Chapter -3

Sedimentology
3.1 Introduction

The term Sedimentology was first defined by the Waddle (1932) as “the study of sediment.” It deals with the scientific study of classification, origin of sediment and sedimentary rocks. In general, Sedimentology is concern with the physical (texture, structure mineralogy), chemical, and biological (fossils) properties of sedimentary rocks. This property when combined together provides wealth of information for interpreting, climate and environmental conditions that prevailed during the geological past (Boggs, 2006). “Sedimentology is the study of the processes of formation, transport and deposition of material that accumulates as sediment in continental and marine environments and eventually forms sedimentary rocks” (Nichols, 2009).

Sedimentary facies is the sum of all organic and inorganic characteristics of sedimentary rocks including color, texture, grain size, mineralogical composition, fossil content, and sedimentary structures (Flügel 2004; Tucker & Wright 1990). Facies assist in interpreting environmental parameters that control deposition and the distribution of organisms and grains. Facies and microfacies analyses also allow for the interpretation of depositional sequences, i.e. the recognition of shallowing /deepening trends. Fossils are also part of the sedimentary facies and one of the most important indicators of ancient environments. From the facies the physical, chemical and ecological parameters influencing the depositional environment can be deduced.

3.2 Parameters for sedimentary facies analysis

In a Sedimentological analysis one of the first step is to recognize sedimentary facies and to interpret them to understand their origin (Reading and Levell, 1996). The aim of sedimentary facies is to recognize the principal processes of sediment transport and deposition which may be directly diagnostic of a particular sedimentary
environment while others can be found in different environments. Walker (1992) suggest that the most useful modern working definition of the term “facies” was given by Middleton (1978) “the more common (modern) usage is exemplified by De Raaf et al. (1965) who subdivided a group of three Formations into a cyclical repetition of a number of facies distinguished by lithological, structural and organic aspects detectable in the field.

The facies may be given informal designations (“Facies A” etc.) or brief descriptive designations (e.g. “laminated siltstone facies”) and it is understood that these will ultimately be give an environmental interpretation; but the facies definition is itself quite objective and based on the total field aspect of the rocks themselves. The key to the interpretation of facies relations and internal characteristics is to combine observations made on their spatial (lithology and sedimentary structures) with comparative information from other well-studied stratigraphic units, and particularly from studies of modern sedimentary environments”. The subdivision in facies is therefore a classification procedure, whose degree of subdivision is determined mainly by the aims of the study whereas the scale at which the subdivision has to be done depends on the detail that we want to achieve but mostly by the quality of rocks available and at last, but not least, the time available.

The Classification of facies is not only based on objective observations but each facies may be individually interpreted in different ways. Facies defined in the field may have ambiguous interpretations. This is because some characteristics that determine a facies may only define for example, a flow of regime which can develop in different environment (as for example current ripples). It is therefore important to recognize the interpretative limitations of individual facies and to have the knowledge of the relationships of one facies to another. It means that the sequence in which they
occur contributes as much information as the facies themselves. Middleton (1978) pointed out that “it is understood that facies will ultimately be given an environmental interpretation”. Interpretation of facies has thus to be closely correlated to their neighbors and have to be grouped into “facies associations” that are thought to be genetically or environmentally related (Reading and Levell, 1996). A particular facies association is thus considered to be a genetically correlated assemblage of spatially related sedimentary facies Boggs (2009), which are interpreted to ideally represent a particular sedimentary environment or a peculiar set of physical, chemical and biological settings (Collinson, 1969 in Reading and Levell, 1996, p.20). The concept of facies distribution and its relationship with distribution of depositional environments in space, was firstly developed and emphasized by Johannes Walther in his Law of the Correlation of Facies (Walther, 1894, p.979 – see Middleton, 1973) who stated “it is a basic statement of far-reaching significance that only those facies and facies areas can be superimposed primarily which can be observed beside each other at the present time” (in Walker, 1992).

Walker (1992) proposes the following definitions: -

**Facies:** “a body of rock characterized by a particular combination of lithology, physical and biological structures that bestow an aspect “facies”) different from the bodies of rock above, below and laterally adjacent.”

- **Facies Association:** “groups of facies genetically related to one another and which have some environmental significance” (Collinson, 1969, p.207).

- **Facies succession:** “a vertical succession of facies characterized by a progressive change in one or more parameters, e.g., abundance of sand, grain-size, or sediment structures”. 
The facies analyses are based on detailed field, macroscopic, and microscopic observations. In the present study first, sections were logged at cm scale and densely sampled. The hierarchical stacking pattern of beds and bed surfaces was examined. Thin sections of the respective samples were examined under the optical microscope. The Dunham classification is used for the description of texture. The abundance of skeletal and non-skeletal grains was evaluated semi quantitatively. Matrix and cements were also examined. This information is then integrated to interpret the depositional environment.

Following are the parameters used to describe the lithofacies present in the study area.

1. **Grain size**
2. **Sorting**
3. **Cement**
4. **Geometry** (thickness, lateral extent, shape, boundary types)
5. **Fossil content**
6. **Nature of Bed** (bed boundary, gradational or erosional boundary, shape, thickness)
7. **Sedimentary structures** (Physical and Biological sedimentary structures)
8. **Digenetic alteration**
9. **Accessory features** (gypsum formation, boring, encrustations, leeching, and krastification).

The Palaeogene sediments in the Kachchh basin comprises of numerous rock type that include both Clastic (sandstone, shale, mudstone) and extensive outcrop of non-clastic/bioclastic carbonates rocks (calcareous mudstone, wackestone, packstone,
grainstone, floatstone, rudestone and boundstone. The Carbonate rocks present in the study area are very rich in fossil fauna especially Naredi, Harudi, Fulra Limestone and Maniyara Fort Formation in the Kachchh basin and Mohamed ki Dhani, Khuyala and Bandah Formation in the Jaisalmer basin. Paleogene sediments in these formation is exposed at different locations and have a very low dip of 1-3° these Formations are easily recognizable in the field due to its different colors and fossil types.

3.3 Methodology

Keeping the objective in mind a detailed topographic study for the two basins (from survey of India toposheet No. 52 A/10 and 62B/2) was done as a part of field and lab work. In field work after few preliminary field traverses the important section such as (Naredi section, Harudi section, Fulra section, Khari village section and Walsara waterfall section in the Kachchh basin and Mohamed Ki dhani and Banda and Khuyala Formation) were chosen for the detailed field Sedimentology.

In this thesis, the classification of facies is based on objective description of rocks that have been divided into different units on the basis of above mentioned 9 parameters, the description of the facies has then be improved with more details regarding components, colour, biogenic features (when present), geometry (thickness, lateral extent, shape, boundary types).

In the study of carbonate rocks analysis in thin section are essential not only to describe but also recognize and paleontological components, for example to determined matrix/cement content, orientation of grains (which sometimes is obliterated by superficial dissolution of uneven distribution of dolomitization). The grouping of facies into facies associations has been based on the interpretation of the position of the depositional environment and on the correlated process that lead to
facies deposition. Facies association are described and interpreted to provide a Sedimentological study of the processes dominating in this palaeoenvironments and an interpretation of the peculiarities of the conditions that drove the deposition of bedforms such as backset bedded deposits.

Thus in order to depict the nature of depositional environment for the Paleogene sediments of Western India the selected exposed outcrop exposures in the two basins were taken for study in all studied 29 sections which in total were systematically measured bed by bed. Among these 29 Sections 23 were from the Kachchh basin and 6 sections from the Jaisalmer basin respectively. Once lithological field data is collected from the field after that under lab analysis more than 50 thin-sections (of the selected samples) of carbonate and non-carbonate rock samples were studied using petrologic microscope to know the framework elements, texture, depositional facies and nature of diagenetic modifications. Selected carbonate thin sections were stained with 2 % dilute HCl solution of Alizarine red - S to distinguish calcite from dolomite.

The staining test has revealed that the presence of calcite in most of the rock samples and dolomite in few samples at some stratigraphic levels. The framework composition has been identified in thin sections under the petrologic microscope with the help of a number of standard reference guides (Carozzi, 1988; Scholle and Ulmar, 2003; and Flugel, 2010). During the process on the basis of field observation and microscopic observation the thirteen lithofacies and ten sub facies are identified from the measured section of the Kachchh and Jaisalmer basin. The description of facies that follows thus comprises the observations done both at a macroscopic scale and at a microscopic scale in thin section. (Table -2) showing summery of the identified major facies in the two basins is given in the end of this chapter.
3.4 Facies description

In the present study, the interpretation of the facies is objective based on the recognition of the processes that formed the beds (Nichols, 2009). The different facies form a facies association that reflects the depositional environment (Collinson, 1969; Reading and Levell 1996). A total of 11 sedimentary facies were identified, that includes (a) six carbonate dominated facies namely, Bioclastic limestone, Nodular limestone, Micritic mudstone and b) pure sedimentary facies namely, Bioturbated sandstone, shale, conglomerate facies and laterite associated trap wash facies. Each of the sedimentary facies is briefly described below along with its physical, biogenic and petrographic characters and is further interpreted briefly. The petrographic study was carried out for the textural and compositional assessment of the sediments. Although the post- depositional modification of grains were also observed but is not dealt herein because it is beyond the scope of the present work.

3.4.1 Shale facies

This is the most abundant lithofacies present in the study area of Kachchh and Jaisalmer basin, i.e in the Naredi, Harudi, Khinsar, Sameri Nala and Matanomadh, sections. This Lithofacies is described by its difference in color, degree of bioturbation, presence of mottling and larger foraminifera. This facies is widely distributed all over the two basins and forms the substantial part of the rock exposed on the basis of physical color of the exposed rocks unit. This lithofacies is further sub divisible into 4 sub facies which are described below.
3.4.2: [F1A] Pale Reddish Brown shale:

This sub facies occurs as bed of shale in form of lenticular bodies. It is generally fragile in nature and is characterised by the presence of yellow color mottling. At places, it is laminated and the laminae are generally defined by presence of very thin silt (Figure 3.1). The shale colour matches (10 R 5/4) of the Munsell colour chart.

**Interpretation:** Presence of mottling results from bioturbation activity and also from in periodic changes as occurring in the lagoonal water (wahi et al., 1991).

**Distribution:** This sub facies is well exposed in the lower part of Naredi Formation.

3.4.3: [F1B] Moderate olive Brown (5Y4/4) / Green Shale:

This sub facies consists of beds of bioclastic shale with bioclast ranges from very less to moderately abundant. The average thickness of shale ranges from 5cm to 100cm. These are highly fractured in nature in the Naredi section while in Phoolon ki Talayi section it shows several burrows as well as bioclasts (Figure 3.2). Here it shares a gradational contact with the overlying fossiliferous limestone. The bioclast mainly consists of broken fragments of bivalves, larger foraminifera and few gastropods.
Interpretation: The accumulation of shell fragments in the shale is indicative of deposition in the lagoonal condition. Open marine Lagoonal conditions usually contains bioturbated mud. Occurrence of the fragmented bioclast indicates occasional influx of storm conditions or might also indicate within habitat re-working.

Distribution: This sub facies is present in the lower part of Naredi Formation, Phoolon Ki Talayi section and in Rodasar section.
3.4.4: [F 1C] Red and Ochre mottled shale:

This sub facies consists of the medium to coarse grained light grey to red and ochre color shale that shares a sharp contact with overlying laterite in top of Naredi Formation and base of Matanomadh Formation. This shale facies is highly pulverized in nature and lacks physical and biogenic sedimentary characters (Figure 3.3). It also contains few lamina of yellow color siltstone within the bedding plane. Fossils are characteristically absent in this sub-facies.

**Interpretation:** The red colored mottles in this sub facies suggests oxidizing condition, presence of crude laminations indicates in a low energy conditions while absence of any marine fossil indicates continental or non-marine depositional environment.

**Distribution:** This sub facies is extensively present in the lower part of Matanomadh and upper part of Naredi Formation in the kachchh basin and Mohamad ki Dhani section in the Jaisalmer basin.

Fig.3.3 Show the outcrop having Red and ochre mottled shale facies (a) in the Matanomadh Road side section (KACHCHH basin) and (b) in Mohammad Ki dhani section (JAISALMER basin) in field.
3.4.5: [F1D] Medium dark Grey (N4) / Black shale Facies:

This sub facies is characterised by the presence of very dark colored fine grained shale that is rich in organic matter. This facies is having beds of thickness of 30 cm. This facies lacks physical sedimentary structures (Figure 3.4).

**Interpretation:** Bed thickness, laminae, color and composition of the facies indicates its formation at vegetated swamps or pond environment having calm and reducing conditions, and perhaps in humid climate. The presence of carbonaceous matter within the shale indicates the development of this facies in the low energy lagoonal environment Hardas and Biswas (1973).

**Distribution:** This facies is present in the Matanomadh and Naredi middle part of Harudi Formation.

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Fig. 3.4 Photo Shows exposed section of black shale facies in the Kachchh basin. (a) At Matanomadh section (b) At Panandro section and (c) at Harudi section. Note the Skolithos burrow in the Figure (a). Diameter of the coin is 25mm.
3.5: [F2] Bioturbated sandstone facies:

This facies is characterised by the presence of 2mt thick light grey medium to coarse grained compact sandstone. It shares a sharp contact with underlying shale facies that is characterized by the presence of root traces *Egadiradixus rectibrachiatus*. This facies lacks any physical sedimentary structure but contain abundance trace fossils.

![Photograph Shows Bioturbated sandstone facies in the Mohammad ki Dhani section.](image)

**Interpretation:** This facies contains abundant root traces in the form of (*Rhizolith*) is interpreted to be developed in the terrestrial environment.

**Distribution:** This facies is exposed in the Mohmad ki Dhani section. This facies can be laterally traced along the Nala for few meters. This facies can be correlated to the Paleocene sediments of the Matanomadh in the kachchh basin.
3.5.1: [F3] Glauconitic mudstone facies: Mudstone occurs as either green or dark green colored unit it contains dispersed fragments of bivalves and Gastropod shells. These are broken at some places the mudstone lacks lamination and appears to be massive the lower and upper boundary of the shale is non-erosive in nature. In one of the section (Phoolon- ki- Talai) the presence of green color is attributed to the presence of Glauconite. The Presence of Glauconite is confirmed by the XRD analysis of the samples. The mudstone is moderately bioturbated.

**Interpretation:** The Mudstone facies was deposited in suspension, generally low energy environment. The occurrence of low diversity, macrofossil in Ghodhtad section in the Kachchh basin and Phoolon ki Talai section in Jaisalmer basin indicates inner shelf condition.

**Distribution:** This sub facies is present in the Rodasar section, Ber section and Phoolon ki Talai section.

3.5.2: [F4] Bioclastic limestone Facies: This is the most abundance facies that is being found in both basins on the basis of type and nature of fossil content, this facies can be sub divided in to eleven subfacies. This facies consists of 5mt thick sequence of fossiliferous limestone shale
alteration. The limestone band are highly fossilized and contains abundant larger benthic foraminifera that are embedded in the carbonate mud.

3.5.3: [F4A] Bioclastic wackestone facies:

This facies consists of mainly larger foraminifer that includes Discocyclina Nummulites and clasts that are embedded in the brownish color matrix of mud. The bioclasts size ranges from 1-3 cm in size. The matrix is coarse grained in nature. The bioclast in facies does not show any specific orientation in the studied sections. This facies is devoid of any trace fossils. This facies is overlain by the white colored hard compact fossiliferous Fulra lime stone and shares a sharp contact.

**Interpretation:** The presence of bioclast with coarse grained matrix suggests this facies was developed in high energy environment where rate of sedimentation was high from the source area.
**Distribution:** This facies is very well developed in the Waior section here it can be latterly traced up to a distance of 1km.

3.5.4: [F4B] *Assilina* limestone packstone facies: *Assilina* occurring

This facies consists of very compact yellowish to brown color fossiliferous limestone. The thickness of the facies ranges from 10 to 60 cm in the studied section. The dominant fossils group consists of *Assilina*, apart from this it contains gastropods mold and casts that are embedded in the fine grained matrix. Under thin section it shows the matrix which has completely replaced the internal structures of the larger foraminifera. This facies is also characterized by the presence of numerous trace fossils such as *Paleophycus*, *Nummipera eocenia*, *Ophiomorpha isp.*, *Aesteriosoma ludwagae* etc.

![Fig. 3.8 Photographs shows Assilina limestone facies exposed in the Naredi Formation KACHCHH BASIN. A) The exposed surface of the Assilina limestone facies in the Kakdi river section. (b) Close up view of the rock type in the hand specimen. (C) Thin section photograph of the same specimen under microscope. Note the matrix that has replaces the internal structure of the larger foraminifera.](image-url)
**Interpretation:** The presence of the Assilina limestone suggests low energy environment.

**Distribution:** This facies is very well exposed in the Kakdi River section near Baranda village (Kachchh basin).

**3.5.5: [F4D] Cross-stratified Nummulitic Packstone facies:**

This facies is characterized by the presence of creamy to yellowish white dense *Nummulitic* packstone. Some of the foraminifera are bored. This facies is exclusively present in the Maniyara fort Formation. This facies is characterized by the presence of hard compact white to buff colored fossiliferous Packstone. The important fossils group includes larger foraminifera, echinoids and large *Thalassinoides* burrows. The main characteristic of this facies is that the larger foraminifera group present in the bed shows some preferred orientation along depositional strike i.e. the low angle cross stratification can be easily observed in the outcrop.

![Photograph shows cross stratified packstone facies exposed in the Rakhdi Nadi section. KACHCHH basin. Height of the man is 170cm.](image)
**Distribution:** The facies exposed in the Fulra limestone and Maniyara Fort formation.

**Interpretation:** The presence of cross stratification facies in the Fulra limestone is interpreted to be developed in shallow marine high energy environment in shore face environment.

**3.5.6: [F4F] Thin bedded Packstone facies:**

This facies comprises of the dirty whitish to greenish colored off white colored Nummulitic limestone which are thinly bedded The shells are randomly oriented but are very compact. This facies is highly bioturbated and has numerous *Thalassinooides* burrows. These rocks are thin bedded to laminated, and layers are continuous over several meters. Weathered surfaces are light to dark grey, whereas fresh surfaces are most commonly light grey. These two facies are generally closely associated in the field, and differ primarily in the smaller degree of bioturbation in the thin-bedded Limestone Facies.

![Photograph shows thinly bedded Packstone facies exposed in the Ratipar section, KACHCHH basin. Height of the girl is 150cm.](image-url)
Interpretation: Based on the textures of the rocks, the nature of the thin, regular beds present in close association with the mottled carbonates and fossils, this facies is thought to have been deposited subtidally and below normal wave base. Presence of burrows and reworking of the sediment in this facies points toward deposition in a high energy, storm dominated environment.

Distribution: This facies is exclusively present at the base of the Fulra Limestone.

3.5.7: [F 4G] Nummulites - Pecten Packstone facies:

This facies is characterised by the white to buff colored compact very hard bioclastic Packstone (Dunham 1962) the bioclasts includes Larger Nummulites such as Discocyclina and Pectene along with Echinoideas and polychaete tubes. The bioclasts lacks any preferred orientation in the exposed studied section. The Pectene and Discocyclina form the major component of the facies and are broken on the exposed surface. The clast size ranges from 1 to 4 cm as far as larger Nummulites is concern where else Echinoideas and Polychaete ranges from 3-10 cm. The nature and deformation of these two forms is discussed in the taphonomy chapter. The facies shares the conformable contact with Fulra limestone.

Fig. 3.11 Photograph shows Nummulites Packstone facies exposed in Ber, Fulra, Rodasar sections, KACHCHH basin. Note the random orientation of the bioclasts in the picture. Coin diameterer is 20mm.
**Interpretation:** The abundance and nature (deformed) of bioclasts suggest this facies was developed in very high energy environment.

**Distribution:** This facies is extensively present in the Ber, Fulra and Rodasar section and can be latterly traced up to several km in the respective studied section.

**3.5.8: [F 4 H] Grainstone facies:**

This facies is characterised by the presence of larger foraminifer with very low percentage of matrix. The *Discocyclina* and *Nummulites Obtusus* form the larger component on the framework for this facies.

![Photographs showing Grainstone facies in Harudi, Waior and Ramiyana sections.](image)

**Fig. 3.12** Photograph shows Grain stone facies exposed in Harudi, Waior and Ramiyana section. (a) Shows larger *Nummulites Discocyclina* exposed in the Waior section. (b&d) in Ramiyana section facies is associated with karstification with the laterite. (C) *N. Obtusus* is the most dominant Nummulites in this facies in Harudi Formation. This facies also shows some signs of burrowing.

At the Harudi section it is overlain by the shale. Here it shares a conformable contact with the underlying carbonaceous shale. At the Ramiyana section this facies share a very sharp contact with the laterite. That forms the karstification features. At Waior section size of *Discocyclina* increases, average size ranges from 2 to 5 cm.
**Interpretation:** The Presence of Borings in the *Nummulites* and abundance of larger foraminifera suggests that low rate of sedimentation, as the fossils remained exposed on the sea floor enabling boring organism to bore them.

**Distribution:** This facies is best developed in the Harudi, Waior and Ramiyana section.

**3.5.9: [F4I] Glauconitic limestone facies:**

This facies is characterized by the presence of light greenish grey hard compact glauconitic limestone. This facies share the gradational contact with the overlying and underlying limestone units in the studied sections.

![Photograph shows Glauconite bearing limestone facies exposed in the field (a) in base of Maniyara Fort Limestone. (b) In the lower most part of the Walsara waterfall section. Note the presence of the echinoid spines projecting outwards from the outcrop. (C) Photomicrograph shows the Glauconite mineral along with bioclast in the base of walsara waterfall section.](image)

The typical fossil in this facies contains larger foraminifera, *Echinoids, Pectene* etc. In waior section it contains *Echinoids* spine along with bivalve’s shells that are arranged...
in a linear fashion. No significant trace fossils were reported from studied section under this facies. The greenish grey color of this facies makes it easy to recognize in the field.

**Interpretation:** Presence of Glauconite mineral in the limestone suggests this facies was developed in the quiet and slightly agitated conditions and fully marine conditions probably near storm wave base. Banerjee *et al.* (2012) also support this view.

**Distribution:** This facies is very well developed in the Walsara, base of Maniyara fort and Ghodhatad section. In these sections it can be traced up to several km.

3.5.10: [F5] Alternating shale and limestone facies:

This facies consist of 6.5 mt alternating sequence of thinly bedded limestone with shale. Limestone bands are thin with an average thickness that ranges from 1 to 16 cm. These bands are dominantly characterized by presence of mega fossils that include *Pecten, Oyster*, bivalve and Polychaete tubes and some degree of bioturbation. Under thin section presence of micrite is seen while the mega fossils are dissolved or completely altered. The shale are non-calcareous, fissile in nature and

![Photograph shows bioturbated limestone and shale facies exposed in the JAISALMER basin. Height of the boy is 152cm.](image)
non fossiliferous. Top and bottom of the limestone bands are undulating in nature and contains thin ferruginous coating.

**Interpretation:** This facies is interpreted to have been developed in the alternating and fluctuating high and low energy conditions.

**Distribution:** This facies present in the Samri nala section (lower part of Te-takkar Member) of Jaisalmer basin.

3.5.11: [F6] Alternating fossiliferous bioturbated limestone – shale facies:

This facies is characterised by 2 mt thick limestone and shale alteration sequence. The shale is highly fragile in nature while the limestone bands are rich in bioturbation. The top band contains *Psilonichnus* traces while the lower band is highly bioturbated.

**Interpretation:** This facies indicate the deposition in the low energy condition

**Distribution:** Samri Nala section Jaisalmer basin
3.5.12: [F7] Nodular limestone facies:

This facies is consists of fine to coarse grained yellowish to greenish grey, light yellowish to off white colored fossiliferous nodular limestone. This facies is exposed at the numerous sections across the two basins can be distinguished in to two types. Nodular marl with mold and cast this facies comprises of very hard yellowish color limestone/marl. This facies is characterized by the presence of mold and cast of the gastropods that are sparsely embedded in the Lithology the mold and cast are 2 - 3.5 cm in diameter. The dominant fossils comprises of Assilina, Nummulites and bivalves. Further this facies is characterized by the presence of gastropod mold and cast (in the Naredi Formation top band). The average thickness of bed ranges from 10 - 100 cm. At the outcrop it is exposed in the form of Nodular bands in Naredi Formation. This band is discontinuous and is present at the base of the section. Here the nodules contain disarticulated bioclastic molds all of juvenile form that are present at the core of the nodule. The inner core of the nodule is structure less but has fossils present both on surface as well as within the matrix of the band in the form of Assilina embedded in the matrix.
**Interpretation:** the presence of mold and cast and the gastropods mold and cast infer to the fact that that lithofacies was developed in the high energy environment.

**Distribution:** Naredi Formation in Kachchh basin and Te Takkar in Khuiala Formation, Sameri Nala section.

**3.5.13: [F8] Bored limestone facies:**

This facies is present in both the basins. It consists of very hard compact unfossiliferous brown to light brown colored compact limestone. It is characterized by the presence of boring in the host sediments. The burrow depth here ranges from 1 to 3 cm in had specimen. The thickness of this facies ranges from 10 to 150 cm in the field. It shares the gradational contact with the under lying shale in the kachchh basin. In the Jaisalmer basin this facies shares a gradational contact with the underlying unfossiliferous limestone.

![Photograph](image1)

*Fig. 3.17* Photograph shows Bored limestone facies exposed in the Harudi Formation (KACHCHH basin) and Samri Nala section (JAISALMER basin) a) Shows the field photograph of the exposed facies in Harudi section (KACHCHH basin) b) show the thin section photograph of the boring. c) Shows the field photograph of the *Gastrochaenolites* boring in the Sameri Nala section (JAISALMER basin) note that here burrows are filled with Fe.
**Interpretation:** the presence of boring indicates firm ground substrate usually formed during low rate of sedimentation and higher rate of lithification. This facies was developed in the low energy sub aerial environment.

**Distribution:** This facies is exclusively present in the middle part of the Harudi Formation and Samri Nala section of the Jaisalmer basin.

3.5.14: [F9] Coral Bioherm facies:

The Coral Limestone Facies crops out in the Maniyara fort Formation at Walsara waterfall and Waior, Ramaniya section. The original lithology is difficult to determine due to alteration, This facies weathers to a bluish-gray color, is thin bedded, and locally contains interbeds of reddish-brown siltstone.

![Fig.3.18](image1.jpg) **Fig.3.18** Shows Coral Bioherm facies exposed in the KACHCHH basin at numerous sections i.e. (a, b, c) Patchy coral reef development in Ramayana and Waior section (c) coralline member upper Ramania stage, colonial type coral at places form bioherms Measuring few feet to 25 to 30 feet.
The Coral Limestone Facies appears to pinch out both north and south of the Walsara waterfall, Rodasar, Waior and Ramania section. Corals are the dominant fossil within this facies, although subordinate numbers of brachiopods and gastropods are also present. This facies consists of the large coral in the form of bioherm that can be laterally traced in the Oligocene sediments of the entire Kachchh basin. It includes few in-situ coral build ups showing colonial coral structure. The average size of the coral ranges from 40 to 200cm.

**Interpretation:** The close association of the Coral Limestone Facies suggests that it might represent deposition in a quiet lagoon. Presence of coral bioherm in the form of isolated patches suggests its formation in shallow water under low energy lagoonal environment.

**Distribution:** This facies is exclusively present in the Rodasar, Walsara, Maniyara fort Ramania Walsara waterfall section in the kachchh basin.

**3.6: [F10] Moldic Dolomite facies:**

This facies is characterized by the presence of hard compact brown colored fine grained dolomite which is having gastropods mold embedded in the matrix. Under thin section this facies consists of mainly euhedral dolomite where the crystals have dark cores and limpid rims. This is an extremely common fabric of dolomites in the studied samples of Walsara and Waior sections. The cloudy cores have been interpreted to reflect mixing zone conditions in which metastable, inclusion-rich dolomite is formed. Rhombic dolomite crystals have a cloudy, rhombic central zone surrounded by a clear rim (Figure 3.20). These crystals are often referred to as zoned dolomite. These “zoned crystals” are interpreted to be formed either by replacement of a CaCO$_3$ such as a micritic limestone, or they may grow into open pore
space, where they form within a precursor limestone, the cloudy centers represent replacement of the precursor CaCO\textsubscript{3}. The clear rims must have formed in empty pore space around the margins of the cloudy rhombs. The empty space may be created by dissolution of CaCO\textsubscript{3} from just beyond the limits of the cloudy replacement rhombs.

![Fig. 3.19 Photograph shows dolomite lithofacies in exposed in the Walsara waterfall section (a) shows the filed photograph of the dolomite. Note the gastropod mold that is embedded in the matrix. b) Photo micro graph showing the zoned dolomite under thin section.]

The CaCO\textsubscript{3} dissolved from the immediately surrounding area is then precipitated syntaxially in the newly created space around the cloudy rhomb. Clear syntaxial rims may also form in optical continuity on dolomite crystals that project into voids. These syntaxial rims may either enlarge earlier-formed clear rims or produce clear dolomite rims on pre-existing cloudy crystals. In addition to these so-called zoned dolomites, some dolomites exhibit fine-scale internal zoning that results from differences in composition, particularly iron composition. Ferrous iron is common in many dolomite crystals as a substitute for magnesium. If this ferrous iron is subsequently oxidized to ferric iron (hematite), it is visible with a standard petrographic microscope. Thus, some dolomite crystals may contain concentric, alternating zones of red, iron-rich and clear, iron-poor dolomite that mark growth stages of the rhomb (Blatt, 1982, p. 313).

**Interpretation:** A shift to more marine conditions led to precipitation of the more inclusion-free, limpid dolomite outer zones that may, in part, be cements (Kyser *et al.*, ...)
2002). Presence of zoned dolomite indicating low energy restricted lagoon indicates end of a sedimentary cycle.

**Distribution:** This facies is exclusively present in Lower part of Walsara waterfall and waior section.

3.7: [F11] Laterite and associated trap wash facies:

This facies is characterized by the presence of Laterite horizon and numerous clay silt horizons and conglomerate association. Laterite is hard compact dark rusty brown in color. 15 m thick section of red ochre. It is easily identified in the field and has reddish to yellowish color claystone generally present at the top of the Naredi Formation. This facies can be further subdivided in to following sub facies

3.7.1: [F11A] Laterite ferruginous sandstone facies:

This facies ranges in thickness from 5 to 20 m and is composed of well-indurated, reddish-brown lateritic argillaceous ferruginous sand stone. In most places the laterite rests with a sharp, often slightly sheared, contact upon the weathered top of the Deccan trap.

**Interpretation:** This facies is interpreted to be formed in the terrestrial environment.

**Distribution:** This facies is exclusively present in Lower part of the Matanomad Formation
3.7.2: [F11 B] Laterised conglomeratic facies:

The thickness of this facies ranges between 5 and 10 m. This facies is represented by one to two meters of boulder trap conglomerate with local calcareous lithic sandstone horizons. The clasts in the conglomerate are deeply weathered and are derived from the underlying Deccan trap. The clasts are set in a matrix of sandy, coarse-grained sandstone. The facies exhibits a reddish to brick red color that grades upward into partly brown and reddish brown. The clast size of this facies ranges from .5 to 10 cm. The clasts are sub rounded to rounded and the sediments are poorly sorted, though locally, they may be moderately sorted (Figure - 3.22). The matrix is composed predominantly of lithic sandstone. No preferred orientation or structure has been observed. This consists of Cracks and fissures resulting from the in-situ weathering of these clasts are also infilled with a calcareous matrix. Mineralogically, the facies is composed predominantly of clasts-supported rocks consisting mainly of pebbles, cobbles and boulders derived from the trap wash rocks of the underlying Deccan trap.

**Interpretation:** This facies is interpreted to be formed in the terrestrial environment.

Fig. 3.21 Photograph shows Laterised conglomeratic facies exposed in the KACHCHH basin at Matanomadh section. Height of the man is 170 cm.
Distribution: This facies is exclusively present in Lower part of the Matanomadh Formation. Biswas (1992) also discussed about the origin of this Laterised conglomerate facies and (Gurav et al., 2012)

3.8 Facies association:

A lithofacies is a body of rock characterized by a particular combination of lithology, biological, and physical structures that are different from the bodies of rock above, below, and adjacent (e.g., bioturbated siltstone facies or hummocky cross-stratified sandstone facies) (Walker, 1992). Facies succession implies certain facies properties change progressively in a specific direction, either vertically or laterally (e.g., a coarsening- and thickening-upward shoreface succession) (Walker and Plint, 1992). These facies successions allow for depositional environment determination when the individual facies alone could have formed in a variety of environments (e.g., trough cross-bedded sandstone of a fluvial or upper shoreface depositional environment). Lithofacies associations consist of groups of facies genetically related to one another and which have some environmental significance (Walker, 1922). For example, a mixed intertidal facies association consists of flaser, wavy, and lenticular bedded mudstone and sandstone facies forming vertically stacked accretionary bank deposits. Lithofacies associations form the building blocks of depositional systems (e.g., point bar in a fluvial depositional environment). The depositional system is determined by combining depositional environments with processes of formation (e.g., tide-dominated deltaic depositional system) (Walker, 1922). In order to present the exposed sedimentary rock strata in the most appropriate way a division into lithofacies and facies association is done. The individual lithofacies are divided on the basis of sedimentary textures, sedimentary structures, color and degree of
bioturbation. Associations of lithofacies are compared and constitute the subsequent division into facies associations.

A definition of the facies associations is provided by the Collinson (1969, p.207) “Group of facies genetically related to one another and which have some environmental significance. Not all facies associations are individually interpreted on the basis of sedimentary structure of grain size. Interpretations are therefore based on the surrounding facies association and formation mechanism. On the basis of interpreted facies association, palaeogeographic reconstructions and facies models are constructed. Brief description of facies associations together with modified depositional environment is presented in table below.

On the basis of the thickness and vertical distribution of the different sedimentary facies (litho and micro) described above Five facies associations from FA1 to FA 6 are recognized and described below.

<table>
<thead>
<tr>
<th>Facies association</th>
<th>Depositional Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3, F4D, F4I F9</td>
<td>FA6 Lagoonal to high energy open shelf environment</td>
</tr>
<tr>
<td>F4F, F10</td>
<td>FA5 Marginal marine, littoral to shallow inner shelf</td>
</tr>
<tr>
<td>F5, F6</td>
<td>FA4 Low energy, Under middle shelf environment.</td>
</tr>
<tr>
<td>F4, F4A, F4B, F4G</td>
<td>FA3 Inner shelf, Littoral to lagoonal</td>
</tr>
<tr>
<td>F7, F1D, F1B, F8</td>
<td>FA2 Coastal marshBlack swamp coastal environment</td>
</tr>
<tr>
<td>F11, F11A, F11B, F1C, F2</td>
<td>FA1 Terrestrial and fluvial</td>
</tr>
</tbody>
</table>

**Table - 3.1:** Shows the facies association and their depositional environment F = facies FA= facies association.
3.8.1: Facies association 1

This (FA) consists of major facies F11, F11A, F11B, F1c, F2, (Figure 11c). The thickness of F10 and F2 individually exceed 4 m in the studied section i.e F11 A& B facies in the Matanomadh section (Kachchh basin) and facies (F2) in Mohamadh ki Dhani section (Jaisalmer basin). In the former it is also characterized by the presence of plant fossils that proves its formation in terrestrial and fluvial setting.

3.8.2: Facies Association 2

This facies association consists of the F7, F1D, F1B, F8 facies. Here we have interaction between trace fossil in the organic rich shale. The shale generally lacks sedimentary structures and is fragile in nature dominant trace fossils includes vertical burrows and *Paleophycus* apart from this association is also characterized by the presence of mold and cast are present along with mega fossils. *Gastrochaenolites* boring is prominent in the buff colored marl. All these indicate that this facies association reflects Coastal marsh Black swamp coastal environment. This interpretation is also supported by presence of facies F1D which is dominated by organic rich carbonaceous shale.

3.8.3: Facies association 3

This facies association consists of four facies namely F4, F4A, F4b, F4G respectively larger foraminifera, *Discocyclina Nummulites* and *Assilina* limestone forms the dominant fossils assemblage in this association these fossils clasts are embedded in the brownish to yellowish color matrix of mud. The type and nature of fossils indicate this association to be formed in Inner ramp to lagoonal environment.
3.8.4 Facies association 4:

This facies association consists of F5 and F6 facies. The alternate limestone and shale are the dominant rock type of this association. Limestones contain numerous fossil groups that is less deformed while shale is unfossiliferous. Limestone is bioturbated and rich in trace fossils. There we have alternate association of limestone and shale. The field characteristic infers low energy under middle ramp environment.

3.4.5 Facies association 5:

This facies association consists of F4F and F10 facies. The dominant lithology comprises of bioclastic limestone and dolomite. The field character shows the rhythmic fluctuation in energy level that is from high to low (Figure 10) apart from this it contains *Thalassinoides horizontalish* with isolated burrows. Facies F10 contains gastropod molds with moldic porosity development in dolomite. These characteristic infer that this facies was developed in the marginal marine, littoral to shallow inner ramp.

3.8.6 Facies association 6:

This facies association comprises of the F4B, F4C, F4D, F4E, F4F, respectively. Fossil assemblage comprises of Yellowish to brownish floor hard compact Assilina limestone, Off-white colored hard compact *Nummulitic* limestone larger foraminifera, echinoids and large *Thalassinoides* burrow consists of the 3 to 10 cm of the bioturbated layers of the grey colored packstone which contains large foraminifer. The presence of diverge range of fossil assemblage indicates that this association can be related to Lagoonal to high energy open marine environment.