Chapter - 4

FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT
CHAPTER - IV

FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT

INTRODUCTION

The term “Facies” was first used by Gressly (1838). Facies is a general body of rock with specified characteristic, which can be handled at outcrops or from boreholes and thus defined on the basis of colour, bedding, composition, texture, fossil and sedimentary structures as well as tectonic setting of depositional basins (Reading, 1986). Facies analysis is a prerequisite for basin analysis. Paleogeographic or environmental interpretation of facies depends heavily on recognition of facies associations. Each facies present an individual depositional event through time and space. Different facies association reflects different depositional environment settings. Facies analysis involves description and classification of a sedimentary unit followed by interpretation of depositional processes and environment setting (Lindholm, 1987). A facies model is an interpretive device, which is erected by the geologists to explain observed facies associations (Miall, 1990). Although certain aspects of a few facies exhibit specific environmental information, yet a better approach is to study the vertical and lateral facies relationship to infer the specific depositional environments.

In the present study, the facies analysis is categorized into two parts i.e. Microfacies for the limestone units and Lithofacies for the sandstone units of the study area. These were later clubbed into one in order to construct a depositional model. Krumbein and Sloss (1963) coined the term ‘lithofacies’ and defined it as ‘the expressions of variation in lithologic aspect’. The term ‘Microfacies’ was introduced by Brown (1943) with reference to the criteria appearing in thin section under the microscope. Earlier, workers raised various objections to the term microfacies. According to Calkins (1943) a ‘microfacies’ must be counter balanced with a ‘megafacies’. Campbell (1944) suggested that instead of ‘microfacies’ it should be called simply ‘under the microscope’. Allings (1945) suggested that microfacies was difficult to define and proposed the term ‘microlithology’ instead of microfacies. Fairbridge (1954) made distinction between microlithofacies and microbiofacies but his concept gained little support. Cloud et. al., (1957) used the term microfacies to characterize minor or less important facies development within larger facies environment.
Cuvillier and Schurmann (1952-1961) reintroduced the term microfacies to characterize paleontological and petrographical criteria in thin sections. Earlier workers have laid emphasis on paleontological criteria but now microfacies include both sedimentological and paleontological criteria. According to Flügel (1972) 'microfacies is the total of all the paleontological and sedimentological criteria which can be classified in thin section, peals and polished slabs'. The earliest thin section studies of carbonates aimed for genetic interpretation (Sorby, 1879) as well as for stratigraphic evaluation and ecological interpretation of fossils (Gümbel, 1873). Probably the oldest microfacies study originated from Peters (1863) when he published a paper entitled 'Uher Foraminiferen in Dachsteinchalk' dealing with paleoecological and paleogeographical questions. Hovelacque and Kilian (1900) published the first illustrated volume of thin section photographs. The practical application of limestone structure in thin section was demonstrated by Udden and Waite (1927). Microscopic studies of carbonate rocks were given substantial impetus by Sander (1936) who described the depositional fabric and by Pia (1933) who presented one of the first comprehensive general surveys of recent carbonates. Microfacies study coupled with sedimentological and paleontological objectives did not begin in earnest until 1960's. The rapid advances made in microfacies studies since then are a result of various factors such as: the exploration of oil and gas, creation of useful limestone classifications (Folk, 1959; Ham, 1962 etc.) and paleontological problems. At the moment an increasing number of papers is available in which the multitude of microfacies criteria are coupled and interpreted in the form of 'facies model' (Wilson, 1975). Microfacies analysis is the most important of the various levels of observations possible in the broad field of carbonate petrography. The analysis helps in the interpretation of depositional environment through identification of different carbonate particles, which form and grow in different depositional and diagenetic environment. This interpretation becomes meaningful when petrography is combined with detailed stratigraphic control. Comparison is then made with depositional models constructed on the basis of the study of Holocene sediments.

The present petrographic study of Jhurio Dome carbonates was carried out for microfacies analysis as well as their textural, compositional and diagenetic characteristics.
CARBONATE TEXTURAL CONSTITUENT

The major textural constituents of carbonates can be divided into allochems (framework grains), sparry calcite and micrite (Folk, 1972). The allochems can be further divided into skeletal grains and non-skeletal grains. Skeletal grains consist of bioclasts whereas non-skeletal grains consist of ooids, pellets and intraclast.

Atleast 50 – 250 point counts per thin section were counted for grain size measurement following the method given by Chayes (1954, 1956) and Van der Plas and Tobi (1965). The elasticity index and frequency was measured for different grains. Roundness and sphericity of the grains were estimated by visual comparison with standard images of known roundness and sphericity (Russell and Taylor, 1937; Krumbein, 1940; Powers, 1953).

In the studied carbonates from Jhurio Dome, bioclasts, ooids, faecal pellets and peloids, intraclasts, sparry calcite and micrite are present in various proportions. Terrigenous admixture is present in most of the samples and averages about 7 percent of the total grains. Dolomite also occurs in few samples. The carbonates are mostly fine to medium grained, however, few samples are also coarse grained. The carbonates are poorly to very well sorted having angular to well rounded grains of low to high sphericity.

SKELETAL GRAINS

Bioclasts are in abundance in the carbonates of the Jhurio Dome and occur throughout with exception of some terrigenous clastic beds and some carbonates. The bioclasts are preserved as whole fossil and sometimes as fragments. However, smaller fragments are difficult to identify especially the ones, which have lost the original wall microstructure. In bioclasts that have lost all traces of original wall microstructure, characteristic outlines of the shells are preserved by micrite envelopes and by internal and external sediment plus cement. The bioclasts comprise about 2 to 38 percent in different thin-sections and averages 14 percent of the total grains within Jhurio Dome carbonates. The various types of bioclasts that have been identified include brachiopod, echinoderm, sponge, ostracods, gastropods, pelecypods, corals, bryozoans, foraminifera and algae. The description of which is as follows:
Brachiopod

The brachiopods constitute about 1 to 11 percent and averages 2.1 percent and occur in almost all the carbonate members of Jhurio Dome. The size generally ranges from silt size to sand size and occasionally much larger fragments and whole fossils up to 10.5 mm occur. The bioclasts are mainly subangular to rounded and occasionally angular. They are characterized by fibrous walled microstructure with fibres aligned parallel and oblique to the wall surface. Some of the fragments represent transverse sections of spines showing concentric wall microstructure. The fragments generally show well-preserved wall microstructure but in some thin sections they show recrystallization, micritization and micro-borings.

Echinoderm

The echinoderms are present in most of the carbonate members of Jhurio Dome and constitute about 1 to 9 percent of the total rock volume and averages 2.2 percent. The size of echinoderm ranges from silt size to a maximum of 4.5 mm. The bioclasts are mainly subrounded to rounded and occasionally subangular to angular. Randomly cut sections of stem plates and spines of crinoids, echinoids and other echinoderm fragments are observed in these carbonates. The bioclasts are porous and the pores are infilled with micrite and occasionally iron oxide. They show overgrowth, coatings and micritic envelopes.

Sponge

The sponges are found mainly in Sponge Limestone, Jumara Coral Limestone and Badi White Limestone Members of Jhurio Dome carbonates and constitute about 2 to 27 percent and averages 2.5 percent of bioclasts. Most of the sponge spicules are monaxons and show characteristic central canal and spicule shape. They are embedded in clayey and micritic matrix and show replacement by drusy calcite. Some calcareous sponge is encrusted by blue-green algae while others show cavities preserved as voids and canals filled with micrite.

Ostracods

The ostracods are found in Dhosa Oolite, Sponge Limestone and Jumara Coral Limestone members of Jhurio Dome carbonate and constitute about 1 to 4 percent and average 0.7 percent of the bioclasts. They occur as mostly disarticulated but
sometimes articulated valves, ranging in size from 0.4 to 1.5 mm. A well-preserved fine prismatic wall microstructure is seen. The ostracod fossil occurs in fine dark carbonate mud and is internally filled by micrite.

Gastropod

The gastropods are found in Dhosa Oolite, Jumara Coral Limestone, Jhura Golden Oolite and Badi Lower Golden Oolite Members of Jhurio Dome carbonate and constitute about 1 to 6 percent and average 0.6 percent. The size generally ranges from silt size to sand size and occasionally much larger fragments and whole fossils up to 15 mm occur. The bioclasts are subangular to subrounded. Gastropod shells are easily identifiable by their characteristic outlines. The chambers are separated by dark fine-grained micritic walls and are internally filled by micrite. Some of the gastropod shells have lost all traces of their wall microstructure during transformation from original aragonite to sparry calcite.

Pelecypods

The pelecypods are found in Dhosa Oolite, Jumara Coral Limestone, Jhura Golden Oolite Members of Jhurio Dome carbonates and constitutes about 1 to 5 percent and average 0.7 percent. The pelecypod debris consists of disarticulated valve fragments, ranging in size generally from 0.1 to 7.5 mm. The bioclasts are mainly subrounded to rounded. These were originally aragonite shells that inverted to calcite by probably dissolution-precipitation mechanism, which obliterated all relict internal shell structure. Grains are identifiable only on the basis of characteristic shapes outlined by micrite envelope. Some are in form of complex pellet grains and are distinguished from intraclasts by their consistent 'tear drop' shape.

Bryozoans

The bryozoan fragments are found in Jumara Coral Limestone Member of Jhurio Dome carbonate and constitute about 1 percent and average 0.1 percent. Individual segment of fenestrate bryozoans is generally seen having a size range of 0.3 to 0.5 mm. The wall microstructure is generally altered but occasionally original fibrous wall microstructure is identifiable. They comprise circular to elongated holes
(zooecia) filled with micrite or sparry calcite. The zooecia are less than 0.3 mm in diameter.

**Corals**

The corals are found in Jumara Coral Limestone and Badi Lower Golden Oolite Members of Jhurio Dome carbonate and constitute about 1 to 17 percent and average 0.8 percent. Scleractinian and solitary coral varieties are encountered. Scleractinian corals have high primary intragranular porosity. Wall structure was entirely obliterated during inversion from aragonite to calcite and is recognizable on the basis of shape of internal chambers and radial arrangement of septa. They occur as rounded bioclasts with altered shell wall and tubes of more than 0.5 mm diameter.

**Foraminifera**

The fragments of foraminifera are found in Sponge Limestone and Jumara Coral Limestone Members of Jhurio Dome carbonate and constitute about 1 to 8 percent and average 0.6 percent. They range in size from 0.04 to 0.6 mm. They comprise uniserial to biserial, miliolid, fusulinid and globigerinids forms. In the well-preserved forms, porcellaneous or fine granular wall microstructure is recognizable. The shell chambers are filled with either micrite or sparry calcite cement and rarely with quartz silt. Some forms show replacement by iron oxide.

**Algae**

The algae are found in all the members of Jhurio Dome carbonates and constitute about 1 to 32 percent and average 3.7 percent. They comprise blue-green algae, green algae (dasycladacean, codiacian and phylloid) and red algal grains. Blue-green algae occur as dark colour encrustations on bioclasts and as laminated and contorted algal mat. Codiacean algae shows mud filled tubes, where mud has not filled the tubes, recrystallization has obliterated the grain. Dasycladacean algae show poor preservation and are identified by central cavity and radiating porous tubes. Most of the lightly calcified structure has been destroyed and only traces of the original structure are remaining. Phylloid algae show relatively good preservation. Some of the marginal tubes have collapsed into the grain interior during dissolution. Red algae occur as encrustations and grains showing fine cellular structure.
Algal stromatoporoid are also found in some of the studied samples showing the general undulating, head shaped colonial form with pore structures paralleling the exterior of the colony as well as pores which run perpendicular to the exterior.

**NON-SKELETAL GRAINS**

Non-skeletal carbonate grains are those that are not of biogenic origin. In the Jhurio Dome carbonates ooids, pellets and peloids and intraclasts constitute non-skeletal grain. The description of which is as follows:

**Ooids**

Ooids include superficial, true and composite ooids. Superficial ooids are abundant whereas composite ooid are scarce. The thickness of cortex in superficial ooids is less than the diameter of the nucleus whereas the thickness of cortex in true ooid is more than the diameter of nucleus. Composite ooids are composed of more than one nucleus. Sometimes the concentric layers of ooids are replaced by iron oxide. The size of the ooids ranges from 0.5 to 15 mm. They constitute 1 to 34 percent and average 9.8 percent of the non-skeletal grains. The ooids are subrounded to well rounded having medium to high sphericity.

**Peloids and Pellets**

Scholle (1978) defined ‘peloids’ (lithic pellet) as an allochems formed of cryptocrystalline or microcrystalline carbonates irrespective of size or origin. In the study area, peloids consist of generally well-rounded, oval and circular grains of cryptocrystalline carbonate. They range in size from 0.02 to 0.7 mm. The peloids appear to be micritized bioclasts, ooids, faecal pellets and pelletal intraclast.

Pellets (faecal) closely resemble peloids in size, shape and composition and it is difficult to differentiate them. Those darker in appearance than the surrounding micrite, possibly because of their higher organic contents and show remarkable uniformity of size and shape are interpreted as faecal pellets. They are rounded to ellipsoidal in shape and range in size from 50 -250 um. The peloids and faecal pellets comprise 1 to 51 percent and averages 7.5 percent.
**Intraclasts**

Intraclasts are fragments of penecontemporaneous, generally weakly consolidated, carbonate sediment that have been eroded from adjoining parts of sea bottom and redeposited to form new sediment (Folk, 1962). They have firm boundaries with rounded outline indicating that they originated in a high-energy environment from erosion of already lithified carbonate sediments. They are thought to form usually by low tides allowing wave attack on exposed, mud cracked carbonate flats. Intraclasts of the 'grapestone type' are also found. These are aggregates of other grains held together by cement and algal encrustations. The intraclasts comprise 1 to 53 percent and averages 5.4 percent.

**SPARRY CALCITE**

This type of calcite generally forms grains or crystal of 10-micron size or more and is distinguished from microcrystalline calcite by its clarity as well as coarser crystal size (Folk, 1962). Bathurst (1971) distinguished sparry calcite by the intercrystalline boundaries in the sparry mosaic, which are made up of plane interfaces and characterized by enfacial junctions. In the studied carbonate rocks, sparry calcite occurs as pore filling. It also fills shell cavities and moulds produced by leaching of mollusk fragments. Some amount of sparry calcite is present as syntaxial cement rims. Interparticle pore filling sparry calcite cement is of granular type (Orme and Brown, 1963). The granular sparry calcite cement comprises small elongate, circular or fibrous crystals that rim the pore space and are designated as isopachous rim cement. Away from the boundary of pore space, crystal size increases and crystals become more equant and anhedral and such type of granular cement is called blocky cement (Dunham, 1969). Sometimes it is difficult to distinguish sparry calcite cement where it is admixed with recrystallized pseudospar. It constitutes 2 to 90 percent and average 9.1 percent.

**MICRITE**

Micrite is a microcrystalline calcite material finer than 4 micron (Folk, 1962). Micrite is thought to form by rapid chemical or biological precipitation of aragonite ooze and its subsequent recrystallization and inversion to calcite. Leighton and Pendexter (1962) defined micrite as consisting of particles less than approximately
31 microns. Bissel and Chilingar (1967) employed the term “micrite” for material whether crystalline or fine grained, which is 50 micron or smaller in diameter. In the present study Leighton and Pendexter’s definition of micrite has been followed. In the studied carbonates, it has occasionally been recrystallized to ‘pseudospar’ that consists of grains more than 30 micron in diameter (Folk, 1965). Micrite constitutes 7 to 91 percent and average 47.1 percent.

**DOLOMITE**

Dolomite occur in samples of the Badi Lower Golden Oolite Member of Jhurio Dome carbonate and constitute about 1 percent, averaging 0.1 percent of the total grains. They are found associated with red algal grains which act as encrustation. Most of the dolomites show dissolution effect, some of them have been infilled by microspar and silica, whereas others show secondary porosity.

**FACIES AND DEPOSITIONAL ENVIRONMENT**

**MICROFACIES DESCRIPTION**

In the present study the Microfacies types (MF) were classified following Carozzi (1989) and are comparable with Standard Microfacies types (SMF) of Flügel (1972) and Wilson (1975) and are shown against each other in parenthesis. A total of nine microfacies types were identified belonging to two following textural groups:

**Group A (Grain supported oolitic biocalcarenite):** This group consists of oolite bearing intraclastic calcarenites with calcisiltite matrix to oolite bearing calcarenite with sparry calcite cement. This group consists of following microfacies:

**Microfacies A1:** ≈SMF type 12 *(Bioclastic packstone, grainstone or rudstone)*: This microfacies consist of ooid bearing biosparite to biosparrudite and less frequent biomicrite with crinoids, echinoids, pelecypods, scaphopods, brachiopods and algae. Pressure solution effect is evident along the ooid contacts. Cement is represented by intergranular sparite, blocky calcite, fibrous calcite and calcite overgrowth (PLATE – III, Photo 1).

**Microfacies A2:** ≈SMF type 14 *(Bioclastic packstone)*: This microfacies consists of grain supported, coated and worn particles mixed with peloids. Bioclasts include gastropods, brachiopods, ostrocods and crinoids. Rare echinoid, pelecypod, foraminifera and algal fragments are also found. The binding material is generally
PLATE – III

Photo 1. Photomicrograph showing Microfacies A1 ~ SMF Type 12 (2.5X).

Photo 2. Photomicrograph showing Microfacies A2 ~ SMF Type 14 (10X).

Photo 3. Photomicrograph showing Microfacies A3 ~ SMF Type 15 (10X).

Photo 4. Photomicrograph showing Microfacies B1 ~ SMF Type 2 (10X).

Photo 5. Photomicrograph showing Microfacies B2 ~ SMF Type 3 (10X).
micrite with patches of intergranular sparite. Pressure solution is evidenced along ooid boundaries. Ooids show evidence of compaction and reworking such as breakage, abrasion and/or truncation (PLATE – III, Photo 2).

**Microfacies A3: ≈SMF type 15 (Oolitic grainstone-packstone):** This microfacies consist of grain supported and pressure welded ooid bearing calcarenites with sparry calcite cement and micrite. Bioclasts include brachiopods, ostracods, pelecypods, gastropods, crinoids, echinoids and algal fragments. Pressure solution is evident along grain contacts (PLATE – III, Photo 2).

**Group B (Bioclastic to Intraclastic calcarenite):** This group consists of bioclastic calcisiltites containing scattered fine grained bioclasts to pressure welded intraclastic biocalcarenites with sparry calcite cement. This group consists of following microfacies:

**Microfacies Bl: ≈SMF type 2 (Microbioclastic calcisiltite):** This microfacies consists of fine bioclasts and peloids with very fine packstone or wackestone texture containing sponge spicules, foraminifera with less frequent ostracods, brachiopods, gastropods, blue-green and green algae, crinoid fragment and other echinoderms (PLATE – III, Photo 4).

**Microfacies B2: ≈SMF type 3 (Pelagic lime mudstone):** This microfacies consist of micrite matrix having scattered fine sand or silt sized bioclasts of brachiopods, foraminifera, sponges, ostracods, coral, bryozoa and codiacean green algae and (?) red algae (PLATE – III, Photo 5).

**Microfacies B3: ≈SMF type 4 (Bioclastic-lithoclastic packstone):** This microfacies consist of intrabiomicrite, oobiomicrosparite with abundant shallow marine detritus represented by crinoids, foraminifera, brachiopods, dasycladacean and codiacean algae. Pelecypods, gastropods and coral fragment are less frequent (PLATE – IV, Photo 1).

**Microfacies B4: ≈SMF type 11 (Grainstone):** This microfacies consists of coarse grained, ooid bearing, grain supported algally coated grains of echinoids, brachiopods, pelecypods bearing biocalcarenite. The intergranular cement of sparry calcite mosaic and syntaxial overgrowth on echinoderm fragments is common (PLATE – IV, Photo 2).
PLATE – IV

Photo 1. Photomicrograph showing Microfacies B3 ~ SMF Type 4 (10X).

Photo 2. Photomicrograph showing Microfacies B4 ~ SMF Type 11 (10X).

Photo 3. Photomicrograph showing Microfacies B5 ~ SMF Type 17 (10X).

Photo 4. Photomicrograph showing Microfacies B6 ~ SMF Type 18 (10X).
PLATE – IV

Photo 1

Photo 2

Photo 3

Photo 4
**Microfacies B5: SMF type 17 (Grapestone or pelsparite):** This is a mixed microfacies of peloids, agglutinated peloids, some algally coated particles and lumps that are in parts small intraclasts. Minor amount of bioclasts such as gastropods, brachiopods and echinoderm fragments are found embedded in micrite and sparry cement (PLATE – IV, Photo 3).

**Microfacies B6: SMF type 18 (Foraminiferal Grainstone):** This microfacies consists of poorly sorted foraminiferal grainstone. The bioclasts are made up of skeletal elements of foraminifera, sponges and algae embedded in grains of spar (PLATE – IV, Photo 4).

**MICROFACIES ASSEMBLAGE AND DEPOSITIONAL ENVIRONMENT**

From all the four sections, nine microfacies were recorded. These microfacies include MF types A1, A2, A3, B1, B2, B3, B4, B5 and B6 which can be equated to SMF types 12, 14, 15, 02, 03, 04, 11, 17 and 18 respectively. These microfacies can be divided into three groups in the order of increasing energy conditions and are as follows:

G-I: consisting of low energy microfacies comprising of MF types B1, B2, B5 and B6;

G-II: consisting of moderate energy microfacies comprising of MF types B3, B4;

G-III: consisting of high energy microfacies comprising of MF types A3, A2 and A1.

The temporal distribution of microfacies in the studied sections of the Jhurio Dome (Figure - 13) shows that, three distinct assemblages of the microfacies belonging to three different SMF Zones which followed each other through time, reflecting an increasing complexity of the depositional environments. These assemblages are categorized into SMF Zones and representative MF types are as follows:

Assemblage-1: consisting of moderate to low energy microfacies zones 3 / 4 comprising of MF type B1, B2, B3 and B4 representing Foreslope to Deep Shelf Margin depositional environment.

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Assemblage-2: consisting of moderate to high energy microfacies zone 6 comprising of MF type A1, A2, A3, B3 and B4 representing Winnowed Platform, Carbonate Shoal or Bar to Bank depositional environment.

Assemblage-3: consisting of low energy microfacies zones 7 / 8 comprising of MF type B5 and B6 representing Restricted Marine Shoal or Open to Restricted Platform (Lagoon) depositional environment.

Assemblage 1 and 2 occurs in all the four sections measured at Jhurio Dome whereas Assemblage 3 is only found in lower part of Badi Nala and Sonwa Nala sections, the equivalent of which is believed to be unexposed at Bhurund and Kaila rivers. Thus, the assemblages can be very well traced laterally. Temporally, Assemblages 1 and 2 occur in 3 to 5 cycles with Assemblage 3 occurring in the first cycle at Sonwa and Badi Nala sections. The cyclicity of these assemblages, are fairly uniform in all the four sections of Jhurio Dome, thus reflecting uniformity in depositional environment, both in space and time. However, all these cycles do not have the same numbers and types of microfacies present within them temporally and laterally, thereby reflecting fluctuation in the depositional environment locally.

The temporal distribution of the three assemblages reflect an inter-relationship of three sub-environment i.e., slope, carbonate shoal and lagoon representing cycles of coarsening upward or deepening - shallowing cycles. However, the change between successive sub-environments is both gradual as well as abrupt. The abrupt change may be attributed to quick transgressive - regressive events probably under the effect of local tectonics (uplift or subsidence due to faulting) or fluctuations of sea level.

The Badi White Limestone Member is interpreted to be low energy slope deposits, probably on the deep shelf margin below storm wave base (Assemblage 1, microfacies B1) or much below fair weather wave base and out of reach of storms. The study of microfacies and their assemblage suggests three main depositional processes for the formation of Golden Oolites (Badi Lower Golden Oolite and Jhura Golden Oolite): i) The high energy physical sedimentation from current flows during transgression characterized by irregular to sharp nature of contact, well preserved bioclasts and abundant reworked intraclasts and large scale cross-bed and wave ripple above fair weather wave base (carbonate shoal), ii) settling of fines from
suspension during fair weather period as distinguished by fine grained beds of calcareous wackestone and grainstone in the sequence which is somewhat bioturbated representing moderate to low energy environment, iii) presence of peloid, agglutinated peloids, forams, sponges, algal coated particles and dolomitic rhombs suggest deposition in low to very low energy conditions within the tidal range. Abundance of coarser rock types and associated wave form structure, presence of bioturbated wackestone and grainstone interbedded with excellent preservation of tempestites in some units indicate deposition above fair weather wave base but below tidal range in carbonate shoal environment. The erosive to sharp nature of contacts, abundance of reworked intraclasts and well preserved bioclasts, vertical stacking of rock types and their associated sedimentary structures are all typical of “tempestites” beds having been deposited during storm events as defined by Aigner (1882). Limestone (and sandstone) beds deposited during storm event are being increasingly referred to as tempestites. Storm beds commonly show marked changes in character with increasing water depth (Aigner, 1982; Aigner and Reineck, 1982). Proximal storm beds are relatively thick bedded, bioclasts dominated and coarse grained whereas distal equivalent are mud dominated. In the present case, relatively thick bedded, bioclasts are dominated and coarse grained grainstone facies (A1 & A3) in Assemblage 2 are therefore interpreted as being deposited by waning currents associated with storm sedimentation. The grainstones with ripples are interpreted as product of wave generated oscillatory flows produced by passage of storm (Mishra and Tiwari, 2006). The homogenous, fine grained beds (microfacies B2, B3 & B4) are interpreted as being the result of intervening fair weather sedimentation. The basal part of Jhura Golden Oolite (microfacies B5 & B6) is interpreted to have been deposited in restricted marine shoal or shelf lagoon when the sea transgressed under tidal influence.

Goradongar Yellow Flagstone Member represents a mixed carbonate-siliciclastic environment in which the carbonates were deposited on the moderate to low energy outer carbonate ramp on the slope where the autochthonous carbonate content was diluted by silt and sand from terrigenous source and the siliciclastic material was reworked during subsequent transgression. Due to low input of terrigenous material during transgression, skeletal derived carbonate particles are important constituents of the sediments within this unit. The Jumara Coral Limestone Member is interpreted
to represent moderate to low energy slope deposits, probably on the deep shelf margin or foreslope below fair weather wave base (Assemblage 1, microfacies B2 and B3). The top of Jumara Coral Limestone Member is composed of lag deposits (Assemblage 2, microfacies A2) formed due to erosion by storm as the sea started regressing. The Sponge Limestone Member is interpreted to represent moderate to low energy slope deposits, probably on the deep shelf margin or foreslope below fair weather wave base (Assemblage 1, microfacies B2 and B3) and is affected by occasional storm in the upper part of the unit (Assemblage 2, microfacies A2).

Intraclasts within the Sponge Limestone Member may be interpreted as “erosional”. According to Folk (1962), intraclast can be differentiated by appropriate modifiers having genetic connotation. It may be referred to as ‘erosional’ and ‘aggregate’ intraclasts. Most of the intraclasts are the result of erosion or reworking of earlier deposited sediments because they are associated with intra-formational erosion surfaces and their lithic character is identified to be eroded layers below. Some intraclasts have irregular shape and appear to be aggregate of smaller grains. Laporte (1967) suggested erosional intraclast to be product of intertidal and aggregate intraclasts as shallow subtidal in origin. In the present case, erosional intraclasts are common in Association 2 (microfacies A2) and are interpreted as deposition in the upper shoreface by storm. This unit contains beds of sandstone which are medium to coarse grained and are interpreted as storm wave dominated shoreface deposits based on lithofacies association.

Callovian-Oxfordian time was marked by a world-wide sea level rise, reaching its peak either in Oxfordian or Kimmeridgian (Vail and Todd, 1981: Hallam, 1984), causing major transgressions in many part of the world. Biswas (1981), Singh (1989) and Fursich (1991) consider Dhosa Oolite Member to mark the maximum transgression in Kachchh. Sea level rise in the Late Callovian and Oxfordian caused increase in water depth in the main part of the Kachchh Basin, causing flooding in the source area and shutting down sediment supply. Oolites from the existing shoals were reworked and redistributed. Low supply of new sediment caused extensive reworking of the sediment bottom by burrowing organism; sediment bottom was also affected by occasional storm events which caused winnowing and removal of sediments thereby resulting in mixing of fauna and sediments of different time periods (Singh, 1989). Early diagenesis produced submarine lithification making
hardgrounds. Rapid rise in sea level brings the productive zone of carbonate below the euphotic zone (e.g., Cojan and Renard, 2002). The production is reduced and finally ceases, thus leading to the development of hardgrounds indicating hiatus and submarine discontinuity. Few workers (e.g., Biswas, 1981) have proposed that probably below and above the Dhosa Oolite Member, there are unconformities and Dhosa Oolite represents deposition close to the wave base. However, this study demonstrates that the same is true for the lower portion of Dhosa Oolite (Dhosa Oolite Sandstone Member) and it may have been actually deposited above the wave base as suggested by presence of wave ripples. Lithofacies assemblage suggests this unit to have been deposited in storm-wave dominated shoreline environment (backshore-shoreface), in the proximity of shore as suggested by presence of wave ripples. The deposition of upper part of Dhosa Oolite i.e. the carbonate unit (Assemblage 2, microfacies A3) took place below the wave base and it can be best described as condensed horizon formed during a major regional transgressive event. Probably, there is no unconformity at the base of Dhosa Oolite as the contact between Gypsiferous Shale Member and Dhosa Oolite Member is straight to erosional and the same is also suggested by Singh (1989). According to Fursich et. al., (1992), the deposition of Dhosa Oolite took place as a result of alternating phases of sedimentation, cementation and large scale bio-erosion in relation to uniform offshore setting well below fair weather wave base but still within the reach of singular storm.

CLASTIC LITHOFACIES DESCRIPTION

Various types of lithofacies in accordance with lithological variation were recognized on the basis of lithological characters, texture and sedimentary structures. These lithofacies have been encountered at different stratigraphic levels in measured sections in the area of investigation. A total of eight lithofacies have been recognized in the study area. The lithofacies identified are as follows:

**Lithofacies 1: Tabular cross-bedded sandstone (Sp):** This facies is composed of tabular cross-bedded, moderately well sorted, medium to coarse-grained sandstone. The sandstone beds are thick and thin bedded. Tabular cross-bedding locally grades laterally into parallel lamination. The foresets show bimodal-bipolar palaeocurrent pattern (Ahmad et. al., 2008). Bed-sets exhibit upward concave geometry defining
sigmoidal cross-beddings that are separated by erosional surfaces, sub-parallel to inclined reactivation surfaces (PLATE I, Photo 5).

**Lithofacies 2: Trough cross-bedded sandstone facies (St):** This facies is up to 1.5 m thick, erosive based, trough cross-bedded, coarse-grained sandstone having bipolar paleocurrent direction (Ahmad et. al., 2008) (PLATE I, Photo 4).

**Lithofacies 3: Wave rippled sandstone facies (Sr):** This facies is composed of fine to coarse-grained sandstones and is found within Dhosa Sandstone Member. Bed contacts are sharp and wavy-type. The increase in grain size indicates shallowing towards top of the unit. Occasional occurrence of interference ripples are observed. Crest of the ripples are straight to sinuous, sometimes rounded and flat. Symmetrical ripples are abundant (PLATE II, Photo 3).

**Lithofacies 4: Laminated Sandstone Facies (SI):** This facies is composed of very thinly laminated, whitish-brown, 1 – 10 cm thick sandstone beds. Mud cracks occur locally. Beds are tabular and some have rippled top. The beds are mostly evenly laminated. Some beds have combination of horizontal lamination and low-angle cross-beds. The bed contacts are sharp. Mud drapes are seen to occur within this unit (PLATE I, Photo 6).

**Lithofacies 5: Herring-bone cross-bedded sandstone facies (S-hb):** The facies is observed in the Athleta Sandstone Member. Herring-bone cross-beds have developed in a 3 m thick sandstone bed. The sandstone is medium-grained, thick-and-thin-bedded, and occasionally laminated. The sandstone shows sharp boundary contact with the overlying fine grained beds and has an erosional base. Herring-bone cross-beds are associated with tabular cross-bedding and laminations (PLATE II, Photo 4).

**Lithofacies 6: Hummocky cross-bedded sandstone facies (S-hcs):** This facies is observed in the Patcham Formation. It consists of 20 to 40 cm thick beds of sandstone, which are light brown, medium-grained and pebbly alternating with micritic limestone, shale and marl. The upper part of the sandstone unit shows hummocky cross-bedding. The hummocky cross-beds are however, poorly developed and may be delineated only on close examination. They are either aggradational or originated from laminae draping shallow and very low angle truncations. Laminae are parallel and conform to the underlying surfaces and show downlap and onlap relationship with
underlying surface at very low angle. The hummocks are commonly built up sets of tabular laminae without erosion (e.g., Brenchley and Newall, 1982; “Active hummocks” of Boss et. al., 1988).

**Lithofacies 7: Massive Sandstone Facies (Sm):** This facies consist of massive, structureless, upto 2 m thick, yellow, brown, white to purple sandstone which is fine to medium grained. Increase in grain size towards top reflects shallowing upward sequence.

**Lithofacies 8: Conglomerate facies (G):** This facies is confined to the upper to middle parts of Purple Sandstone Member. It is composed of clasts of quartzite and vein quartz with maximum clast size of 40 cm. The clasts are imbricated, rounded to sub-rounded and moderately spherical in shape. The matrix is mainly composed of coarse sand and granules of vein quartz at the base and finer to medium-grained sand at the upper part of the section. The conglomerate beds show wavy contacts with sandstone beds. The lower and upper bounding surfaces are erosional (PLATE II, Photo 5).

**LITHOFACIES ASSEMBLAGE AND DEPOSITIONAL ENVIRONMENT**

Individual facies may not be diagnostic of any particular environment. Lithofacies assemblage signifies collection of multiple facies resulting from genetically related accumulation and modification. It constitutes several lithofacies that occur in combination, and typically represent one depositional environment. Lithofacies interpretation forms the primary tool for identifying the depositional conditions under which the sediments were deposited and preserved. In this study, two distinct assemblages (Figure - 13) have been identified based on association of lithofacies with one another, their textural characteristics and sedimentary structures and their environment of deposition is interpreted.

**Assemblage A: Wave Dominated Inter Tidal / Sub Tidal Deposits**

Assemblage A consists of a tabular package, essentially dominated by different types of sandstone facies like tabular cross-bedded sandstones, herring-bone cross-bedded sandstone, trough cross-bedded sandstone, ripple bedded sandstone and parallel laminated sandstone. Mud drapes are seen to occur within this unit. The sandstones are fine to medium-grained, moderately sorted with wavy to straight bed contacts.
Tabular cross-sets are present mostly in large-scale but small scale tabular as well as trough cross-sets are also there. Herring-bone cross-sets are present in medium-grained, hard and compact, moderately sorted sandstones. Parallel lamination is seen in thinly bedded medium to fine-grained sandstones. This assemblage is internally characterized by an overall coarsening-upward succession.

**Interpretation**

Tabular geometry of the facies assemblage A suggests deposition in a flat-lying area. Large-scale tabular cross-bedded sandstones can be interpreted to be a deposit of inter-tidal flood ramps, lateral accretion of tidal channel bars (e.g., Casshyap and Aslam, 1992; Allen & Leather, 2006). Presence of small-scale cross-bedding in assemblage with lamination suggest mixed tidal flat depositional environment. (e.g., Reineck and Singh, 1980). Moderately sorted sandstones and paucity of silt and clay indicate sediments were subjected to prolonged reworking by wave and tidal currents. The erosional base, trough cross-bedded, bipolar paleocurrent directions in adjacent depositional units suggest deposition in tidal sand bars in a subtidal environment (Hiscott, 1982; Dalrymple et. al., 1990; Dalrymple, 1992; Sultan and Bjoklund, 2006). Thus these tabular cross-bedded and moderately well-sorted sandstones which lack any significant amount of mud or silt content indicate their deposition in shoreface to near-shore environment as in such settings, tabular cross-sets and planar lamination form during the construction and migration of upper shoreface - beachface bars (Allen and Leather, 2006).

Ripple bedded sandstone facies represents shallow water sand deposits in tidal depositional settings. Flat and rounded tops of the ripple bedform reflect planning-off during tidal reversal (Klein, 1970). Undulation in ripple-crests implies a transition from low energy to high energy conditions. The wave- or current generated ripple beds are common in sandy tidal flats or relatively shallow tidal channel margin (Meyer et. al., 1998).

When the tidal currents are too slow to produce ripples, they produce sand layers from suspension (Dalrymple, 1992), as seen in parallel laminated sandstones. The parallel laminated sandstone facies can be formed during occasional periods of storm in intervening periods of low sediment influx and in intermittent inter-tidal environment. The presence of mud drapes suggests tidal influence during deposition. The
interpretation is supported by the cyclical thickening and thinning trends of beds that indicate variation in tidal currents (Kvale and Archer, 1990). Cross-beds associated with laminated beds suggest their deposition on beach-face environment under the influence of strong tidal and longshore currents. Their environment of deposition can be interpreted to be inter-tidal (e.g., Khalifa et. al., 2006). The presence of herringbone cross-beds reflects the bed load deposition by reversing tidal currents of equal bed shear intensity and bottom current velocities. Flow direction reversals are associated with both rising flood and falling ebb stage of tidal cycle and these reversals are generally bi-polar in orientation. Reading (1986) and Reineck & Singh (1980) attributed these sedimentary structures to tidal environment of nearshore (barrier associated) deposits. Collinson & Thompson (1984) attributed this facies to have formed in inter-tidal and shallow sub-tidal environment. Reading (1986) attributed herring-bone type cross-bed in sandstone as diagnostic feature of tidal currents. Collinson & Thompson (1984) attributed these structures to inter-tidal and shallow sub-tidal environment. Lesser occurrence of herring-bone cross-beds presumably record relatively weak tide (e.g., Chakraborty et. al., 1999). The presence of herringbone cross bedding suggests subordinate tidal currents, strong enough to produce bedform migration (Buatois and Mangano, 2003). Occurrence of characteristic sedimentary structures like parallel lamination, mud drapes and ripples associated with herring-bone cross-beds are interpreted to have been deposited in upper sub-tidal to lower inter-tidal sub-environment.

Coarsening upward sequence of the facies assemblage suggests an increase in flow velocity and sand supply linked to tidal flat shallowing. Tidal flats that developed under progradational phase and are dominated by waves are characterized by a coarsening-upward succession, consisting of fine sediments at the base and progressively coarser sediments toward the top in an uninterrupted vertical sequence. This common relationship reflects increasing energy in a progradation from subtidal to intertidal parts of the tidal flats.

Assemblage B: Storm-Wave Dominated Shoreline Deposits

Assemblage B is made up of symmetrical and asymmetrical ripple bedded sandstones, interference ripple-bedded sandstones, tabular and trough cross-bedded sandstones in large as well as small scale, hummocky cross-bedded sandstones, laminated
sandstones, clast-supported polymictic conglomerates which at its base is matrix-supported and massive sandstone lithofacies. The sandstones are fine to coarse grained with wavy to straight bed contact. At places the unit is interbedded with carbonaceous shale and contains fossils towards its top. Clast-supported conglomerates are coarse-grained and have subangular to subrounded clasts of quartzite and vein quartz. Matrix-supported conglomerate occurs as thin bands at the base. Average size of the clasts of conglomerate is 1 cm. The lower bounding surface of conglomerate is uneven with erosional cut-and-fill structures. In general, the conglomerate is poorly sorted, unstratified, shows thick-and-thin behavior, however towards the base the clasts are oriented along the bedding planes. The sandstones of this assemblage are bioturbated. This assemblage is internally characterized by an overall coarsening-upward succession.

**Interpretation**

Most progradational, wave dominated sequence commence in fine grained offshore or shelf facies and coarsen upwards through a series of facies reflecting increasing wave power into foreshore facies. The sequence commonly ranges in thickness from 10 to 60 m, with thickness reflecting the depth of the inshore part of the basin and the rate of subsidence during deposition (Klein, 1974). Facies in this sequence can be compared with those in modern beach face sub-environments, allowing processes to be identified and the paleo-wave regime to be constructed.

Reineck and Singh (1980) reported symmetrical wave ripples from 4 m deep water of offshore region and asymmetrical wave ripples from 0 to 2 m deep water of backshore-shoreface zone of Gulf of Gaeta, Italy. Asymmetrical ripples can either be the manifestation of moderately deep offshore water or of much shallower water within the range of backshore-shoreface environment. Abundant asymmetrical ripples with crests oriented parallel to current direction are also an upper shoreface feature (Reading, 1986). Symmetrical ripple marks with rounded crests reflects planning-off during tidal reversal. The facies suggests deposition in wave-dominated shoreface environment (Allen & Leather, 2006). Abundance of symmetrical ripple marks indicate that the deposition probably took place on the shoreface under the constant influence of waves (De Raaf and Boersini, 1971, Allen and Leather, 2006). Occurrence of interference ripple marks is significant. They indicate a depositional
setting of extremely shallow water regime of backshore-shoreface environment. Interference ripples indicate temporary emergence and a shallow depth of water over the bars (Mukhopadhyay & Chaudhuri, 2003). Large-scale tabular cross-bedded sandstones indicate high energy combined-flow condition in a storm-influenced lower shoreface environment (e.g., Duke et. al., 1991). Small-scale tabular cross-bedding represent deposition in tidal sandsheet bars in upper shoreface. High angle trough cross-bedded sandstones oriented in current direction flowing parallel to shore are product of upper shoreface deposited by longshore currents. Abundance of low angle trough cross-beds is indicative of storm-dominated deposition above fair-weather wave base in the mid-to-upper shoreface (e.g., Lackie and Walker, 1982; Plint, 1988; Chakraborty et. al., 1999).

Occurrence of hummocky cross-bedded sandstone is a diagnostic feature of stormy conditions. The hummocky cross-bedded sandstone is interpreted as a shelf-storm deposit formed in a zone affected by storm waves and wind induced currents (Harms et.al., 1975). Hommocky cross-stratification has been widely reported in wave dominated sequences and although its hydrodynamic origin is not understood at present, it is felt to reflect storm wave deposition above storm wave base (Harms et. al., 1975; Dott and Bourgeois, 1982). The hummocky cross-stratification can grade upwards through flat lamination into wave ripple lamination as storm wanes but the upper parts of storm generated beds are commonly reworked by bioturbation below fair weather wave base or by a combination of bioturbation and normal wave processes above fair-weather wave base. Collision and Thompson (1984) found this hummocky cross-bedded sandstone structure in shallow marine shelf sediments and interpreted to have formed by action of storm waves below depth of normal fair-weather wave reworking. Einsele (1992) described it as a feature of storm induced lower shoreface deposit worked upon by combined flow regime of storm-wave induced oscillatory stress. This structure is usually well developed in a zone of significant combined flow, i.e., above the storm wave base, where high energy flow conditions with a strong oscillatory component (orbital velocities >0.5mtr/sec) develop (Einsele, 1992).

Large-scale tabular cross-bedded sandstones indicate high energy combined-flow condition in an upper shoreface environment. At places towards the basal part the
cross-beds occur as erosive based cosets which are interpreted as the product of migrating longshore troughs or channels. Above the erosive surface, seaward directed cross-beds are seen to occur. This erosive based unit is interpreted as rip channel in a barred shoreline where the channels reworked the bars as they migrate onshore. Towards the top, the coarsening upward, high wave energy sequence is bounded by conglomerate-lined erosional surface interpreted as transgressional lags. High energy deposit is evidenced by high proportion broken shells with convex up orientation and abundance of reworked granular to sand sized sediment particles. Coarse grained sediments (quartz sand/ granules and carbonate detrital grains) might have been derived into deeper environment by lateral transfer of these sediments through high energy waves (storm). The basal part of the conglomerate is stratified and can be interpreted as subarial sheet floods or wave driven bedform traction, longitudinal bedforms (Miall, 1996). The conglomerate unit suggests deposition in shore-parallel bars and rip channel during dissipative phases of stormy condition (Patel et al., 2008). The massive sandstone may be interpreted as deposited as sheet floods. Thus the facies can be interpreted as developed under stormy condition in the upper shoreface environment.

The parallel laminated sandstone represents offshore transport of sand during storms on the shoreface (Cheel, 1991; Brenchly et al., 1993; Allen & Leather, 2006). Depositional condition for the facies comprised wave and storm related processes operating on a shallow marine shelf. Sands and silt were emplaced and deposited under oscillatory current related to storm and their late-stage phases. Evenly laminated sandstones are produced by heavy storms, which erode sand from upper part of the beach and transfer them into suspension in turbulent water where they settle down in deeper part (e.g., Reineck and Singh, 1980; Araby and Motilib, 1999). As a whole, presence of trough and tabular cross-beds, parallel lamination and hummocky cross-beds indicate deposition in upper shore-face (e.g., Storms et al., 2005). Further, general lack of herring-bone structures, which are believed to be diagnostic feature of tidally influenced shallow marine and coastal deposits, again indicates a wave dominated and/or storm-dominated shoreface environment.

Shoreface sediments are controlled to a large degree by waves and wave induced currents. Shoreface sands occur down to a depth of 10 to 20 m below mean sea level,
where normal wave action ceases. These sands generally exhibit decreasing grain size with growing water depth. While the upper shoreface deposits may contain gravelly sands and display multi-directional sedimentary structures (trough cross-beds and low angle tabular cross-beds), the lower ones consist of fine to very fine-grained sand. Here, the primary sedimentary structures consist mainly of planar laminated and small scale cross-beds. The bed forms and internal sedimentary structure along the beach-shoreface profile reflects transformation of deep water waves (oscillatory flow) to shoaling waves, generating land directed flow and return flow into the foreshore zone under upper flow regime.

At depths or near fair weather wave base, long-crested symmetrical wave ripples, produced earlier by rare storm waves are bioturbated during normal fair weather conditions. Landward these inactive ripples pass into active ripples which become increasingly asymmetric. These are associated with small or large scale cross-bedding. On the inner shelf and parts of the outer shelf, either hummocky cross-stratified sand layers or thinner graded sandy and silty beds with cross stratified and sometimes with ripple tops are typical. At greater water depths on the outer shelf, the current component of the combined storm flow becomes dominant, leading to current rippled fine sand and silt beds.

DEPOSITIONAL MODEL

Depositional models are summaries of sedimentary environments or systems, which can be used for comparison to other environments or systems. Depositional models provide a guide for future observations, evaluate the validity of existing concepts, and can be used as a tool for prediction of geologic situations with incomplete data (Walker, 1979; Miall, 1999). Models can be created from experimentation, simulation, theory, and the simplification of multiple observations from the study area.

The present study focuses on the framework in which the processes took place that are responsible for the deposition of Kachchh Basin sediments. The objective is the development of a model that will improve the understanding of the genesis of facies formed under these conditions, facilitate their recognition in the field, and deepen the insight into the depositional processes that play a part in their formation. Thus a conceptual model has been constructed to provide an idea about the environments of
deposition of the study area (Figure - 14). Facies, their interrelationship and assemblage are taken into consideration for the interpretation of depositional model. This model will be used more as an explanatory tool than for predictive purposes.

In the Late Triassic / Early Jurassic time, during the early stages of India's northward drift away from Gondwanaland, the Kachchh rift basin was formed by subsidence of a block between Nagar Parkar Hills and the southwest extension of Aravalli Range. The opening of the Kachchh basin to the north of Saurashtra peninsula coincided with the transgressive phase of the sea onto the coastal areas of other parts of Gondwanaland including the western margin of Indian plate during Jurassic-Cretaceous time (Krishnan, 1968). A shallow epicontinental Jurassic sea ingressed into the Kachchh basin (Biswas, 1987; Krishna, 1987). Much of the Mesozoic sedimentation took place during the early rift phase of the evolution of India's western continental margin. First, between basin margin Nagar Parkar fault and Island Belt fault (Kaladongar-Khadir-Bela fault system) was filled up by granite-cobble fanglomerates and arkoses in the rift valley stage and then between the Island Belt and the Mainland was filled by continental to paralic valley fill elastics dated as Rhaetic by Koshal (1984). The first marine transgression started with extension of graben upto Kathiawar uplift by activation of North Kathiawar fault during rift-rift transition of Indian plate movement. The graben was inundated forming a gulf. The carbonates of the basin were deposited during this period.

At Jhurio Dome, the lowest exposed unit is Badi White Limestone Member (Early Bajocian) of Jhurio Formation which is interpreted to be deposited during the transgressive phase (Figure - 15) on the basin margin or foreslope. The overall transgressive phase continued up to the deposition of upper part of Jumara Coral Limestone Member when the sea began to recede. The intervening sequence is marked by transgressive - regressive cycles. The Badi White Limestone Member is overlain by Badi Golden Oolite Member and the microfacies suggest shallowing upward of the basin. The depositional environment passes from deep shelf margin or foreslope to winnowed platform (carbonate shoal) at the top of the Badi Golden Oolite Member. This member is overlain by Jhura Golden Oolite, the deposition of which starts in open to restricted platform (lagoon). At this point, the sea again starts to engulf the basin and the deposition took place at winnowed platform (carbonate
Figure 14. Envisaged Depositional Model for Jhurio Dome, Kachchh, Gujarat.
Figure 15. Transgressive - Regressive cycles at Jhurio Dome, Kachchh Basin
shoal). Further transgression resulted in the deposition of Goradongar Flagstone Member which represents a mixed carbonate-siliciclastic environment in which the carbonates were deposited on the outer carbonate ramp on the slope where the autochthonous carbonate content was diluted by silt and sand from terrigenous source (siliciclastic ramp supposed to be prevalent toward east of Jhurio Dome). The Goradongar Flagstone Member is capped by Jumara Coral Limstone Member and the microfacies association suggests shallowing of the basin as the deposition passes from slope to carbonate shoal. The Jumara Coral Limestone Member is overlain by Purple Sandstone Member and the lithofacies assemblage suggests a storm-wave dominated shoreline depositional environment for this unit. Thus, this unit represents a regressive phase and is the last unit of Jhurio Formation. Transgression marks the beginning of Sponge Limestone Member (Patcham Fm.) and the microfacies within the unit suggest deepening - shallowing - deepening sequence and the depositional environment changes from deep shelf margin or foreslope to winnowed platform and back again to foreslope or basin margin. During the shallowing phase of this unit clastic sediments were deposited and are interpreted as storm dominated shoreline deposits evidenced by the presence of hummocky cross beds (although not well preserved) at Bhurud River and Sonwa Nala sections. The Chari Formation marks the beginning of clastic dominated regime from carbonated dominated regime below and it begins with the deposition of Ridge Sandstone Member at Jhurio Dome. This unit represents a regressive phase and is interpreted as wave dominated inter-tidal / sub-tidal deposit. This unit is overlain by Athleta Sandstone Member and represents continued regression and is interpreted to be deposited in wave dominated inter-tidal / sub-tidal environment based on lithofacies assemblage. The unit is overlain by Gypsiferous Shale Member which represents deposition in probably restricted lagoon condition. The unit is overlain by Dhosa Sandstone Member of Late Callovian - Early Oxfordian age and it marks the beginning of transgressive phase and is interpreted on the basis of lithofacies assemblage as deposits of storm-wave dominated shoreline environment. In Early Oxfordian time, proto-oceanic stage was reached with complete inundation of the embayed basin. The top of Chari Formation comprises of oolitic carbonate known as Dhosa Oolite Member which represents condensed horizon formed during a major regional transgressive event.
The variation in lateral thickness of the units can be attributed to local tectonic disturbances within the basin during rift-rift phase of the basin. This phase is marked by numerous faulting parallel and perpendicular to the major rift. These local faults control the deposition of sediments to a great extent. The anomalous thickness of Purple Sandstone Member at Kaila River section suggest deepening of the basin towards east, most probably due to faulting (?), thereby providing more accommodation space for the deposition of Purple Sandstone Member. The basin experienced progressive east to west uplift during Early Callovian after the deposition of Patcham Formation (Sponge Limestone Mb.) thereby causing pinching out of Athleta Sandstone Member towards the west. Also during this time, the fault (?) between the Kaila River and Sonwa Nala reactivated causing the basin uplift towards the east, thereby forming a graben in the centre of the studied area.

Present approach to study the sedimentation history is based on the concept that modern depositional environments provide the ‘key to the past’ when analyzing them. Further work is required on facies and tectonic for reconstruction of a much realistic model for the basin.