FACIES CHARACTERIZATION AND ASSOCIATED DIAGENETIC MODIFICATION USING CORE STUDIES AND WELL LOG DATA OF THE EOCENE CHORGALI FORMATION, POTWAR SUB-BASIN, PAKISTAN

A thesis submitted in the partial fulfillment of the requirements for the degree of

Master of Philosophy in Geology

by

Waleed Hussan

Supervisor: Dr. Mumtaz Muhammad Shah

Department of Earth Sciences,

Quaid-i-Azam University, Islamabad, Pakistan

Session: 2020-2022

Declaration

I hereby declare that the work **"Facies characterization and associated diagenetic modifications using core studies and well log data of the Eocene Chorgali Formation, Potwar Sub-basin, Pakistan"** presented in this thesis is my own effort and hard work, except where otherwise acknowledged and that the thesis is written and composed by me. No part of this thesis has been previously published or presented for any other degree or certificate.

Dated:

Mr. Waleed Hussan

CERTIFICATE

The Department of Earth Sciences, Faculty of Natural Sciences, Quaid-i-Azam University, Islamabad, Pakistan accepts this thesis submitted by Mr. Waleed Hussan in its present form, as satisfying the thesis requirements for the degree of Master of Philosophy in Geology.

Supervisor: ___________________

Dr. Mumtaz Muhammad Shah

External Examiner: ___________________

Dr…………….

Chairman: __________________________

Dr. Mumtaz Muhammad Shah

Dated: __________

DEDICATION

I dedicate my thesis to my beloved parents and respectable teachers whose prayer and guidance has always been a beacon for me to climb to the top of a greasy hill.

ACKNOWLEDGEMENT

All glories beto Allah almighty Who has given me hopes to accomplish this research work. It’s a pleasure to me to acknowledge my deepest thanks to my thesis advisor, Dr.Mumtaz Muhammad Shah, Associate Professor at department of Earth Sciences, Quaid-I-Azam University Islamabad. He supervised me in a unique way whenever and wherever we ran into a trouble spot His friendly and sincere style has always been a beacon for us at every moment.

I also express my deepest thanks to Higher Education Commission and HDIP for providing me Core data. I am very thankful to both the personalities for providing me access to their core labs for core studies.

It gives immense pleasure to acknowledge my friends who companied me and provided me a friendly and tension free environment at each and every moment. Specifically, I am very thankful to Irfan Zia for his support throughout writing this research work and Muhammad Umais too. At last but not the least, we would express our deepest thanks and gratitude to our parents whose prayers have always opened the doors of mercy from Allah almighty.

ABSTRACT

The Balkassar Oilfield is located in the eastern Potwar sub-basin, and lies on the Soan Syncline southern flank of the Himalayan collisional regime. Present study is conducted to understand the depositional environment, diagenetic modification and electrofacies of Eocene Chorgali Formation. The study based on core studies, petrography and well logs analysis. The Formation consist of light to dark gray color limestone with shale intercalations. Five microfacies have been classified on the basis of core studies and petrography which are as follows: Non-laminated mudstone, mud-wackstone, larger foraminifera wack-packstone, Mixed bioclastic wack-packstone and shale lithofacie. Based on depositional texture and fossils assemblages suggest that the Chorgali Formation is deposited in supra tidal to middle shelf depositional settings.

Further analysis shows that the Formation underwent different diagenetic changes mainly showing micritization, compaction, cementation, neomorphims, dissolution and stylolitization. These features are passing through different diagenetic environments. Three electrofacies are developed by K mean clustering method which is limestone, shaly limestone and calcareous shale.

Contents

List of Figures

List of Tables

Chapter No. 1

INTRODUCTION

1.1 Background of the study

The Chorgali Formation has great importance in petroleum system of the Upper Indus Basin. About 80% reserves in North America, Carbonate strata is linked with dolomites and 50% of world' s hydrocarbon reserve are hosted in dolomites(Dunham at al., 1980). The world largest oil field is Ghawar oil field (i.e. almost 1/8th of the world known reserves) consist of dolomite and limestone of Permian age(Cantrell et al., 2004). The Chorgali Formation is composed primarily of shales, limestones and dolomites, and is an important target for hydrocarbon exploration and production in the region. The Chorgali Formation has a significant importance in hydrocarbon exploration because of its stratigraphic position and depositional environment.

This thesis aims to provide a comprehensive understanding of the Chorgali Formation as it is drilled in the Balkassar well 07. In order to achieve this goal, the thesis will employ a multi-disciplinary approach, combining field observations, well logs, and laboratory analysis of rock samples. The focus of the study will be on the sedimentological, diagenetic, and petrophysical characteristics of the Chorgali Formation in Balkassar well 07.

The study will provide new insights into the depositional environments, diagenetic modifications, and electrofacies of the Chorgali Formation as seen in Balkassar well 07 and electrofacies in Balkassar OXY 01 well. Furthermore, this research will provide a detailed analysis of the diagenetic modifications in the Formation.

1.2 Location and accessibility to the study area:

The Early Eocene Chorgali Formation is considered an important hydrocarbon-bearing Formation in the Potwar Sub-basin and has been explored for oil and natural gas.The Balkassar oilfield is located in the middle of the Potwar Plateau within the Upper Indus Basin, Punjab, Pakistan (Figure 1a), and is part of the Himalayan Active Foreland Folds and Thrust Belt of northern Pakistan. The location of Balkassar well 07 is shown in Figure 1b. Thecore study has been done in Hydrocarbon Development Institute Islamabad (HDIP). Balkassar OXY 01 well is used to classify the electrofacies. This well is also present in Balkassar field. The petrophysical data was provided by DGPC.

1.3 Aims and objectives of study

The aims and objectives of facies characterization and diagenetic modification of the Chorgali Formation in the Potwar Sub-basin would likely include;

- To conduct Core study and sampling for thin section preparation.
- To construct the Microfacies of the Chorgali Formation by details petrographic study of prepared thin sections.
- To developed the depositional environment and depositional facies of the Chorgali Formation.
- To study the diagenetic modification of the Chorgali Formation.
- To conduct the Electrofacies analysis of the Choragali Formation using Well log by K mean clustering method.

1.4 Nomenclature

There have been numerous studies that have used different nomenclature for the Chorgali Formation in the Potwar Sub-basin of Pakistan.The detail investigation of funna and facies has been done by Gill's (1953) of Bahader beds named as Chorgali formation. Gee (1932) and Gill's (1953) described the Chorgali Formation as "it consists of thick green shale and thin limestone with numerous foraminifera of hill limestone of 15 to 25m in Salt Range area. Cotter (1933) also reported the calcareous beds of limestone and shale lies over the Margala Hill Limestone. Shah describes the Chorgali Formation as "it consists of dolomitic limestone and shale in lower part and argilacous limestone in upper part at Chorgali Pass". Jugan and Abbas (1991) classify the depositional environment of the Chorgali Formation intertidal to supratidal environment during the episodes characterized by regression of sea in early Eocene.

1.5 Literature Review

Integrated field and core description, petrography and stable isotopes(Muchez et al., 1991; Travé et al., 1998; Van Geet et al. 2002) help to work out predictive exploration models. Latif and Iqbal (1986) also studied the Chorgali Formation in Hazara area. The Chorgali Formation is consisting of limestone, marly limestone, argillaceous limestone, marl and subordinate shales.

On the basis of funnl assembledges Gill (1953), Iqbal (1965), Fatmi (1973), Shah (1977) and Baqri et al (1977) assigned the age of the Chorgali Formation (Bhadrar beds) as Early Eocene. Durrani(1999) worked on micro facies and depositional environment in Chorgali pass and Khair-e- Murat. Mujtaba (2001) carried out detail work on deposition environment and diagenetic changes in the Chorgali Formation. He also worked on development of secondary porosity witin the limestone and dolomite facies of the Chorgali Formation in the Salt Range and Potwar Sub-basin.

Benchilla et al (2012) worked on sedimentological and diagenetic evolution of the Chorgali Formation in Salt Range. Gazi (2010, 2014) worked on microfacies, deposition environment and foraminiferal assemblages of the Chorgali Formation. Effect of diagenesis on the quality of reservoir at Khair-e-Murat range was studied byAwais (2015). Awais (2018) worked on petrophysical parameters in the Chorgali Formation Potwar Sub- basin.

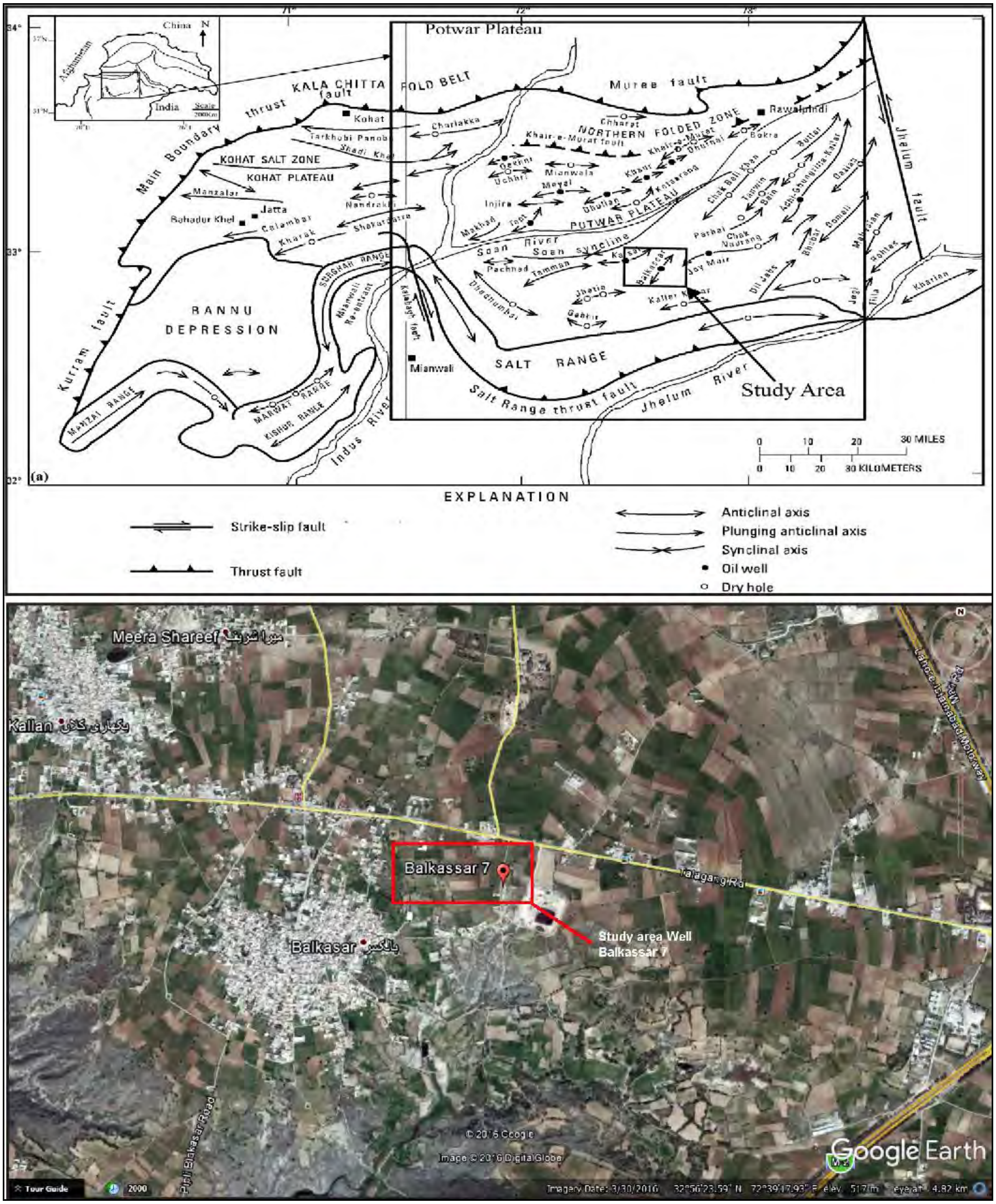


Figure 1 :A. Structural geology map of Potwar Plateau (modified after Khan et al., 1986; Gee & Gee., 1989; Kazmi & Rana, 1982; Khan et al., 1986). B. Google Map showing Balkassar well 07 location.

Chapter No. 2

REGIONAL GEOLOGY AND STRATIGRAPHY

2.1 Introduction

The Balkassar oilfield is located in the Potwar Basin and is one of the most significant oil-producing fields in Pakistan. The field is located in the northern part of the Potwar Plateau, and it is characterized by a complex structural and stratigraphic setting. The field is composed of a series of anticlines, synclines, and faults that have controlled the accumulation and preservation of hydrocarbons.

The Indian Plate lies on the eastern tip of southern Super Land called Gondwana (Valdiya 1977 and 1984). The Gondwana is made up of typically continental crust and crystalline base. This has been confirmed by studying the seismic data. The basal crystal in Pre-Cambrian era consolidated, while the Indo-Pak Plate was developed over the time of Palaeozoic.

On the basis of physiographic and geological the Indo-Pak plate has been divided into three major principal divisions from north to south that is:

- The Himalaya
- The Himalayan Fordeep
- The peninsular Region

The collision of Indian and Eurasian Plate in Hamalayan ranges comprises of series of south verging fold and thrust belts developed over the Indian craton (Powal et al 1973). The Hamalayan are the most active collision in the world. The western extend of plateform and the thrust of Hamalayan belts are from Burma to India, Nipal, Southern Tibet Northren Pakistan and extent to Afghanistan to Central Iran. At the southern end the Hamalayan the thrust leaves their products in Punjab plain Pakistan and Ganga basin India and these products transported towards southwards (Ray 1982, Johnson et al, 2009). The Peneinsular region is composed of magmatic rocks, gneiss, and granite indicates the peninsular region of Indian plate and the Deccan plateau are covered most of peninsular region.

Gansser (1981) divided Himalayan's into three main divisions that are:

- Sub-Himalaya
- Lesser Himalaya
- Higher Himalaya

Sub-Himalaya lies between Main Boundary Thrust (MBT-north) and Main Frontal Thrust (SRT-South). The sedimentary sequence of Pre-Cambrian to Neogene age is involved in deformation which is external zone of Himalaya Orogeney. It can also characterize into following zones.

- The Punjab Platform zone
- The Soan Syncline zone
- Northern Potwar deformed zone (NPDZ)

The Lesser Himalaya is very thick skin is located between the Indus Suture Zone (MMT-North) and the Main Boundary Thrust (MBT-South). It mostly composed of high grade metamorphic rocks and igneous intrusion on exposure.

The Higher Himalaya lies in between the Main Mantle Thrust (north) and Main Central Thrust (South). The sequence is superimposed by massive 10-15km thick of high grade metamorphic rocks, whose base is marked by MCT and form Precambrian Central Crystalline Thrust Sheet (Ganseer, 1981).

2.2 Generalized introduction of study area

The current study is focus to investigate the Chorgali Formation of Balkasaar 07 well and OXY 01. The Balkassar oil field is present in Potwar Plateau which is a part of Upper Indus Basin. The Potwar Plateau, located in northern Pakistan, is a structural feature of the Alpine-Himalayan orogenic belt. The plateau is characterized by a number of geological structures that were formed as a result of the collision between the Indian and Eurasian plates. These structures include faults, folds, and thrusts. The MBT is a reverse fault, which has caused the uplift of the Potwar Plateau and the Sub-Himalayas. The MBT is responsible for many earthquakes in the region. The fault is a major boundary between the Indian Plate and the Eurasian Plate, and marks the northern limit of the Indian Plate's northward movement. Folds are also a common structural feature in the Potwar Plateau. The most prominent fold is the Potwar Anticline, which is a large arch-shaped fold that runs parallel to the MBT. It is formed due to the compression caused by the collision of the Indian and Eurasian plates. The Potwar Anticline is a major hydrocarbon-bearing structure and is an important source of oil and gas in the region. The fold is composed of rocks ranging in age from Precambrian to Paleogene, with the oldest rocks exposed in the core of the anticline

In summary, the Potwar Plateau is a unique geological structure formed by the collision of the Indian and Eurasian plates Shah et. al., (1977). The plateau is characterized by a number of faults, folds, and thrusts, which have been formed as a result of the ongoing tectonic activity in the region. The MBT, Potwar Anticline and other thrusts are the major geological structures in the plateau, which have played an important role in the Formation and evolution of the region and are important for thehydrocarbonexploration.

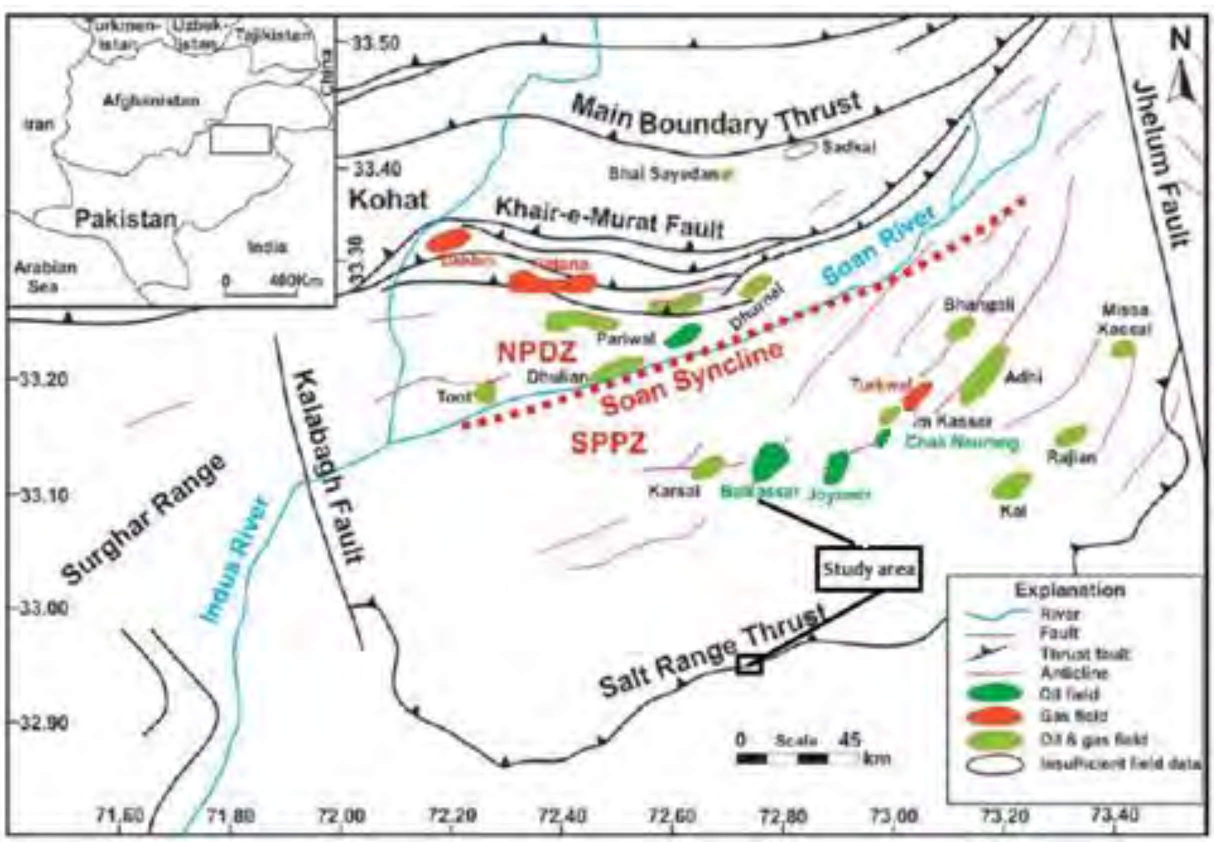


Figure 2. Location map of study area (shown in rectangular inset) and investigated wells of the Chorgali Formation with generalized oil and gas field of Potwar Basin in northern Pakistan (after Riaz et al,2009, Chen and Khan 2009).

2.3 Stratigraphy of the Area

The stratigraphic nomenclature used in this thesis is based on the guidelines and regulations of the Stratigraphic Committee of Pakistan (Shah, 1977). A simplified stratigraphic column of the Cainozoic strata found in the Potwar Plateau and the neighbouring areas is displayed in Figure 2.2. Sedimentation in the Salt Range-Potwar Plateau and adjoining areas began in the Late Precambrian and continued until the Pleistocene. This stratigraphic section can be divided into four groups from bottom to top: 1) Basement complex, 2) Salt Range Formation, 3) Platform section, and 4) Molasse section (Khan et al., 1986). The basement complex is thought to be composed of metamorphic and volcanic rocks of the Indian Shield (Yeats and lawrence,1984), which are similar to those exposed in Kirana Hills (part of Sargodha High) south of Salt Range. The Eocambrian Salt Range Formation is mainly evaporitic, with a variety of facies (marl, anhydrite etc.); the importnt one being halite. The platform section is comprised of Cambrian to Eocene shallow-water sediments with major unconformities.

The platform section of the Soan Syncline consists of Cambrian to Eocene shallow-water sediments, with unconformities at the base of the Permian, the base of the Paleocene, and between the platform sequence and the overlying Miocene to Pleistocene synorogenic molasse section. The molasse section comprises the Rawalpindi and Siwalik Groups. During the Cambrian to Eocene period, sedimentation occurred in marine, occasionally partially restricted to littoral and subaerial conditions. Early in the Paleocene, a marine transgression from the west over-stepped all older strata in the region, leading to the deposition of Paleocene and Eocene shallow-marine, locally evaporitic carbonates and coastal brackish water clastics, which reached a maximum thickness of 760 m in the west, thinning towards the east. In Late Eocene time, Himalayan orogenic movement uplifted the strata, leading to weathering throughout Oligocene time.

The southeast region of the area experienced the most severe erosion, leading to the complete erosion of Eocene and Paleocene sediments. During Miocene, an orogenic foredeep was formed, trending northeast-southwest. Subsequently, the depocenter shifted to the southwest, resulting in the accumulation of a molasse layer of up to 6100 m thick, derived from the rapid erosion of rising mountains in the north. The Pleistocene saw a period of significant orogenic activity, including folding, faulting, uplift and detachment shortening. This was followed by the deposition of the Lei conglomerate in structural lows, which were later tilted by gentle tectonic movement. Finally, the region was peneplaned and covered with a 30-46 m thick Sub-Recent alluvium blanket.

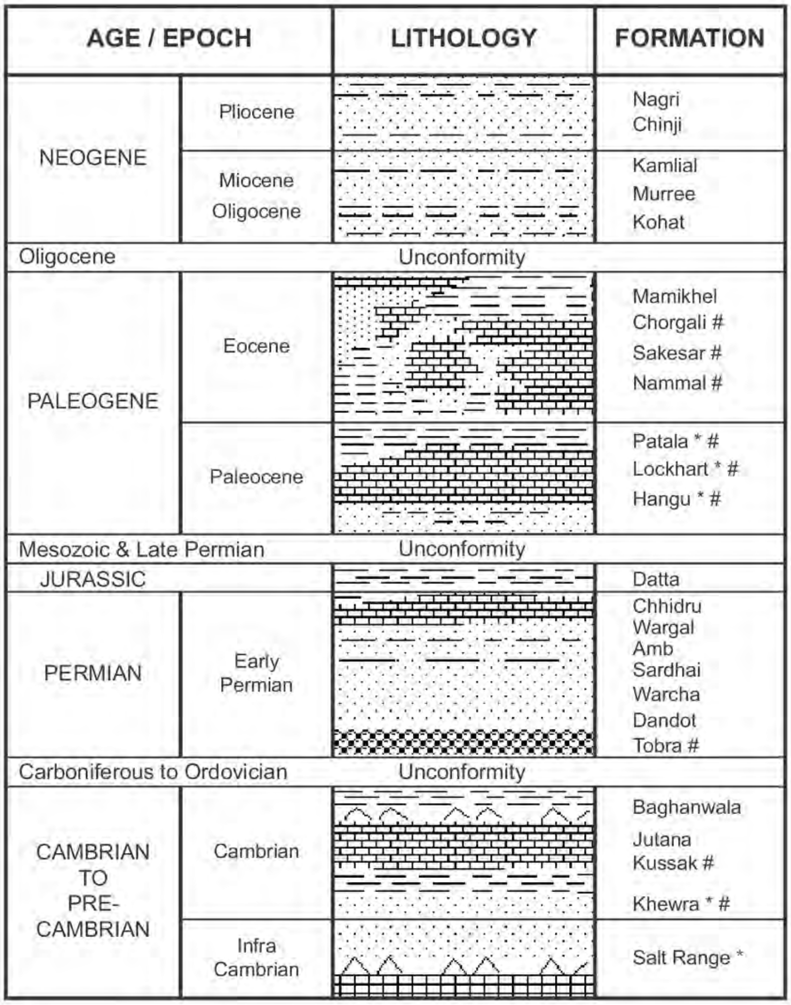


Figure 3 Stratigraphy column of Potwar Basin (modified after OGDCL, 1996; Zaidi et al., 2013)

Chapter No. 3

METHODOLOGY

3.1 Introduction

The following data set and date analysis will use to obtain the desire results.

3.2 Data set

1. Core Studies: The first step in the research methodology was to conduct core studies of the Balkassar 07 well. In this step, the core samples will be examined and described, focusing on the facies characterization and diagenetic modifications. This will involve the description of lithology, sedimentary structures, textures, and diagenetic features. The core logs were prepared to better understand characteristics of the Chorgali Formation.

2. Thin Section Analysis: The next step in the research methodology was to analyze the thin sections from the core samples. This step will involve detailed microscopic assessment of the sedimentary structures and textures, fossils as well as the diagenetic features. This will allow for the determination of the facies characteristics and the diagenetic modifications.

3. Geophysical Data Analysis: The final step in the research methodology was to analyze the geophysical data of the Balkassar OXY 01. This involved to characterize the electrofacies of the Chorgali Formation.

3.3 Data analysis:

The collected data was analyzed in the context of microfacies, depositional environment and associates diagenetic modification within the Chorgali Formation. Microfacies are established based on lithology and fossils contend and follow the rules of Standard Microfacies (SMF). Using Easycore software the detail investigation has been made to better understand the lithological variation with the rock of Chorgali Formation. The total number of cores investigated is 10 and 24 thin section have been prepared for petrography. The thin section helps to better understand the composition, fossils and diagenetic modification of rocks. Wells logs of Balkassar OXY 01 used to characterize the electrofacies of the Chorgali Formation.

3.4 Interpretation of data:

Data interpretation involves the understanding of data and using it to draw a conclusion. Thedetail investigation of the Chorgali Formation has been made base on microfacies, deposition environment, and diagenetic feature. Diagenesis plays a vital role in changing the reservoir characteristics of rocks. Also well logs used to characterize the rocks type and electrofacies of Balkassar OXY 01 well. The current study may be helpful to better understand the variation within the Chorgali Formation which may be necessary for Hydrocarbon exploration.

3.5 Work flow

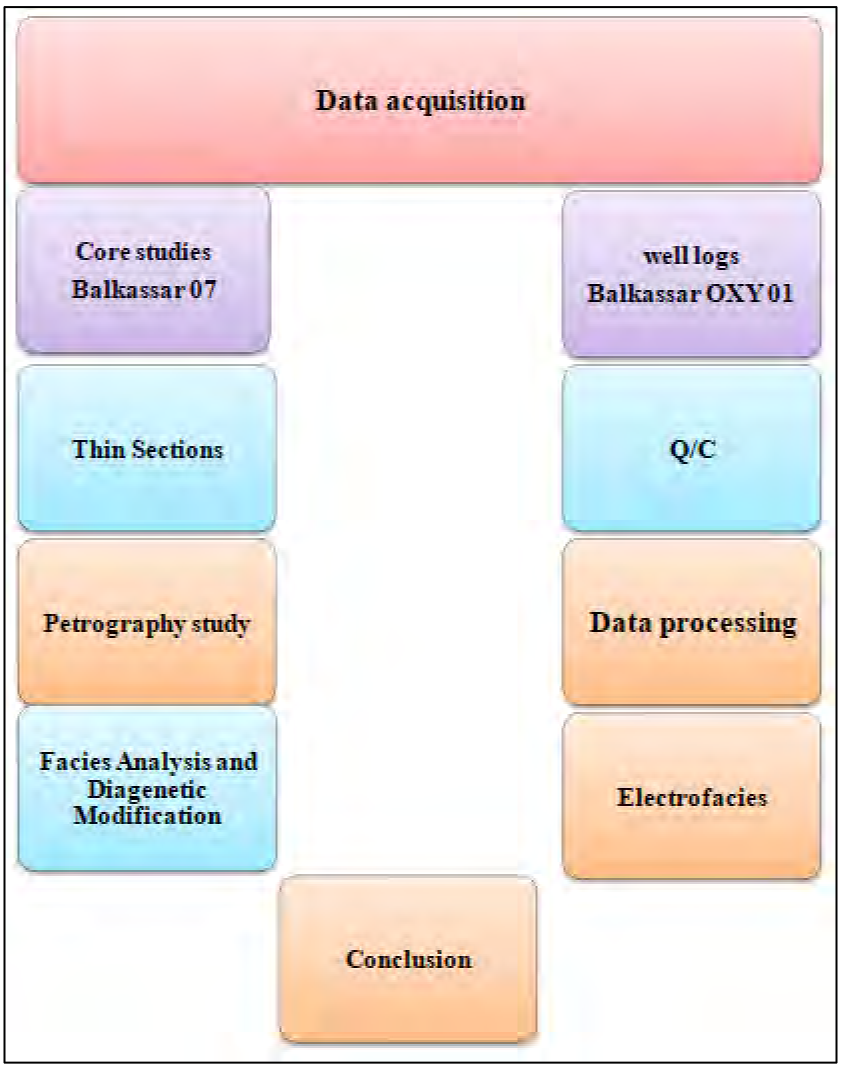


Figure 3.1: Photographs representing the work flow of research work

Chapter No. 4

CORE STUDIES

4.1 Introduction

Well cores samples are important source of direct observation. These samples help us to better understand the rocks type and their behavior under different environmental condition. The cores of the Chorgali Formation are thoroughly investigated in HDIP lab Islamabad.The observation is based on lithological variation, color, sedimentary structure and fossils basedon visual observation and hand lanse. The ten cores have been studied and total length of these cores is 17.71 meters. 24 samples have selected for thin section for detail petrography.

4.2 Lithological description of core No.17

The observation is based on lithological variation, color, sedimentary structure and fossils content on visual observation and hand lanse. Core 17 drilled from 7869-7870.8ft, so the total length of core is 1ft and 8 inches. The general observation made by using hand lanse and electron microscope. One interval has considered in core 17 based on lithological variations (fig 4.1). The detail is given below:

4.2.1 Interval 1 (7869-7870.8ft):

This core is uppermost part of the Formation. The interval is consist of grayish color mud supported limestone and classified as mudstone to wackestone. Randomly oriented bioclast including fossil fragment are observed. A few vertical fractures filled with blackish material and vertical styolites are seen. Few unfilled fracture have been observed and included as secondary porosity. Larger foraminifera’s like assilina are encountered at some portion of interval. One sample is taken for thin section at the depth of 7869.8ft (Fig 4.1).

4.3 Lithological description of core No.18

This core depth interval is of 7882-7884.4ft. Total available core length is 2.4ft and investigated by using general observation and through hand lanse and electron microscope. Only one interval is classified on core 18 the detail is given below (Fig 4.1):

4.3.1 Interval 2 (7882-7884.4ft)

This interval shows grayish color limestone and classified as mudstone to wackstone with open and filled fracture. Fracture is filled with calcite material and their intensity is very low. Some part of the core is containing randomly oriented bioclast and larger foraminifera (Fig 4.1). One sample is taken for thin section at the depth of 7883ft.

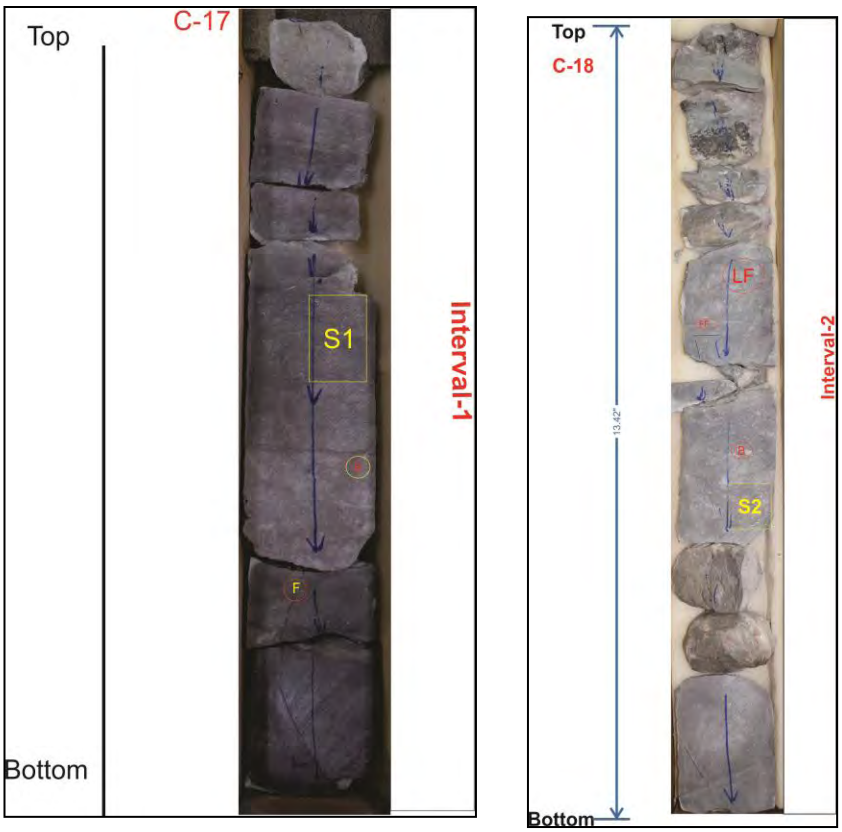


Figure 4.1: Photograph showing the core 17 and 18 of the Chorgali Formation. S1 and S2 represent Samples for thin sections. LF (Larger forums), F (Fracture),B (Bioclasts).

4.4 Lithological description of core No.19

The depth of interval core 19 is 7892-7897ft and total core length is 5ft. the core is indicating two types character, one hard massive limestone and second shows the fissile character of shally limestone with no fossils content has been seen. Four intervals have been classified on the basis of visual appearance and their description given below (Fig 4.2).

4.4.1 Interval 3 (7892-7894.4ft)

This interval show dark gray color limestone classified as mudstone to wackstone. It contains vertical fracture filled with calcite material and multiple calcite veins. Largerforaminifera have been observed at some portion of interval (Fig 4.2). Stylolites and bioclasts are also present.

4.4.2 Interval 4 (7894.4-7895.1ft)

This interval is total different with the upper portion contain shally limestone having a fissile character and classified as mudstone to wackstone (Fig 4.2). The intensity of larger foraminifera's is very low as compared to upper parts.

4.4.3 Interval 5 (7895.1-7895.7ft)

Small portion of the core with dark gray color limestone classified as mudstone to wackstone based on visual observation. It contain vertical and horizontal calcite filled veins also the intensity of larger foraminifera's are very low (Fig 4.2).

4.4.3 Interval 6 (7895.7-7897ft)

This interval shows grayish color limestone classified as mudstone to wackstone. Few beds of larger foraminifera are also seen with bioclast (Fig 4.2). Fracture is filled with calcite material. Stylolites are also seen.

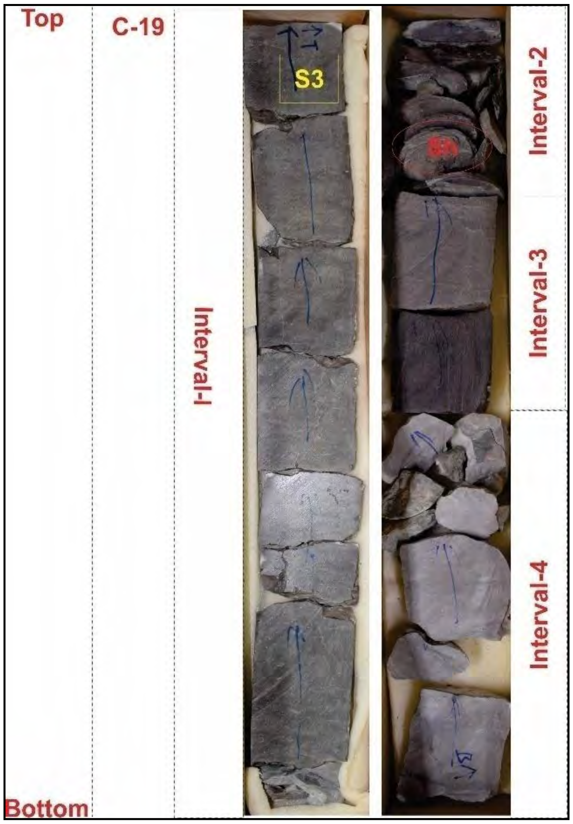


Figure 4.2 Photograph represents top and bottom of core section also intervals. S3 and Sh represents sample for thin section and shaly limestone respectively.

4.5 Lithological description of core No.20

This core depth interval is 7901-7912.3ft and the total length of the core is 11.3ft. The core is very fine at the top and become coarser at the bottom but the variation is very small. This core contains no fossil at the top but few larger foraminifera's are observed at the bottom section (Fig 4.3). It's also show different colors with vertical filled calcite vein.

4.5.1 Interval 7 (7901-7904.1ft)

This interval showsthin to thickly bedded mudstone. The grains are very fine and there is no fossil can observe but the vertical vain are filled with calcite (Fig 4.3). This section shows quite low energy conditions.

4.5.2 Interval 8 (7904.1-7906ft)

This interval shows off white color limestone classified as mudstone. Vertical calcite filled fracture are predominant in this interval (Fig 4.3). There are many episode of fracture system present in this section. No fossil has been seen.

4.5.3 Interval 9 (7906-7908.5ft)

This lithological unit is different form upper unit composed of grayish color sandy mudstone With small amount algae, nummulities and other bioclast are present.

4.5.4 Interval 10 (7908-7909.2ft)

This portion of the core is highly fracture composed of half white color algal mudstone. Fractures are mostly filled with blackish material. Fossils intensity is very low few bioclast and larger foraminifera's are seen (Fig 4.3).

4.5.5 Interval 11 (7909.2-7909.6ft)

This small interval is composed of mudstone to wackestone with some fossils fragments are seen. Intensity of foraminifera is very low at this portion of the core(Fig 4.3).

4.5.6 Interval 12 (7909.6-7910.2ft)

This portion shows variation in lithology and color from the upper part of the core. It composed of off white color mudstone. No fossils or bioclast are observed. Algal mats have prominent features on it.

4.5.7 Interval 13 (7910.2-7910.7ft)

This portion composed of grayish color sandy limestone classified as mudstone to wackstone. Bioclast and larger foraminifera are present. Fractures are filled with calcite.

4.5.8 Interval 19 (7910.7-7912.3ft)

A few inches portion is mainly composed of mudstone with algal mat as a prominent feature. Fractures are filled with calcite and no fossils or bioclast are seen. This lithological unit in totally different from upper unit composed of grayish color limestone classified as mudstone to wackstone wit algal mats is prominent feature (Fig 4.3). Fractures are filled with calcite. Larger foraminifera, algae, some benthic fossils are present. Calcite vain and stylolite are also present.

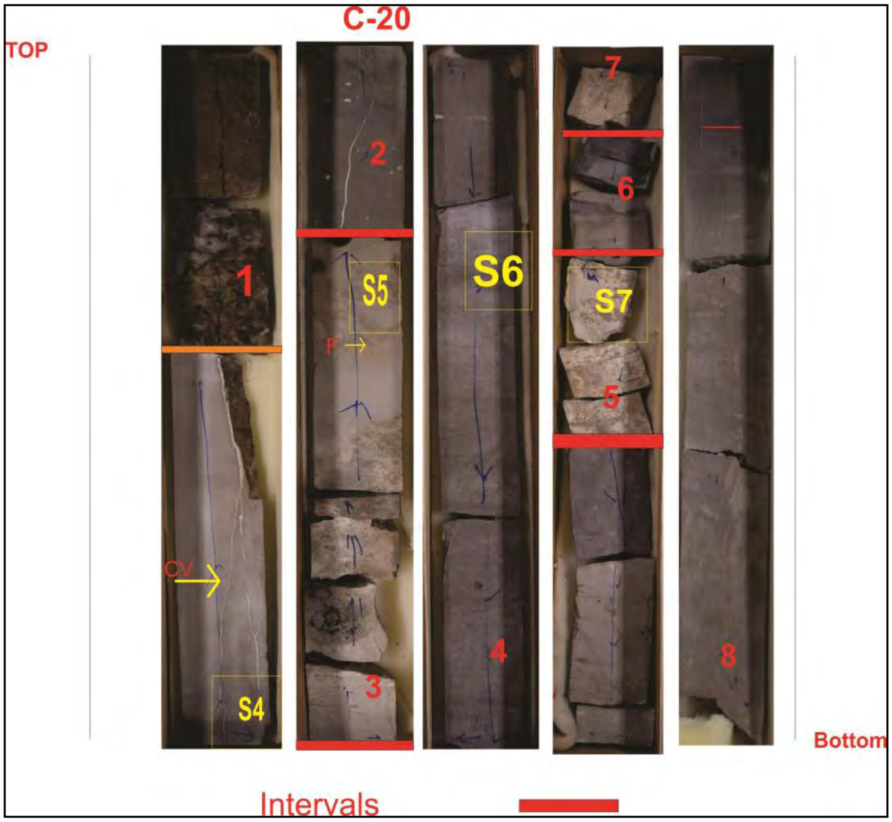


Figure 4.3 :Photographs represents the core-20. 1-8 represent intervals, CV (Calcite vain) and F (Filled fracture).

4.6 Lithological description of core No.21

Lithological the core is composed of predominantly fine-grainedmudstone and some portion of wackstone to packstone. In packstone larger forums are predominant. It started at the depth of 7920ft and ended at 7935.9ft and the total length of core is 15.9ft (Fig 4.4). Four intervals has classified on the basis of visual appearance and their description given below.

4.6.1 Interval 20 (7920-7920.9ft)

Lithologically this interval is composed of grayish color limestone classified as packstone. Different type of fossil e.g. nummulities, assilina and fossils fragment are present at different patches. It also contains larger foraminifera with abundant bioclast (Fig 4.4) Fracture is filled with blackish material and few stylolites are present.

4.6.2 Interval 21 (7921-7935ft)

The interval is comprises very fine grain half white to cherish color mudstone with no fossils can identified. Fractures are filled with calcite few open fractures are also present. The intensity of stylolites are very high. Few open fracture and fracture filled with blackish material can also identify during core study (Fig 4.4).

4.6.3 Interval 22 (7935-7935.9ft)

The small portion of core comprising of fine-grained mud to wackostone. Larger forums are present in patches. Fractures are filled with whitish material (Fig 4.4) styolites and bioclast has been identified.

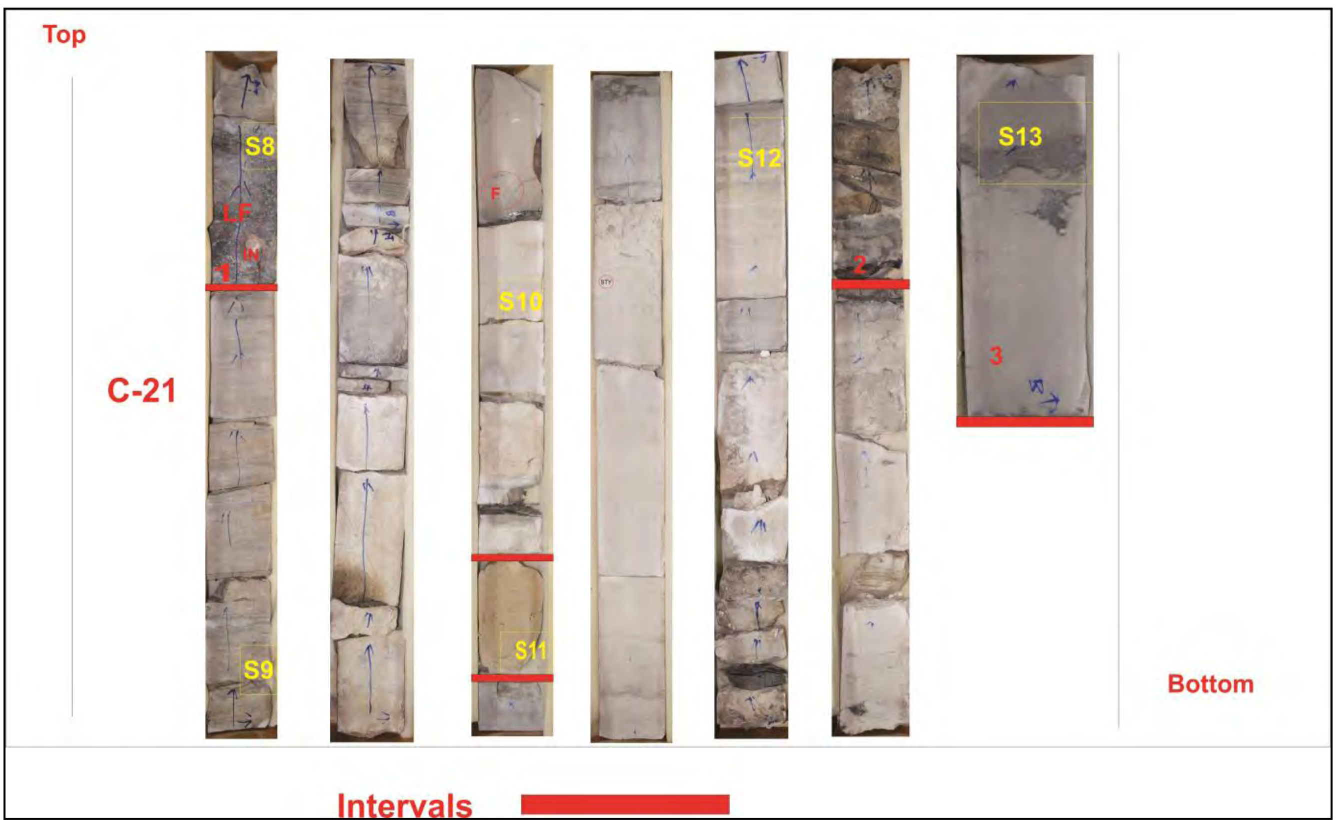


Figure 4.4 : Photographs shows the core-21 of the Chorgali Formation. S8, S9, S10, S11, S12 and S13 represents samples taken for thin section. LF shows larger foraminifera's.

4.7 Lithological description of core No.24

The depth of the core is 7956.9-7963.6ft and this core predominantly consists of light grey to creamish color mud-wackstone. Fracture are filled with calcite however few open fracture are also present. Bioclast are dominant at the upper portion of the core (Fig 4.5).

4.7.1 Interval 23 (7956.9-7957.2ft)

Interval 1 consists of gray color limestone having a composition of mud-wackstone. Bioclast are present with filled fracture.

4.7.2 Interval 24 (7957.2-7957.7ft)

Interval 2 consists of creamish to lite brown color fine to medium grained mudstone .Vertical fracture are filled with calcite. Few bioclast are seen.

4.7.3 Interval 25 (7957.7-7958.8ft)

Lithologically this interval is composed dark gray color mud-wackstone with randomly distributed bioclast. Fracture are randomly oriented and filled with calcite however few are filled with blackish material.

4.7.7 Interval 26 (7958.8-7963.6ft)

This interval is composing of medium grained mud-wackstone. The percentage of bioclast is high as compare to above intervals. Calcite filled veins and dissolution are identified at the end of the core.

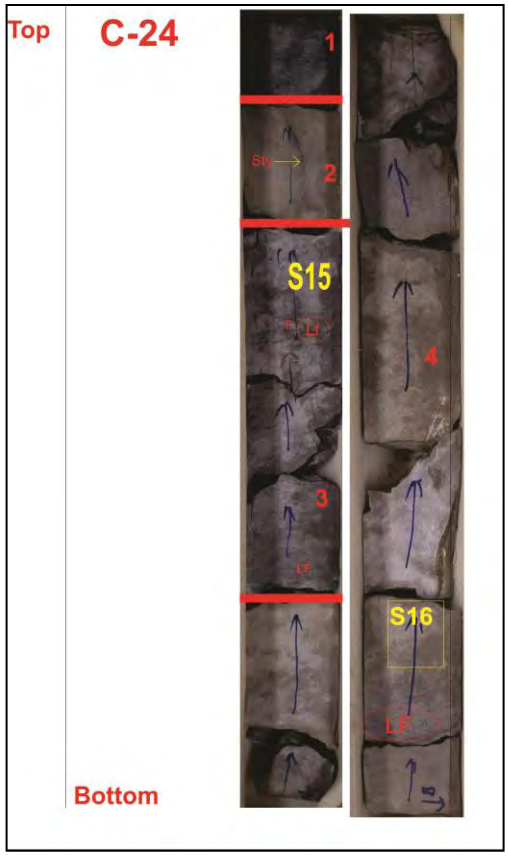


Figure 4.5; Photographs represents different patches of larger Foraminifer's (LF). Sty represents the Stylolites.

4.8 Lithological description of core No.25

The core depth interval is 7979-7981 and mainly composed of limestone classified as wackstone to packstone. Larger benthic foraminifera's bivalves are also present. Fractures are filled with calcite. Small vugs and stylolites are also seen.

Figure 4.6: Photographs represents the interval of core-25 of Chorgali Formation

4.9 Lithological description of core No.26

This core lithologically composed of off white to grayish color limestone classified as wackstone to packstone. All type of fossils and bioclast are present. Fossils intensity is very high. The core is started at the depth of 7986-8003.5. Description of different intervals is given bellow.

4.9.1 Interval 27 (7986-7996ft)

This interval is composed of off white to grayish color limestone classified as wackstone to packstone. The intensity of fossils is very high. Fracture is filled with blackish material and calcite vain is also present (Fig 4.7). Larger benthic foraminifers with bioclast are present. Nummulities, assilina and bivalves are prominent.

4.9.2 Interval 28 (7996-8001.8ft)

This interval is composed of dark brown color shale with fissile character (Fig 4.7).. No fossil can see. Fracture is filled with calcite and mineral pyrite can also see.

4.9.3 Interval 29 (8001.8-8003.5ft)

It composed of grayish color limestone classified as mudstone to wackstone. Fossil are randomly distributed from top to bottom. Larger foraminifera's algae and planktons are present. Assilina and nummulities are observed (Fig 4.7). Fracture is filled with calcite and styolites are present.

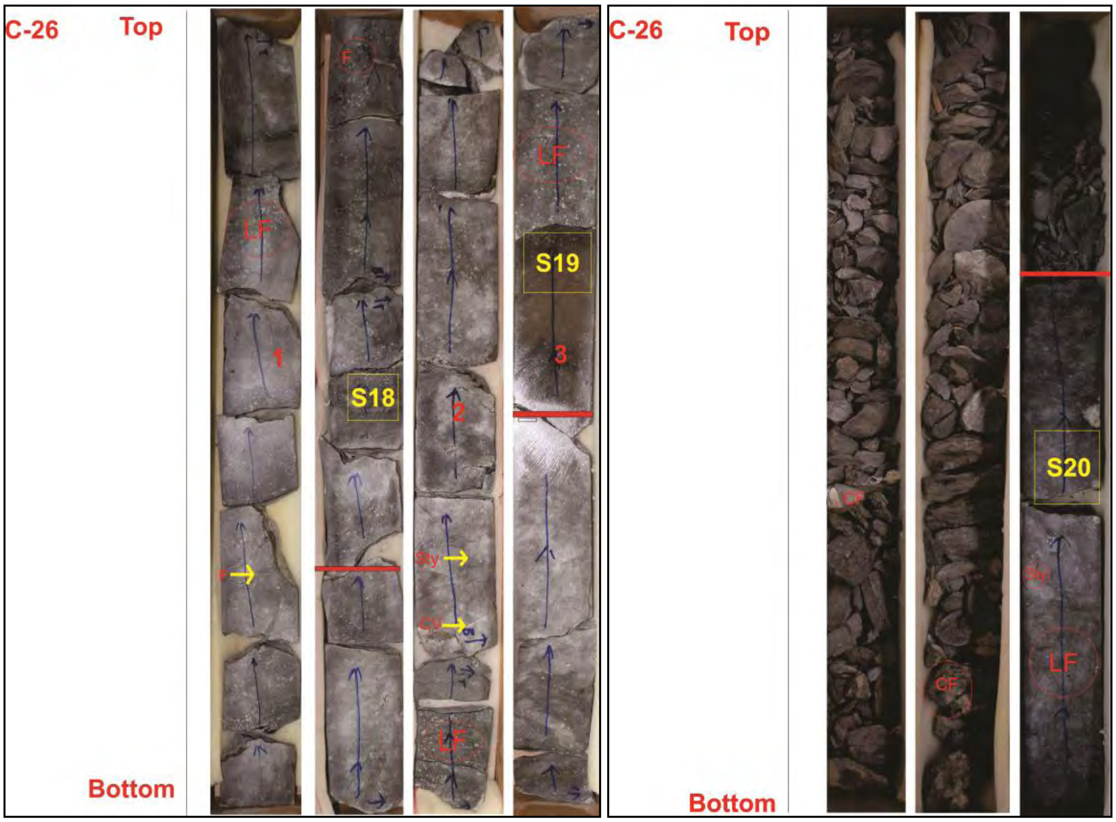


Figure 4.7: Photographs represents core 26 and larger foraminifera's (LF), Calcite filled veins (CV), shallylimestone (Sh) and Stylolites (Sty)

4.10 Lithological description of core No.27

The core is composed of packstone, wackstone and shale. The upper part of the core is highly fossiliferous. Core started at the depth of 8006-8020.6ft. The description of intervals is given below.

4.10.1 Interval 29 (8006-8010ft)

It composed of half white to grayish color limestone classified as wackstone to packstone. The fossil intensity is very high. Larger benthicforaminifera, bivalve, Gastropods Nummulites and algae are observed. Fracture is filled with blackish material but their intensity is very low. Stylolites and a few vugs are also seen.

4.10.2 Interval 30 (8010-8011.5ft)

This interval consists of grayish color limestone classified as mudstone to wackstone. Fossil intensity is low as compared to upper part of core. Open fracture and stylolites are present. Larger benthic foraminifera and planktons are seen.

4.10.3 Interval 31 (8011.5-8015.6ft)

This interval composed of brownish color shally limestone with fissile character. No fossil have seen. Fracture is filled by quartz and calcite. Pyrite is present in it.

4.10.4 Interval 32 (8015.6-8017.2ft)

Interval is composed of half white to grayish color limestone classified as wackstone to packstone. It is grain dominate and highly fossiliferous. Larger foraminifera's, plankton and bioclast are present.

4.10.5 Interval 33 (8017.2-8020.6ft)

Lithologically this interval composed of grayish color limestone classified as mudstone to wackstone. Fossil intensity is low as compare to above unit. Nummulities, planktonic organism with larger forums are present. Bioclast and stylolities are also present.

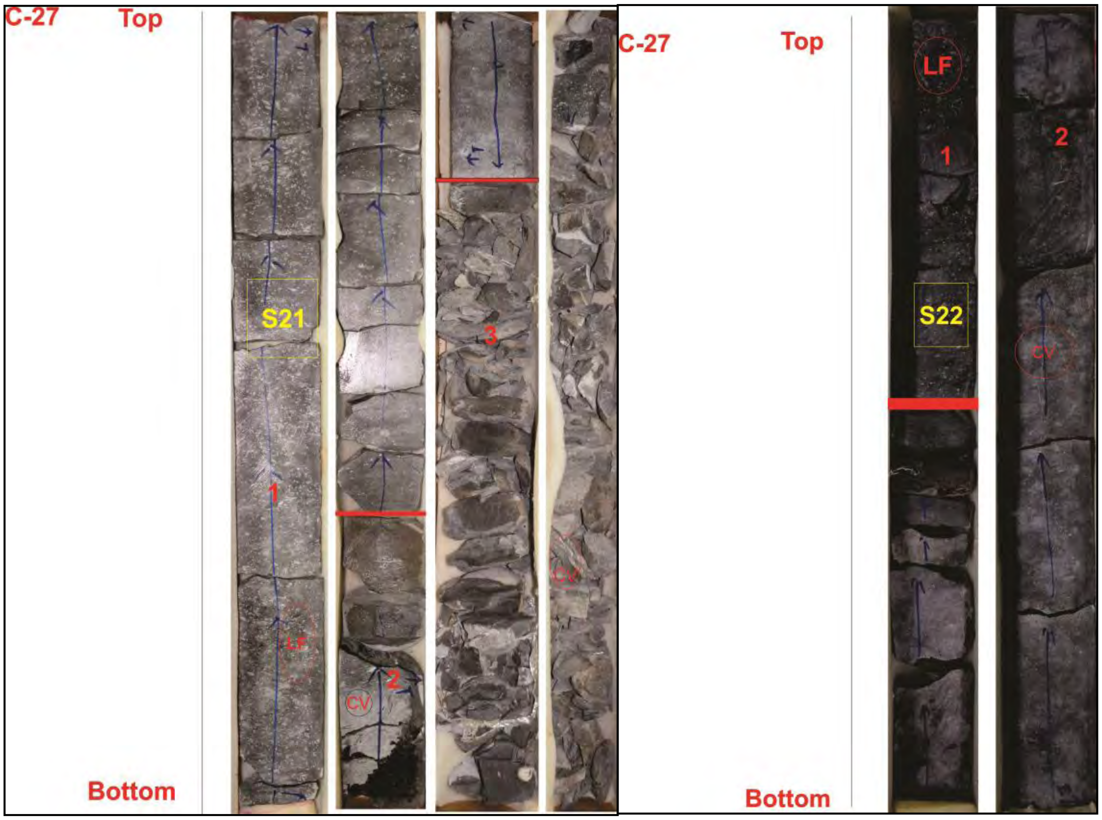


Figure4.8: Photograph represents the shally limestone (sh), Calcite filled veins (CV), Larger forums (LF) and intervals of core-27 with top and bottom.

4.11 Lithological description of core No.28

The starting depth of is 8022-8034.9ft. So the total core length is 12.9ft and mainly composed of limestone (wackstone to packstone).Fossils are increases when going deep. Larger foraminifera, algae, some benthic fossils are present. Calcite vain and stylolite are also present. The description of intervals is given below.

4.11.1 Interval 34 (8022-8032.1ft)

This interval is composed of grayish color wack- packstone with fossil are present in different colonies. Few beds are highly fossiliferous including larger forum, planktons and bioclast are present. Nummulities and assilina are found abundantly at different parts. Open and filled fracture with prominent stylolites is present. Few vugs are also seen.

4.11.2 Interval 35 (8032.1-8034.9ft)

This interval is highly fossiliferous as compared to upper part of core. Lithologically it is composed of half white to grayish color limestone classified as wackstone to packstone. Few beds are highly fossiliferous including larger forum, planktons and bioclast are present. Nummulities and assilina are found abundantly at different parts. Open and filled fracture with prominent stylolites is present.

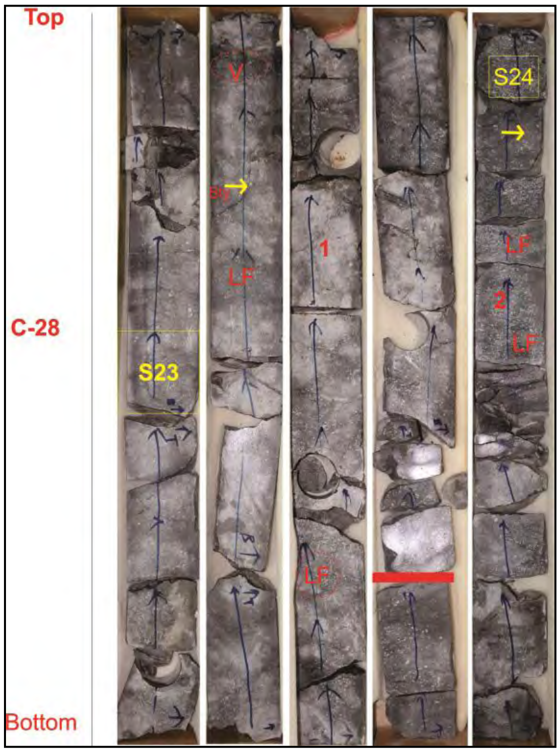


Figure 4.9: Photographs represents the core-28 of Chorgali Formation. Larger forums (LF), stylolites (Sty) and intervals(1,2)

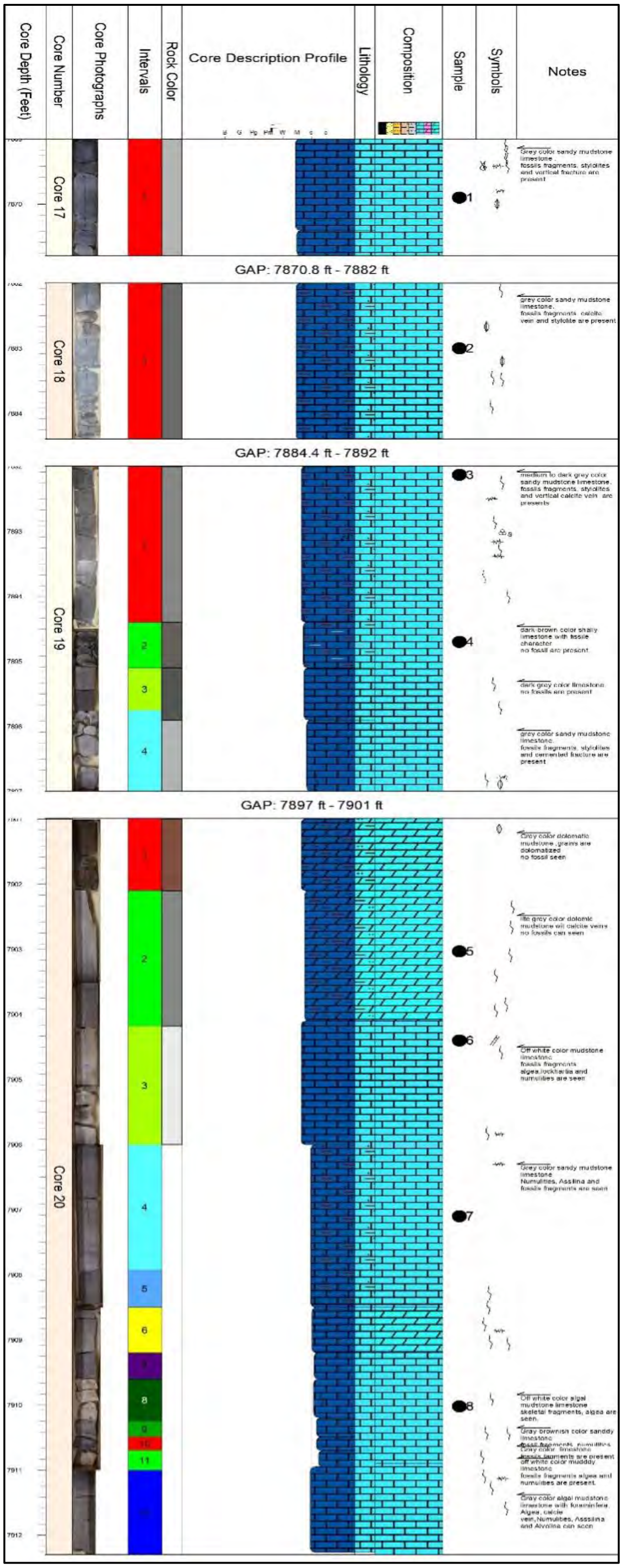


Figure 4.10: Core log of Core 17, Core 18, Core 19 and Core 20

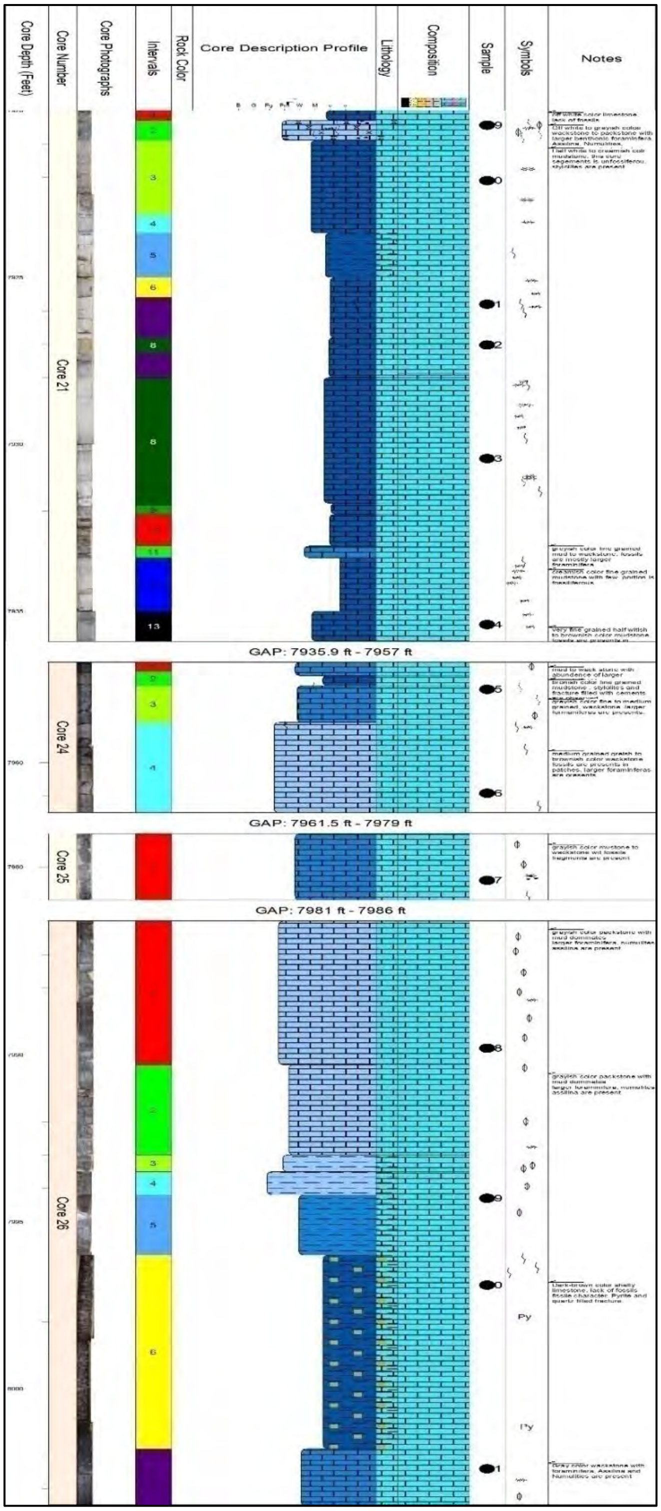


Figure 4.11: Core log of Core 21, Core 24, Core 25 and Core 26

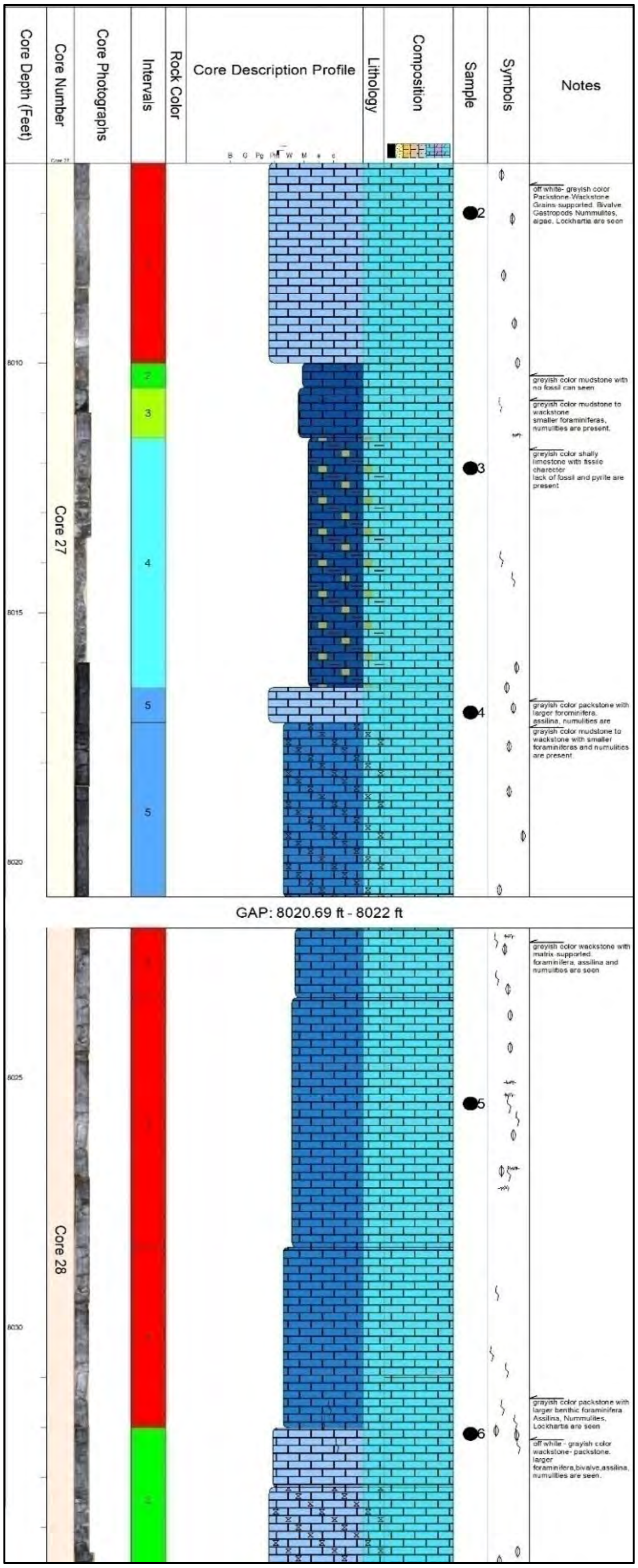


Figure 4.12: Core log of Core 27 and Core 28

Chapter No.5

FACIES ANALYSIS

5.1 Introduction

Walker, (1986) Reading (1986) and Mujtiba et al.,2001 classified the Environment interpretation of ancient limestone. It involves the same facies approach as is used for silicaclast, along with more detailed laboratory studies to identify microfacies. Brown (1943) suggested the name of microfacies and has been defined as “the total of all the paleontological and sedimentological criteria which can be classified in thin section, polished (Fluegel, 1982) and peels. Choquetta and Meyers (1992) described that the dolomite and limestone can be grouped into microfacies on the basis of crystal size characteristics, texture, inferred depositional texture, proportions of dolomite, calcite and non-carbonate minerals, and nature of grain and skeletal molds.

Microfacies identification of the Chorgali Formation is based on the study of total 24 thin section of Balkassar 07 well for which total 10 cores have been studied. Through these studies carbonates have been classified according to Dunham’s classification (1962) into five rocks types.

1. Non-Laminated Mudstone (CF1)

2. Mud-Wackstone Microfacies (CF2)

3. Larger Foraminifera Wacke-Packstone Microfacies (CF3)

4. Mixed Bioclastic Wack-PackstoneMicroofacie (CF4)

5. Shale Lithofacies (CF5)

5.2 Non-Laminated Mudstone (CF1)

The microfacie is characterized on the basis of depositional texture that is mudstone. It is represented by samples S4, S5, S6, S9, S10, S11, S12, S13 in the core of the Chorgali Formation (Balkassar 7 well).This microfacie is mainly consisting of micrite ranging from 93 to 97 % and the presence of allochems is less than 3%. Fracture is filled with sparry calcite but a few open fracture are also present. Styololites seams are also present. It contains few allochems which include forams and bioclasts. The name is suggested because it is predominantly composed of micrite having no lamination and the allochems are less than 2-3%. By following the classification scheme of Dunham (1962) and Folk (1959) this microfacies named as mudstone. (Fig 5.1).

Non laminated mudstone represents deposition in the lower intertidal zone, because the laminations do not survive in the lower intertidal zone (Flugel 2010). This microfacies is interpreted to have been deposited in a lower intertidal setting, as indicated by the absence of diagnostic marine fossils and laminations, as well as the presence of burrows (Flügel 2010).

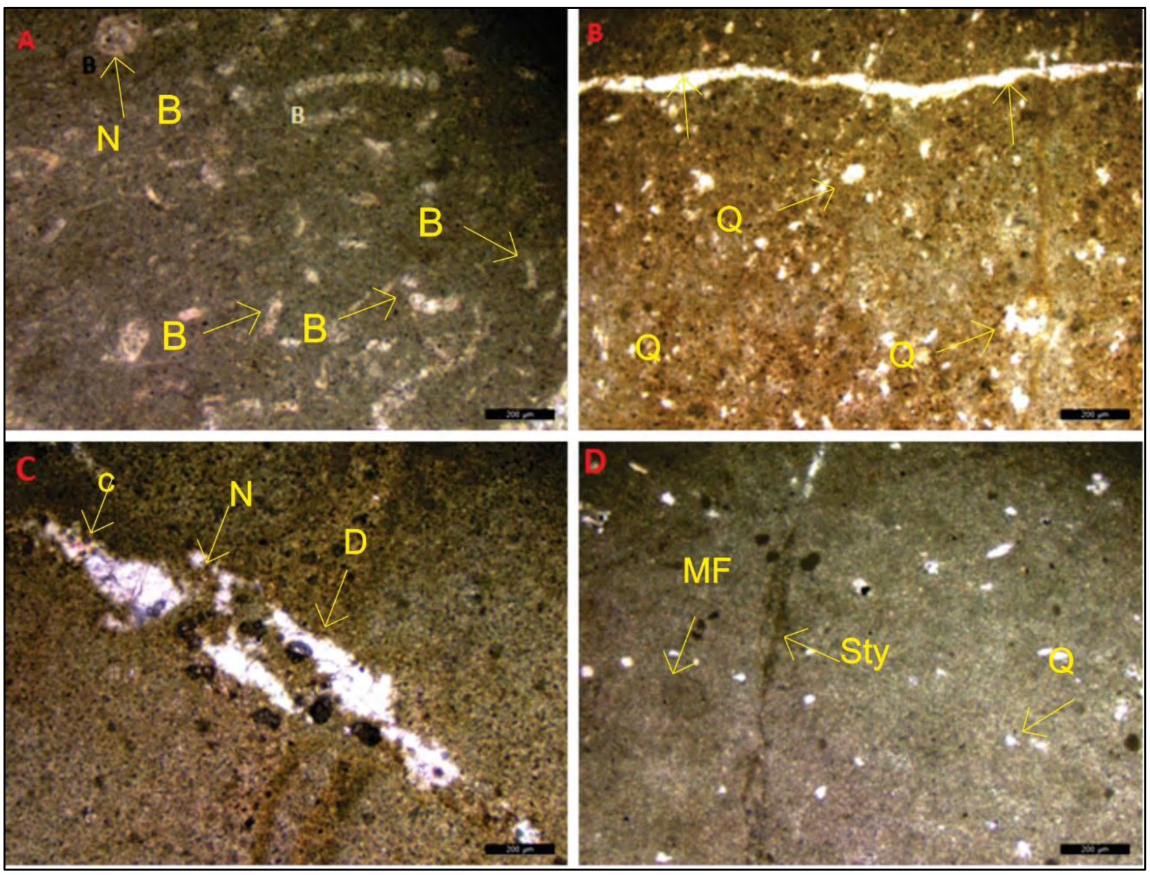


Figure 5.1: Photograph representing the Non-laminated Mudstone (CF1). N showing Nummulities, B bioclast, C calcite cement, D dissolution, Sty stylolities, Q quartz and MF micritized fossils.

5.3 Mud-Wackstone Microfacies (CF2)

The microfacie was classified on the basis of Dunham (1962) classification. It is represented by a samples S14, S16, S19, S21 and S22. Petrographically the facies is composed of 10-15 percent of allochems and the cementing material is micrite. The micite is also converted into spar in some amount. Allochemical material comprises of planktonic forams and some skeletal fragments. Micrite act as cementing material. Calcite filled veins are also present. The average relative abundance of biogenic grain is: Nummulities (7%),Lockhartia (4%) Miliolid (1%) , Echinoderms (1%) and Algae (1%)(Fig 5.2).

Dueto the abundance of Micritic matrix suggests deposition in low energy. So this facies have been restricted to the inner shelf.

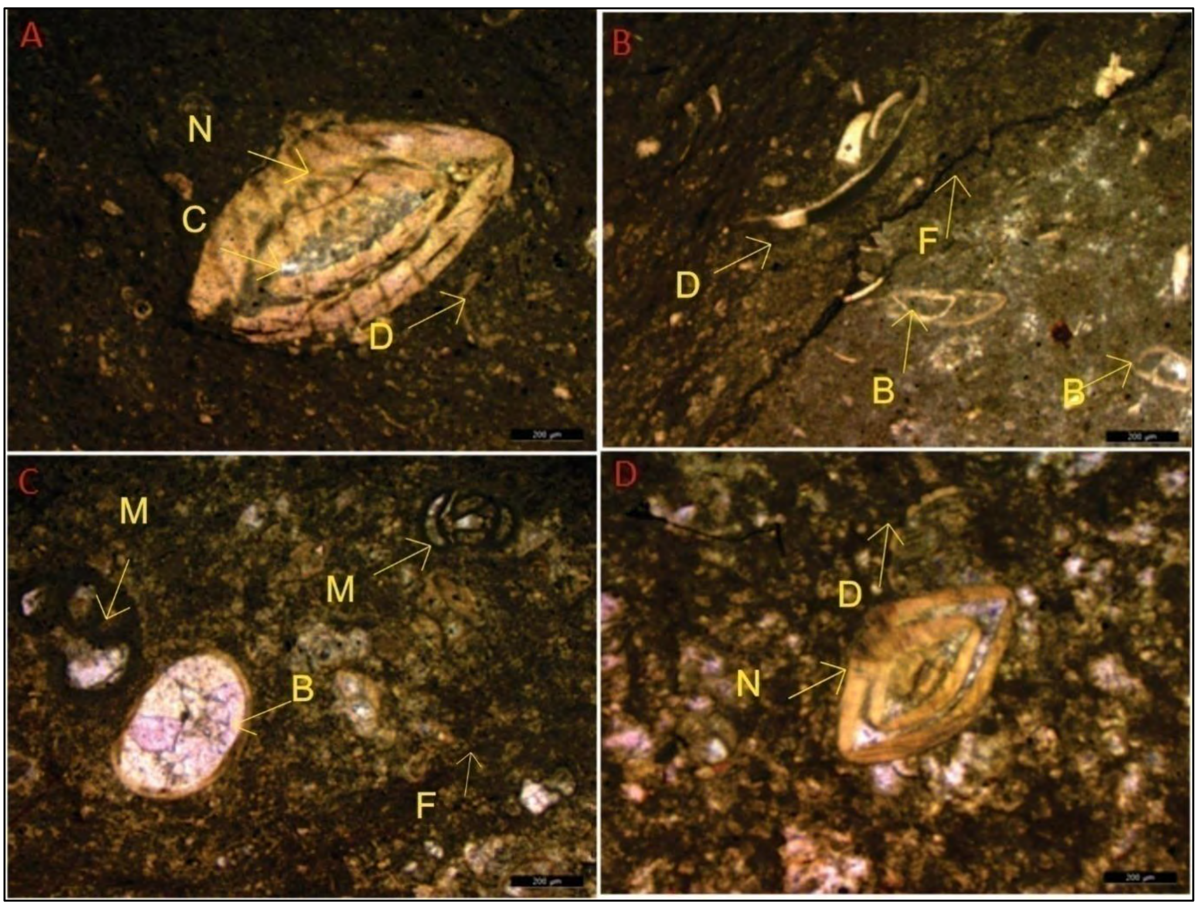


Figure 5.2: Representing Mud-Wackstone of the Chorgali Formation: A. Nummulites atacicus (N) B.Bioclast (B) and open fracture (F) C. Miliod (M) and bioclast mold filled with anhydrite cement (B) . D Nummulites mamillatus (N).

5.4 Larger Foraminifera Wacke-Packstone Microfacies (CF3)

CF3 is characterized on the basis of wack-packstone depositional texture with abundance of larger foraminiferas. Petrographically the biogenic grains are well preserved and the allochemsabundance range from 30-50%. These allochems are larger benthic foraminifera i.eNummulities, Assilina, Lockhartia,Alveolina, Echinoderms and algae (Fig 5.3). The bioclast ranges from 30-60% with an average of 45% and different species of nummulities, assilina and lockhertia has been identified. The micrite act as a matrix varying from 30-70% but in some patches sparite is also present.The average relative abundance of biogenic grain is: Nummulities (11%), Assilina (7%), Alveolina (7%), Lockhartia (4%), Algea(1%) and Echinoderms (1%). CF3 microfacie can be shown in Fig 5.3.So the CF3 have been deposited under shallow subtidal condition on the middle shelf.

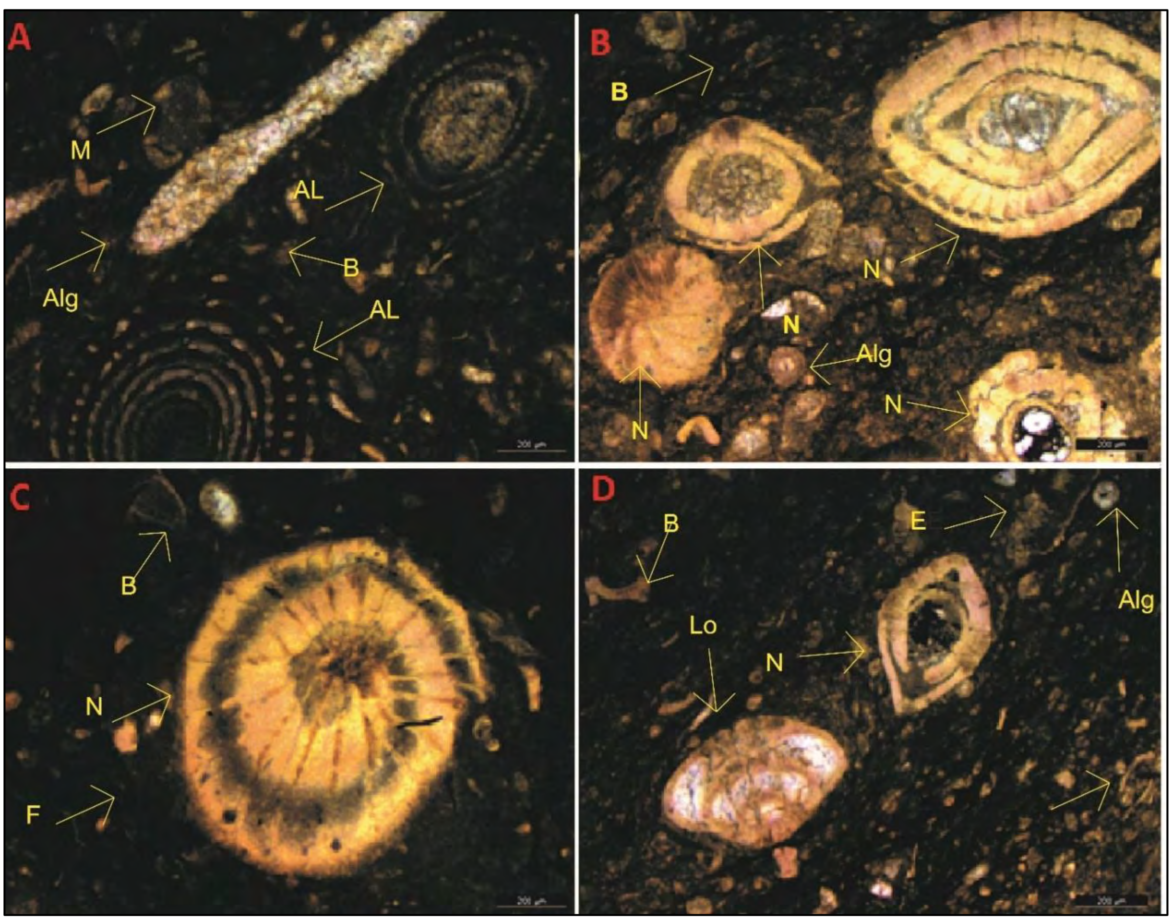


Figure 5.3:Representing larger foraminifera wack-packstone. A. Alveolina indicatrix,(AL)Algea(Alg) , Miliolid (M)B.Nummulites atacicus(N) , Nummulitesdjodjokartae (N) C. Nummulite mamillatus (N) D. Lockhartia conditi (Lo) Algae (Alg) Echinoderms (E) Bioclast

5.5 Mixed bioclastic Wack-PackstoneMicrofacie (CF4)

The facie is characterized on the basis of Dhunm classification (1962) and the percentage of fossils is very low. Bioclast are predominant in CF4 with micrite as matrix and bioclasts are mostly fossils fragments. The depositional texture of CF4 is wack-packstone with partially and fully micritized allochems. CF4 also contains shall fragments of Lockhartia and other bioclasts. The relative abundance of biodebris is approximately 30-40% and othe fossils includes: Lockhartia (5%). Nummulities (3%) and Echinoderms(1%) (Fig 5.4). So CF4 is deposited on open lagoon setting upto mid shelf.

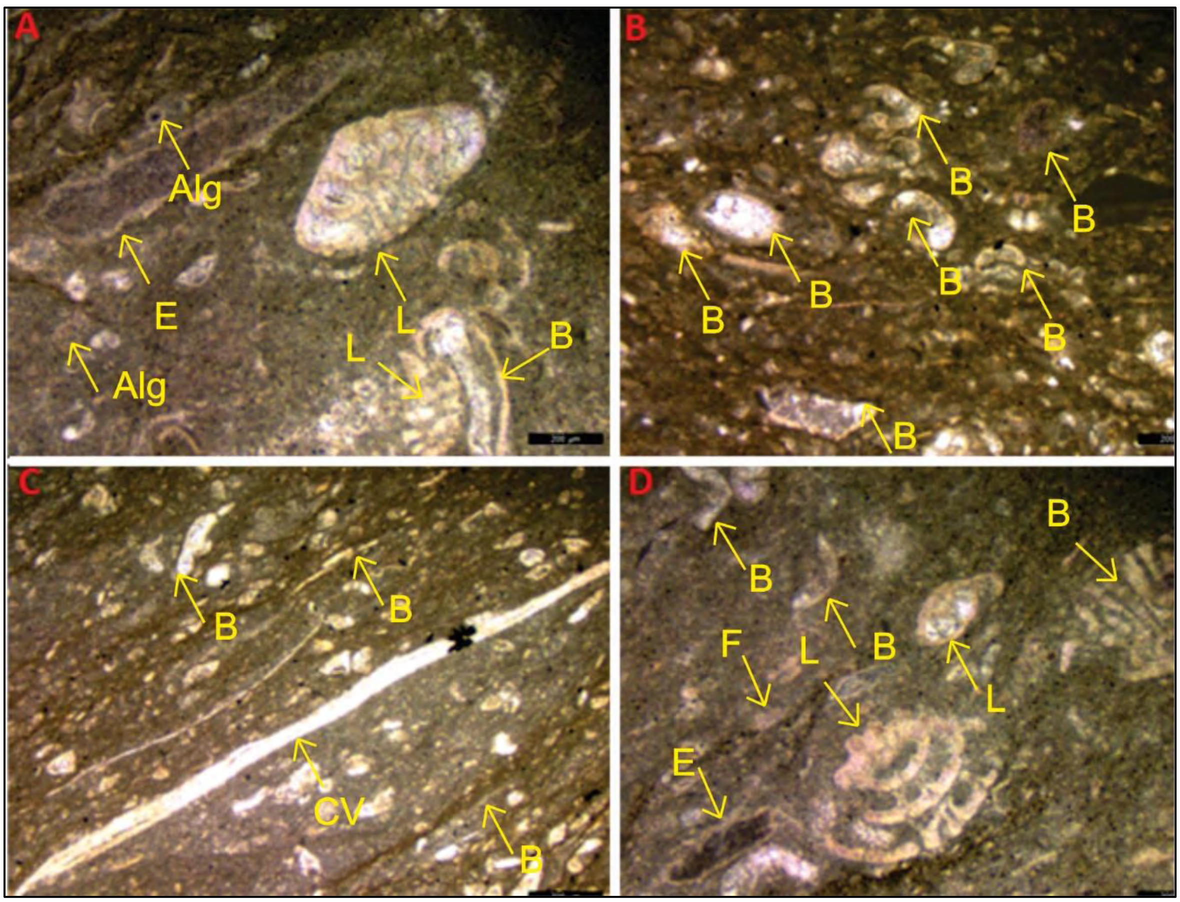


Figure 5.4: Representing mixed biolclasticwack-packstone. A. Echinoderms (E), Lockhartia (L) B. unidentified bioclast fragments. C. calcite veins (CV) D. Lokhartia (L).

5.6 Shale lithofacies (CF5)

The lithofacie is composed of shale in the core studies and shows brownish to grayish in color. The total thickness shale bedare 2.9m encountered at two different depths in core number 26 and 27. CF5 Shows fissile character with no fossils is present. Calcite filled veins are seen.

Chapter No.6

DEPOSITIONAL ENVIRONMENT

6.1 Introduction

Microfacies types are used in manuscript in the difference of sedimentological and biological environmental factors present in the Chorgali Formations. According to Fluegel (1982), sedimentological factor include organic activities, water movement or energy level, influx from continents, sedimentation of non-carbonate particles carbonate extraclasts, and the progression of cementation during early diagenesis. Meanwhile, biological factors comprise light and water depth, water energy and oxygen supply, salinity of water, water temperature, and composition and consistency of substrate. ON the basis of vertical distribution, type of facies and fossil assemblage of the five microfacies of the carbonates of the Chorgali Formation, as see in the studied sections(core studies), suggest that the original carbonate sediments be deposited in three environmental zones of a tidal flat classification: subtidal, intertidal, and supratidal. The description of these systems together with investigative features is given below.

6.2 Subtidal Zone

The subtidal zone, which is located seaward of the intertidal zone (Figure 6.1), is typically characterize by muddy sediment and is critical for the growth of tidal flats. This zone can enlarge for hundreds of kilometers, depending on the geographic setting. It is often limited to 200m from the shore, and is exposed to shallow, low-energy conditions which mix the sediment into suspension and transport it to the flats during storm-tide conditions. Organisms such as algae, foraminifera, sponges and bryozoans are abundant in this zone, and its composition is typically subjugated by homogenized pelleted muds which lack primary sedimentary structure. The subtidal sediments are never expose to air and typically have grey color.

The above mentioned characteristic are encountered in CF2 (mud-wackstone),CF3 (larger foraminifera wack-packstone)and CF4 (Mixed Bioclastic Wack-Packstone) lies in this zone as shown in model (Fig 6.1). While the Shale lithofacie(CF5) have been deposited in lagoonal environment (shallow subtidal zone).

6.3 Intertidal zone

Intertidal sediments are those which are deposited between the normal high and low tides and are exposed to the air either just the once or two times in sunlight hours, depending on the tidal regime and local wind conditions (Shinn, 1983a). These sediments form a belt which lies seaward of the supratidal flats and landward of the subtidal zone (Fig 6.1). Therefore the burrowing organisms, laminated sedimentary structures are commonly not present in either recent or early intertidal accumulation also the range of fossils is low. Furthermore, intertidal sediments in humid areas are nearlyhard to differentiate from near subtidal sediments.Intramicritizationis common in this zone and formed due to the degeneration and modification of algal lamination.Keeping in view the above mention diagnostic features the CF1 (Non-Laminated Mudstone) deposited in this zone (Fig 6.1).

6.4 Supratidal Zone

Supratidal sediments are deposit above the mean high tide, with most of the time exposed to subaerial conditions as they are only flooded by spring and storm tides. Two-fold a month, spring tides appear, while storm tides appear randomly in certain seasons. Mud cracks, laminations, algal structures and birds-eye structures are the diagnostic sedimentary structures of the supratidal zone. Early diagenesis is marked by dolomite, which forms on supratidal conditions.So there is no facie is deposited in this zone.

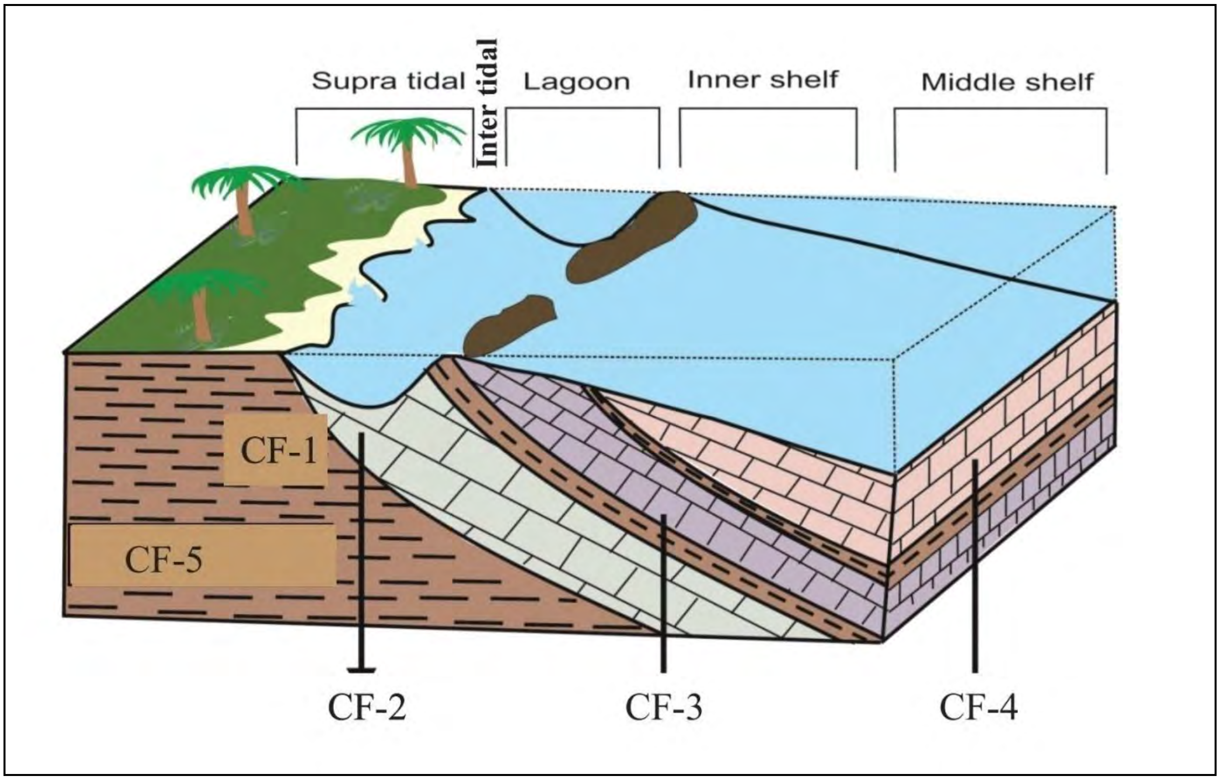


Figure 6.1: Photograph representing the depositional model of the Chorgali Formation.

Chapter No. 7

DIAGENETIC MODIFICATIONS

7.1 Introduction

The digenetic modification in the Chorgali Formation is the combination of processes that modify the composition and depositional texture throughout time form deposition to deep burial (Carozzi). The infraction of marine and meteoric waters and with subsurface solution is the main feature of the diagenesis in limestone. These features leave unique imprints at the time of its reaction with the limestone. These imprints have distinctive diagenetic environment and qualified in time as a diagenetic phase.

The evolution of carbonate sediments begin in the marine phreatic environment and at the time of deposition limestone can follow the different pathway to reach the final burial. To understand the diagenetic sequences, there is need to study the texture and geochemical signatures of limestone. There are many factors that affect the diagenetic evolution, such as climate, tectonic framework, composition flow rate of water and the length of residence time within a particular diagenetic environment.

There are six process of diagenesis (Tucker 1990): Micritization, cementation, neomorphism, dissolution, compaction and dolomitization. There are three principal environments in which carbonate diagenesis operates: marine environment, meteoric and burial environment. The precipitation of cements and alteration of grains by micritization and borings can be happened in low latitude, shallow-marine environments and sea floor diagenesis. Cementation of carbonates also takes place on tidal flats and in supratidal zones which are flooded by seawater. CaCO3 in tidal flat condition leads to the development of cemented pavements, and these are mostly polygonal cracked, buckled, folded and thrust in tapee structure.

Meteoric diagenetic environments is the zone in which rainfall derived groundwater is in contact with sediments of rocks and water table separates the vadose and the phreatic zones. There are three processes that operate in meteoric digenesis': precipitation (cementation) dissolution and mineralogical transformation. Dissolution is creating porosity in micro scalewhile on larger scale karst termed used. In subsurface krast represent the fissure and caves. According to Goudie (1983) meteoric cements consist of zones and meters of thick in finally crystalline secondary carbonates, which is termed as calcrete or caliche and these are micritic or microspar grade cement fill pore spaces. The conversion of high-Mg calcite and low aragonite to low-Mg calcite and the addition of low magnesium calcite cement, results in significant chemical and textural changes during meteoric diagenesis.

Thoroughly study of core nd thin sections(24) indicate burial diagenesis. Limestone is directly affected by lithostatic pressure in deep burial environment. Which directly controls the temperature, pressure, circulation of fluids and pore-water chemistry? The most important processes during deep burial diagenesis are: dewatering, mechanical compaction, decrease of porosity, micro facture, chemical compaction, cementation and various types of replacement by dolomites and other minerals.

The Chorgali Formation has been described in these chapters on the basis of petrography observations. The Chorgali Formation passes through various post depositional processes. The diagenesis started as the formation gets deposited and pass from marine diagenesis into burial meteoric diagenesis (Bathurst, 1966, 1975; Scholle and Ulmer-Scholle, 2003). The Chorgali Formation shows all three diagenetic environments such as aragonite to calcite transformation (marine diagenetic environments), various stylolites shows burial diagenesis and later stage tectonic effect causes the fracture and uplift to the surface for meteoric diagenesis (Haneef, 2015). The diagenetic modification in the Chorgali Formation of Balkassar07 well, includes multiple episodes of cementation, dolomitization, mechanical and chemical compaction, micritization etc. These diagenetic processes occurred in above noted diagenetic environments. Fracturing and other changes took place during the uplifting of the region. These diagenetic changes are briefly discussed below.

7.2 Diagenetic Changes

7.2.1 Micritization

According to Longman (1980) early diagenesis occurs at surface or in the shallow subsurface after or during the sedimentation of strata. It alters the nature of carbonate sediments by dissolution, cementation or chemical or mechanical compaction. The micritization isused by the circulation of fluids and also showintergrangular cementation.

The diagenesis is start with micritization in the Chorgali Formation. The aragonite (high Mg calcite) which is unstable near surface at low pressure (Rupnagar, 1987) will move through multiple phases to get stability. The dissolution afterward replaced by calcite deposition. The micritization noted in the Chorgali Formation varies from partial to intense (Fig 7.1). In some cases the allochems are completely micritized and there is no indication of original allochems.

7.2.2 Compaction

The reduction of volume takes place during the compaction. Due to the expulsion of water took place during the compaction of lime mud and shale. The thickness of lamina reduced and bulk density increased due to compaction. There are two types of compaction took place in the Chorgali Formation: Mechanical and chemical compaction

7.2.3 Mechanical compaction

The evident of mechanical compaction is brittle discontinuities such as broken allochems and lamination which provide a path way for the fluid circulation. There are different types of fracture. Some fracture is filled with calcite and others are open and vacant (Fig 7.1). Fractures are formed by mechanical compaction caused b burial and or tectonic activity.

7.2.4 Chemical compaction

Stylolites are most prominent feature in carbonate rocks during chemical compaction and the intensity of chemical compaction can easily monitored from the dissolution pattern. In the studied thin section stylolitization took place very frequently. There are two types of stylolites origin were identified i.e. burial stylolite and tectonic stylolite (Dunham 1922).

7.2.5 Cementation

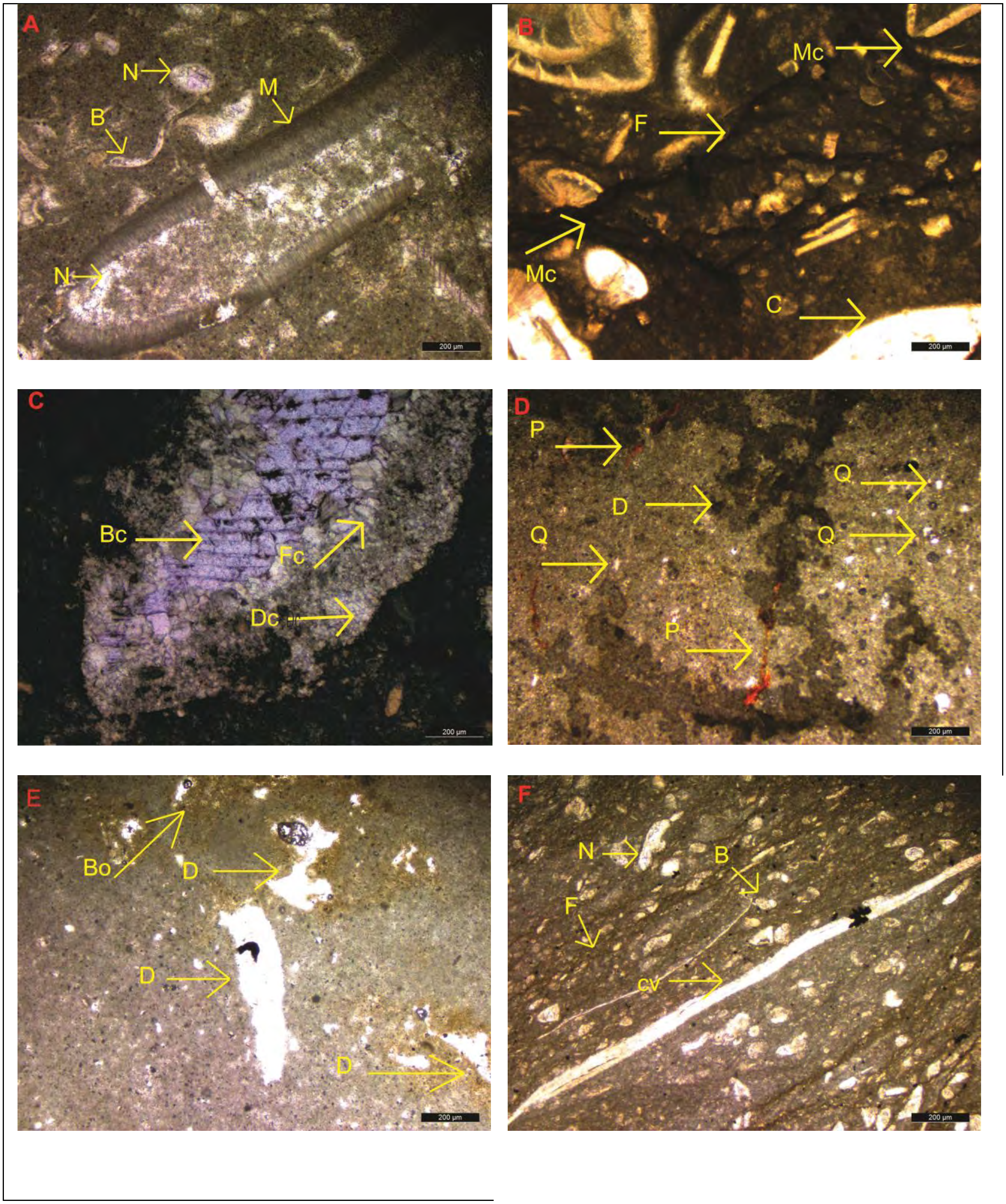
The predominant cement in the Chorgali Formation is calcite. Calcite is filled in fracture, micro molds and in microvugs. Cementation is also took place along the stylolites and along fractures. Bladded cements, fibrous cements and dursy cements are observed during the petrographic study (Fig 7.1).

7.2.6 Dissolution

In the Chorgali Formation dissolution caused open spaces by removing the different shell of foraminifera and these open spaces are refilled by calcite cements. Different types of porosity have been produced by dissolution such as moldic and vuggy (7.1). Also intense twinning along is caused by dissolution and dislocation of crystal is caused by burial loading or tectonic deformation.

7.2.7 Neomorphisms

Neomorphism is the process of replacement of aragonite by calcite and this will happen by dissolution of aragonite and calcite is precipitate on that place and the original shell or cement structure is preserved in neomorphic calcite (Fig 7.1). The Formation of calcite spar from micrite is also observed during petrography.



Figur 7.1: Photograph representing different diagenetic features of the Chorgali Formation. B showing bioclast, Micritization (M), Neomorphism (N), Mechanocal compaction (Mc), open fracture (F), Calcite cement (C)Bladded cements (Bc), Fibrous cement (Fb), Drusy

Chapter No. 8

ELECTROFACIES

8.1 Introduction

Lithology is very important to characterize the facies based on different computational techniques. To understand the variation in the reservoir cluster analysis is used which classify the data into group and sub groups on the basis of similarities (Cornish, 2007). K-means Clustering is an unsupervised learning algorithm which is used to group observations into clusters based on their similarity. It is one of the most used clustering algorithms in machine learning and data mining. The aim of this algorithm is to divide a dataset into K clusters, as a resultthe observations within a cluster are more comparable than observations in different clusters. K-means is frequently used in analyze geophysical data such as seismic data and electrofacies. It is a useful tool for finding pattern and clusters in data that are not simply visible to the human eye. This makes it a great tool for Geoscientists who are pointed for meaningful trends in their data. In this chapter, we will use K-means Clustering to analyze the electrofacie of Eocene Chorgali Formation. K-means Clustering is an unsupervised learning algorithm which is used to assembly observations into clusters based on their similarity. It is one of the most use clustering algorithms in machine learning and data mining. The aim of this algorithm is to split a dataset into K clusters, so that the observations within a cluster are more comparable than observations in different clusters. K-means is regularly used in analyzing geophysical data such as seismic data and electrofacies (Cornish, 2007). It is an effective tool for finding patterns and clusters in data that are not easily visible to the human eye. This makes it a great tool for geoscientists who are searching for significant trends in their data. In this chapter, we will use K-means Clustering to evaluate the electrofacies of the Eocene Chorgali Formation of the Balkassar OXY 1 well.

According to Euzen and Power (2012) electrofacies is the set of distinctive log signature which shows specific lithology. The lithology of the Chorgali Formation is limestone with intercalation of shale where GR shows high values. K means clustering separate the various lithological units of the Chorgali Formation by using electrofacies analysis.

Group of data point is called clusters and there are different methods of clustering but we can use the K mean clustering which can describe below.

8.2 K Mean clustering

K-Means Clustering is a type of centroid-based clustering which uses a mean vector to describe the clusters of data points. This method classifies the data points into a pre-defined number of clusters based on the nearest mean (Wang et al., 2012).K Mean clustering is used to classify the facies of the Chorgali Formation encountered in Balkassar OXY 01 well. It classifies, number of data point into clusters by taking mean of each clusters called centroid (Wang et al., 2012).

8.2.1 Work flow

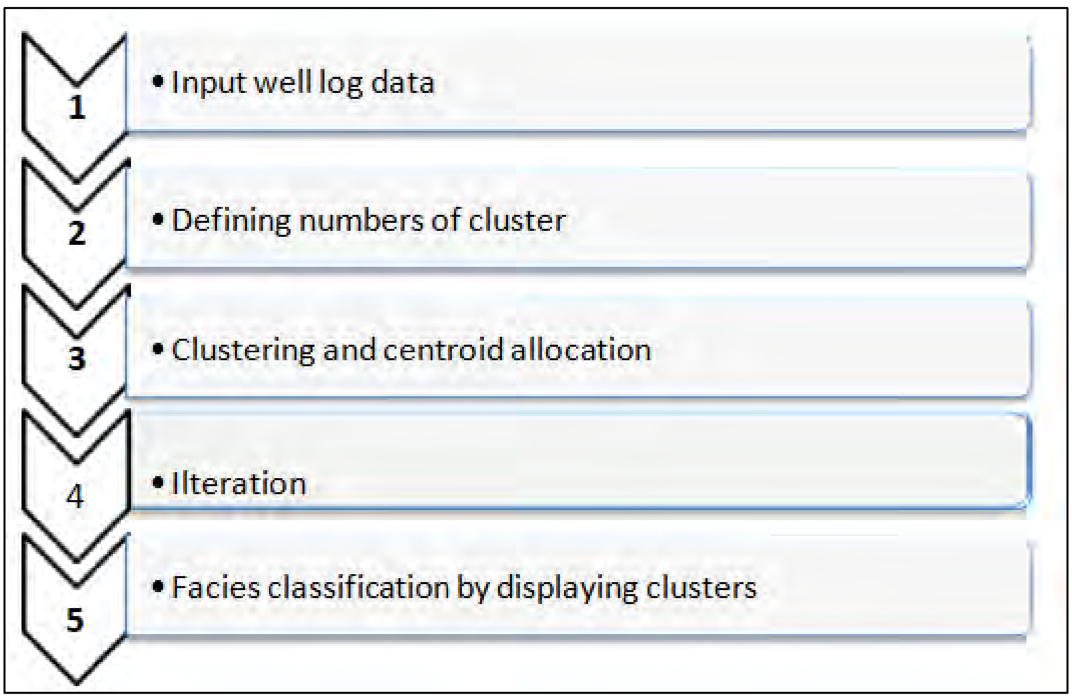


Figure 8.1: Generalized work flow of K mean clustering for facies characterization of Chorgali Formation

8.2.2 Cluster Analysis of the Chorgali Formation

Facies characterization is important to understand the variation with the reservoir rocks. The Chorgali Formation show different lithology during the core studies of Balkassar 07 well. Facies analysis is mostly performed on outcrop and core samples but well logs are also important and used to facies characterization based on well logs response. So, K means clustering subdivide the data to further classify the interval based on lithology. This method is used on the well logs of Balkassar OXY 01 well and analysis has performed on the Chorgali Formation. GR, LLD, RHOB and NPHI logs curves is used to perform analysis.

8.2.3 Selection of clusters numbers

Different data points are obtained from the log data curves and plotted on the cross plots. It also creates the data points based on count rate of data point of specific range that defines its frequency shown in Fig. 8.2.The cluster numbers are selected randomly after data displayed on crossplots. There are three clusters of the Chorgali Formation which are randomly selected as shown in Fig. 8.2.

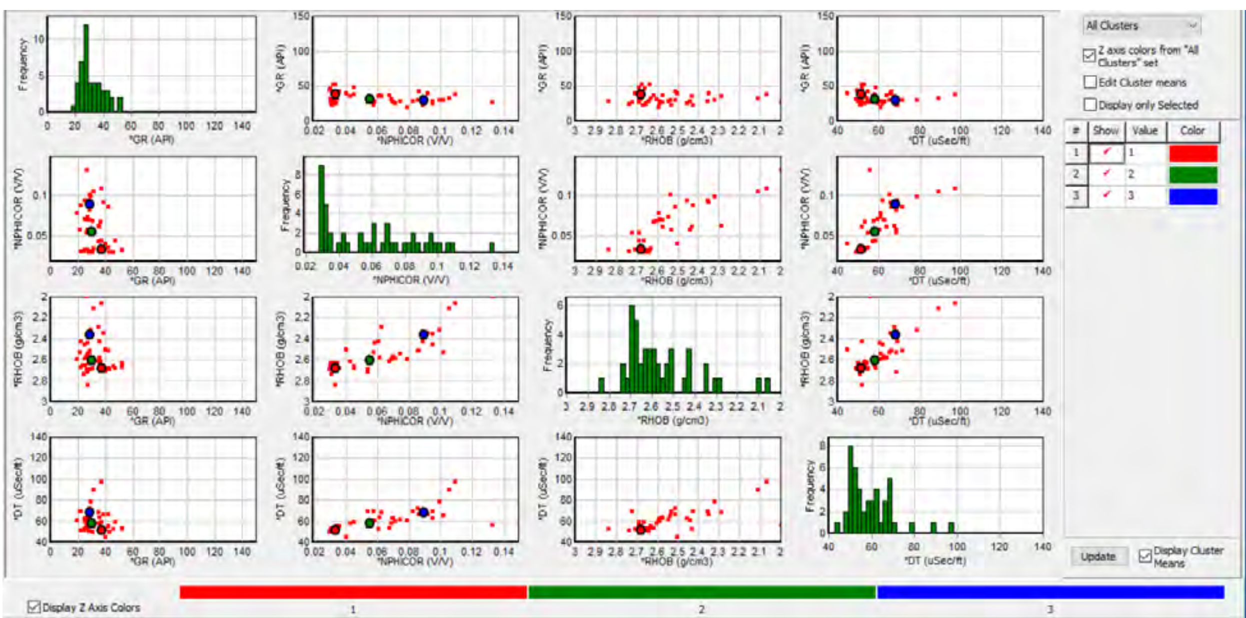


Figure 8.2: Crossplots showing numbers of cluster and curves show in the form of crossplots. Red color indicates data points and the colored point assumed cluster means. Diagonal shows the frequency histograms.

8.2.4 Data classification

The mean value has been taken after selection of cluster of each log curve. The mean values of each clusters are shown in table 1.Mean values is used in further steps of K mean clustering. This will help to understand the logs curves.

Table 1: Calculated Mean values for each cluster set.

Cluster	#	Cluster	*GR		*NPHICOR		*RHOB		*DT	
#	Points	Spread	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
1	0		37.52		0.03292		2.6778		51.495	
2	0		30.297		0.05476		2.6036		58.052	
3	0		28.972		0.08895		2.3635		68.088	

The data points are assigned to each cluster. Then the iteration is used by clustering technique to get finalized mean value of the clusters. K mean clustering is based on this mean value. After iteration finalized mean values and other statistical details of each cluster are shown in Table 2.

Table 2 : Tables show the statistical results of cluster analysis.

Cluster	#	Cluster	*GR		*NPHICOR		*RHOB		*DT	
#	Points	Spread	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
1	20	1.043	27.003	3.77	0.04999	0.01823	2.6321	0.08599	57.198	6.269
2	13	1.558	31.008	5.802	0.09489	0.01641	2.2962	0.2054	71.375	11.18
3	13	0.9062	42.014	5.933	0.04041	0.01185	2.6344	0.08038	53.084	3.683

The tables results have been shown in Table 2 are displayed on crossplots shown in Fig 8.3. The data point colors representing the specific cluster of data in crossplots. Mean value is plotted at the center of each cluster and representing by bold points of same color. Centroid is shown in the center points. The color bar has been shown at the bottom of the cross plots. The plotted log data on cross plots are classified into three clusters as shown in Fig.2.

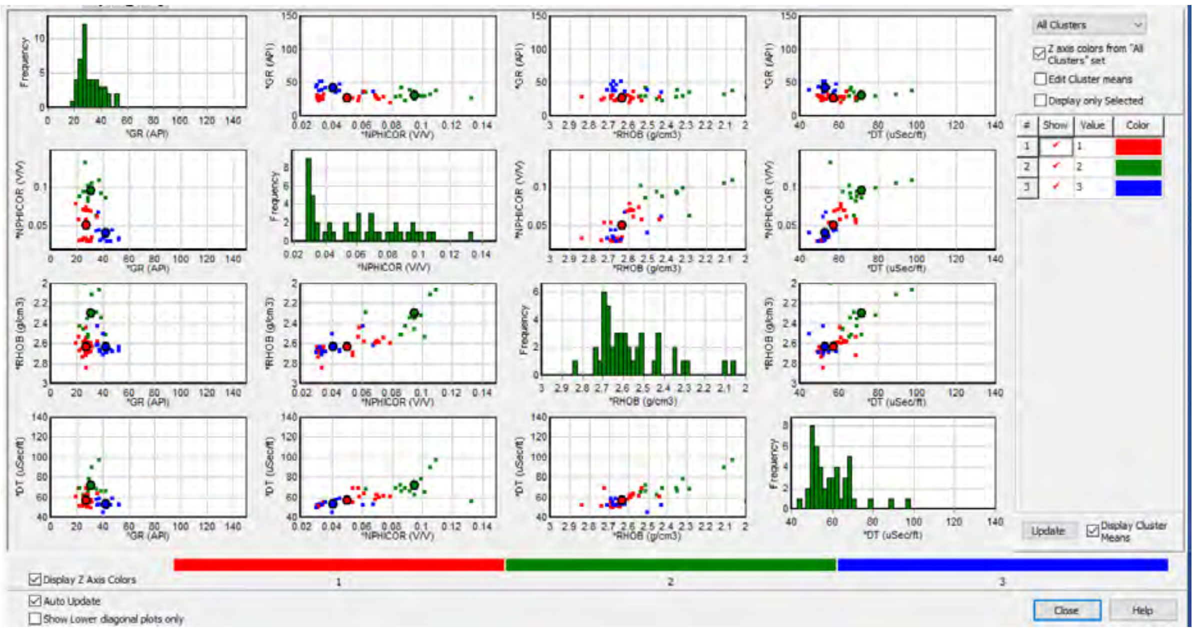


Figure 8.3: Crossplots of the clusters set between log curves. The colored points shows the clusters points. Frequency cross plots are present diagonally in the photograph.

8.3 Facies Classification of the Chorgali Formation (Balkassar OXY 01)

The classification of facies is based on Kmean clustering. There are three facies are classify on the basis of logs values. The description of these facies is given below.

Numeric	Text	Shading
1	Limestone	
2	Shaly Limestone	
3	Calcareous shale	

Figure 8.4: Photograph shows three color codes of Electrofacies and each color shows specific facie.

8.3.1 Limestone

Limestone is most dominant facie marked in the Chorgali Formation of studied well. The limestone is represented by green color. It is characterized by low GR and DT values as shown in Fig 8.5.

8.3.2 Shaly limestone

Shaly limestone is second dominant facie marked in studied well. This facie is represented by pink color as shown in Fig 8.5. The values of GR and DT are comparatively higher inShaly limestone.

8.3.3 Calcareous Shale

The value of GR and DT is comparatively higher in calcareous shale. The shaly contend get increased in limestone. It is represented by brown color as shown in Fig 8.5.

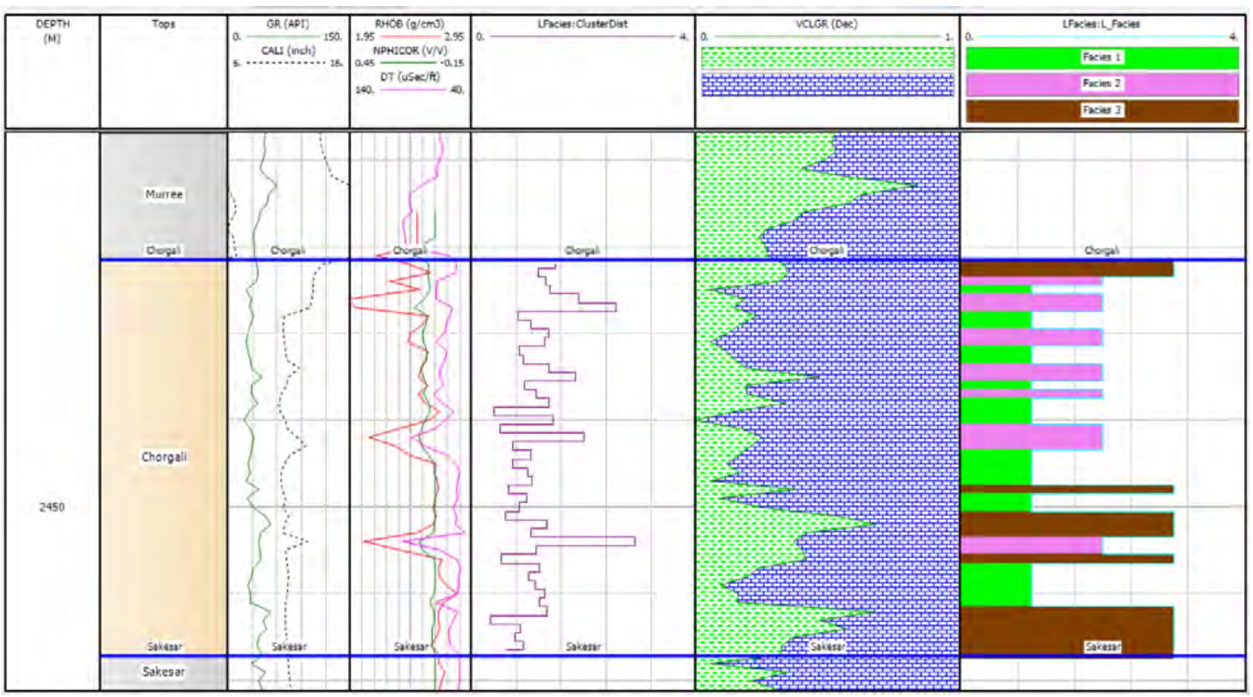


Figure 8.5: Photographshows Electrofacie of the Chorgali Formation in Balkassar OXY 01 well. Green color represents limestone facie, pink showsshaly limestone and brown shows calcareous limestone.

Chapter No. 9

CONCLUSIONS

The Chorgali Formation has been studied in current research works. Following conclusion have been prepared based on core studies, petrography and electrofacies of Eocene Chorgali Formation.

- In the Chorgali Formation five microfacies have been identified based on petrography, which are Non- laminated mudstone (CF1), Mud-wackstone (CF2), Larger foraminifera wack-packstone (CF3), Mixed bioclastic wack-packstone (CF4) and Shale lithofacie (CF5).
- These microfacies indicates supra tidal to middle shelf environment of deposition.
- The diagenetic modification includes Micritization, Compaction including mechanical and chemical compaction, Dissolution, Cementation and Neomorphism.
- Micritization is very common in thess Chorgali Formation and the identified cementation includes Dursy, bladed and fibrous in diagenetic study.
- By using K means clustering threeElectrofacies have been generated which are limestone, shaly limestone and calcareous shale.
- On the basis of microfacies, the Eocene Chorgali Formation has been deposited in low energy carbonate shelf.

REFERENCES

Afzal, J. (2011). Evolution of Larger Foraminifera during the Paleocene-Early Eocene Interval in the East Tethys (Vol. 252).

Ameeni, S. J., Ahmad, A., Ahmad, N., & Ahsan, N. (2013). Biostratigraphy of Chorgali Formation, Jhalar Area, Kala Chitta Range. *Sci-Int*, *25*(3), 567–577.

Awais, M. (2015). Reservoir evaluation of the Eocene Chorgali Formation using Outcrop data and Geophysical logs of Meyal Oil Field.

Awais, M., Hanif, M., Ishaq, M., &Iu, J. (2020). An integrated approach to evaluate dolomite in the Eocene Chorgali Formation, Khair-e-Murat Range, Pakistan: Implications for reservoir geology. *J Himal Earth Sci*, *53*(1).

Awais, M., Hanif, M., Jan, I. U., Ishaq, M., & Khan, M. Y. (2020). Eocene carbonate microfacies distribution of the Chorgali Formation, Gali Jagir, Khair-e-Murat Range, Potwar 107 Plateau, Pakistan: approach of reservoir potential using outcrop analogue. *Arab J Geosci*, *13*.

Baqri, S. R. H., Hussin, A., Sanjeeda, K., & Iqbal, N. (1997). Biodiversity of gastropods in the Eocene time during the closure of Tethy Sea in the Central Salt Range, Pakistan. In S. A. Mufti, C. A. Woods, & S. A. Hussain (Eds.), *Biodiversity of Pakistan* (pp. 305–316).

Bathurst, R. C. (1966). Boring algae, micrite envelopes and lithifcation of molluscan biosparites. *Geological Journal*, *5*, 15–32.

Benchilla, L., Swennen, R., Akhtar, K., &Roure, F. (2002). Sedimentology and diagenesis of the Chorgali Formation in the Potwar Plateau and the Salt Range, Himalayan foothills (N-Pakistan), P 4.

Brown, S. (1943). Suggested use of the word microfacies, Suggested use of the word microfacies. *Economic Geology*, *38*.

Choquette, P. W., & Pray, L. C. (1970). Geologic nomenclature and classification of porosity in sedimentary carbonates. *American Association of Petroleum Geologists Bulletin*, *54*, 207–250.

Cantrell, D., Swart, P., & Royal Hagerty. (2004). Genesis and characterization of dolomite, Arab-D Reservoir, Ghawar field, Saudi Arabia. *GeoArabia*, *9*(2), 11–36. https://doi.org/10.2113/geoarabia090211

Choquetta, M. (1992). described that the dolomite and limestone can be grouped into microfacies on the basis of crystal size characteristics.

Dunham, R. J. (1962a). Classi rocks according to depositional texture. *American Association of Petroleum Geologist Memoir*, *1*, 108–121.

Dunham, R. J. (1962b). Classification of carbonate rocks according to depositional texture. *Memoir of American Association of Petroleum Geologists*, *1*, 108–121.

Durrani, M. M. (1999). Microfacies and deposition of Environment of Chorgali Formation, Chorgali Pass.

Fahad, M., Khan, M. A., Hussain, J., Ahmed, A., &Yar, M. (2021). Microfacies analysis, depositional settings and reservoir investigation of Early Eocene Chorgali Formation exposed at Eastern Salt Range, Upper Indus Basin, Pakistan. *Carbonates and Evaporites*, *36*(3). https://doi.org/10.1007/s13146-021-00708-7

Fatmi, A. N. (1973a). Lithostratigraphic units of Kohat-Potwar Province, Indus Basin. *Indus Basin. Geological Survey of Pakistan Memoir*, *10*.

Fatmi, A. N. (1973b). Lithostratigraphic units of Kohat-Potwar Province, Indus Basin. Geological Survey of Pakistan Memoir.

Fatmi, A. N. (1973c). Lithostratigraphic units of the Kohat-Potwar Province, Indus Basin, Pakistan. *Pakistan Geol. Surv., Mem*, *10*.

Flügel, E. (1982). *Microfacies Analysis of Limestone*. Springer-Verlag.

Folk, R. L. (1962). Spectral Subdivision of Limestone Types. *American Association of Petroleum Geologists*, *1*, 62–84.

Ghazi, S., Ali, A., Hanif, T., Sharif, S., & Arif, S. J. (2010). Larger benthic foraminiferal assemblage from the early Eocene Chorgali Formation, Salt Range, Pakistan. *Geol Bull Punjab Univ*, *45*, 83–91.

Ghazi, S., Ali, A., Hanif, T., Sharif, S., & Sajid, Z. (2014). Microfacies and Depositional Setting of the Chorgali Formation. *Pakistan Journal of Science*, *66*(2), 156–164.

Ghazi, S., Ali, A., Hanif, T., Sharif, S., Sajid, Z., & Aziz, T. (2014). Microfacies and depositional setting of the early Eocene Chorgali Formation.

Gill, W. D. (n.d.). 1953: Facies and fauna in the Bhadrar Beds of the Punjab Salt Range. *Pakistan. Jour. Palaeont*, *27*, 824–844.

Gill, W. D. (1953). Facies and fauna in the Bhadrar Beds of the Punjab Salt Range, Pakistan. *J Paleontol*, *27*, 824–844.

Hanif, M. (2011). Stratigraphy and Paleoenvironmental of Paleocene-Eocene boundary interval in the Indus Basin (Vol. 327).

Hanolkar, S., &Saraswati, P. K. (2019). Eocene foraminiferal biofacies in Kutch Basin (India) in context of palaeoclimate and palaeoecology. *J Palaeogeogr*, *8*(1), 1–16.

Jamal, T. (2015). Microfacies and Diagenetic Fabric of the Chorgali Formation in Bhuchal Kalan, KallarKahar. *Journal of Himalayan Earth Sciences*, *48*, 14–25.

Jurgan, H., & Abbas, G. (1991). On the Chorgali Formation at the type locality. *Pak J Hydrocarb Res*, *3*(1), 35–46.

Kamran, S. M., Khan, M. S., Siddiqi, M. I., & Munir, M. H. (2006). Micropaleontology and depositional environment of the Early Eocene Margalla Hill Limestone and Chorgali Formation of Khairi-Murat Range, Potwar Basin, Pakistan. *Pakistan Journal of Hydrocarbon Research*, *16*.

Kazmi, A. H. (1982). Tectonic map of Pakistan: Geological Survey of Pakistan.

Kazmi, A. H., & Jan, M. Q. (1997a). *Geology and tectonics of Pakistan*. Graphic Publishers.

Kazmi, A. H., & Jan, M. Q. (1997b). Graphic Publishers, Karachi Dickson JAD (1965) A modifed technique for carbonates in thin section. *Nature*, *205*(4971).

Kazmi, A. H., & Rana, R. A. (1982a). Tectonic Map of Pakistan. Geological Survey of Pakistan.

Kazmi, A. H., & Rana, R. A. (1982b). Tectonic map of Pakistan, scale 1:2000000, 1st edn. *Geological Survey*.

Khatoon, S., Rafiqui, H. B., Iqbal, N., Roohi, G., Hasan, A., Chaudhry, B., & Sarwar, A. (2001). *The study of some gastropods fossils from BradrarBads (Chorgali Formation)* (Vol. 34).

Lillie, R. J., Johnson, G. D., Yousaf, M., Zaman, A., & Yeast, R. S. (1987). Structural development within the Himalayan Foreland Fold and Thrust Belt of Pakistan. *Mem Can Soc Petrol Geol*, *12*, 379–392.

Moghal, M. A., Saqi, M. I., Hameed, A., &Bugti, M. N. (2007). Subsurface geometry of Potwar sub-basin in relation to structuration and entrapment. *Pak J Hydrocarb Res*, *17*, 61–72.

Mujtaba, M. (1999). Depositional and diagenetic environments of Chorgali Formation. (Early Eocene) Salt Range Potwar Plateau, Pakistan

Mujtaba, M. (2001a). Depositional and diagenetic environment of Chorgali Formation (Early Eocene)Salt Range Potwar Plateau.

Mujtaba, M. (2001b). Depositional and diagenetic Environments of Carbonates of Chorgali Formation (Early Eocene) Salt Range-Potwar Plateau .P 187.

Mujtaba, M., Jurgan, H., & Abbas, G. (1989). Depositional environment and porosity development in Lower Eocene Limestone Formation of Surghar Range. *HDIP International Report*.

Owais, M., Hanif, M., Khan, M. Y., Ishaq, M., Iu, J., & Swati, M. (2016). Lithological studies and petroleum system potential of the Eocene Chorgali Formation using outcrop data and geophysical logs. In *Potwar Plateau, Pakistan. International Conference on Earth Sciences Pakistan*.

Scholle, P., & Ulmer-Scholle, D. (2003). A color guide to the petrography of carbonate rocks: Grains, textures, porosity, diagenesis. *American Association of Petroleum Geologists Memoir*, *77*.

Shah, S. M. I. (1977). Stratigraphy of Pakistan. *Geological Survey of Pakistan Memoir*, *1*, 12–138.

Mujtaba, M. (2001). Depositional and diagenetic environment of Chorgali Formation (Early Eocene) Salt Range Potwar Plateau.