EVALUATION OF PALEOENVIRONMENT, RESERVOIR CHARACTERIZATION, MICROFACIES AND DIAGENETIC FABRICS OF EOCENE SAKESAR LIMESTONE WESTERN SALT RANGE, UPPER INDUS BASIN, PAKISTAN

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ABSTRACT

In western Salt Range (Nammal George) and Balkassar Oil field (Balkassar POL-1 and OXY-2), Eocene Sakesar Limestone has been investigated for the Evaluation of Paleoenvironment, reservoir characterization, microfacies analysis and diagenetic fabric. The research work was carried out for the outcrop samples, picked from the Sakesar Limestone of western Salt Range and two wells selected in Balkassar Oil field (Balkassar POL-1 and OXY-2) Potwar Plateau, district Chakwal, Pakistan. Twenty eight (28) outcrop samples of Sakesar Limestone were collected from Nammal George. The microscopic study revealed three microfacies and six (6) sub-microfacies with distinct texture, fossils content and allochem types. These microfacies are Wackestone Microfacies, Mud-Wackstone Microfacies, Mudstone Microfacies and sub microfacies are uniserial foraminifer, Lockhartia species, dasycladacean algae, bioclasts, milliolids and Ranikothalia sub-microfacies.

On the basis of presence of biota, micritic matrix in various microfacies, the Sakesar Limestone is interpreted to be deposited in the inner to middle shelf settings. In the western Salt Range, Sakesar Limestone has been affected and modified through various diagenetic events. The diagenetic fabrics includes the stylolites, calcite filled micro fracture, aragonite to calcite transformation, micritization, cementation, neomorphism, mechanical compaction and chemical compaction. Six (6) samples were selected from the outcrop samples for the permeability and porosity tests, carried out in hydrocarbon development Institute of Pakistan (HDIP), ranges from 3.15% to 19.49% and 0.021 to 0.117milli darcy respectively. Rock porosity and permeability were affected by the depositional, diagenetic and deformational processes.

The used data for Petrophysical analysis is obtained from Landmark Resources (LMKR) with the approval of Directorate General of Petroleum Concession (DGPC). The petrophysical analysis for Balkassar POL-1 and OXY-2 is carried out by using geographic software and gamma ray, sonic, caliper, neutron, density and resistivity logs were used to identify the subsurface lithology of the Sakesar Limestone. While, paleoenvironment is recognized by identification of cylindrical shape in gamma ray log curve. The Surface (3.15 to 19.49) porosity and subsurface porosity for Balkassar POL-1(9.8%) and Balkassar OXY-2 (1.92) is correlated, clearly suggesting that the surface porosity is higher and subsurface is lower which may be due to overburden pressure.

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ABBREVIATIONS

DGPC	Directorate General of Petroleum Concession
GRlog	Gamma ray reading of formation
GRmin	Gamma ray minimum
GRmax	Gamma ray maximum (shale)
HDIP	Hydrocarbon Development Institute of Pakistan
HKS	Hazara-Kashmir Syntaxis
KIA	Kohistan Island Arc
LLS	Laterolog Shallow
LLD	Laterlog Deep
LMKR	Landmark Resources
MFT	Main Frontal Thrust
MBT	Main Boundary Thrust
MKT	Main Karakoram Thrust
MMT	Main Mantle Thrust
SRT	Salt Range Thrust
SMF	Standard Microfacies
Sh	Saturation of Hydrocarbons
Sw	Saturation of Water
Vsh	volume of shale
Sh	Saturation of Hydrocarbons
Sw	Saturation of Water
T.D	Total Depth
ρb	formation bulk density
ρf	fluid density

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CHAPTER 1

INTRODUCTION

1.1 Description of research area

The research section selected in western Salt Range, the accessible Sakesar Limestone in the front of Nummal College Mainwali Punjab, Pakistan. The name Sakesar Peak is given to another locality in central Salt Range. The Salt Range has been recognized as a “Museum of Geology” due to presence of geological features and sedimentary sequence ranging from Pre-Cambrian to recent. It is one of the most researched area, located in the Upper Indus Basin Pakistan. It has the best exposure of sedimentary rock, studied widely for many aspects and a lot of literature published on various structures and formations. Geographically, Salt Range has been divided into Central, Eastern and Western parts. Salt Range lies at the edge of an active fold and thrust belt, named as “Potwar Plateau” formed in response to the collision of Eruasian plate and Indian plate (Tahirkheli,1979) which, started about 55 million years ago (Eocene) due to north-west movement of Indian plate. Salt Range located at the southern margin of Himalayan collision zone Pakistan (Shah, 1977). Eocene age Sakesar Limestone of western Salt Range consists of Limestone with minor clays. Sakesar limestone is a proven reservoir for hydrocarbon in many oilfields of Potwar Sub-basin (Ghazi et al., 2010).

The Potwar sub-basin is considered one of the most important, oldest and potential areas for the exploration of hydrocarbons where in 1914, the Attock Oil company made first discovery of oil commercially at Khaur (Khan et al., 1986). The successive discoveries comprise of Khaur (1914), Dhulian (1935), Balkassar (1944), Joya Mair (1945), Karsal (1956), Meyal (1968),Adhi (1978), Dakhni (1983), and Dhurnal (1984) fields (Khan et al., 1986).

Sakesar Limestone acting as a reservoir in Balkassar OXY-02 and POL-01 and outcrop samples from western Salt Range are selected in order to find the paleoenvironmental setting, diagenetic fabrics, microfacies and reservoir characterization of the Sakesar Limestone.

1.2 Location of study area

Geographically, the research area is located at latitude of 32°40′59.46 ″N to 32°40′58.63″N and longitude of 71°47′17.22″E to 71°47′16.51″N. The research area is located in the Nammal Gorge, western Salt Range Upper Indus basin, Pakistan. Twenty eight (28) samples were collected from Sakesar limestone located at the front of Nummal College. The subsurface well log data is taken from Balkassar POL-1 having latitude 32°56′22.05″N and longitude 72°40′51.95″E, Balkassar OXY-2 with latitude 32°55′17.77″N and longitude 72°39′43.05E″, of Pakistan Oil field limited located in Potwar Plateau, district Chakwal.

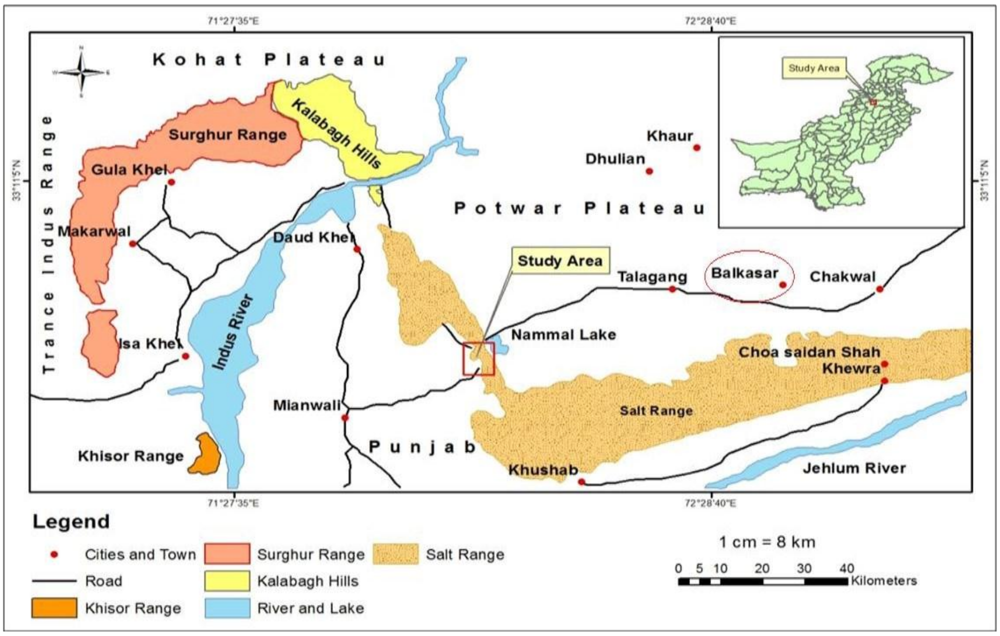


Figure 1.1 Map of study area Nammal Gorge and Balkassar Oil field (Modified after Raza, 2015).

1.3 Accessibility of the study area

The study area is easily accessible from all parts of Pakistan through a network of metalled roads. The research area is located at a distance of 30 km to the north-east of district Mianwali along the Mianwali – Talagang road, near to Nammal College and Nammal Dam.

Figure 1.2 Accessibility map of the study area (adopted from Google).

1.4 Previous work

The (Gee, 1945) has introduced for the first time, the term “Sakesar Limestone” for the most prominent Eocene Sakesar Limestone in the Salt Range, after the Sakesar peak in the Salt Range (N 32°31′30″, E 71°56′49″). The Stratigraphic Committee of Pakistan (Fatmi, 1973) gave the name “Sakesar Limestone” after its type locality at Sakesar peak in the central Salt Range. The Sakesar Limestone is widely distributed in western, central and eastern Salt Range, as well as in Surghar Range and Trans Indus Range. Sakesar peak in Bhadrar village located in eastern Salt Range, (Fatmi, 1973) consider this peak highest point as a reference section in Salt Range.

Sakesar Limestone is dominantly represented by Limestone consists of minor amount of Marl, Chert nodules and medium bedded to massive. The pioneer working on foraminiferal biostratigraphy of the marine Paleogene strata in the Salt Range had been carried out by the Davies and Pinfold (1973). They established the stratigraphy and demonstrated the age diagnostic benthonic larger forminifera. They also describe the lithology of Sakesar Limestone consists of corals, mollusks and larger benthonic foraminifera.

Ghazi and Zeb (2010) worked on lower Eocene Sakesar Limestone of central Salt Range related to microfacies analysis, diagensis and sedimentalogy. Boustani and Khwaja (1997) established the microfacies of Sakesar limestone from central Salt Range and concluded that there are two main microfacies (Packstone and Wackstone) of Sakesar Limestone which are further sub-divided into sub-microfacies based on the dominant bioclast and interpreted restricted lagoonal environment for the deposition of Sakesar Limestone.

1.5 Aims and objectives of research

The purpose of the current research work is to understand the various petrographic and wireline logs parameters, to know about the paleoenvironmental conditions, diagenetic fabric and microfacies assemblage. The current research is carried out in order to achieve the following objectives;

- To identify the microfacies of Sakesar Limestone in western Salt Range.
- To identify the diagenetic fabrics.
- To delineate the paleoenvironmental conditions by using log analysis as well as petrographic analysis of thin sections.
- To determine reservoir characterization of out crop samples.
- To achieve the petrophysical analysis of selected wireline logs in the selected wells (Balkassar POL-1 and OXY-2).
- Correlation of outcrops porosity with wireline logs porosity.

1.6 Methodology

The following methodology has been applied to achieve the above mentioned objectives in the present research.

1.6.1 Field work

The field work was carried out in the vicinity of western Salt Range. The Sakesar Limestone comprise of limestone with small intercalations of clay and chert at the outcrop near Nammal dam, Mianwali. The outcrop section was measured and a total of 28 samples were collected randomly from 32 meter area. The samples were collected from compact, unweathered parts of different exposed beds of Sakesar Limestone.

Figure 1.3 Filed photographs of study area, western Salt Range, Pakistan.

1.6.2 Laboratory works

The collected samples were carried to Hydrocarbon Development Institute Pakistan (HDIP) for the thin section preparation and determination of the reservoir potential, porosity and permeability. By analyzing the thin sections different microfacies and diagenetic fabrics were observed.

1.6.3 Well Data

Bore hole data for Balkassar OXY-2 and POL-1 is obtained from Land Mark Resources (LMKR) with approval of Directorate General of Petroleum Concession (DGPC). Complete suite of log is provided by LMKR for the reservoir characterization.

CHAPTER 2

TECTONICS

2.1 Regional tectonics

Wegener (1915) published the idea about the supercontinent "Pangaea" in his book "Origin of the continents and Oceans". According to his theory, once all continents being part of an earlier supercontinent named Pangea. According to (Smith et al., 1981) Pangea starts splitting about 300-200 Ma and due to subsequent rifting a new major oceans "Tethys" formed, which separated the "Eurasia Continents" in the north from the "Gondwana Continent" in the south. Gondwana Includes the Africa, Arabia, India, Australia and Antarctica and Eurasian contains the most of Asia, northern Europe and numerous small fragments of continent, which consists of crust of Precambrian and cover of Paleozoic. The Tethys oceans was subdivided into southern ocean called "Neo-Tethys" and northern ocean called "Paleo-Tethys" (Smith et al., 1981). According to (Valdiya 1981, 1994) the Indo-Pakistan subcontinent belong to the east of Gondwana land .The Indo-Pakistan plate, is surrounded in the south side by Indian ocean and in the north side by Himalayas. Due to tectonic collision sea-floor spreading, continental drift formation of Himalayas and accretion of Indo-Pakistan plate with Eurasian took place.

Indo-Pakistan plate has been divided by Wadia (1994) into three basic geologic and physiographic parts from north to south.

- Himalaya
- The Himalayan fordeep
- The Peninsular region

Himalaya fold and thrust belt is considered the world most active and extensive collision belt, extending westward side from Burma through India, Nepal and southern Tibet area into northern Pakistan.

During Eocene collision between Indian Plate and Kohistan Island Arc (KIA) take place, as the Neo-Tethys ocean closed (Tahirkheli et al; 1979). According to (Seeber et ali; 1981) under thrusting of Indian plate towards northward below the Eurasian plate is still in headway and due to this thrusting, major tectonic features of northern Pakistan area developed, including the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT), Salt Range and Trans Indus Ranges Thrust (SRT and TIRT).

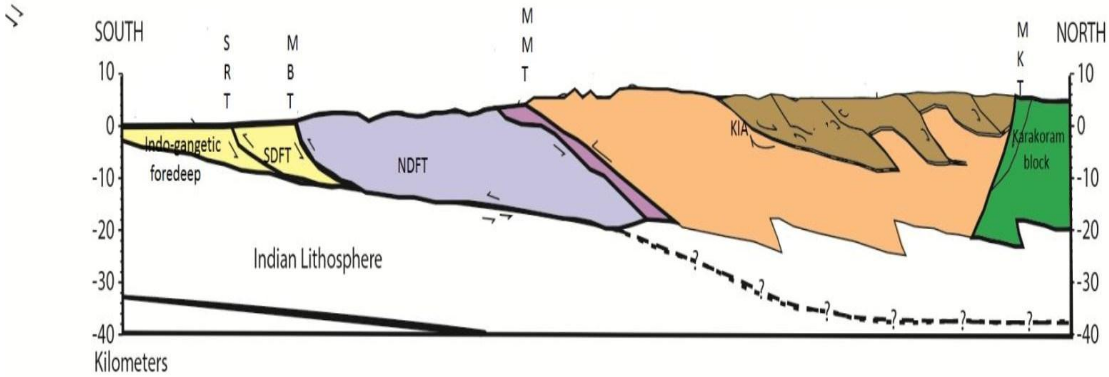


Figure 2.1. Different tectonic terrains of North Pakistan separated by regional faults (Hauc et al (1998) and Lave & Avoua (2001).

2.2 Regional tectonics and structure geology of Salt Range

The Potwar Plateau lies along the northern side of Salt Range and Salt Range Thrust (SRT) on the southern side while its eastern side is bounded by Jehlum river and west side by river Indus. There is northern slope of the salt range, gentle in nature and passing gradually into the Potwar basin (Fig2.2). Large allochthonous block is formed by the salt range and Potwar basin, that is almost thrusted and differentially rotated along a decollement at the base or within an incompetent sequence of evaporites which directly overlies at metamorphic basement (Gansser 1964; Crawford 1974; Seeber and Ambruster 1979; yeats et al., 1984; yeats and Lawrence 1984; Lillie et al., 1987; Wadia 1994; Grelaud et al., 2002; Seeber et al., 2013). According to Krishnan (1996) the Salt Range area and Potwar Plateau can be divide into;

- Salt Range
- Soan Syncline
- Anticlinal Zone
- Faulted zone

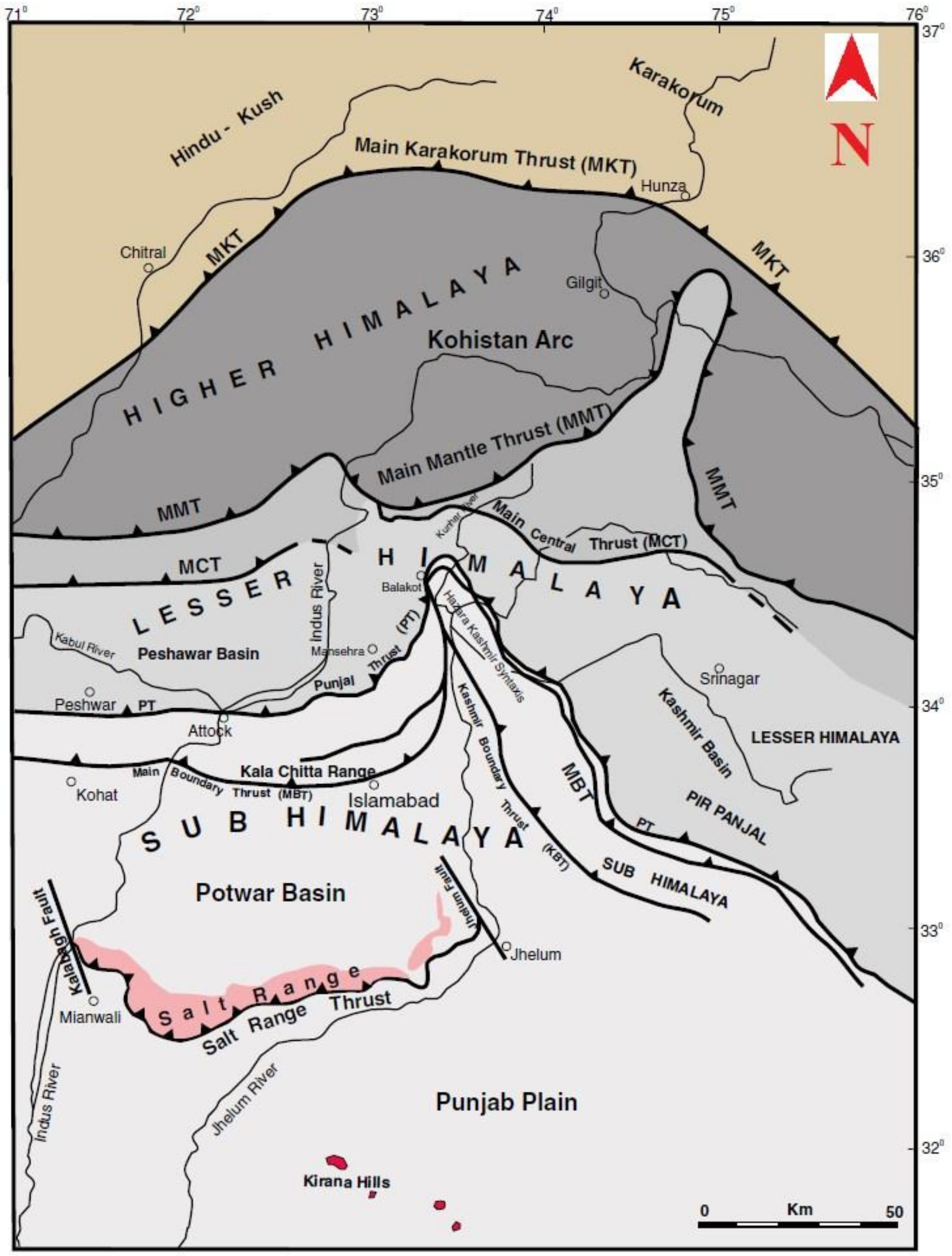


Figure 2.2 Generalized tectonic map of northern Pakistan, showing subdivisions of the Himalayan mountains (modified after Gansser 1981; Kazmi and Rana 1982).

2.3 Salt Range Thrust

Along the foot hills of Salt Range, Salt Range Thrust (SRT) marking the southern most extremity of Himalayas (Nakata, 1989). The thrusted area is mostly covered by the Quaternary alluvium and conglomerates (Kazmi and Jan, 1997). In area of Kalabagh and Jalalpurand, this thrust is visible showing that the Paleozoic rocks overlying the Quaternary or Neogene deposits of Punjab plain (yeats et al., 1984). Along the SRT there is also a southward transport of Potwar Plateau and Salt Range, in the form of a large block over the Jehlum plain. So, SRT has the surface appearance of the preeminent edge of a decollement thrust (Yeats et al., 1984).

2.4 Jehlum Fault

The eastern limit of Salt Range area is marked by the Jehlum fault. This fault is pointed in (1997) by the Kazmi as a left-Lateral strike slip fault, originated along the western margin of the axial zone of the Hazara-Kashmir Syntaxis (HKS). In (1987) Baig and Lawrence reported, that Jehlum fault is the left-lateral strike slip fault and stated that along this fault there are highly deformed Abbottabad,Murree and Hazara formations in between Muzaffarabad and Balakot area. Baig and Lawrence in (1987) reported, that Jehlum fault disrupt the Main Boundary Thrust (MBT) and termination of east ward continuation of some of the structures of northwest Himalayan fold and thrust belt by Jehlum fault, showing the young major tectonic feature in the syntaxial zone.

2.5 Kalabagh Fault

This fault marks the western limit of Salt Range and is extended to about 20 km of the Indus River (McDougall 1989., McDougall and Khan 1990). Kalabagh fault cuts the folds and faults in the Eocambrian of the Salt Range formations into the Quaternary conglomerates of Kalabagh formation. According to Gee (1980) the tectonic fragment of Permian and older rocks occur along the Kalabagh fault. The salt range formation of western salt range forms the diapirs, are located along the high-angle faults, include the right-lateral tear faults. At Kalabagh area near the river Indus, some of the largest of these diapirs are found.

2.6 Structural style

Structurally the salt range is very complex, consists of three basic structural styles.

- Compressional deformation (Thrusting and Folding)
- Transform deformation (Strike faults)
- Extensional deformation(Normal fault)

2.6.1 Compressional deformation

This kind of deformation is responsible for the uplifting of the Salt Range, representing southern part of Himalayan Orogeny (Krishnan 1966). Thrusting occur due to Compressional deformation and lowermost thrust Main Frontal Thrust (MFT) brought the whole sequence above the Alluvium of river Jehlum and the late Quaternary conglomerates (Baig and Lawrence 1987). Towards the north side there is increase in the effect of compression on strata (Krishnan 1996). The Salt Range formation was brought to the surface by high angle fault bounded narrow horsts and the surface salt range formation is easily eroded and these fault bounded horsts form deep gorges, in which some classic stratigraphic sections Khewra, Nilawahan and Warchha gorges are found. In this process the salt range formations act as decollement zone. The existence of detached zone under the salt range and Potwar basin is confirmed by seismic and gravity data (Gee 1989 and Grelaud et al., 2002).

2.6.2 Extensional deformation

In Salt Range area, a number of normal faults are observed which shows extensional deformation. Mostly tectonic activity is responsible for extensional deformation but it can also take place due to salt diapirism. Due to upward movement of salt range formation salt, salt diapirs formed (Ghazi et al., 2014).

2.6.3 Transform deformation

Mostly strike slip faults formed due to transform deformation. In salt range are strike slip fault are well developed. Jehlum and Kalabagh strike slip fault mark the western and eastern boundaries of salt range. The sense of shear Jehlum fault is left lateral while Kalabagh fault is a right-lateral strike slip fault (Gee and Gee 1989). Tear fault which is some small scale and high angle strike slip faults are also present in salt range area. Due to presence of these faults, southward movement of salt range becomes easier.

CHAPTER 3

STRATIGRAPHY

3.1 Stratigraphy of Salt Range

The stratigraphic units of Salt Range area ranges from Pre-Cambrian to Recent. Periods like Tertiary, Carboniferous, Devonian, Silurian and Ordovician are absent in Salt Range. The Precambrian age rocks of Salt Range are called "Salt Range Formation". It is widely distributed and 800-200m thick in Salt Range (Fatmi 1973., Gee and Gee 1989). Salt range Formation act as a zone of decollement between overlying sequence and underlying rigid basement. This Formation is mainly composed of clays, gypsum, marls, dolomite, anhydrites, Salt Rock and occasionally oil shale. In Salt Range oldest exposed rock units is Salt Range Formation and the youngest are the recent conglomerates. According to (Gee and Gee 1989) the Precambrian rocks base is not exposed and it's confirmed through subsurface data that beneath the Salt Range formation sequence of metamorphic rocks are present.

Several regional and local scale unconformities punctuated the whole sequence of Salt Range rocks. The very first stratigraphic break in deposition (unconformity) is marked by the "glaciofluvial conglomerate deposits" of the Tobra Formation, which overlying the Cambrian succession (Ghazi et al; 2012). The famous Permo-Triassic boundary separates the Chiddru Formation of Zaluch group form Mianwali formation of Triassic age and the next unconformity is between the Paleocene age Hangu Formation and Samana Suk Formation of Jurassic age. In Salt Range area, the break in deposition also noted between the early Eocene and Mio-Pliocene sequence. In between the Mio-Pliocene sediments and the recent conglomerates the last major unconformity has been recognized.

Table 3.1 Generalized exposed stratigraphic units with major breaks in deposition in the Salt Range, Pakistan modified (Ghazi et al; 2014).

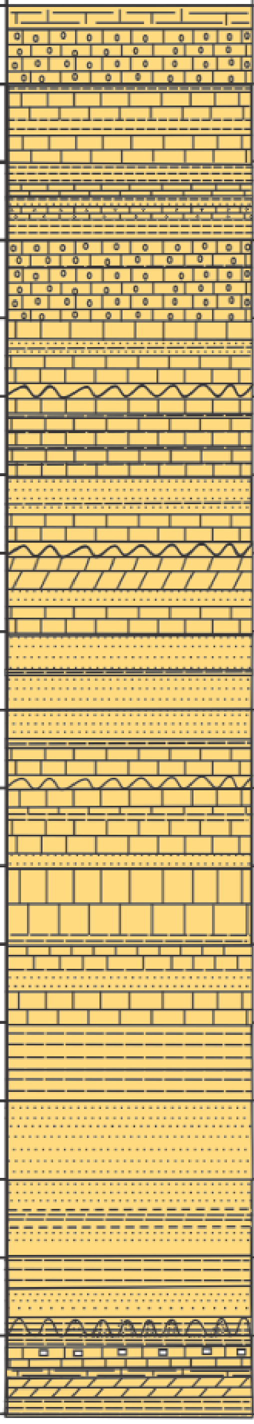
ERA	PERIOD	EPOCH	GROUP	FORMATION
CENOZOIC	Pleistocen		Siwalik	Lei Conglomerate Soan Formation
	Pliocene	Late Middle Early		Dhok Pathan Formation Nagri Formation Chinji Formation
	Miocene	Middle Early	Rawalpindi	Kamlial Formation Murree Formation
	Eocene	Early	Chharat	Chorgali Formation Sakesar Limestone Nammal Formation
	Palaeocene	Middle Early	Makarwal	Patala Formation Lockhart Limestone Hangu Formation
MESOZOIC	Cretaceous	Early	Surghar	Lamshiwal Formation
	Jurassic	Late Middle Early		Chichali Formation Samana Suk Formation Shinawari Formation Datta Formation
	Triassic	Late Middle Early	Musakhel	Kingriali Formation Tredian Formation Mianwali Formation
PALEOZOIC	Permian	Late	Zaluch	Chhidru Formation Wargal Formation Amb Formation
		Early	Nilawahan	Sardhai Formation Warchha Sandstone Dandot Formation Tobra Formation
	Cambrian	Middle Early	Jhelum	Baghanwala Formation Jutana Formation Kussak Formation Khewra Sandstone
PROTEROZOIC	Precambrian			Salt Range Formation (Base not exposed)

The exposed Paleozoic rocks of Salt Range include the Jehlum group, consisting of Khewra Sandstone, Kussak, Jutana and Baghanwala Formations. Khewra Sandstone has conformable contact with Salt Range Formations and is overlain by Kussak Formation. In Jehlum group the Kussak Formation has conformable contact with Jutana Dolomite and in turn Jutana is underlain by

Baghanwala Formation. According to (Fatmi, 1973) the Jehlum group rocks are continental to shallow marine in nature, sandstone being the major lithology. Nilawahan group and Zaluch group are the younger Paleozoic rocks in the area. The origin of Nilawahan group is continental and is composed of predominantly Sandstone and Shales. Nilawahan group includes the Tobra, Dandot, Warchha Sandstone and Sardhai Formations. Amb Formation, Wargal Limestone and Chiddru Formation of Permain age belong to Zaluch group. Zaluch group, the upper Permian composed of "marine carbonates" (Shah, 1977). In between Baghanwala Formation of Jehlum group and Tobra formation of Nilawahan group has conformable contact and there is also conformable contact between Nilawahan group and Zaluch group.

The Mesozoic rocks in Salt Range include the Musakhel group comprising of Mianwali, Tredian, and Kingriali Formations of Triassic age and Surghar group including Datta, Shinawari and Samana Suk Formation of Jurassic age while, the Chichali, Lumshiwal and Kawagarh Formations having Cretaceous age, belongs to Surghar group. Mesozoic rocks belong to so many wide variety of environments including the deltaic, fluvial, deep and shallow marine (Fatmi, 1973). Lithologies of these rocks are mostly composed of Sandstone, Dolomite, Limestone and Shale. The Cenozoic rocks of Salt Range area includes Makarwal, Chharat, Rawalpindi and Siwalik groups. The Makarwal group is comprised of Paleocene age Hangu Formation, Lockhart Limestone and Patala Formation. The Makarwal lithologically is composed of bioclastic Limestone, Sandstone and Shale. The Formations included in Chharat group is Nammal, Sakesar and Chorgali of Eocene age containing Shale, Marl and Limestone. Rawalpindi group of Salt Range area include the Murree and Kamlial Formations of Miocene age, consisting of Siltstone, Clay stone, infraformational conglomerates and Sandstone. Siwalik group is comprised of Chinji, Nagri, Dhok Pathan and Soan Formations. Lithologically this group is mainly composed of Sandstone, Conglomerates, Claystone and Siltstone. Siwalik group conformably overlies the Rawalpindi group.

Table 3.2 Showing Stratigraphy of the Western Salt Range, Pakistan (Modified after Gee, 1980).



Age	Formation	Lithology	Description
Early Eocene	Sakesar Limestone*		Massive and nodular limestone, with marl
Early Eocene	Nammal Formation		Light grey calcareaus shales and limestone
Late Paleocene to Early Eocene	Patala Formation		Green shales and thin limestone
Paleocene	Lockhart Formation		Grey, semi-nodular and marly limestone
Paleocene	Hangu Formation		Impure limestone, sandstone and shale
M. Jurrassic	Samana Suk Formation		Grey and purple bedded limestone with shale interbeds
E. Jurrassic	Datta Formation		Sandstone with limestone and carbonaceaus shales
L. Triassic	Kingriali Formation		Massive light colored dolomite and dolomitic limestone with sandstone
M. Triassic	Tredian Formation		Massive and purplish sasndstone, with thin carbonaceaus bands
E. Triassic	Mianwali Formation		Olive-green and grey shale with thin limestone and sandstone
L. Permian	Chhidru Formation		Limestone, marl and calcareous sandstone
L. Permian	Wargal Limestone		Massive grey limestone; with occasional carbonaceaus shale at base
M. Permian	Amb Formation		Calcareous sandstone and impure limestone
E. Permian	Sardhai Formation		Dark purple and lavender clays and subordinate sandstone
E. Permian	Warchha Sandstone		Red and light colored sandstone and grits
E. Permian	Dandot Formation		Olive-green sandstone and shales
E. Permian	Tobra Formation		Conglumeratic sandstone and shale
Camb-Late Precambrian	Salt Range Formation		Red gypsiferous marl with rock salt, gypsum-dolomite and occasional oil shale

3.2 Stratigraphy of Eocene Sequence

The Eocene age strata is well exposed in the Salt Range, Potwar Plateau and Trans-Indus Range, which constituting Nammal, Sakesar and Chorgali formations (Gee,1989) of cherat group.

3.2.1 Nammal Formation

The name to Nammal Formation has been formally given by the stratigraphic committee of Pakistan for the "Nammal Limestone and Shale" of (Gee, 1935) and "Nammal Marl" of Danilchik and Shah (1967) occurring in the Salt Range and Trans Indus ranges. This Formation mainly comprises of Shale, Limestone, Marl and well developed in Salt Range and Surghar ranges. The shaly content of this Formation is grey to olive green whereas the limestone and marl has light grey to bluish grey in colors (Shah, 2009). There is a lower contact of Nammal Formation with the Patala Formation and upper contact with Sakesar Limestone (Shah, 2009).

3.2.2 Sakesar Limestone

In 1935 Gee, for the first time introduce the well known Eocene "Sakesar limestone" unit of Salt Range and Trans Indus Range (TIR). Sakesar peak (latitude 30°31′N and 71°56′E) in the Salt Range has been designated the type locality. The Sakesar unit mainly comprised of subordinate Limestone, limestone with marl, creamy to light grey in color. And in the upper part there is nodularity with massive and prominent formation of chert. The color of marl is also creamy to light grey, having persistent horizon near the top (Shah, 2009). Sakesar Formation thickness varies from 70m to 150m. In Chichali pass its thickness is about 220m and at Surghar ranges 300m thick. Its lower contact with Nammal Formation is confirmable and fossils of this formation are foraminifer's i.e Assilina, Laminosa, Lockhartia, Operculina, Gastropods, Nummulitoids, Brachiopods, Alveolina, Milliolid, Lockhartia, Sakesaria cotteri and Rotalia trochidiformis (Shah, 2009).

3.2.3 Chorgali Formation

The term "Chorgali bed" of Pasco (1920) has been formalized as Chorgali Formation by the Stratigraphic Committee of Pakistan. The section exposed in the "Chorgali pass" at a latitude of 33°26′30″ N and longitude of 72°41′69″ E in the Khair-e-Murat Range, has been chosen as the type section. According to (Cheema et., 1977), the formation is composed of shale and limestone. In Salt Range the Chorgali Formation is divided into two parts. The lower part consists of shale and limestone, while the upper part is mainly limestone. The shale of the lower part is greenish grey and limestone is light grey and argillaceous. In the upper part, the limestone is white and cream in color. A rich fossil assemblage including the foraminifers, mollusks and ostracodes has been reported by Davies and Pinfold (1937), Eames (1952) and Latif (1970).

CHAPTER 4

MICROFACIES OF SAKESAR LIMESTONE

4.1 Introduction

The Microfacies is "the total of all the paleontological and sedimentological criteria, which can be classified in thin sections, peels and polished slabs" (Flugel ,2004). In this chapter microfacies of Eocene age Sakesar limestone are documented in detailed. In present study 28 samples were picked from 32 meter selected field area in western Salt Range. The microscopic analysis for the carbonate rocks samples is based on the identification of microfacies types which can be identified by using composition of limestone, distribution of fossils and depositional texture of specific samples (Tucker and Wright, 1990., Flugel, 2004). The study area dominantly contains Mudstone, Wackstone, Mudstone-Wackstone microfacies and these microfacies contains the benthic foraminifer, Ranikotalia and foraminiferal bioclasts.

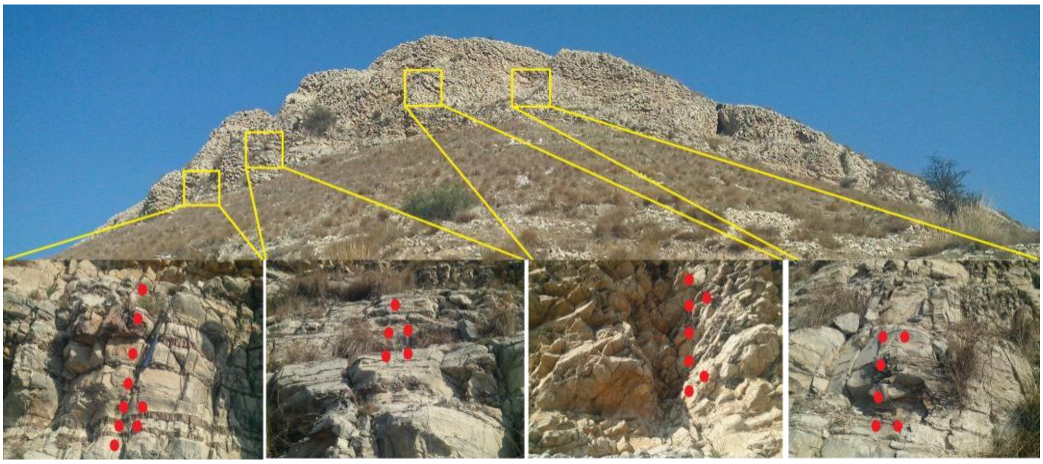


Figure 4.1 shows the study area Nammal George western Salt Range, Pakistan.

The Dunham (1969) and Folk (1962) classification was adopted during the present study. According to Dunham classification (1962) the texture which is mud supported called mudstone, contains less than 10% grains and more than 90% mud. The texture which is grain supported are called Wackstone, contains more than 10 % grains and less than 90 % mud. Packstone is grain supported having lime mud between grains and if there is no mud between grains called Grainstone.

4.2 Microfacies description

The obtained microfacies are compared with standard microfacies (SMF) types of Fugal (2004) and for the interpretation of paleoenvironment. The microfacies abbreviation for Sakesar Limestone is SL-MF, SL stands for Sakesar Limestone, MF for microfacies and 1, 2, 3 for recorded three types of microfacies. Based on thin section and laboratory study following three microfacies and six (6) sub-microfacies are recognized with distinct texture, fossils content and allochem types. These microfacies are described as below;

- Wackestone Microfacies (SL-MF-1)
- Mud-Wackstone Microfacies (SL-MF-2)
- Mudstone Microfacies (SL-MF-3)

4.2.1 Wackestone Microfacies (SL-MF-1)

This microfacies contain more than 10% skeletal/ non-skeletal grains and categorized as wackstones, with an average 1:3 grain to matrix ratio. The allochems present in this microfacies constitutes 25-27% and matrix percentage is 73-75. The allochem includes the dasycladacean algae, Lockhartia, foraminiferal bioclasts and other bioclasts. The sub microfacies of Sakesar Limestone wackstone along with its details petrographic description are as following;

4.2.1.1 Bioclastic Foraminiferal wackestone sub-microfacies

Bioclastic Foraminiferal wackstone sub-microfacies is represented by the Plate 4.1 (A&B). This sub microfacies contain abundant larger benthic forminifera e.g., uniserial foraminifer (4%), Lockhartia species (3%) with bioclasts (14%). The grain to matrix ratio is 1:3, grains are 21% and matrix is 79%.

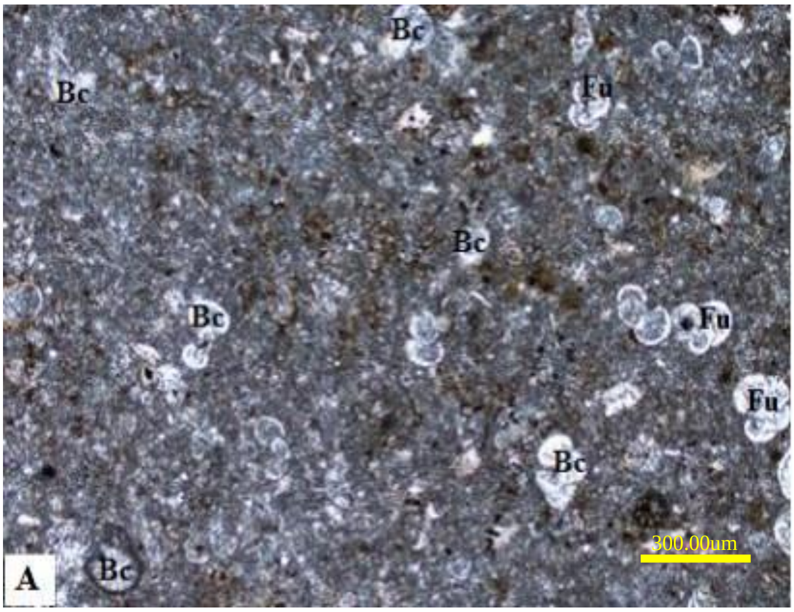


Plate 4.1 A. Photomicrograph of bioclastic foraminiferal wackestone showing uniserial foraminifer (Fu) and bioclast (Bc) embedded in fine grained micritic back ground.

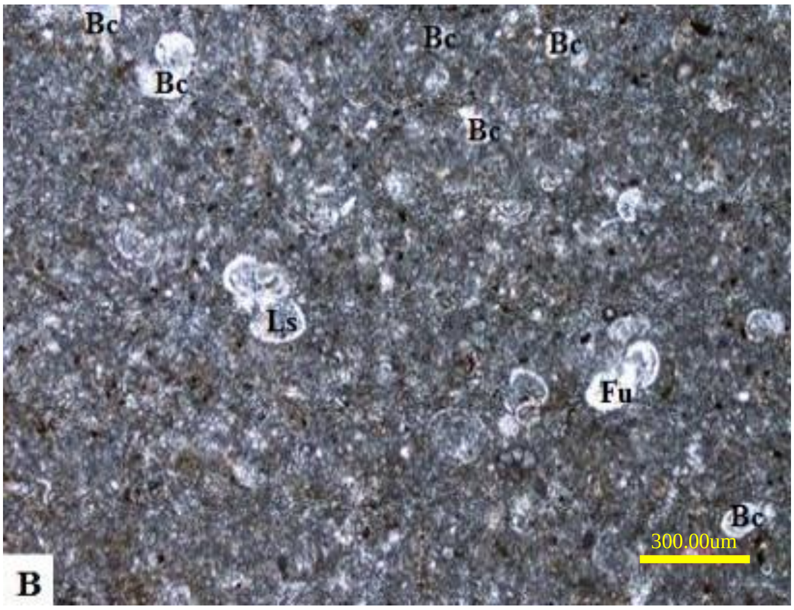


Plate 4.1 B. Photomicrograph of bioclastic foraminiferal wackestone sub-microfacies showing uniserial foraminifer (Fu), Lockhartia species (Ls) and other bioclast (Bc) embedded in fine grained micritic back ground.

4.2.1.2 Bioclastic Algal Foraminiferal wackestone sub-microfacies

The bioclastic algal foraminiferal wackstone sub-microfacies is displayed in plate 4.2 (A&B). Its grains to matrix ratio is 1:3, grains are 21% and matrix is 74%.

The bioclast is 16% including forams bioclast (Fb) and other bioclasts (Bc). The identified grains facies are dasycladacean algae (4%), uniserial foraminifer (6%).

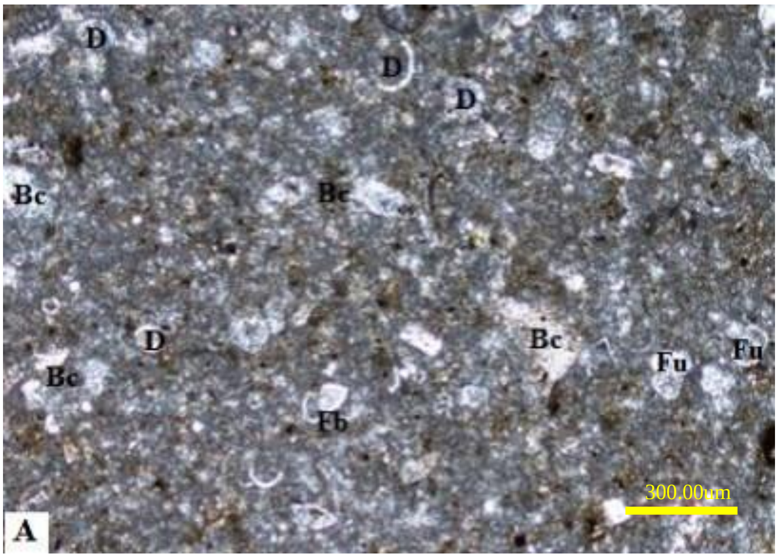


Plate 4.2 A. Photomicrograph of bioclastic algal foraminiferal wackestone sub-microfacies showing uniserial foraminifera (Fu), foraminiferal bioclasts (Fb), dasycladacean algae (D) and other bioclasts (Bc).

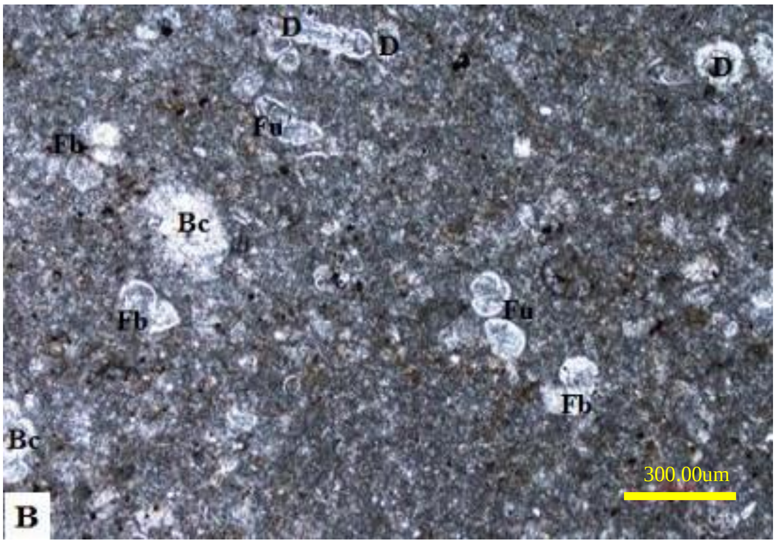


Plate 4.2 B. Photomicrograph of bioclastic algal foraminiferal wackestone sub-microfacies showing uniserial foraminifer (Fu), dasycladacean algae (D), foraminiferal bioclasts (Fb), and other bioclasts (Bc).

4.2.2 Mud-Wackstone Microfacies (SL-MF-2)

This microfacies is mud supported and has approximately 10% skeletal / biogenic grains. 1:9 is the grain to matrix ratio. The matrix constitutes almost 90% and the grains constituents almost 10 %. The skeletal grains includes the Lockhartia, miscellanea, other bioclasts, bivalve, gastropod shell, milliolids and other palnktonic forminifer. The sub-microfacies of mud-wackstone along with its petrographic descriptions are described below.

4.2.2.1 Bioclastic Algal Foraminiferal Mud-Wackestone sub-microfacies

Bioclastic foraminiferal mud-wackstone sub-microfacies are shown in plate 4.3 (A&B). Biogenic grains are Ranikothalia species and algae. The grains to matrix ratio is 1:9 and grains are approximately 10%. The average relative abundance of the biogenic grains is Ranikothalia species (4%), algae (3%), other foraminifer bioclast (3-4%).

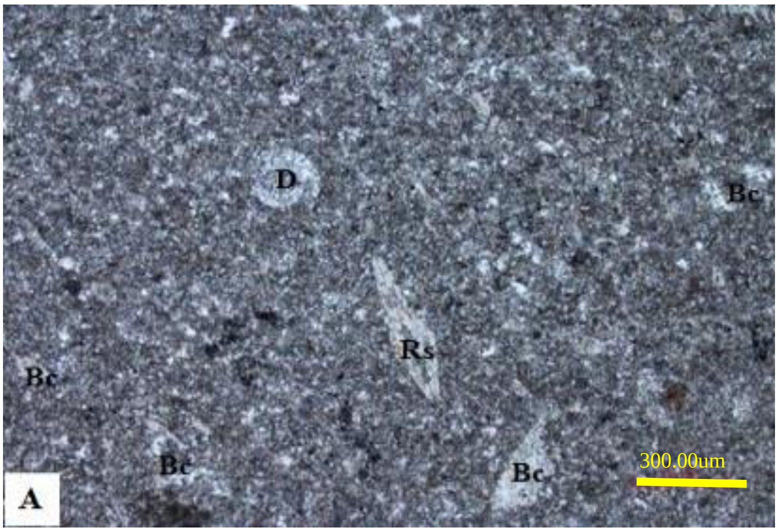


Plate 4.3 A. Photomicrograph of bioclastic algal foraminiferal mud-wackestone sub-microfacies, showing recrystallized Ranikothalia (R), Dasycladacean algae (D) and other bioclasts (Bc).

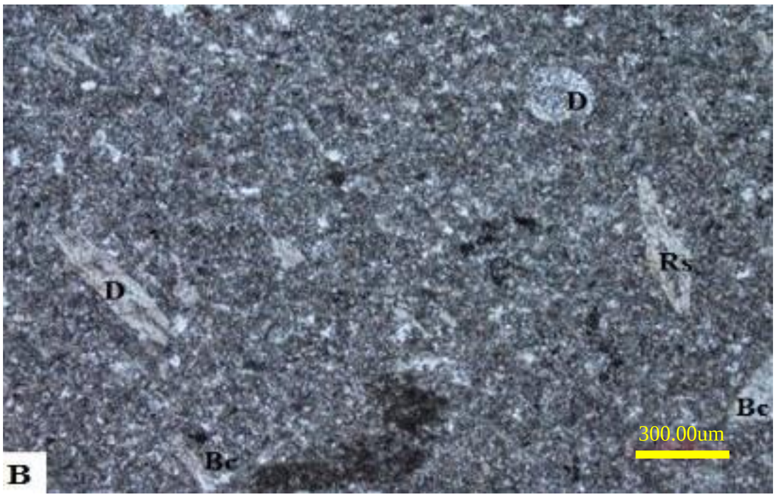


Plate 4.3 B. Photomicrograph of the bioclastic algal foraminiferal mud-wackestone sub-microfacies, showing recrystallized Ranikothalia (R), Dasycladacean algae (D) and other bioclasts (Bc).

4.2.2.2 Bioclastic Foraminiferal Mud-Wackestone Sub-Microfacies

Bioclastic foraminiferal mud-wackstone sub-microfacies are shown in plate 4.4 (A&B). This microfacies is characterized by the presence of Miliolid species. Its grains to matrix ratio is 1:9, grains are approximately 10% and matrix is approximately 90%. The grains include (6%) recrystallized bioclast, milliolids. The uniserial foraminifer of this microfacies include 2-3%.

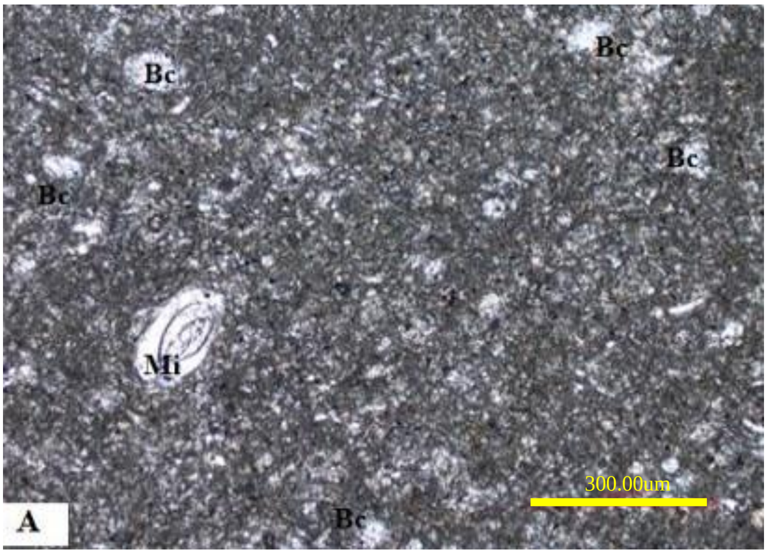


Plate 4.4 A. Photomicrograph of bioclastic foraminiferal mud-Wackestone sub-microfacies showing recrystallized bioclasts of Milliolids (Mi), and other recrystallized bioclast (Bc).

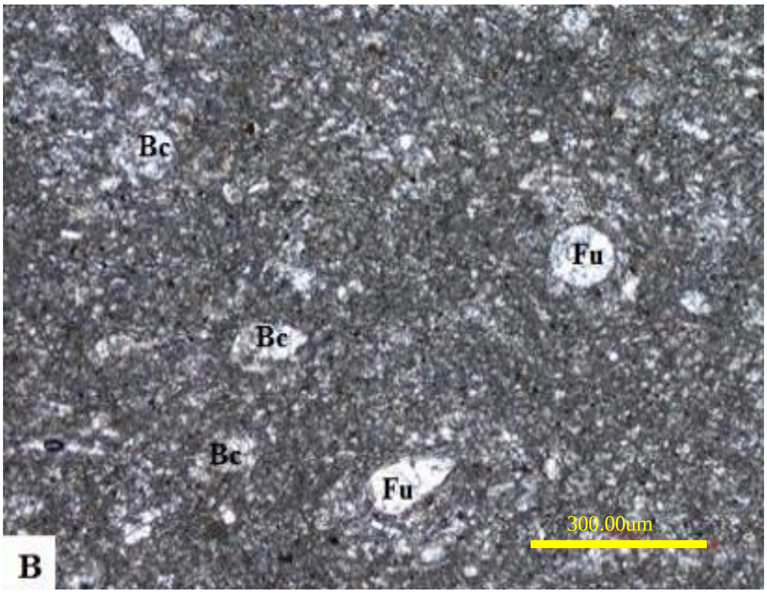


Plate 4.4 B. Photomicrograph of bioclastic foraminiferal mud-Wackestone sub-microfacies showing recrystallized uniserial foraminifer bioclasts (Fu) and other recrystallized bioclast (Bc).

4.2.3 Mudstone Microfacies (SL-MF-3)

This microfacies is mud supported and has approximately 9% skeletal/biogenic grains. On outcrop the mudstone microfacies is comprised of light grey, poorly fossilferous and medium bedded. The grains to matrix ratio is 1:9. The matrix constitute almost 91% and the grains constitute almost 9%. The skeletal grains include Lockhartia, miscellanea, bivalve, bioclasts, gastropods shell and other palnktonic foraminifera. The sub-microfacies of mudstone with its petrographic descriptions are as below.

4.2.3.1 Bioclastic Algal Foraminiferal Mudstone sub microfacies

This microfacies is characterized by the presence of algae and benthic foraminifera. 1:9 is the grain to matrix ratio, grains are approximately 8% and matrix is about 92%. The grains include (3%) bioclast and benthic foraminifer of this microfacies include Ranikothalia species (3%), dasycladale algae (2%). This sub-microfacies are shown in plate 4.5 (A&B).

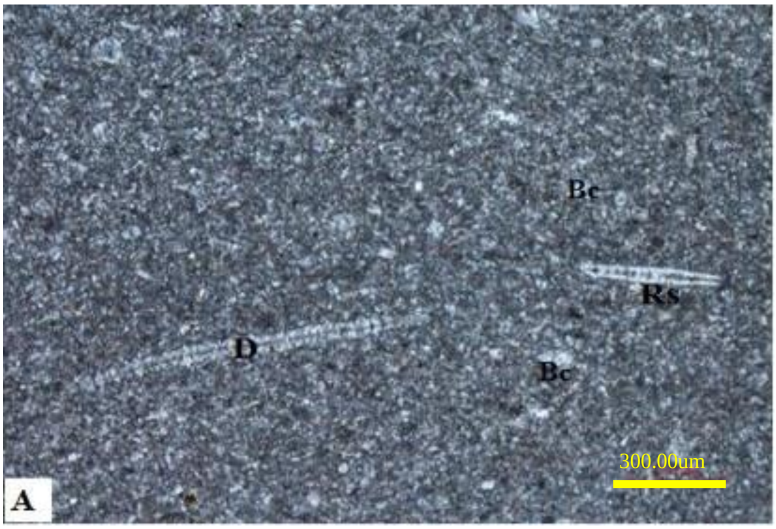


Plate 4.5 A. Photomicrograph of bioclastic algal foraminiferal mudstone sub-microfacies, showing dasycladacean algae, Ranikothalia sp, recrystallized bioclast (Bc).

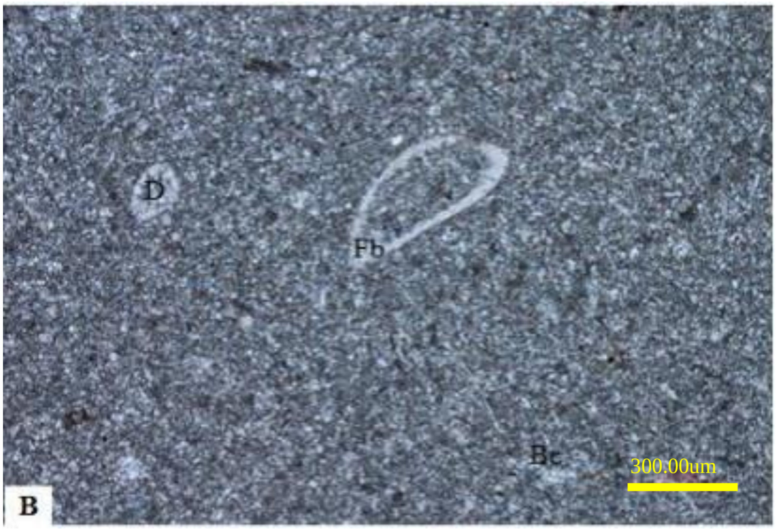


Plate 4.5 B. Photomicrograph of bioclastic foraminiferal mudstone sub-microfacies, showing dasycladacean algae, and other recrystallized forams bioclast (Bc).

4.2.3.2 Bioclastic Foraminiferal Mudstone sub-microfacies

Bioclasts Foraminiferal mudstone sub-microfacies are shown in plate 4.6 (A&B). There is biogenic grains are of foraminifer bioclasts. The grains to matrix ratio is 1:9.and grains are approximately 9%. The average relative abundance of the biogenic grains is foraminifer bioclast (5-6%) and other bioclasts are (3-4%).

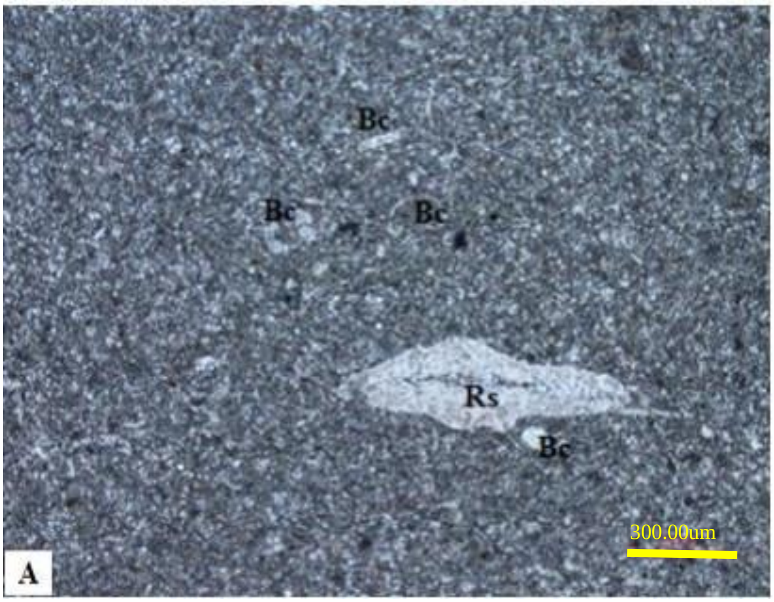


Plate 4.6 A. Photomicrograph of shows the bioclastic foraminiferal mudstone sub-microfacies showing Ranikothalia sp (Rs) and other recrystallized bioclast (Bc).

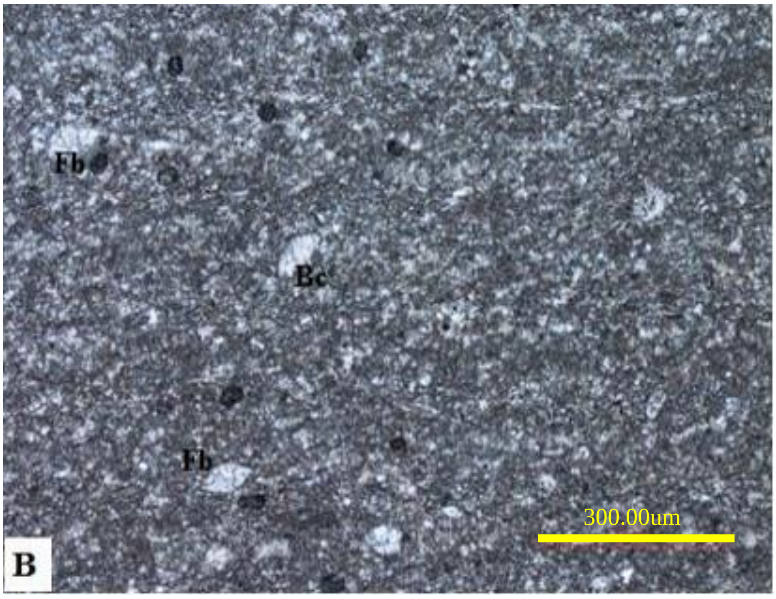


Plate 4.6 B. Photomicrograph of bioclastic foraminiferal mudstone sub-microfacies, showing recrystallized bioclasts of foraminifera (Fb), and other recrystallized bioclast (Bc).

Table 4.1 showing grains and matrix of microfacies and sub-microfacies of the Sakesar Limestone in the western part Salt Range, Pakistan.

Thin Sections Microfacies	Bioclast %	dasycladacean algae %	Lockhartia%	uniserial foraminifer %	Milliolids %	Ranikothalia %	Grains : Matrix %	Grains %	Matrix %	Sub Microfacies
Plate 4.1 (A & B) (Wackestone)	14		03	04			1:3	21	79	Bioclastic Froaminiferal Wackestone
Plate 4.2 (A & B) (Wackestone)	16	04		06			1:3	26	74	Bioclastic algal Froaminiferal Wackestone
Plate 4.3 (A & B) (Mud-Wackestone)	3-4	03				04	1:9	10	90	Bioclastic algal Froaminiferal Mud-Wackestone
Plate 4.4 (A & B) (Mud-Wackestone)	06			2-3	02		1:9	10	90	Bioclastic Froaminiferal Mud-Wackestone
Plate 4.5 (A & B) (Mudstone)	03	02				03	1:9	08	92	Bioclastic algal Froaminiferal Mudstone
Plate 4.6 (A & B) (Mudstone)	5-6			3-4			1:3	26	74	Bioclastic Froaminiferal Mudstone

Table 4.2.shows the minor amount and abundance of sub- microfacies of Sakesar limestone.

Thinsection No	Bioclast	Dasycladacean algae	Lockhartia	Uniserial foraminifer	Miliolids	Ranikothalia
SL-MF-2a	●	●				■
SL-MF-2b	●	●			●	●
SL-MF-3a		●			●	●
SL-MF-3b		●			●	●
SL-MF-05	●	●			●	
SL-MF-07	●			●		
SL-MF-8a	●		●	●	●	
SL-MF-8b	●	●	●	●		
SL-MF-9a	●	●	●			
SL-MF-9b	●	●	●			
SL-MF-10	●		●	●		
SL-MF-11b		●		●	●	
SL-MF-13	■	●		●		
SL-MF-14a	■			■	●	
SL-MF-14b	■			■	●	
SL-MF-15a	●			●	●	
SL-MF-15b	●			●	●	
SL-MF-16a	●	●		●		
SL-MF-16b	●			●		
SL-MF-17	●					●
SL-MF-19a	■	●	●	●		
SL-MF-19b	■	●	●	●		

Legend
Abundant ■
Few ●

4.3 Paleoenvironment and depositional model of Sakesar limestone

One of the best and basic tenets of geology is the "present is the key to the past". If we document the distribution of organisms today and to understand what environmental variables controls those organisms distributions, then we can use these information to reconstruct the paleoenvironment by using the fossils as a paleoenvironmental indicators. Interpreting paleoenvironment by using microfossils is demonstrates the aspects of paleontology and shows how knowledge got through study of fossils can be used to know about the environmental conditions in the past.

The data from the study area was compared with published literature in order to account for microfacies analysis to determine the paleoenvironment for Sakesar Limestone of the study area. The presence of abundant limes mud and lack of biota suggests low energy condition (Flugel, 2004). The association of lockhartia, milliolids and algae suggests that the wackstone microfacies is deposited in restricted low energy and inner shelf environment. For mud-wackestone microfacies the abundance of bioclasts such as algae and larger benthic foraminifera and association of rare bivalves and milliolids suggests that mud-wackstone microfacies is deposited in high energy and shallow shelf environment (Flugel, 2004). So mud-wackestone microfacies deposited in high energy, inner shelf environment. Mudstone microfacies is characterized by the following diagnostic features, presence of micrite as matrix, presence of foraminifera, ranikothalia and algae.

Presence of micrite as matrix, poor-sorting and lack of grain alignment shows deposition below normal wave base (Flugel, 2004). Presence of Foraminifera and Echinoderms indicates open-marine conditions of normal salinity while the presence of Algae indicates shallow, sunlight water (Flugel, 2004). Therefore the Mudstone microfacies is interpreted to represent deposition in a warm, open marine condition of normal salinity, in an inner to middle shelf environment (Fig 4.2).

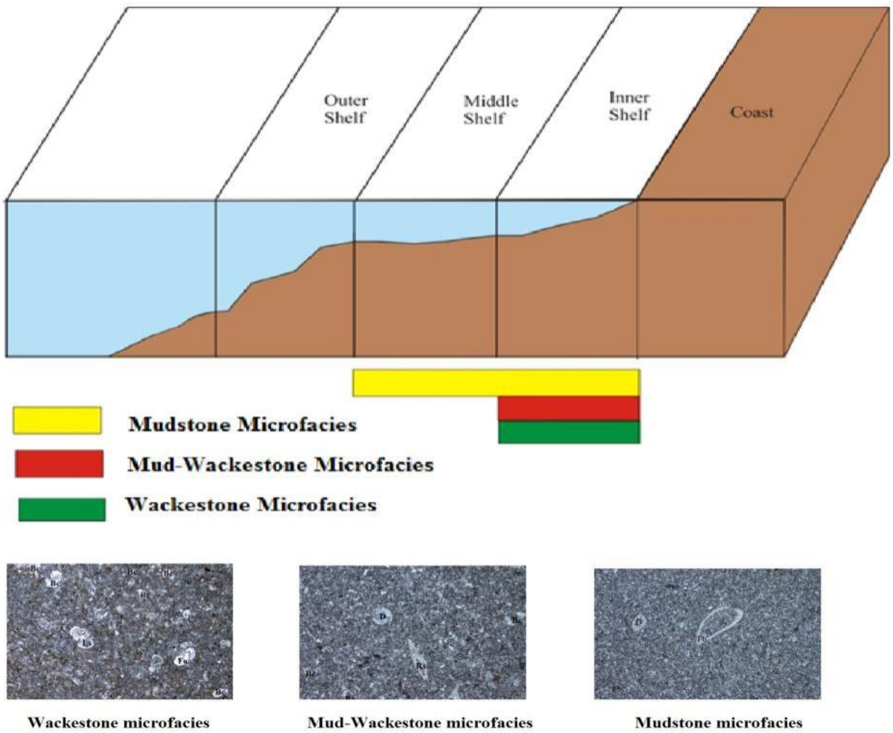


Figure 4.2. shows the depositional model for Sakesar limestone.

CHAPTER 5

DIAGENESIS

5.1 Introduction to diagenetic fabrics of Sakesar Limestone

Particularly, carbonate rocks are easily soluble as compared to other natural minerals because it is highly soluble in acidic water and vulnerable to diagenetic changes (Flugel, 2004). Diagensis is the set of various processes that includes, all chemical and biological changes which affects the sediments after deposition. On one hand it lithifies the sediments with subsequent cementation while on the other, it encompasses the dissolution which results in the karst topography (Tucker and Wright, 1990). The major diagenetic process of carbonates consists of micritization, cementation, dissolution, neomorphism, compaction, dolomitization and stylolitization, controlling the mineralogy, composition of sediments, the chemistry of pore-fluid and their flow rates in terms of tectonic, geological history of sediments, changes in sea level and different pore fluids influx and climates (Tucker and Wright,1990).

The affects of diagenetic process varies from formation to formation in carbonates or changes take place possibly intraformational, vertically either laterally (Tucker and Wright, 1990). Diagenetic process also effect the porosity, permeability of rock sediments and properties that control the rock sediments potential, as a reservoir for water, gas and oil (Tucker, 2001).

5.2 Diagenetic Fabrics

Diagensis plays a vital role in the case of Sakesar Limestone. It affect the barrier for the fluid flow or it may create best way for the fluid migrations. So, diagenesis has affect on reservoir porosity and permeability. The impact of diagenetic events also affect a sediment's porosity, permeability and properties that control a sediment's potential as a reservoir for oil, gas or water (Tucker, 2001). Some of the diagenetic fabrics are as following;

5.2.1 Compaction

The term compaction refer to the alteration occurs in the actual fabrics of rocks, under shallow to the deep burial condition, due to the pressure of overlying material. The change in fabrics take place either by mechanical disintegration of constituents grains or chemical dissolution across the boundary of grains. Due to compaction, reduction in porosity create changes in the thickness of Stratigraphic strata and fracturing in the grains constituents took place. The reduction of pore space is responsible for the reduction of sediments volume and the exclusion from its interstitial water (Friedman and Sanders, 1978). The compaction process has effect on the Sakesar limestone after its depositions due to which physical and chemical rearrangements, variations in the sediments bulk volume take place. Compaction is of two types;

- Physical compaction
- Chemical compaction

5.2.1.1 Physical compaction

The physical compaction is associated typically with larger forminifera and implicate in the local fracture, lacking any considerable dislocation across the fractures. The order of the observed features of mechanical compaction, include the closer grains packing, close grains contacts and decrease in the primary interparticle porosity in grains supported limestone (Mahboubi et al., 2010). Physical compaction declines the porosity and reduce the packing and sediments squeezing (Vincent et al., 2007).

5.2.1.1.1 Calcite filled micro fracture

Fractures in the carbonates rocks are important secondary features which are formed either by compaction or formed in the response to the regional tectonic forces (Tucker and Wright, 1990; Flugel, 2004). Permeability and the effective porosity is sometime improve by various stages if fracturing, which cause to provide best interconnectivity. The veins develop in the rocks through precipitation of minerals from the circulating fluids within a joint or fracture and this process is called healing of fractures or joints (Ramsay and Hubber, 1987). The plate 5.1 shows the calcite filled micro fracture.

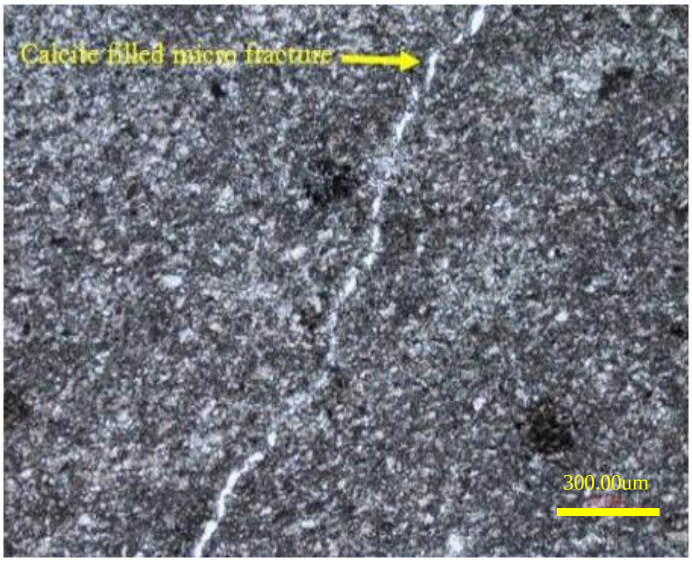


Plate 5.1 show the calcite filled micro fracture.

5.2.1.2 Chemical compaction

It is also called the pressure dissolution fabrics which results in the formations of different sorts of stylolite and solution seams originating, as a result condition of deep burials. The facies Sakesar Limestone has been subjected to different variety of chemical alterations, rather than the mechanical compaction alterations which are summarized as follows.

5.2.1.2.1 Stylolites

Stylolites within rocks are irregular planes of discontinuity, which are mostly common characterized by the seams of insoluble residues of parent rocks. Stylolites formed tectonically, as a result of recrystallization and pressure solution, in the response of mechanical agents rather than the chemical agents (Park and Schot, 1968). Stylolites develop in the last diagenetic events, plate 5.2 shows stylolite. The impact of stylolite development on reservoir performance may vary from one part of a reservoir to another. Stylolite in Sakesar Limestone was noted in most of thin section. The growth of stylolites and related pressure solution features may adversely affect reservoir continuity, by producing barriers or impedance to fluid flow (Dunningtion, 1967; Mossop, 1972 and Wong, 1981).

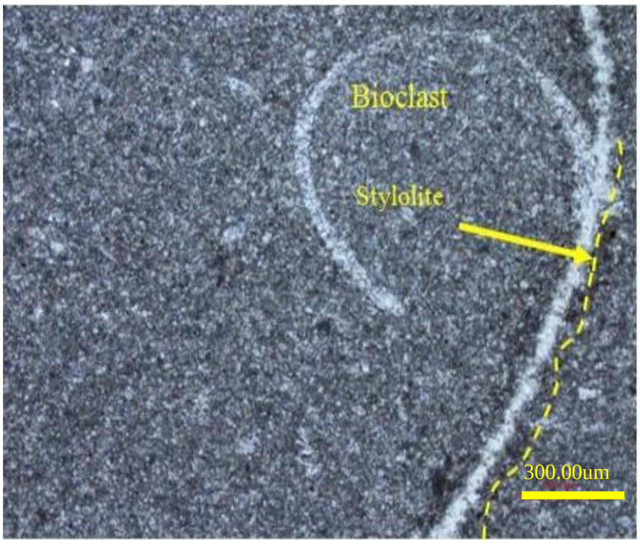


Plate 5.2 shows the filled with spar cross cuts the bioclast and Stylolite and calcite filled micro fracture.

5.2.1.2.2 Aragonite to Calcite transformation

Aragonite is itself unstable mineral and is replaced low magnesium calcite, which preserve the morphology and outlines of previously dissolved fabric as shown in Plate 5.3. Calcite is more stable in general than aragonite, although as the temperature and pressure change, one of the two minerals may convert to the others. So, the effect of aragonite to calcite transformation noted in Sakesar limestone.

Plate 5.3 shows the aragonite to calcite transformation.

5.3 Micritization

The term micritization refers to the conversion of allochemical constituents of carbonates rocks into the micrite or lime mud, through boring activity of the endolithic algae (Bathurst, 1976). The micritization is the most earliest event in Sakesar limestone, as well as of paragenetic sequence (Vincent et al., 2007). In micritization process, voids are completely saturate or some time create bridge with grains to grains through magnesium or calcite and process represent the shallow marine phreatic environment (Tucker and Wright,1990). Micritization prevent cementation perform positive role in reservoir development and also protected allochems form dissolution so has a negative role. Micritization has been identified in thin section SL-MF -14a and shown by plate 5.4.

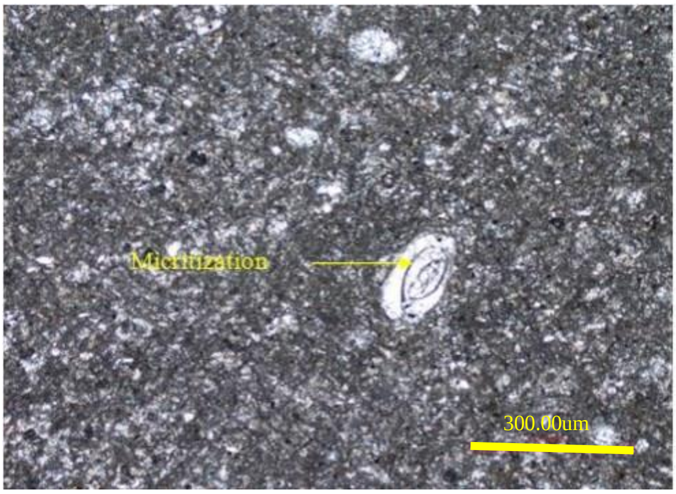


Plate 5.4 shows the micritization.

5.4 Cementation

Cementation is use for the harding, binding of clastic sediments. These cementing materials come from pre-existing rock fragments of mineral matter in the pore spaces. Common cementing materials are calcite, silica, iron-oxide and clay minerals. Cementation is the widely distributed event of diagenesis in Sakesar Limestone and reduce the reservoir property e.g porosity and permeability. It destructs the reservoir badly, block the passage for hydrocarbon. Different cementation types identified in Sakesar Limestone are as follows.

5.4.1 Blocky cementation

Blocky cementation mainly consists of medium to coarse grain of calcite crystals, lack of showing someone specific alignment, composed of high magnesium and also low magnesium-calcite. This type of cementation precipitated after the dissolution of aragonite cement filling remaining pore spaces. This type of cementation also take place through the recrystallization of pre-existing cementating material. Plate 5.5 shows the blocky cement.

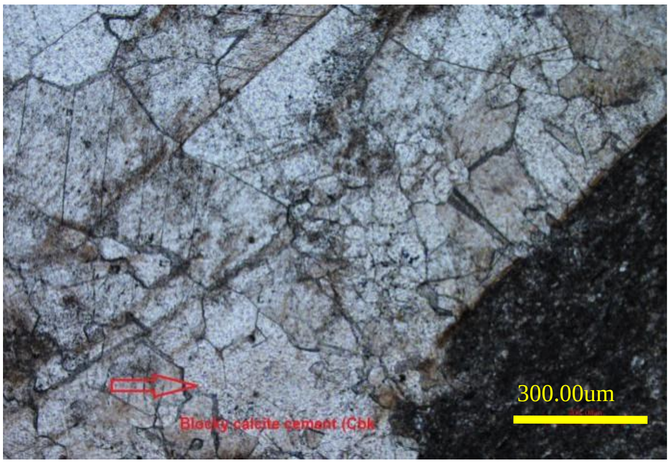


Plate 5.5. shows the Blocky cementation (Cbk).

5.4.2 Fibrous cementation

The composition of this type of cementation is fibrous crystals, which are growing normal to substrate and show some significant length elongated parallel to the c-axis. The crystal style in this type of cementation is fibrous are needle like or columnar and mostly form the isopachous crusts and shown by plate 5.6.

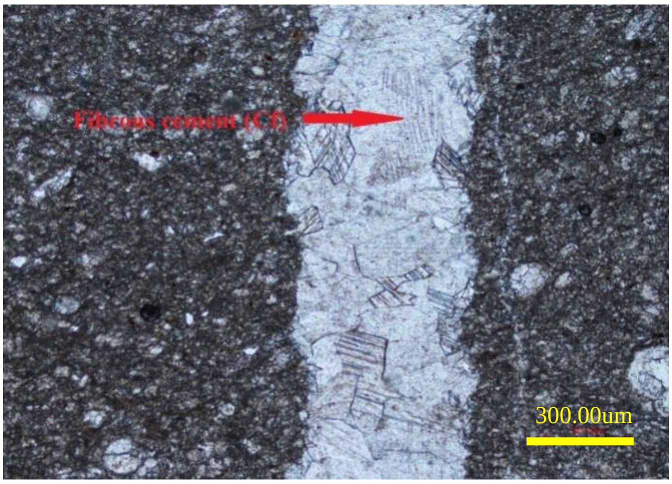


Plate 5.6. shows the Fibrous cementation (cf).

5.4.3 Bladed cementation

Bladed cementation is not fibrous nor equidimensional. This type of cementation has elongated prismatic crystals composed of aragonite and high Mg.calcite. Bladed cementation mostly found in the marine phreatic and marine vadose environment (Flugel, 1982). This type of cementation noted in wackestone and mudstone microfacies are shown in plate 5.7.

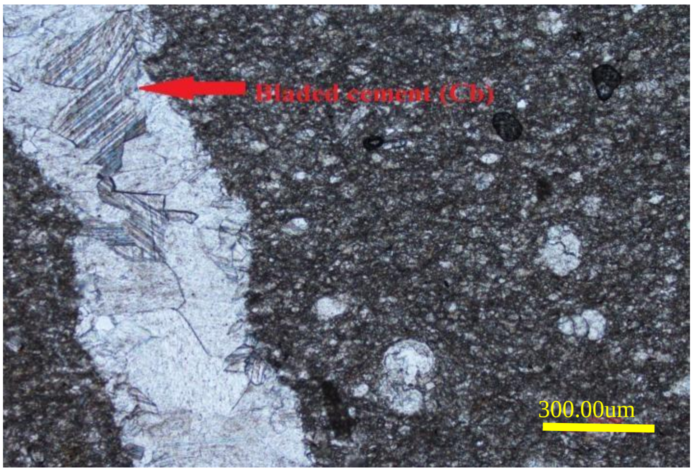


Plate 5.7. shows the Bladed cementation.

5.4.4 Granular mosaic cementation

The composition of granular mosaic cementation is mainly small, comparatively same dimensional voids-filling crystals of calcite, that are commonly found in the interparticle voids. Origin of this cementation is meteoric to vadose, meteoric to phreatic and burial environment (Flugel, 1982).

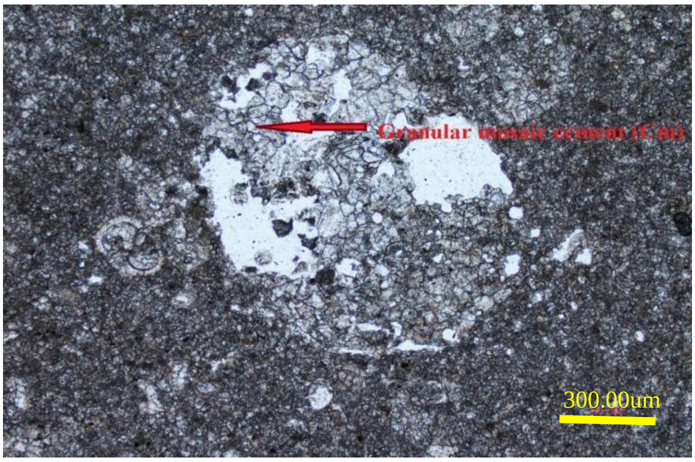


Plate 5.8. shows the Granular mosaic cementation.

5.5 Neomorphism

The term neomorphism use for the substitution and recrystallization, take place during the existence of water, by dissolution and precipitation between one mineral and itself or polymorphs. Neomorphism takes place through dissolution and precipitation in the presence of water (Bathurst, 1976; Tucker, 2001). Neomorphism resulted in a reduction of reservoir quality, mostly destruct the porosity and sometime led to enhance reservoir quality. According to Folk (1965) the mineralogy may be change or not in neomorphism and noted on microscopic level in the SL-MF-3, which indicate the meteoric diagenetic environment under shallow moving water which are super-saturated with calcium carbonate (Heckel, 1974), as well as in subsurface diagenetic environment (Boggs, 2009).

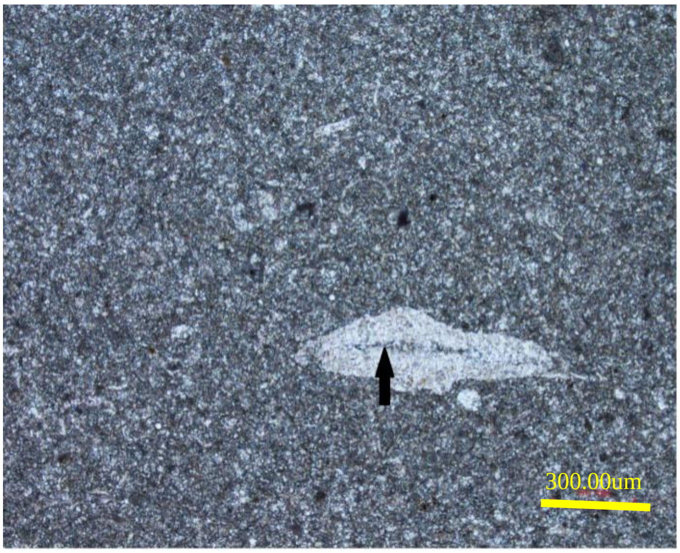


Plate 5.9 arrow shows the neomorphism.

5.6 Diagenetic Environment

On the basis of diagenetic features, cementation type and microfacies environment of diagenesis is specified. Diagenesis in Sakesar Limestone of selected area takes place in three main phases marine, meteoric and burial with specific characteristics and diagnostic feature.

5.6.1 Marine environment

In Sakesar Limestone marine diagenetic environments are recognized by the presence of micritization, fibrous or bladed cementation. In this case cement type is mainly isopachous crust of fibrous to bladed calcite (Scholl and Ulmer-Scholl, 2003). The diagenetic feature micritization is prominently identified in Sakesar Limestone which is formed in marine environment. The micritization in the Sakesar Limestone is very severe and is observed in the form of micrite envelops which may have formed as a result of mechanical disintegration or due to biological erosion of large calcareous biota e.g; Nummulites/algae by endolithic algae (El Ghar and Hussein, 2005; Melim et al., 2002).

5.6.2 Meteoric Environment

The presence of neomorphism, blocky cementation, granular mosaic cementation show meteoric environment. The early stage of blocky cementation, granular mosaic cementation, molds dissolutions and micrite cement, as well as neomorphism of primary marine minerals are the signs of meteoric diagenetic realm (Tavakoli et al., 2011). The neomorphism is noted in some of the selected Sakesar Limestone samples microfacies. The neomorphism observed in Sakesar Limestone is of aggrading type because it is ultimately led to the formation of blocky calcite cementation, which shows different size of crystal from micro spar into the blocky calcite cementation.

5.6.3 Burial Environment

The mechanical compaction, calcite veins formation, fractures, stylolites and chemical compaction shows the indication of an overall burial diagenetic realm for Sakesar Limestone. The burial diagenetic environment is conventionally segmented into shallow and deep burial and however the exact boundary is not well-defined (Flügel, 2010). The mechanical compaction is also responsible to the variation in porosity reduction. The formations of chert nodules in Limestone take place as a replacement of carbonate by siliceous precipitation of pore-filling silica or as siliceous biota solution precipitation in the initial diagenetic stage at a shallow burial (Blatt and Middleton, 1980; Noble and Van Stempvoort, 1989). The solution seams stylolites and are the characteristic features of shallow burial environment and development of fractures and veins shows that it formed in deep burial realm.

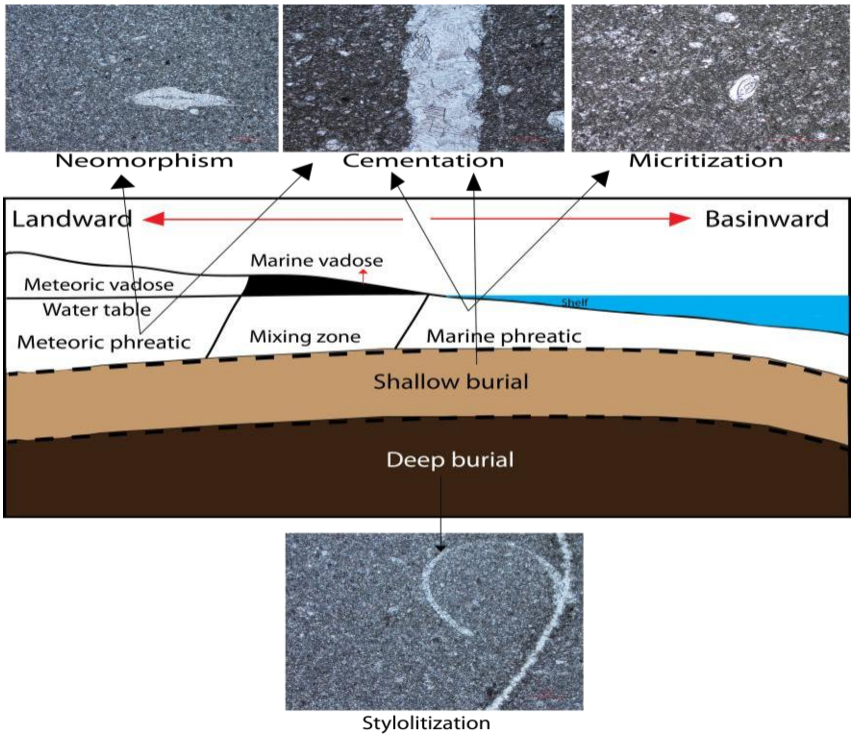


Figure 5.1 shows the simplified scheme of major diagenetic environments, proposed for the Sakesar Limestone (modified after Flügel, 2010).

CHAPTER 6

RESERVOIR CHARACTERIZATION

6.1 Introduction

Carbonate reservoir act as best reservoir, constituting of more than 60% of world oil and 40% gas reserves. It comprises of most important percentage of hydrocarbon reserves and focus the world geoscientists on carbonate exploration as well as carbonate reservoir analysis. In order to study the carbonate reservoir, have a comprehensive look on paleoenvironment, microfacies, diagenetic fabrics and reservoir characterization like porosity and permeability is needed. According to (Fatmi, 1973) Sakesar Limestone of western Salt Range act as a proven reservoir. This chapter of research study emphasis on the qualitative and quantitative reservoir analysis of Eocene Sakesar Limestone of out crop data. Core plug data are used, to accurately identify the quantity of porosity and permeability form the out crop data of Sakesar Limestone. Quantitative analysis of porosity and permeability for out crop sample is done through Hydrocarbon Development Institute of Pakistan (HDIP) laboratories.

6.2 Plug Porosity and Permeability analysis

6.2.1 Plug Porosity analysis

Porosity test for the selected out crop samples are determined in Hydrocarbon Development Institute of Pakistan (HDIP) laboratory by using porosimeter. Low and high estimated values for porosity samples are noted from 3.17% to 19.492%. Plug porosity test for the selected samples were performed at 500 psi over burden pressure. Porosity is measured for 6 selected samples because normally estimated visual porosity from the petrographic analysis provides exaggerated porosity values.

6.2.2 Plug Permeability analysis

Core plug permeability test for the selected outcrop samples were carried out in Hydrocarbon Development Institute of Pakistan (HDIP). At 400 psi over burden pressure permeability is measured. Plug permeability for Sakesar limestone samples ranges from 0.11 to 0.021 milli darcy.

6.3 Methodology use for plug permeability and porosity measurement.

6.3.1 Out crop sample porosity measurement

To find out the porosity for out crop samples porosity in HDIP "PHI-220 Helium Porosimeter" apparatus was used. PHI-220 is used to find the direct pore volume of rock sample, density of grains and volume of grains. It is controlled by a computer and statistical parameters.

6.3.1.1 Features of PHI-220 Porosimeter

- It is controlled and the data acquisitions take place through computer.
- It is use the window base program and also represent data graphically like density of grains versus type of rocks for control of quality checks.
- It is connected to an external coreholder (whole core of plug core) for finding of direct volume of pores at different pressures.
- It has different size chambers for the measuring of grain volume ,mostly 1.0′,1.5′ or 30 mm diameter chambers are used.

6.3.1.2 Specification of PHI-220 Porosimeter

- It has a wide range to measure the porosity from 0.1 to > 40%.
- Measures the porosity at different Psi.
- It has a pressure transducer accuracy of 0.11% (0-250) Psi.
- Core size ranges from 1.5′,1.0′ up to 3′ long.

Figure 6.1 show the Helium Porosimeter PHI- 220(Google).

6.3.2 Outcrop sample Permeability measurement

In Hydrocarbon Development Institute of Pakistan (HDIP) gas Permeameter is used to find out the permeability of rock sample. The permeameter system is configured to use the gases and liquids at ambient temperatures. In HDIP permeability test is performed at 400 psi overburden pressure.

6.3.2.1 Features of gas permeameter (BPS-805)

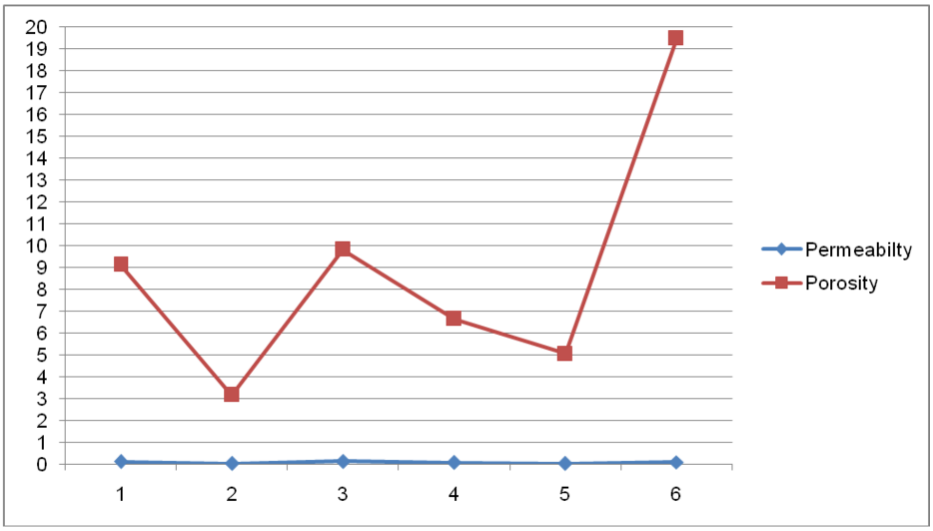
- Use the core holder, with overburden pressure control system.
- It has back pressure regulator
- It has computer control data acquisition system and easy to use its data acquisition software.
- It has complete system to perform permeability test.

6.3.2.2 Specification

- Its ability to maximum confining pressure is 9500 psi
- Its maximum temperature for operating is ambient to 40 C
- For this core diameter 1.5″ is standard and optionally 1.0″ to 30mm

Table 6.1 shows the permeability and porosity of selected samples

Sample No	Porosity (%)	Permeability (milli darcy)
S1	9.118	0.107
S4	3.157	0.021
S6	9.825	0.117
S11	6.644	0.058
S12	5.038	0.011
S18	19.492	0.076



Graph 6.1.Represents the porosity on y-axis and permeability on x-axis.

6.4 Correlation of out crop sample with subsurface porosity.

For the porosity and permeability determination 6 samples from Sakesar Limestone in western salt range is selected and subsurface porosity is taken from logs of Balkassar POL-1 and OXY-2 through petrophysical analysis of both wells. Usually surface porosity is high as compared to the subsurface porosity and as a result of the deep burial depth, Sakesar Limestone undergoes more extensive diagenetic changes than those exposed at the surface. This phenomenon reveals that exposed part of Sakesar Limestone is less effected by diagness as compare to subsurface. Porosity is mainly controlled by grain shape, size, sorting and cementation material.

6.4.1 Porosity from logs of Balkassar POL-1 and OXY-2

The average porosity from both the wells are taken through petrophysical analysis. In Balkassar POLl-1 the average porosity take from the density and neutron porosity which is 9.838 % and in Balkassar OXY-2 porosity is take from sonic log because of problem with logs not properly run in Sakesar reservoir zone, revealing 1.92 % of porosity.

6.4.2 Porosity from the outcrop sample

The following table shows the outcrop sample porosity for selected six (6) samples.

Table 6.2 shows the porosity of selected samples.

Sample No	Porosity (%)
S1	9.118
S4	3.157
S6	9.825
S11	6.644
S12	5.038
S18	19.492

CHAPTER 7

PETROPHYSICS

7.1 Introduction

It is the study of physical as well as chemical properties of rocks and their interaction with fluids. It is also considered "a discipline use for the evaluation of subsurface formations for hydrocarbon accumulations and based on well logs measurement data, laboratory data, and with the fundamental laws of math and physics" (Tiab and Donaldson, 2004). The physical and chemical properties of subsurface reservoir consists of porosity, lithology, saturation and permeability etc. These reservoir properties in petrophysical analysis are measured indirectly with the help of wireline well logs or by direct methods like core analysis and mud logging. Wireline log is itself "the process used to measure the reservoir by lowering a string which is equipped with special measuring tools into the well borehole". Logging continuously measure and record the different properties of rocks in the flushed zone, transition zone and uninvaded zones of borehole (Fig 7.1) against depth.

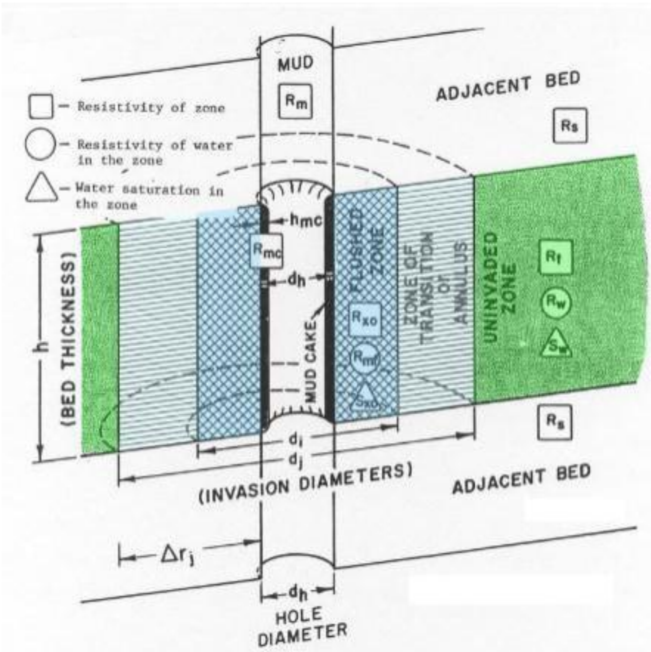


Figure 7.1 Photograph of typical borehole environments/zones (modified from Schlumberger courtesy, 1972)

Two types of wireline log is run mainly in bore hole i.e.,

- Open-hole logging which is performed in the open well bore without casing.

➢ Cased-hole logging when the bore hole is cased when it needs to be cased.

For the interpretation of physical and chemical properties of reservoir different types of wireline logs i.e., nuclear, acoustic and electrical use. The petrophysical analysis of the Sakesar Limestone is carried out by utilizing the open-hole logs information. In this chapter Petrophysical analysis of the Sakesar Limestone in Balkassar POL-1 and OXY-2 is described through the wireline logs. In both wells, reservoir intervals of the Sakesar Limestone is taken in order to evaluate the different reservoir parameters.

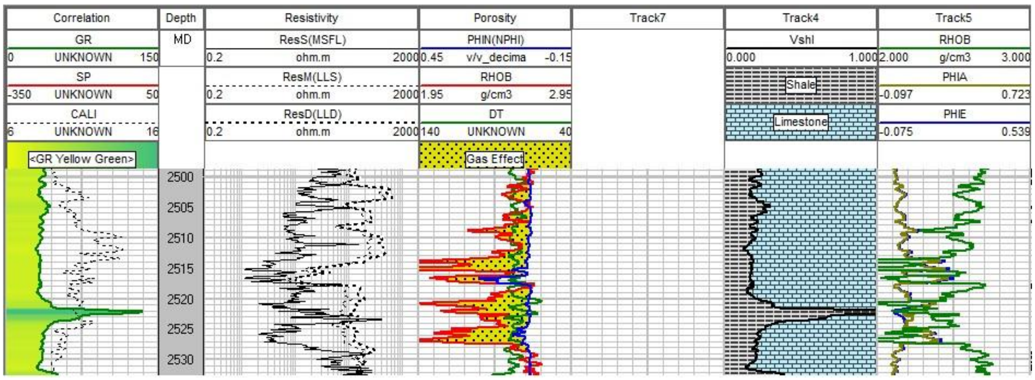


Figure 7.2 The petrophysical analysis and interpretation of the Sakesar Limestone in Balkassar POL-1 well through geographic software.

7.2 Petrophysical Analysis of Balkassar POL-1

For petrophysical analysis following available well logs were used.

➢ Bit size
➢ Calliper log
➢ Gamma ray log
➢ Density log
➢ Neutron log
➢ Sonic log
➢ Spontaneous potential log
➢ Resistivity logs

7.2.1 Work flow for petrophysical analysis

The following chart summarized the Petrophysical analysis, done by using different well logs.

Table 7.1. Flow chart representing the work flow of Petrophysical analysis

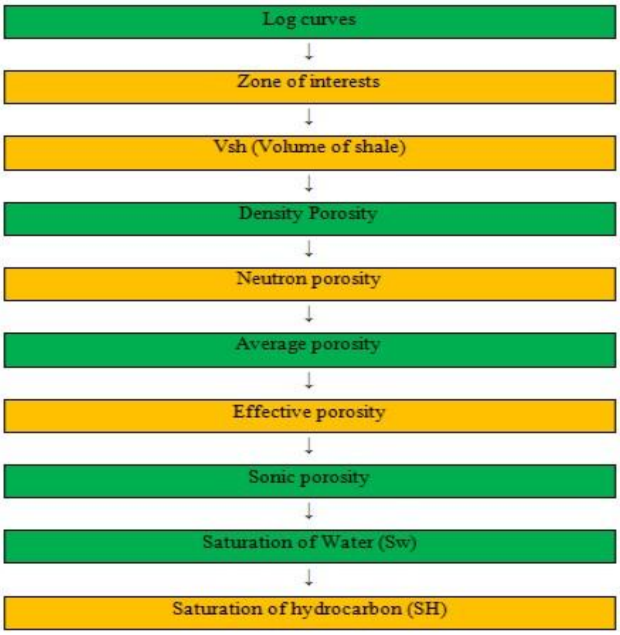


Table 7.2 Detailed information of Balkassar POl -1

Operator	Pakistan Oil filed Ltd	**Spud date**	15 dec,2004
Classification	Development	**T.D reached on**	19 april,2005
Concession	Balkassar D & P lease	**F.T.D FM**	Sardahi
Location	Lat:32°56′22.05″ and Long:72°40′51.95″	**Rig release on**	June 04,2005
District	Chakwal	**Status**	Oil producer
K.B	1823 FT	**Gl elevation**	1798 ft
Drilling cont	POL own RIG	**Rig type**	N-1 cont.EMSCO SCR-II
Spud date	15 dec,2004	**T.D reached on**	19 april,2005
Status	Oil producer	**Rig release on**	June 04,2005

Table 7.3 Formation tops and Thickness for Balkassar POL-1

Formation	Top(ft)
Nagri	Surface (0)
Chinji	519.06
Kamlial	1429.87
Murree	1544.81
Chorgali	2436.5
Sakesar	2475.6
Patala	2605.18
Lockhart	2634.14
Dhakpass	2667.68
Sardahi	2695.121

7.2.2 Selected log Curves

It includes all the curves selected for the study and find the values for all the parameters. At different depths, logs curve show the different values for one parameter.

Table 7.4 Showing zones of interest.

Zone	Starting depth	Ending depth	Total thickness
1	2500m	2530m	30m

7.2.3 Zone of Concern (reservoir zone)

The interested zone has been marked on the basis of Low Gamma Ray (GR), Shallow Lateral Log (LLS), Deep Lateral Log (LLD) values, mud cake formation and cross over between density and neutron log. The value of Deep Lateral Log should be higher than Shallow Lateral Log and cross over between density and neutron log indicates, the presence of hydrocarbon in the zone of reservoir. One zone is mark by the use of above mentioned logs.

7.2.4 Calculation of volume of shale (V_{sh})

Shale volume was calculated through “Gamma Ray Log” and for the evaluation of shaley content, it was presumed that the radioactive minerals are distracted in the clean rock as contrast to shaley rock. For the quantitative evaluation of shaley content, clean and dirty zone are marked and in clean zone the Gamma ray log give low value while in dirty zone it give high value because of the presence of radioactive minerals. Gamma Ray log is mostly used for the calculation of shale volume in the permeable zone by using of formula;

$$\text{Volume of shale}(\text{VSH}) = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Whereas;

GR = stands for the gamma ray reading of logs value

GR=stands for the minimum value of gamma ray (clean formation i.e. sand)

GR= stands for the max value of gamma ray (dirty formation i.e. shale)

Table 7.5. Shows GR minimum and GR maximum value of the well.

Well Name	GR Minimum	GR Maximum
Balkassar POL-1	32	124

Table 7.6. Values of the Vsh for the prospective zone.

Prospective zone	Petrophysical property	Average value
Sakesar limestone	Volume of shale (V_{sh})	19.96%

7.2.5 Porosity

“It is the ratio of the void spaces over the total volume of the rock and by symbol “φ”, expressed either in percentage or decimal (metric units). It depends upon mostly compaction, diagenesis, size of grain, orientation, packing, sorting, sphericity and sphericity. The diagenetic processes effect the porosity (primary porosity and secondary porosity), developed through the diagenetic processes like dissolution, pressure solution and tectonic forces etc. By use of log curves porosity can be calculated i.e ; density porosity, neutron porosity and sonic porosity etc.

7.2.6 Density Porosity

The density log measure the electron density of a formation and identify evaporites, minerals, gas bearing zone, determine hydrocarbon density and evaluate shaley sand reservoir and complex lithology.

Density porosity is "the porosity determined from the density log curve, density of matrix and the density of fluid". Take values of the density from density log curve against different lithology and then put these values in the following formula;

$$\text{Density porosity}(\Phi_{den}) = \left(\frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}\right)$$

Whereas,

$\Phi_{density}$= stands for the density derived porosity

ρ_{ma} = stands for the density of matrix

ρ_b = stands for the bulk density

ρ_f = stands for the fluid density (1.1 for salt mud, 1.0 fresh mud, 0.7 for gas)

Table 7.7. Values for density porosity for the prospective zone.

Prospective zone	Petrophysical property	Average value
Sakesar limestone	Density porosity (Φ_{den})	0.177

Table 7.8. Shows values of matrix density and fluid density of limestone.

Well Name	Formation Lithology	Matrix density	Fluid density
Balkassar POL-1	Sakesar limestone	2.71	1.1

7.2.7 Neutron Porosity

It is the log of porosity which measure the concentration of hydrogen ions in formation. In the free shale formation, whereas pores filled with water or oil then the neutron log measures directly from the log curve, the liquid filled porosity.

Neutron Porosity = Value at any point on the Neutron Log curve.

7.2.8 Average Porosity

It is calculated from density and the neutron porosity, formula for the average porosity is;

Average Porosity= (Density porosity +Neutron porosity) / 2

Table 7.9. Shows values of average porosity of ND.

Prospective zone	Petrophysical property	Average value
Sakesar Limestone	Average ND (Φ)	9.838%

7.2.9 Effective porosity (φ_e)

It is actually the "sum of all interconnected pore spaces" and in the case of "core analysis" and the "petroleum engineering", the definition of effective porosity considers the total porosity. It is calculated from volume of shale and average porosity by using the following formula;

$$\text{Effective porosity}(\emptyset_{e}) = \emptyset_{avg} * (1 - V_{sh})$$

Whereas;

$\emptyset_e$ = Stands for Effective porosity

$\emptyset_{avg}$ = Stands for Average porosity

1-Vsh = Stands for Volume of sand

Table 7.10. Values of effective porosity for the prospective zone.

Prospective zone	Petrophysical property	Average value
Sakesar limestone	Effective porosity $(\emptyset_e)$	7.9%

7.2.10 Water Saturation (Sw)

The percentage (%) of voids that contain water is termed as "water saturation". If only water is present in the pores then formation has water saturation of 100% denoted by Sw and the endure fraction contains oil or gas is entitle as "hydrocarbon saturation" which is indicated by (Sh) and is identical to 1-Sw. The most basic and appropriate equation to calculate the saturation of water is the "Archie's equation". The Archie's equation;

$$S_W = \sqrt{R_w / R_t * \emptyset_a^2}$$

Where;

Sw = Stands for water saturation

Rw = stands for water resistivity

Rt= stands for true zone resistivity (LLD)

$\emptyset_a$= average porosity (ND)

Table 7.11. Shows values of average water saturation in zone.

Prospective zone	Petrophysical property	Average value
Sakesar Limestone	Water Saturation (SW)	29 %

7.2.11 Saturation of hydrocarbons

It is calculated simply by using the formula $S_H = 1 - S_w$

Where;

S_H = stands for Saturation of hydrocarbon

S_w = stands for Saturation of water

Table 7.12. Shows values of average hydrocarbon saturation in zone.

Prospective zone	Petrophysical property	Average value
Sakesar Limestone	Hydrocarbon Saturation (Sh)	70.9

Table 7.13 shows the petrophysical analysis results for POL-1.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	DEPTH	CALI	SP	GR	LLD	RHOB	NPHI	DT	PEF	Vsh	PHID	PHIA	PHIE	SW	SH
2	2500	9.2543	-7618.9453	37.8128	350	2.6873	0.0094	75.7577	4.4654	0.174897	0.014099	0.01175	0.009695	0.90985	0.09015
3	2501	9.3946	-7620.1587	37.5232	84.4974	2.6088	0.0134	69.5824	4.5071	0.172464	0.062857	0.038129	0.031553	0.570634	0.429366
4	2502	10.3543	-7621.3721	34.2298	562.8477	2.6667	0.0059	76.4544	4.329	0.144788	0.026894	0.016397	0.014023	0.51412	0.48588
5	2503	10.7911	-7622.5854	33.2697	604.2922	2.5003	0.008	76.9065	4.2858	0.13672	0.130248	0.069124	0.059674	0.1177	0.8823
6	2504	10.3799	-7623.7988	37.8197	316.4456	2.6298	0.015	73.2487	4.2073	0.174955	0.049814	0.032407	0.026737	0.346932	0.653068
7	2505	9.7651	-7625.0117	43.4338	90.4853	2.61	0.0093	77.706	4.2239	0.222133	0.062112	0.035706	0.027774	0.588845	0.411155
8	2506	10.5978	-7626.2251	40.7072	253.5487	2.5737	0.0017	78.9905	4.7537	0.19922	0.084658	0.043179	0.034577	0.290887	0.709113
9	2507	10.8234	-7627.4385	35.8095	285.9913	2.5044	0.0016	75.3526	4.2827	0.158063	0.127702	0.064651	0.054432	0.182927	0.817073
10	2508	10.6959	-7628.6519	33.9499	82.9138	2.5199	0.0118	74.7693	4.1582	0.142436	0.118075	0.064937	0.055688	0.338238	0.661762
11	2509	11.5253	-7629.8652	36.5103	224.9791	2.3036	0.0023	75.959	4.4897	0.163952	0.252422	0.127361	0.10648	0.104694	0.895306
12	2510	13.3072	-7631.0781	36.7928	479.6854	2.4816	0.014	79.9352	4.2359	0.166326	0.141863	0.077932	0.06497	0.117176	0.882824
13	2511	12.0875	-7632.2915	33.7101	415.9667	2.6238	0.01	79.1894	4.5994	0.140421	0.05354	0.03177	0.027309	0.30866	0.69134
14	2512	13.7348	-7633.5049	30.9653	451.4637	2.5853	0.0119	74.4209	4.524	0.117355	0.077453	0.044677	0.039434	0.210687	0.789313
15	2513	12.344	-7634.7183	34.9069	412.9305	2.5097	0.0056	80.1044	4.2755	0.150478	0.12441	0.065005	0.055223	0.151407	0.848593
16	2514	11.7431	-7635.9316	35.0616	204.3949	1.9515	0.0266	73.5833	3.7922	0.151778	0.471118	0.248859	0.211088	0.056214	0.943786
17	2515	11.4389	-7637.1445	34.8486	21.8088	1.9307	0.0371	76.3289	3.3973	0.149988	0.484037	0.260569	0.221486	0.164358	0.835642
18	2516	10.6548	-7638.3579	34.1078	27.8626	2.5248	0.0177	80.7922	4.461	0.143763	0.115031	0.066366	0.056825	0.570922	0.429078
19	2517	10.3216	-7639.5713	34.02	10.4576	2.1313	0.1404	80.4192	3.6379	0.143025	0.359441	0.24992	0.214176	0.247464	0.752536
20	2518	10.2515	-7640.7847	35.7151	154.9376	2.64	0.0045	75.9782	4.462	0.15727	0.043478	0.023989	0.020216	0.669788	0.330212
21	2519	10.9343	-7641.998	32.3498	152.0014	2.4854	0.0012	78.2556	4.3827	0.12899	0.139503	0.070352	0.061277	0.230586	0.769414
22	2520	10.8447	-7643.2109	36.9433	215.9395	2.4174	0.0095	67.1065	4.0455	0.167591	0.181739	0.09562	0.079595	0.142337	0.857663
23	2521	10.9526	-7644.4243	45.3278	146.5078	2.0679	0.0265	71.9793	4.0608	0.238049	0.39882	0.21266	0.162037	0.077699	0.922301
24	2522	10.417	-7645.6377	124.7854	119.9779	2.0999	0.0121	68.9766	4.0627	0.90576	0.378944	0.195522	0.018426	0.093386	0.906614
25	2523	10.9851	-7646.8511	74.1394	171.2479	2.3554	0.006	81.6591	4.1057	0.480163	0.220248	0.113124	0.058806	0.135102	0.864898
26	2524	11.8474	-7648.0645	46.8212	101.972	2.469	0.0114	72.861	4.0987	0.250598	0.149689	0.080545	0.06036	0.245897	0.754103
27	2525	9.7127	-7649.2773	41.3446	153.6033	2.1672	0.0572	74.8069	3.2246	0.204576	0.337143	0.197171	0.156835	0.081844	0.918156
28	2526	10.1371	-7650.4907	38.1522	133.7791	2.2727	0.0594	78.5401	3.4872	0.17775	0.271615	0.165507	0.136089	0.104476	0.895524
29	2527	9.7521	-7651.7041	36.6055	133.0394	2.0044	0.0363	74.02	3.6545	0.164752	0.438261	0.23728	0.198188	0.073077	0.926923
30	2528	9.7428	-7652.9175	35.7161	232.5365	2.5597	0.0145	78.6074	4.3605	0.157278	0.093354	0.053927	0.045445	0.243208	0.756792
31	2529	9.3355	-7654.1309	33.117	201.7627	2.65	0.0044	78.08	4.7164	0.135437	0.037267	0.020834	0.018012	0.675844	0.324156
32	2530	9.4746	-7655.3438	36.8515	182.8561	2.6122	0.0083	79.7038	3.8705	0.166819	0.060745	0.034523	0.028764	0.428421	0.571579
33										0.199606	0.177632	0.09838	0.078743	0.290109	0.709891

7.3 Well Balkassar Oxy-2

Table 7.14 shows the formation top in Balkassar oxy-2.

Formation Top	Formation Top Value
Nagri	0.00
Chinji	558.37
Kamlial	1,410.55
Murree	1,574.52
Chorgali	2,441.63
Sakesar	2,496.19
Patala	2,623.59
Lockhart	2,652.24
Hangu	2,688.81
Chorgali	2,892.11

Table 7.15 Detailed information of Balkassar Oxy-2.

Well Name	Balkassar-oxy-02	**Well Type**	DEVELOPMENT
Operator	Oxy	**Spud Date**	19/08/1993
Province	Punjab	**Completion Date**	13/10/1993
Latitude	325517.77	**Longitude**	723943.05
Concession	Balkassar	**Depth Ref. Elevation(m):**	543.15
Total Depth(m)	2,895.60	**Well Bore Name**	Balkassar-oxy-02
Depth Reference	Kb	**Formation Top**	CHORGALI

For well (Balkassar OXY-2) logs only sonic porosity is determined, because in Sakesar limestone (reservoir zone) most of logs are not run properly and it create problem to play with it for the whole petrophysical analysis. So, porosity is determined through sonic log by using the Wyllie time equation;

$$\Phi_s = \Delta tlog - \Delta tma / \Delta tf - \Delta tma$$

Whereas ;

$\Delta tlog$ = Value taken from sonic log curve

Δtma = 47.6 µs/ft(Standard value for limestone)

Δtf = 189 µs/ft(Standard value for limestone)

For porosity identification Sakesar zone is marked with the help of available well tops of formations. In Balkassar Oxy-2 Sakesar ranges from 2496-2623 and sonic porosity for whole Sakesar formation is 1.92 %.

Table 7.16 shows the excel sheet of sonic porosity of Oxy-2.

Depth	DT log value	Sonic Porosity	Depth	DT log value	Sonic Porosity	Depth	DT log value	Sonic Porosity	Depth	DT log value	Sonic porosity
2496	50.59	0.021145686	2534	63.53	0.112659123	2572	49.25	0.011669024	2610	54.04	0.045544554
2497	49.3	0.012022631	2535	64.52	0.119660537	2573	49.17	0.011103253	2611	49.99	0.016902405
2498	49.2	0.011315417	2536	49.23	0.011527581	2574	49.59	0.01407355	2612	50.17	0.018175389
2499	49.58	0.014002829	2537	48.21	0.004314003	2575	49.09	0.010537482	2613	51.51	0.027652051
2500	49.67	0.014639321	2538	49.39	0.012659123	2576	50.39	0.019731259	2614	50.56	0.020933522
2501	49.21	0.011386139	2539	50.68	0.021782178	2577	52.97	0.037977369	2615	49.62	0.014285714
2502	49.34	0.012305516	2540	50.91	0.023408769	2578	51.99	0.031046676	2616	48.88	0.009052334
2503	48.95	0.009547383	2541	49.85	0.015912306	2579	51.63	0.028500707	2617	49.67	0.014639321
2504	50.79	0.022560113	2542	50.35	0.019448373	2580	50.07	0.017468175	2618	49.68	0.014710042
2505	51.59	0.028217822	2543	50.26	0.018811881	2581	49.69	0.014780764	2619	48.48	0.006223479
2506	51.65	0.02864215	2544	49.82	0.015700141	2582	48.84	0.008769448	2620	48.54	0.006647808
2507	52.05	0.031471004	2545	49.78	0.015417256	2583	48.03	0.003041018	2621	51.88	0.030268741
2508	50.91	0.023408769	2546	50.11	0.017751061	2584	48.43	0.005869873	2622	49.6	0.014144272
2509	51.01	0.024115983	2547	50.26	0.018811881	2585	48.41	0.00572843	2623	49.6	0.014144272
2510	51.88	0.030268741	2548	50.44	0.020084866	2586	49.21	0.011386139			Average =0.01951
2511	50.08	0.017538897	2549	50.16	0.018104668	2587	48.79	0.008415842			
2512	49.78	0.015417256	2550	49.39	0.012659123	2588	47.86	0.001838755			
2513	49.69	0.014780764	2551	48.2	0.004243281	2589	49.42	0.012871287			
2514	50.1	0.017680339	2552	49.11	0.010678925	2590	48.77	0.008274399			
2515	50.05	0.017326733	2553	50.56	0.020933522	2591	49.15	0.01096181			
2516	50.47	0.02029703	2554	49.55	0.013790665	2592	50.04	0.017256011			
2517	49.33	0.012234795	2555	49.55	0.013790665	2593	49.86	0.015983027			
2518	49.3	0.012022631	2556	49.67	0.014639321	2594	50.01	0.017043847			
2519	48.25	0.004596888	2557	51.38	0.026732673	2595	58.66	0.078217822			
2520	51.67	0.028783593	2558	50.27	0.018882603	2596	50.13	0.017892504			
2521	51.74	0.029278642	2559	50.19	0.018316832	2597	49.96	0.01669024			
2522	48.21	0.004314003	2560	49.75	0.015205092	2598	48.33	0.005162659			
2523	48.09	0.003465347	2561	48.75	0.008132956	2599	47.71	0.000777935			
2524	48.7	0.007779349	2562	48.85	0.00884017	2600	49.35	0.012376238			
2525	48.61	0.007142857	2563	48.78	0.00834512	2601	49.39	0.012659123			
2526	49.72	0.014992928	2564	48.98	0.009759547	2602	48.95	0.009547383			
2527	49.01	0.009971711	2565	49.47	0.013224894	2603	48.96	0.009618105			
2528	49.98	0.016831683	2566	49.76	0.015275813	2604	48.16	0.003960396			
2529	58.26	0.075388967	2567	49.99	0.016902405	2605	48.36	0.005374823			
2530	53.26	0.040028289	2568	50.28	0.018953324	2606	48.96	0.009618105			
2531	54.27	0.047171146	2569	49.75	0.015205092	2607	49.13	0.010820368			
2532	55.68	0.057142857	2570	50.21	0.018458274	2608	51.9	0.030410184			
2533	61.72	0.099858557	2571	49.92	0.016407355	2609	53.54	0.042008487			

7.4 Identification of Paleoenvironment through Gamma ray (GR) Log

The gamma ray log is considered mostly for the prediction of various lithologies in well borehole by measuring, the emission of gamma ray radiation from different rocks lithology. In most of sedimentary rocks, Russell (1944) and Bigelow (1992) observed the radioactive particles. In 2002 Tzortzis and Tsertos, measure the potassium, uranium and thorium concentration in cyprus, found that all these radioactive particles are present in Marl, Chalk, Limestone, Gypsum, Sandstone, and Red clay soil and its means that source of radioactive is associated with varying in composition ,depends on environment of deposition. So, for this reason gamma ray log is use to interpret the environment of deposition. In (1991) Cant present the five different gamma ray log curves shape, use for the interpretation of the depositional environment and also considered the core study with the relation of logs as important tool for the facies interpretation in the subsurface.

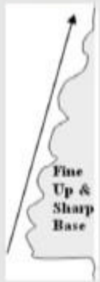
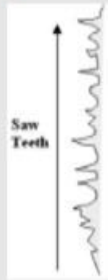
Type of log motif shape	Cylindrical/box shape	Funnel shape	Bell shape	Symmetrical shape	Serrated/saw tooth shape
Sediment supply	Aggradation	Progradation	Retrogradation	Petrograding & retrograding	Aggrading
GR trend					
Characteristic	Sharp top and base with consistent trend	Abrupt top with coarsening upward trend	Abrupt base with fining upward trend	Ideally rounded base and top	Irregular pattern/spikes of GR log
Grain size	Relative consistent lithology	Grain size increases	Grain size decreases	Cleaning upward trend change into dirtying up sequence from top	Inter-bedded shale's and sands
Depositional Environment	Aeolian (sand dunes), fluvial channels, carbonate shelf (thick carbonate), reef, submarine canyon fill, tidal sands, prograding delta distributaries	Crevasse splay, river mouth bar, delta front, shoreface, submarine fan lobe	Fluvial point bar, tidal point bar, deltaic distributaries, proximal deep sea, setting	Sandy offshore bar, transgressive shelf sands and mixed tidal flats environment	Fluvial flood plain, mixed tidal flat, debris flow and canyon fill

Figure 7.3 shows different log curve related to the environment of deposition modified (after cant 1992 Cant).

The gamma ray trend in Balkassar POL-1 is cylindrical shape and according to cant (1992) the cylindrical shape represent that lithology of formation may formed in aeolian, tidal carbonates, fluvial channels, carbonate shelf (thick carbonate), reef, submarine canyon fill and this all take place during aggradations. Shell (1982) present that cylindrical shape of GR log indicates the slop channel, Fluvial channels and tidal channel. Form all the above discussion its conform that environment of deposition for Sakesar Limestone of selected area is inner to middle shelf.

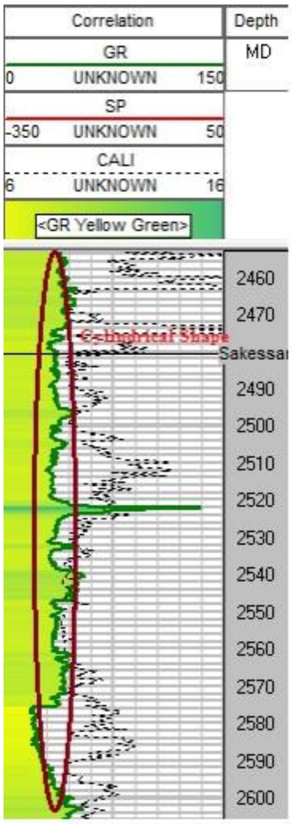


Figure 7.4 Gamma ray log curve shows the cylindrical shape in Balkassar (POl-1).

CONCLUSIONS

- The Eocene Sakesar Limestone is chosen at Nammal George, infront of Nammal College, near Nammal dam for the study of paleoenvironment, reservoir characterization, microfacies analysis and diagenetic fabrics.
- Based on the laboratory study and petrographic analysis three (3) microfacies and six(6) sub-microfacies has been identified.
- The diagenetic fabrics of Sakesar Limestone is identified including the cementation, micritization, neomorphism, calcite filled micro fracture, Aragonite to calcite transformation, chemical and mechanical compaction.
- Three (3) diagenetic phases marine, meteoric and burial are recognized with diagenetic fabrics for diagenetic environment.
- The impact of diagenesis and sedimentology are displayed, that the Sakesar Limestone act as a reservoir of secondary origin.
- With the help of petrophysical analysis water saturation, hydrocarbon saturation, volume of clay, effective porosity, average porosity is determined for Balkassar POL-1 and Sonic porosity for Balkassar OXY-2.
- The average porosity of POL-1 is 9.8 %and OXY-2 is 1.92%.
- The surface porosity and permeability for Sakesar Limestone is find through six (6) samples of out crop in HDIP and its values ranges from ranges from 3.15 to 19.49% and 0.021 to 0.117 milli darcy.
- By correlation its conformed that surface porosity is high as compare to subsurface porosity.
- Paleoenvironment for Sakesar Limestone is identified by using of gamma ray log and on the basis of biota, micrite matrix in various microfacies presence confirm the inner to middle shelf.

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