions as well as fragments of woods along with plant rootlets are preserved in the rocks. Intense burrowing in coarse grained rock makes difficulty to examine individual burrows. The trace fossils include Balanoglossites, Diplocraterion, Monocraterion, Pholeus and Skolithos.

Interpretation:

This subfacies is highly bioturbated, which indicates the deposition in areas where wave and current stratification is over shadowed by biological
reworking (Howard 1972). Such conditions with slow to negligible rate of sedimentation could have existed at either offshore or in a protected shoreline environment such as back barrier lagoon. As suggested by Warme et al (1971), Reineck and Singh (1973), Ronan (1975) intense burrowing is found in some modern lagoonal sediments. As suggested by Howard (1975) in modern estuarine environments, the abundance and diversity of biogenic structures increases seaward, especially in estuaries with fresh water influx, while the bioturbation is comparatively less in the sediments deposited in low salinity environments i.e. inner estuary portion, as suggested by Dorjes and Howard (1975). Thus this feature indicates deposition in marine influence as well as protected enough to allow reworking by burrowing animals which dominate over wave and current stratification. Such kind of conditions occurs on a subtidal to lower part of intertidal region. Very gentle gradient of the depositional basin and the development of extensive tidal flats are evidenced by the horizontal stratification and abundant bioturbation, which is perpendicular to bedding planes. According to Runkel et al. (2007) the nearshore marine association is dominated by fine to coarse grained sandstone with *Skolithos* trace fossils. As per them, this association has a suite of sedimentary structures such as swaley, trough and planar cross-strata that are typical of deposition at or above fair weather wave base in a shore face setting.

The coarse grained sandstones are moderately sorted to unsorted in nature as well as presence of pebbly band and scoured erosional bottom surfaces probably suggests storm lag deposition within a lagoonal conditions. These bioturbated sandstones are overlain by trough cross-bedded sandstone at most of the places, which could be the typical feature of lower shoreface deposits as suggested by Howard (1972), Reineck and Singh (1973).

Terrestrial conditions are indicated in the uppermost part of the sequence by the plant rootlets and fossil wood. It could be near shore coastal terrestrial region or tidal marshy region, where sandstones were deposited by a stormy transgressive sea. This subfacies overall suggests deposition during mesotidal or macrotidal shoreline conditions in form of tidal lags.
3.2.4 Intraformational Conglomerate Facies (ICF)

Description:

The facies is defined on the basis of presence of conglomerate bands of intrabasinal origin. This facies is developed in Chadwa Dungar Member (CDM), Piludi Lake Member (PLM) and Dhosa Oolite Member (DOM) of Jumara Formation. In Jhuran Formation it is developed in Rathi Dungar Member (RDM) and Sir Edmund Lake Member (SELM). Most extensive development is in Chadwa Dungar block, Samtiya Dungar block and Bharasar dome area, which belongs to CDM and PLM. In DOM, the top part is represented by the facies, which is found at many places in the study area. In Jhuran Formation, at the base of RDM the facies is developed east of Wandhaya village, while at the base of SELM it is exposed in Rathi Dungar as well as northwest of Sir Edmund Lake.

The facies incorporates the rocks which contains different clasts of the underlying rocks. These are composed of rounded to elongated clasts of marl and argillaceous to silty claystone. The colour of the clasts ranges from white, yellowish to reddish. The clasts are varying in size and composition - polymictic. Some of the clasts are showing bifurcated nature and subaqueous dehydration crack on the surface, which is suggesting dehydration under water at the time of diagenesis. It is mainly matrix supported, but at places clast supported nature is also found. Matrix is mainly calcareous and yellowish to reddish in colour.

The topmost part of DOM contains large broken blocks of the rock suggest collapse of lithified burrow systems – mainly of Thalassinoids. It contains reworked rounded to elongated pebbles. Majority of these pebbles are bored and / or encrusted by bivalves and brachiopods. Reddish brown ferruginous crust has been formed on the surface of intraformational autoclastic conglomerate. Here also matrix is calcareous to ferruginous.

Thin section study indicates that these are matrix supported conglomerates having mud pebbles. Small quartz grains – rounded to subangular with few felspars are floating in matrix. Few quartz grains show
undulose extinction. The rock is mainly matrix supported. Cement is mainly calcareous to even highly ferruginous in certain cases. In certain sections both found together. Calcareous material is largely micritic and in few cases sparitic also. These are highly fossiliferous contains bivalves, gastropods, brachiopods, foraminifers, bryozoans and ostracods.

This facies lacks in any distinct physical structures. Bioclasts are abundant in it. It includes mainly bivalves, *belemnites*, brachiopods etc. The facies on the top part of DOM is having large sized ammonites and *belemnites* in it. Most of the fossils have preserved their original structures. Trace fossils are almost negligible except the borings found in the pebbles as well as *Diplocraterion* and *Palaeophycus*.

**Interpretation:**

This facies suggest high energy conditions in shallower subtidal part where due to interaction with substrate, waves were converted in to unidirectional currents and hence in such part current is dominated over wave action. This is supported by the alignment of pebbles, absence of physical structures like symmetrical wave ripples as well as by erosional scoured base. The pebbles in the conglomerate are interpreted as being of concretionary origin.

Boring and encrustation of the pebbles from more than one sides is due to repeated reworking and colonization, as suggested by Aigner (1985). During the stormy events the pebbles are overturned, while during the calm period it becomes bored and encrusted. Due to repetition of such stormy events pebbles becomes overturned and bored and encrusted from more than one side, which represents multiple events. According to Ball et al. (1967), Aigner (1985) the sharp contact, mostly scoured at the base of the facies, is most likely due to erosional episodes during storms.

Different hard and prominent beds with a mixture of ferruginous and calcareous material as matrix suggest high energy to stormy conditions with low rate of net sediment supply. Further it is supported by some of the boulders, which contain ammonite fossils in their core part. These boulders are
mixed with fossiliferous lag deposits indicating high energy conditions. Along with clasts, surrounding matrix is also found bored, which suggest early diagenesis and formation of hard grounds. This is caused due to lack of fresh sediment supply and calm periods following the storm episodes.

Deep event erosion is indicated by the fragmented *Thalassinoides*. Such kind of vertical zonation of trace fossils within sediments were reported by Wetzel (1979), Ausich and Bottjer (1982). Overall the facies indicates deposition in storm generated much shallower substrate conditions.

3.2.5 Gray Shale Facies (GSF)

**Description:**

This facies is defined on the basis of dominance of argillaceous material over the arenaceous material. The facies is typically developed in Piludi Lake Member (PLM) and Dhosa Oolite Member (DOM) of Jumura Formation. It is also developed in Rathi Dungar Member (RDM) of Jhuran Formation as found on Bhuj – Mandvi road as well as Samatra – Wadasar road and Wandhaya – Ajapar road. The extensive development is at the Prag Sar block and Bharasar dome area, which belongs to PLM. In DOM also the facies is typically developed and found spread over at many places of the study area along with Dhosa Oolite bands.

The facies is dominating in argillaceous material. Shales are mainly yellowish to greenish and even red–ferruginous to black in colour. The rocks are finely laminated and intercalated with oolitic limestone bands as found in DOM. The shales are composed of clay material and mica flakes along with silt size quartz grains. Calcareous material is subordinate, but glauconite and fragments of plants are visible. Thin bands of gypsum and evaporite vein deposits are common in the shale sequence. So, the composition varies from clayey, ferruginous to carbonaceous. The rocks are massive, fissile to non–fissile and moderately compacted to loose. The shales are showing quick gradational lower contact and gradational, abrupt to erosional upper contact. Sideritic nodules are also present in between shale sequence.
The shales are finely laminated. At certain places, the facies is represented by silty material and in such cases planar cross-stratification and symmetrical to asymmetrical ripple marks found on the top surface. Fossil content is less and mainly represented by fragmented belemnites and ammonites. Leaf impressions and plant residues are common in black shales. Trace fossils are rare in the facies. Laminations of the rocks are disturbed, whenever burrows are present.

**Interpretation:**

Dominance of fine grained material—shales, indicate that the sediments were deposited in quiet water of low wave and current energy. Shallow marine environment in reducing conditions is suggested by the predominant argillites along with ferruginous material. Shales are generally considered to be deposited during the regressive phase of depositional system within sedimentary basin. The presence of gypsum bands indicate the evaporation process i.e. the body is separated from the sea - a protected environment e. g. lagoonal conditions. Occurrence of sideritic nodules in shale sequence is significant and indicates brackish water or fluctuating salinity condition and moderately low pH and oxygen content as suggested by Woodland and Strenstrom (1979). The presence of black colour is also significant in shale sequence. This colour may be originated by weathering in source area, developed through insitu oxidation or reduction at the time of deposition or as a result of diagenetic changes after burial of plant residues.

This facies is lacking in physical sedimentary structures, so it is difficult to interpret the environment, but it appears to have been deposited under quiet water conditions. Lacking in biogenic activity may be due to the poor exposures, as shales are easily weathered out. Occurrence of biogenic structures in ferruginous silty bands depicts favourable conditions for infaunal elements and oxygenated aerobic conditions. As suggested by Morgan (1970) fine grained sediments are also deposited in estuarine marshes and interdistributary bays. The material probably deposited in intertidal flats
associated with barrier systems, which is suggested by the mudstones and cross-stratified siltstones.

The repetition of the facies indicate that the basin is slowly subsiding one. The subsequent deposition again shallow the basin. Overall the facies indicates the deposition in a lagoonal to sub tidal condition, as evidenced by the evaporite deposits, bioturbation and abundant leaf impressions.

3.2.6 Dhosa Oolite Limestone Facies (DOLF)
Description:

This facies is defined on the basis of occurrence of oolitic limestone bands, which are famous as Dhosa Oolite bands – a marker horizon for Mesozoic sequence in Kachchh Mainland separating Jumara Formation from the Jhuran Formation. Dhosa Oolite is the most consistent lithological feature of Jumara Formation. Such bands are peculiarly developed at many places and the physiography is such that they are easily identified in the field from a distance. The facies is developed only in Dhosa Oolite Member (DOM) of Jumara Formation. It occurs at many places of study area, almost in each block, but the most impressive development is at Chadwa Dungar block, Samtiya Dungar block and near Wandhaya village. Total number of such bands in the study area varies from three to six, which are alternating with shales of GSF. Thickness of individual band ranges from 0.15 m to 1.5 m.

The facies is characterized by the presence of ooids in various proportions. These are the fossil rich oolitic limestone, often sandy and nodular in appearance. The oolites are 2 to 4 mm in size and yellowish to grayish green in colour found enclosed in muddy matrix. Texturally the rocks are submature to immature, contain angular to subrounded quartz grains embedded in the matrix of mud along with the ooliths. Lithological variations are seen from section to section. Usually the topmost band of the facies is conglomeratic. Generally three to four types of lithologies can be distinguished in the top most bands of the lithofacies by the colour and crystallinity, proportion and presence of peloids, detrital grains as well as ooids and aggregate grains. The mixing of
lithologies and large broken blocks are ascribed to the burrowing activity of organisms. On the surfaces of Dhosa oolite dissolution effects and crust development is seen. In most of the cases calcite veins are found within Dhosa oolite bands with the development of nailheadspar crystals. Sometimes, the oolitic grains having micritic veins in the fractures are indicating fracturing and penetration of cement. Recrystallisation is also seen along with ferruginous material. All the quartz fragments are corroded and few are coated with either ferruginous or calcareous material. This facies shows gradational upper and lower contacts except the topmost band of conglomerate, which shows erosional contact.

Thin section study reveals that the rocks are submature to immature, contains angular, silty to medium sand size quartz with few feldspar content, scattered in micritic mud. Some amount of silty matrix is also found. The cement is micritic to microsparitic, but in some cases ferruginous patches have also been observed. Among the fossils brachiopod fragments, bivalves, gastropods, echinoid plates and spines, foraminifers, bryozoans and ostracods are abundant.

This facies is lacking in any distinct physical structures. Bioclasts are numerous. It includes bivalves (maximum oysters), brachiopods, cephalopods (belemnites abundant) and gastropods. The fossils are smaller to larger in size. These are almost unaltered to completely recrystallised or neomorphosed especially ammonites. Fossil wood is also common. Fossil shells are frequently bored and encrusted. The fossils of Dhosa oolite are often corroded, sometimes showing limonitic crust (Spath, 1933). Trace fossils include Rhizocorallium and Zoophycos.

Interpretation:

As per Singh (1989) the facies represents transgressive condensed horizon at the time of lower Oxfordian followed by a hiatus during middle and upper Oxfordian. The rocks are mainly calcareous. Ferruginous material also found in form of ooids. Further coarser - rudaceous and arenaceous material is absent, which in general suggests low energy condition and low rate of net
sediment supply. The transgressive phase, which persisted throughout the DOLF is further evidenced by uniform conditions and the negligible sediment supply. The features of facies indicate prolonged phases of omission and frequent erosive intervals leading to very slow rate of sedimentation. This suggests an environment far away from terrigeneous input. These features having wide geographical distribution, which suggest an off shore position well below fair weather wave base. Erosion most likely was caused by off shore currents, which winnowed finer sediment leaving lag deposit behind. Thus relatively uniform off shore setting, well below fair weather wave base indicated by DOLF.

The physical structures are almost absent and the presence of features such as hard grounds, iron crust etc, which are the characteristics of zone of condensation suggests the transgressive horizon for the DOLF. As suggested by Aigner (1985), ooids and oncoides show their origin on shoals and banks in very shallow agitating water, from where they derived in shelf environment of oolitic limestone by some exceptionally strong events. Most abundant trace fossils are Zoophycos and Rhizocorallium, which suggest low energy conditions with oxygenated substrate.