MICROFACIES ANALYSIS OF WARGAL FORMATION EXPOSED IN NAMMAL GORGE, WESTERN SALT RANGE, UPPER INDUS BASIN, PAKISTAN

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أطلبوا العلم
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2015

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of B.S in Geology

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Dated: 19/ 06 / 2015

Certificate

This thesis is submitted by **Mr. Suleiman Ali and Mr. Sadiq Raza** and is accepted in the present form by Department of Earth & Environmental Sciences, Bahria University, Islamabad as the partial fulfillment of the requirement for the degree of **Bachelor of Sciences in Geology,** 4 years program (Session 2011 – 2015).

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ABSTRACT

The carbonates of Middle-Late Permian age Wargal limestone constitute important petroleum reservoirs in the Salt Range area. Permian rocks are the most important HC reservoirs in Pakistan. These reservoirs are productive throughout the Indus Basin predominantly in the Upper Indus Basin. Somewhere else, e.g. in the North Sea Basin in the use of out crop data and microfacies techniques for constructing the dynamic depositional model has significantly increased the knowledge to characterize reservoir rocks.

In this study the outcrop data and microfacies from the key study section i.e. Nammal Gorge of Western Salt Range have been used for understanding the depositional dynamics and biostratigraphic properties of Wargal Limestone. The presence of reef forming organisms (Bryzones, foraminifers, echinoderms and bivalves) supports the model. The thickness of the formation in the Nammal Gorge section is 75m. On the basis of outcrop and petrographic data four microfacies are identified. These microfacies are WF-1 (Packstone-Grainstone Microfacies), WF-2 (Peloidal Packstone-Grainstone Microfacies), WF-3 (Wackstone-Packstone Microfacies), and WF-4 (Medium Bedded Mudstone Microfacies). The microfacies type of Wargal Limestone is suggested to be deposited in the inner to middle shelf environment.

ACKNOWLEGMENT

All praises are for Almighty Allah, Who has blessed us with this precious life, showered his blessings during the difficult times, enabled us to complete our degree and accomplish this project successfully. We also owe to the Holy Prophet (P.B.U.H) for the true guideline of life that are the source of enlightenment and inspiration that helps us to choose the right path.

We are glad to acknowledge the support and encouragement of our supervisor Mr. Mumtaz Ali Khan, Lecturer, Department of Earth and Environmental Sciences, Bahria University Islamabad campus, for supervising us through this project and his candid advices for the future.

We are highly obliged to Mr. Khalid Latif Kaif, Research Associate, NCE in Geology, University of Peshawar and Mr. Hafiz Shahid Hussain Yousafzai, Research Assistant, NCE in Geology, University of Peshawar for their utmost support and guidance.

We extend our gratitude to Dr. M. Tahir Shah, Director, NCE in Geology, University of Peshawar, for allowing us to carry out our study at the NCE state of the art Laboratories.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nammal Gorge contains well exposed section of Wargal Limestone on the northeast limb of a faulted anticline. The lowermost few meters of section in the core of anticline are not exposed. Teichert (1966) & Kummel and Teichert (1970) mentioned the rock in the Nammal Gorge and reported a thickness of 146m and strata that dip is northeast. Nammal Gorge is approximately 30 km east of Mianwalli.

The Permian rocks have been divided into Nilawahan Group and Zaluch Group. The Nilawahan group shows dominantly a continental sequence that consist of arenaceous and argillaceous sediments that passes conformably into the overlying Zaluch Group that comprises of siliclastic carbonates mixed with the lithofacies of Amb formation, carbonates of Wargal limestone and clastic-carbonate mixed lithologies of the Chiddru formation. The upper part of Permian separated from Triassic by a para-conformity while the lowermost bed rest disconformably on Cambrian.

The Middle to late Permian Wargal limestone consist of limestone and dolomite which comprises abundant micro-fauna including bryzones, brachiopods, bivalves, gastropods, ammonides, trilobites, crinoids and conodonts (Kummel and Teichert, 1970; Shah, (1977) and the micro-flora reported from this formation including pollens and spores (Kummel and Teichert (1970). The present study is intended to carry out detail micro-facie analysis for the Wargal formation in the Nammal gorge.

1.2 Location and Accessibility

The area is located in District Mianwalli of Punjab. The Nammal Gorge is situated in the South of Islamabad at a distance of 200 Km approximately. The area is located on the Grand Trunk road from Peshawar to Karachi and it is easily accessible through this road throughout the year. It took 4-5 hours to reach Nammal Gorge from Islamabad. The path in the gorge is rocky, bushy, and unsteady and is along the water channel that comes from the spill of the Nammal Dam (Fig. 1.1).

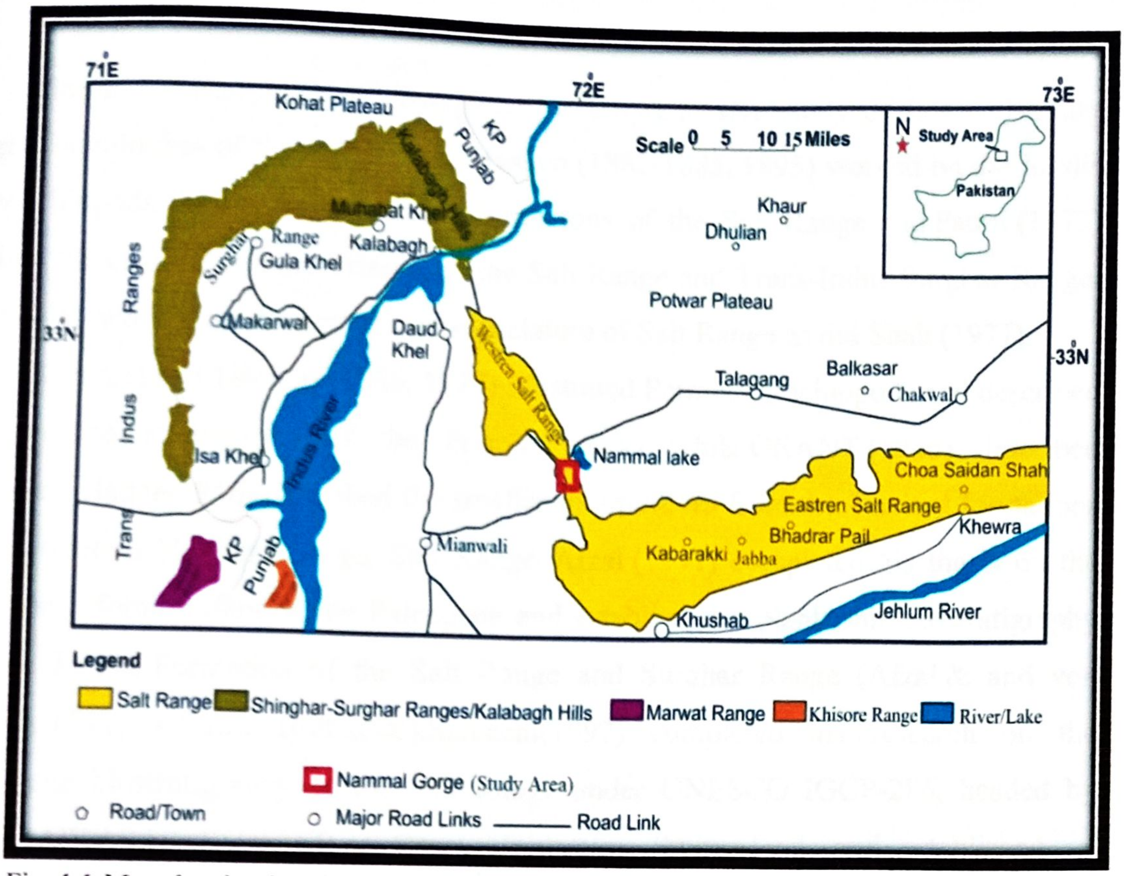


Fig. 1.1 Map showing location of the study area. The study area (Nammal Gorge) is marked with red box.

1.3 Previous Work

The Salt Range has been focused by geologists in the past from all over the world to study stratigraphy of Cambrian age, the Permian-Triassic boundary, and Lower foraminiferal biostratigraphy Lower Tertiary age. The notable and very first detailed work for salt range was done by Gee (1935, 1945), who dedicated almost his entire geological career for the study of the Salt Range. His initial work related to solving the controversy regarding the age of the "Saline Series", a burning topic of that time, and did a great contribution by producing a geological map (more recently six sheets on a scale 1:50,000 have been published by the Geological Survey of Pakistan excluding the Trans-Indus Surghar Range). The salt range is well documented and studied by many researchers like (Gee, 1980; Burbank and Reynolds, 1984; Yeats et al., 1984; Danilchick, 1961).

Davies and Pinfold (1937) completed a comprehensive study of Lower Tertiary larger foraminifera of the Salt Range. Waagen (1882-1885, 1895) worked on the fossils of brachiopods preserved in Permian formations of the Salt Range and Fatmi (1973) studied the ceratoids of the Triassic of the Salt Range and Trans-Indus Surghar Range. Fatmi also worked on stratigraphic nomenclature of Salt Range as did Shah (1977).

Kummel and Teichert (1966, 1970) illustrated Permian brachiopods and described the detailed stratigraphy of the Permian rocks while GRANT (1966) described trilobites. Haque(1956) described the smaller foraminifera from the Tertiary formations of the western Nammal Gorge, Salt Range. Afzal (1997) completed his thesis on the planktonic foraminifera of the Paleogene and established a planktonic biostratigraphy for the Patala Formation of the Salt Range and Surghar Range (Afzal & and von Daniels,1991; Afzal& Butt,2000).Sameeni(1997) completed his research on the Paleogene biostratigraphy of the Salt Range under UNESCO IGCP-286, headed by Prof. LUKAS HOTTINGER of Basel University, Switzerland, and established an alveolinid biostratigraphy for the Eocene succession of the Salt range (Sameeni & Butt, 1996, 2004; Sameeni & Hottinger,2003). Ashraf and Bhatti (1991) worked on the nano-fossils of the Patala and Nammal formations of the Khairabad area of the Western Salt Range.

1.4 Aims and Objectives

This research is aimed at using the outcrop data and utilizes micro-facies analysis to understand the depositional environment of the Formation under investigation. The present study is aimed to achieve the following objectives;

- Record and designate microfacies of Wargal limestone.
- To study fossils present in Wargal limestone.
- To draw a depositional model for the Wargal formation

1.5 Methodology

This research involves the extensive field and laboratory work.

1.5.1Field Work

Fieldwork data from the study sections were collected in the period from 29th December 2014 to 31st December 2014. Optical distance meter, clinometers, brunton compass, and measuring tape used for measuring the stratigraphic thickness of section on traverses at right angle of the strata, geological hammer was used to collect the carbonates samples of Wargal limestone bed by bed exposed rock unit. The total of thirteen carbonate samples were collected at significant lithological changes for subsequent laboratory study.

1.5.2Laboratory Work

a) Thin Section Preparation

All thin section was prepared in the 'Thin Section Laboratory' of Department of Geology, University of Peshawar, and using state of the art equipment (Fig. 1.2).

Fig. 1.2 Photograph showing thin section preparation laboratory of NCE in Geology, University of Peshawar.

b) Microscopic Study

The thin sections were studied under the Nikon polarizing microscope with attached digital camera of Nikon and a 32 inch LCD at the sedimentology laboratory of National Centre of Excellence in Geology, University of Peshawar (Fig. 1.3). Different features like allochems, matrix, ooids, peloids and fossils were studied in detail and microphotographs were taken for interpretation and description.

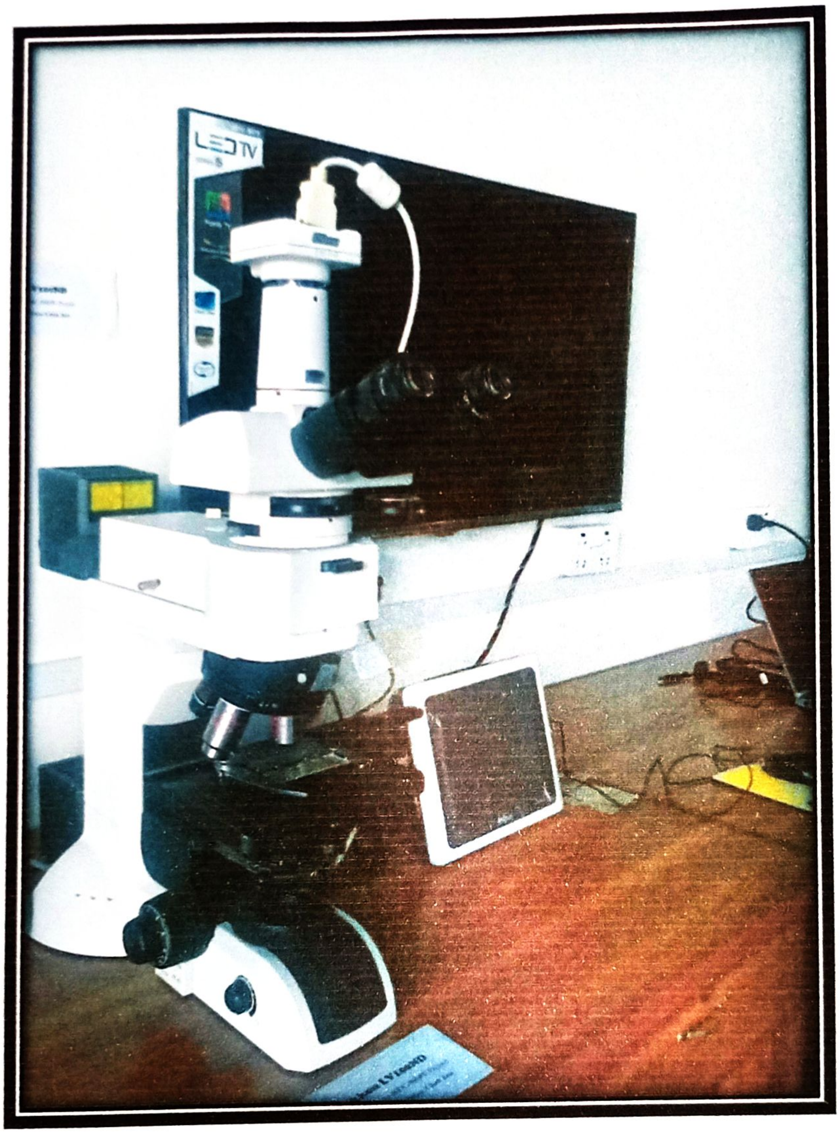


Fig. 1.3 Photograph displaying the Nikon Polarizing microscope with Nikon camera and LCD at Sedimentology Laboratory, NCE in Geology, University of Peshawar.

c) Graphic Software

The Corel Draw X5 v15.0.0.486 portable graphic software was used for the construction of microfacies charts, sequences interpretation charts, correlation charts and facies modeling diagrams.

CHAPTER 2

GENERAL GEOLOGY

In this chapter brief overview of the regional tectonic settings and stratigraphic framework of the Salt Range is presented. The detailed litho-stratigraphic description of the Wargal limestone at Nammal Gorge is also included in this chapter.

2.1 Regional Tectonic Setting

The Salt range is essentially a complex salt anticlinorium with a series of salt anticlines. It is widest in its central part, between Khewra and Warcha, where it also contains the best exposures of Paleozoic and Eo-Cambrian sequence. The structure along its northern slope is comprised of simple, broad, shallow folds followed by a gentle monocline. Southward the folding becomes tighter and the folds are commonly faulted. Along the southern scarp the structures are more complicated and comprise east-west trending faults and over folds. The Eo-Cambrian evaporites are exposed in some of these overfolded and faulted anticlines. Though the general trend of the folds is east-west in the Central Salt Range, a few north-south trending and northward plunging anticlines, which are actually "nose" type structures, have also formed.

In the east the Salt Range loses its stature and bifurcates into two narrow northeast trending ridges, the Diljabba and the Chambal-Jogi Tilla. The later comprises steeply dipping monoclines, complicated by complex thrusts and tear faults, whereas the Diljabba Hill is a steeply dipping anticline traversed by Diljabba-Domeli thrust. While, in the west the Salt Range takes a northwest bend near Warcha. Its structure remains the same and it is separated by the Kalabagh Fault from the Trans-Indus Ranges and is truncated by Salt Range Thrust in the south.(Kummel and Teichert, 1970)

2.1.1 Salt Range Thrust

This thrust fault runs along the southern margin of the Salt Range, betweenJhelum and Indus Rivers, and it have pushed the older rocks of the Salt Range upon the less deformed Tertiary sequence of the south-lying Jhelum Plain. The thrust zone is largely covered by Recent fanglomerates. However at places (e.g., near Jalalpur and Kalabagh), the thrust is exposed and shows the Paleozoic rocks overlying the Neogene or Quaternary deposits of the Jhelum Plain (Gee 1945, 1989; Yeats et al. 1984). Seismic reflection profiles, gravity, and drill hole data indicate that the Salt Range and Potwar Plateau are underlain by a decollement zone within Eo-Cambrian evaporites. Along the Salt Range Thrust, effective decoupling of sediments from the basement along the salt layer has led to southward transport of the Salt Range and Potwar Plateau in the form of a large slab over the Jhelum Plain. The Salt Range is thus the surface expression of the leading edge of a decollement thrust (Lillie et al. 1987).

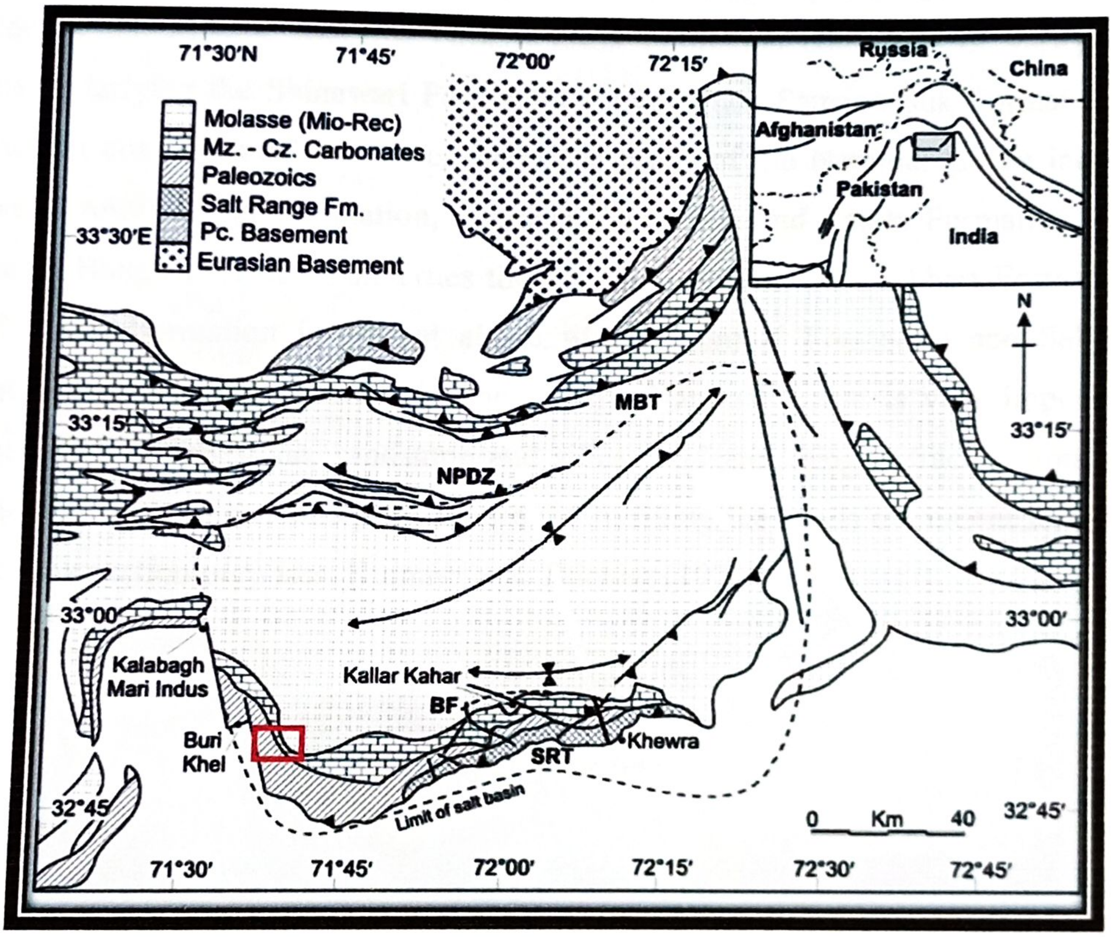


Fig. 2.1 Geological map of Northern Pakistan , showing location of study area(after Cotton and Hemin A. Koyi, 2000)

2.2 Stratigraphy of Nammal Gorge

Nammal Gorge is exposed in Western Salt Range. Rocks present in Nammal gorge are ranging in age from upper Permian to Eocene. Different lithologies of Permian, Mesozoic and Cenozoic are best exposed in this gorge. The Nammal Gorge, Salt Range, Pakistan, preserves a record of the interacting Triassic open-marine carbonate sedimentation, cyclic siliciclastics progradation and fluctuating relative sea level. The oldest rocks exposed in Nammal Gorge belong to the Permian Zaluch Group which is overlain by the Triassic Musakhel Group. The Late Permian Zaluch Group is mainly limestone having abundant fossils of brachiopods, gastropods,trilobites etc. The Permo-Triassic Boundary (P-T Boundary) separates the Zaluch Group (Chiddru Formation) from the Musakhel Group (Mianwali Formation) of Triassic age and this boundary is Para-conformity. The Tredian Formation is of sandstone while, Kingriali Formation largely consists of Dolomitize limestone. On top of the Triassic sequence there is a thick succession of the Jurassic (Surghar Group) Datta Formation consisting of variegated sandstone underlying the Shinawari Formation above which Samana Suk Formation is present which comprises of limestone. Paleocene rocks of the Nammal Gorge include (Makarwal Group) Hangu Formation, Lockhart Formation and Patala Formation. The sandstone of Hangu Formation underlies the nodular limestone of Lockhart Formation. Shale of Patala Formation is present above which Nammal Formation and Sakesar Limestone are present(Cherat Group).Economically Nammal gorge is very important. Large quantities of limestone, sandstone and silica sand are being extracted from the gorge. The quarries of limestone present here are fulfilling the needs of cement factories as well as construction purposes. Kummel and Teichert (1970).

Age	Group	Formations
Eocene	Cherat Group	Sakesar Formation
		Nammal Formation
Paleocene	Makarwal Group	Patala Formation
		Lockhart Formation
		Hangu Formation
		Samanasuk Formation
Jurassic	Surghar Group	Datta Formation
Triassic	Musakhel Group	Kingriali Formation
		Tredian Formation
		Mianwalli Formation
Permo-Triassic Boundary		
Permian	Zaluch Group	Chiddru Formation
		Wargal Formation
		Amb Formation

Table 2.1 Showing stratigraphy of the study area.

2.3 Wargal Limestone

Noetling (1901) coined the term "The Wargal group" to a predominantly calcareous unit overlying the Amb Formation in the central Salt Range. The name Wargal Limestone, as approved by the Stratigraphic Committee of Pakistan was introduced by Teichert (1966). For the same rock unit, the name "Middle Products Limestone" was used by Waagen (1879). The contact of the Wargal Limestone with the underlying Amb Formation is well-defined and is placed at the basal sandy limestone of the formation above the uppermost shale unit of the Amb Formation. The upper contact with the Chiddru Formation is transitional. The fauna consists of abundant bryozoans, brachiopods, bivalves, gastropods, nautiloids, ammonoids, trilobites and crinoids. In addition Kummel and Teichert (1970) reported pollen and spores, ostracods and conodonts from the formation. The Formation is mainly formed by grey, medium or thick-bedded to massive, partly sandy limestone and dolomite with few, thin intercalations of dark-grey to black shale. The Wargal Limestone is highly fossiliferous (Waagen 1879-1891, Reed 1944, Rao and Verma 1953, Grant 1966, Teichert 1966, Kummel and Teichert 1970, Pakistani-Japanese Research Group 1985). On the basis of its faunal content, the Wargal Limestone has been dated as Late Permian (late Murgabian to early Dzhulfian). The palaeo-environment is interpreted as generally shallow marine, with the exception of few strata which might have been deposited under deep-water conditions (Pakistani-Japanese Research Group 1985). The thickness of Wargal Limestone is 180 m-200 m in the Salt Range and 150m in the Khisor Range.

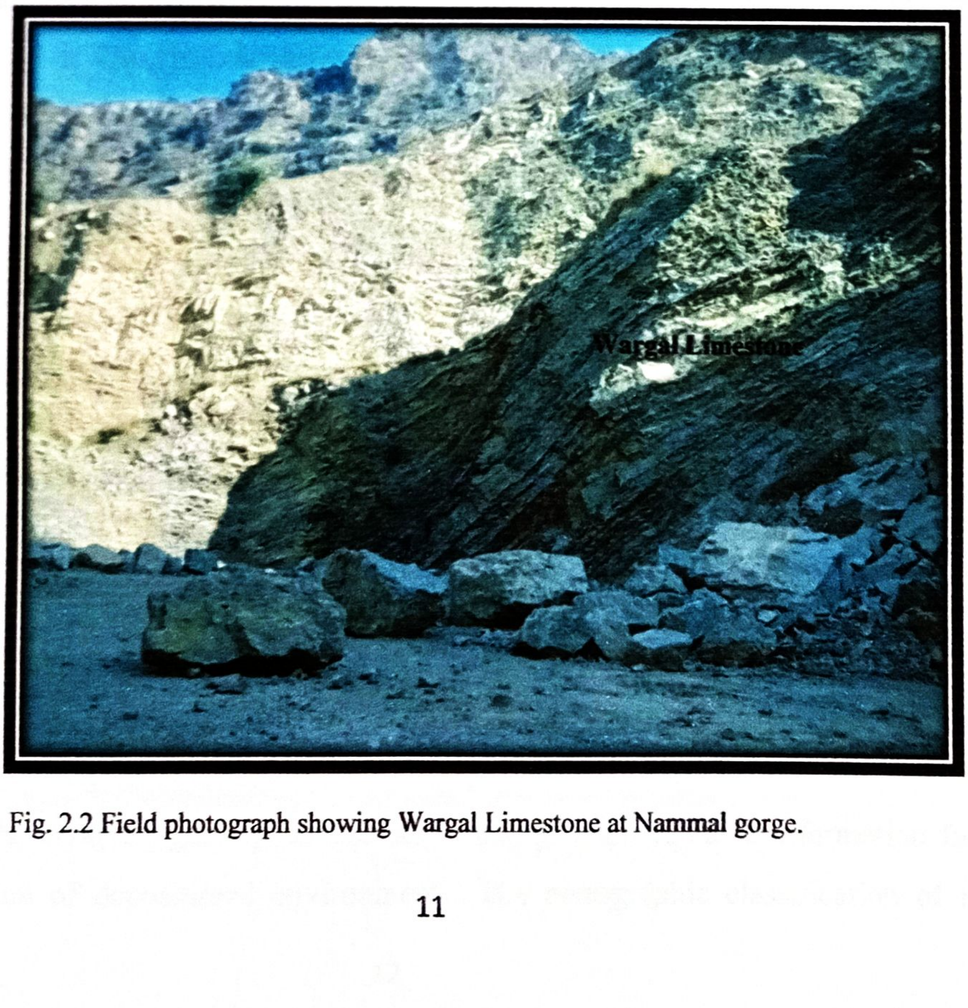


Fig. 2.2 Field photograph showing Wargal Limestone at Nammal gorge.

CHAPTER 3

MICROFACIES ANALYSIS

3.1 General Introduction

Middleton (1978) defines the term Facies as "lithological, structural and organic aspects of a rock which can be detectable in the field". In carbonate rocks the term facies refers to the total of all the paleontological and sedimentological criteria which can be classified in thin sections, peel and polished slabs (Flugel, 2004). Different microfacies can be recognized by rock composition, depositional texture and fossil distribution of specific samples (Tucker & Wright., 1990; Flügel, 2004). On the basis of fauna, trace fossils and lithology, the lateral subdivision of a stratigraphic unit are called biofacies, ichnofacies and lithofacies, respectively. Facies that are genetically related and have some significance are grouped as facies associations, whereas facies characterized by a change in one or more parameters in a vertical successione.g. sedimentary structure, abundance of sand and grain size is termed as facies succession. A particular depositional system involving many examples from recent sediments and ancient rocks is known as a facies model. A facies model is said to be static when interpreted under fixed pattern of processes while a dynamic facies model is used for interpreting lateral and vertical facies distribution under different conditions.

3.2 Microfacies Analysis (Methods):

For facies analysis 13 rock samples were collected from the studied section Nammal Gorge. The microfacies analyses of the lithofacies are based on the investigation of rock thin sections using Digital Camera fitted Nikon Petrographic Microscope at the Department of Geology, University of Peshawar. The lithofacies description is based on the outcrop investigations and microfacies analysis is based on microscopic investigation of thin sections. The microfacies analysis details the allochems, matrix, textural features, fossilscontent of the lithofacies. Abundance, type and size of the foraminiferal tests along with invertebrate fauna (bryozoans, brachiopods, bivalves, gastropods and echinoids) provide valuable information for the interpretation of depositional environments. The petrographic classification of rocks follows the Dunham (1962) classifications of carbonate rocks and Pettijonns (1987) classification for sandstone facies.

3.3 Field Observations:

Field work forms on the basis for studying sedimentary deposits. Criteria that can be studied in outcrops and cores in facies analysis are lithology, texture, rock, color, bedding, sedimentary structures and diagenetic features and fossils and biogenic structures. A highly recommended description of field methods is given by Tucker (1982).

3.4 Lithology, Texture and Rock Colors:

3.4.1 Lithology:

The sedimentary rocks are classified into siliciclastic rocks (claystone/mudstone, siltstone and sandstone), conglomerate and breccias, carbonate rocks (limestone and dolostone), mixed siliciclastic-carbonates (marls, argillaceous and sandy limestone), evaporates (gypsum, anhydrite, salt), siliceous sedimentary rocks (cherts), phosphorites and organic-rich rocks.

Carbonates rocks make up 20 to 25 percent of all sedimentary rocks in the geological record and are classified into limestone and dolomites (dolostones). Limestone consists of more than 50% $CaCO_3$. They comprise of limestone and dolomitic limestone. Dolomites are comprise of more than 50% $CaMg\ (CO_3)_2$ and are subdivided into calcitic dolomites (50-90% dolomite) and dolomites. Mixed siliciclastics-carbonates lithologies include marls (a sediment consisting of 65-35% carbonates and 35-65% clay), argillaceous limestone (a limestone containing an appreciable amount of clay, less than 50%) and sandy limestone (a limestone containing an appreciable amount of quartz sand).

3.4.2 Textures:

The textures of major limestone types can be characterized in the field by using the classification of Dunham (1962). Much more information is provided by the size, shape and sorting of grains, the ratio of matrix to grains and the fabrics. The textural composition of beds and lamina may be characterized by the distinct vertical gradations in grain size (graded bedding). Normal grading are coarser grains at the base, finer at the top and reverse or inverse grading are those where the coarser grains at top, finer at the base are important in the interpretation of depositional processes.

3.4.3 Rock colors:

Many limestone's are a shade of gray, but limestone can be display distinctive rock colors which need a more precise terminology (Folk 1969). Dolomites are often creamy yellow or brown in color. Rocks color can be characterized by simple verbal descriptions (e.g. medium to dark gray) or by comparing fresh rock fracture surfaces with standard color schemes (e.g U.S. National Research Council Rock-color Chart based on the Munsell Color System Goddard et al 1948). Colors of carbonate rocks are strongly controlled by thedepositional conditions, diagenesis and recent weathering.

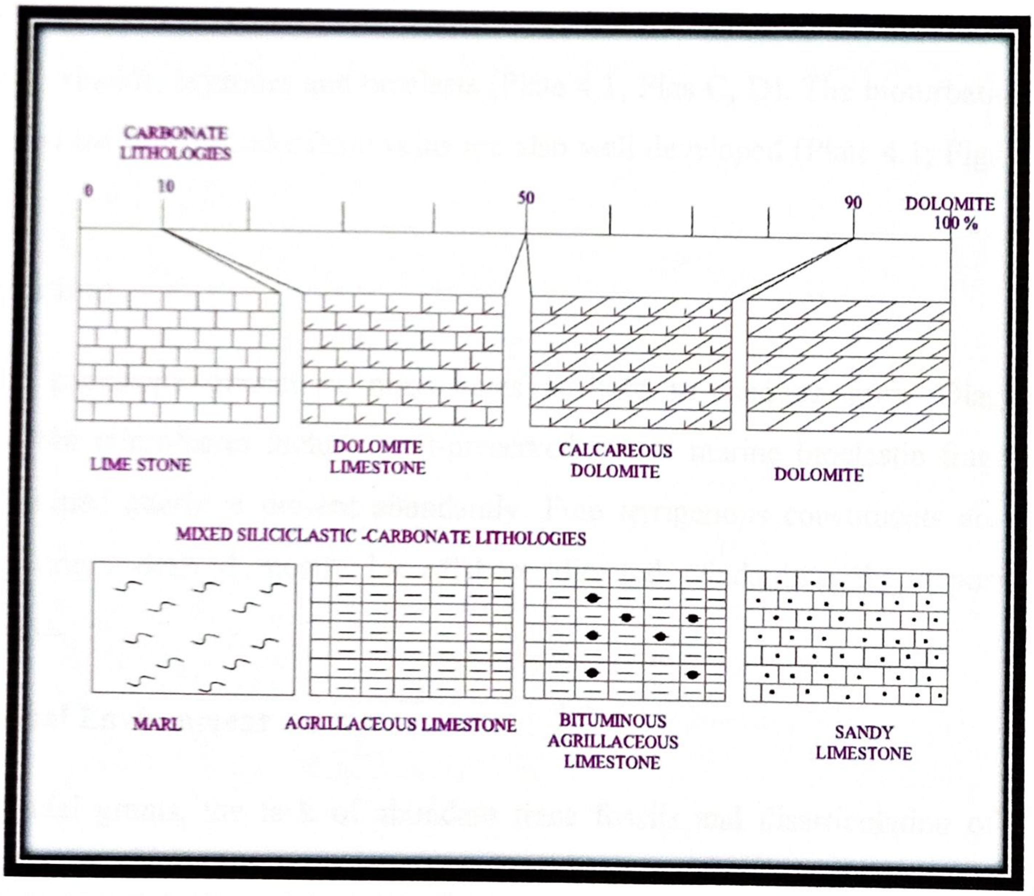


Fig 3.1 Common lithologies of carbonates rocks and mixed carbonate-siliciclastics rocks. The symbols used are those from the standard Shell Legend.

CHAPTER 4

MICROFACIES OF WARGAL LIMESTONE

The carbonates of Wargal limestone at Nammal Gorge in Salt Range, Upper Indus Basin of northwest of Pakistan have been grouped into four facies. These microfacies are compared to Flugel (2004) which describes the different settings in the formation.

4.1 Facies Analysis

4.1.1 Packstone-Grainstone Microfacies WF-1

The WF-1 facies is represented by the grayish sandy limestone in the Nammal Gorge section, lying at the base of the formation. Under the microscope (Appendix 1: In thin sections 11,12 & 13), the facies characterized with huge amount of quartz grains with the poor preservations of the fossils. The fossils observed in this facies are gastropods, crinoids, bryzones and bioclasts (Plate 4.1; Figs C, D). The bioturbation had been affected the texture and calcite veins are also well developed (Plate 4.1; Figs A, B, E, F).

Interpretations

The packstone--grainstone microfacies is light to medium gray. Diagnostic features of the microfacies include well-preserved sparse marine bioclastic fragments. The fine grained quartz is present abundantly. Fine terrigenous constituents are extra basinal in origin derived mostly by offshore directed winds into the depositional environments.

Depositional Environment

Peloidal grains, the lack of abundant trace fossils and disarticulation of body fossils are evidence that the packstone--grainstone facies was deposited in a high to moderate energy environment, probably above fair weather wave base. Fragmentation of bioclasts is due to reworking by wave or tidal processes in a relatively shallow-water environment and from extensive bioturbation. Bryozoans, gastropods, and crinoids indicate a normal salinity marine environment (Heckel, 1972).

PLATE 4.1

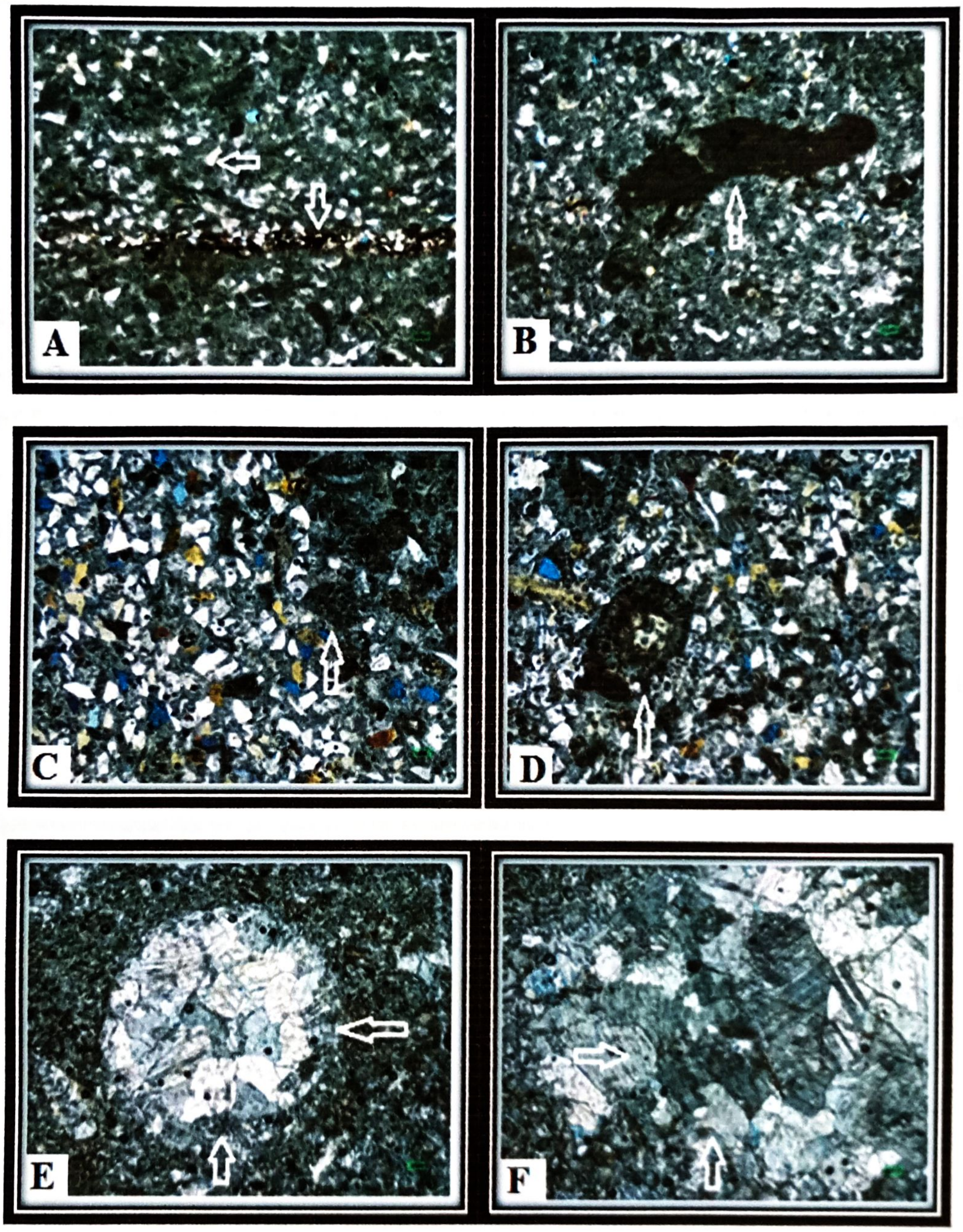


Fig 4.1 Photomicrograph showing (A) quartz grains and calcite veins, (B) bioturbation, (C) fossil bryzones, (D) fossils crinoids and (E & F) calcite veins structure.

4.1.2 Peloidal Packstone-Grainstone Microfacies WF-2

The WF-2 microfaciesis represented by the dark grey fine crystalline limestone in the Nammal Gorge section. In the petrographic studies (Appendix 1: In thin section 8), the facies are characterized with non-skeletal grains include peloids (Plate 4.2; Fig H) and ooids (Plate 4.2; Fig G). The peloids and aggregate grains are cemented.

Interpretation

Peloids have varied origins and environmental associations. Algal or fungal boring and micritization of grains are common in a variety of open marine to restricted or coastal settings with relatively slow or intermittent sedimentation rates (Scholle et al., 2003). In particular, areas subject to occasional storms that move grains from active areas of formation to quite sites of destruction are especially prone to peloids formation. Such sites include back barrier or back bar grass flats, lagoons and protected deeper shelf settings (Scholle et al., 2003).

Depositional Environment

The presence of non-skeletal grains like peloids, ooids signify that the sediments were battered and elated from the adjacent areas by strong currents and wave actions. This indicates that the WF-2 was deposited in the restricted middle shelf environment (Wright., 1992; Flugel., 2004).

PLATE 4.2

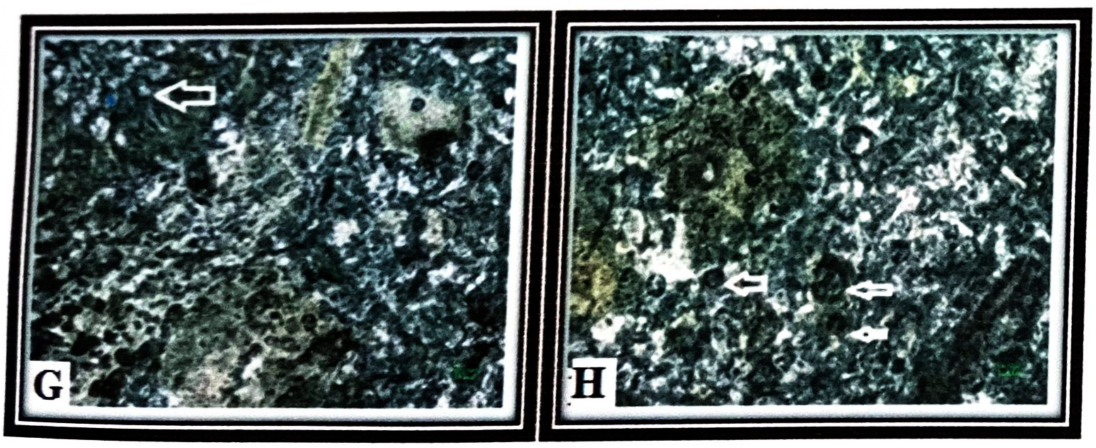


Fig 4.2 Photomicrograph showing (G) ooids and (H) peloids.

4.1.3 Wackstone-Packstone Microfacies (WF-3)

The WF-3 microfacies is represented by the dark grey fossiliferrous limestone in the Nammal Gorge section. In the petrographic studies (Appendix 1: In thin section 2,3,4,5,6,7,9,10), the facies are characterized by the bioclastic wackstone-packstone depositional texture with the preservation of bioclasts of bryzones, trilobites, fusulinids, gastropods, crinoids along with the calcite veins(Plate 4.3; Figs I, J, K, M, N, O, P). The calcite veins are cross cut to each other (Plate 4.3; Fig L).

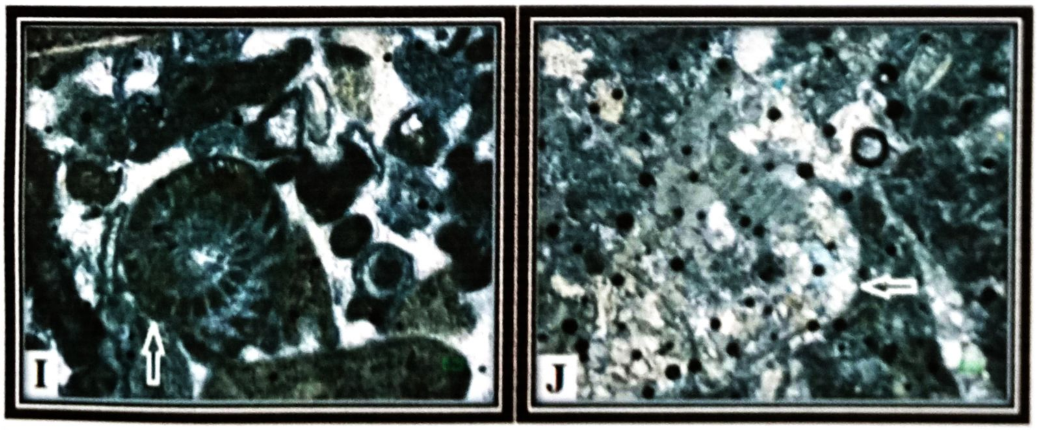
Interpretation

The brachiopods are the particularly common in Paleozoic and Mesozoic limestone of shallow marine origin. These were largely benthic, sessile organism (Tucker.,2001). All brachiopods are marine organisms, but the group exhibits a significant salinity range into both brackish (hypo saline) and slightly hyper saline settings (Scholle et al., 2003). The poor preservation of the bryzones and fusulinids foraminifera is attributed to the high continental influx during the deposition of the WF-2 facies and indicates a proximal middle shelf depositional setting.

Depositional Environment

High diversity of fauna like (crinoids, gastropods, bryzones) peloids, interclasts and micrite matrix suggests that WF-3 was deposited in the middle shelf environment (Wright.,1992; Flugel,2004).

PLATE 4.3



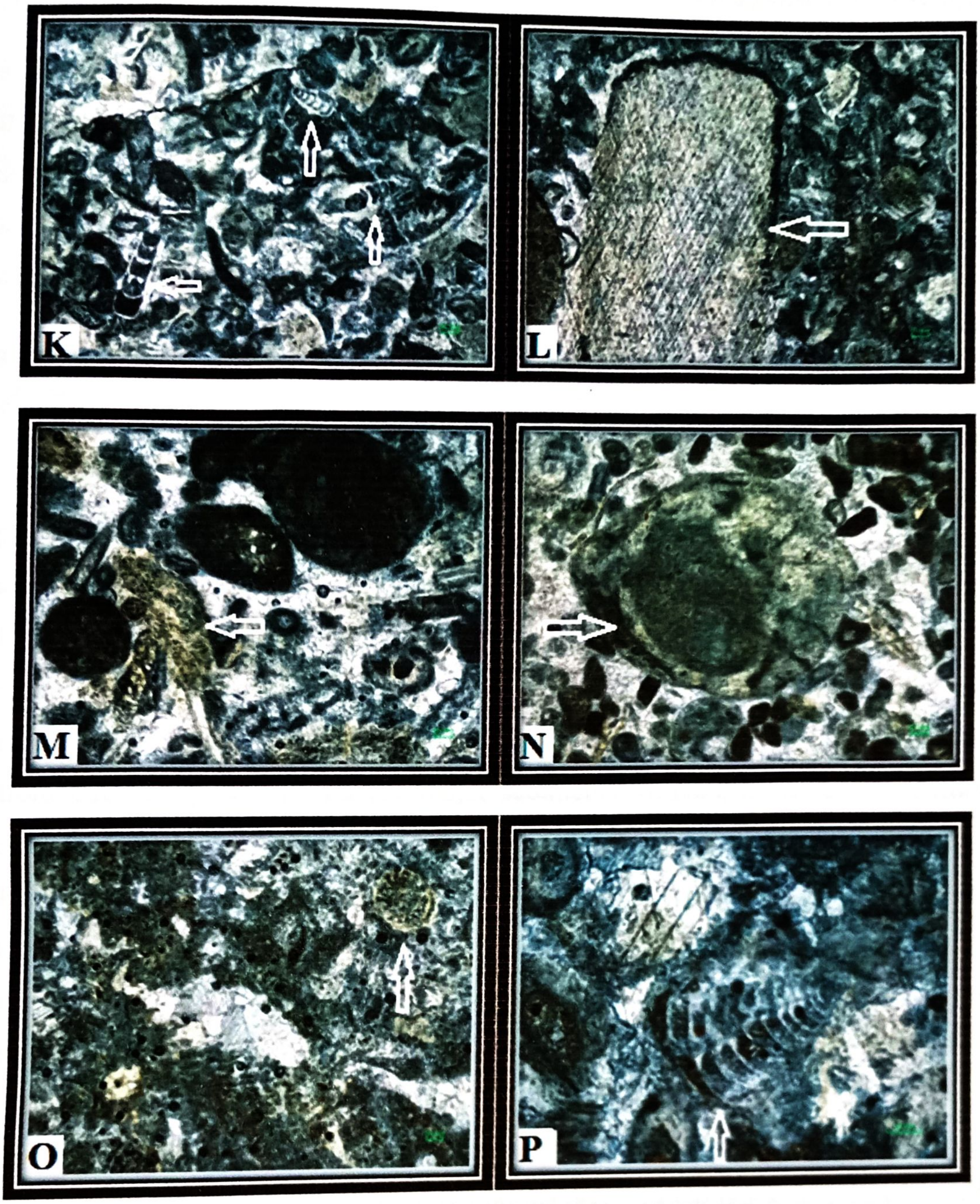


Fig 4.3 Photomicrograph displaying(I) fusulinids, (J) calcite veins, (K) gastropods bioclasts, (L) cross-cut calcite veins, (M) bioturbation, (N) brachiopod fragment, (O) crinoids fossils and (P) trilobite.

4.1.4 Medium Bedded Mudstone Microfacies (WF-4)

In the Nammal Gorge section, facies WF4 is represented by the grayishcolor muddy limestone, which is hard and highly fossiliferrous. Under the microscope, facies WF-1(Appendix 1: In thin section 1) is observed as a mudstone depositional texture with the preservations of the different fossils like trilobites, brachiopods, bryzones, crinoids with the mixture of bioclasts (Plate 4.4; Fig. Q, R, S, T, V). The calcites veins are clearly observed. The facie also shows the bioturbation effects (Plate 4; Fig. U). The diagenetic fabric of this facie includes iron leaching and calcite fractures (Plate 4.4; Fig. S). The matrix present is micritic in nature.

Interpretation

Crinoids are completely marine, normal salinity organisms. Crinoids (also known as sea lilies) were particularly important rock forming constituents in Paleozoic (especially Devonian to Pennsylvanian) strata. Paleozoic forms occurred mainly as attached or "rooted" organisms (pelmatozoans) in shelf and shelf margin setting (although they also lived in deeper water) (Scholle et al., 2003). Gastropods are extremely wide ranging group of organisms. They are originated at all latitudes and in normal marine, brackish, hypersaline and fresh water as well as in sub-aerial environments. They hardly ever are major sediments formers, however, apart from in stressed (especially hypersaline or freshwater setting). Warm water forms usually are thicker shelled than cold water forms (Scholle et al., 2003).Brachiopods are particularly common in Paleozoic and Mesozoic limestone of shallow marine origin. These were largely benthic, sessile organism (Tucker., 2001). Almost all brachiopods are sessile, attached organisms that live in shelf water ranging from high to low latitude settings (Tucker, 2001).Bryozoans live only in normal sea water with a normal salinity (Taylor., 2005). The presence of diverse fauna and micrite matrix indicates sub-tidal marine conditions. The dominance of lime mud within the depositional fabric is indicative of low energy conditions as agitated water does not allow settling of lime mud (Tucker.,2001).

Depositional Environment:

The presence of lime mud and presence of fossils like crinoids, bryzones, gastropods and brachiopods indicates that the WF-4 microfacies were deposited in the open marine inner shelf environment (Wright.,1992, Flugel.,2004).

PLATE 4.4

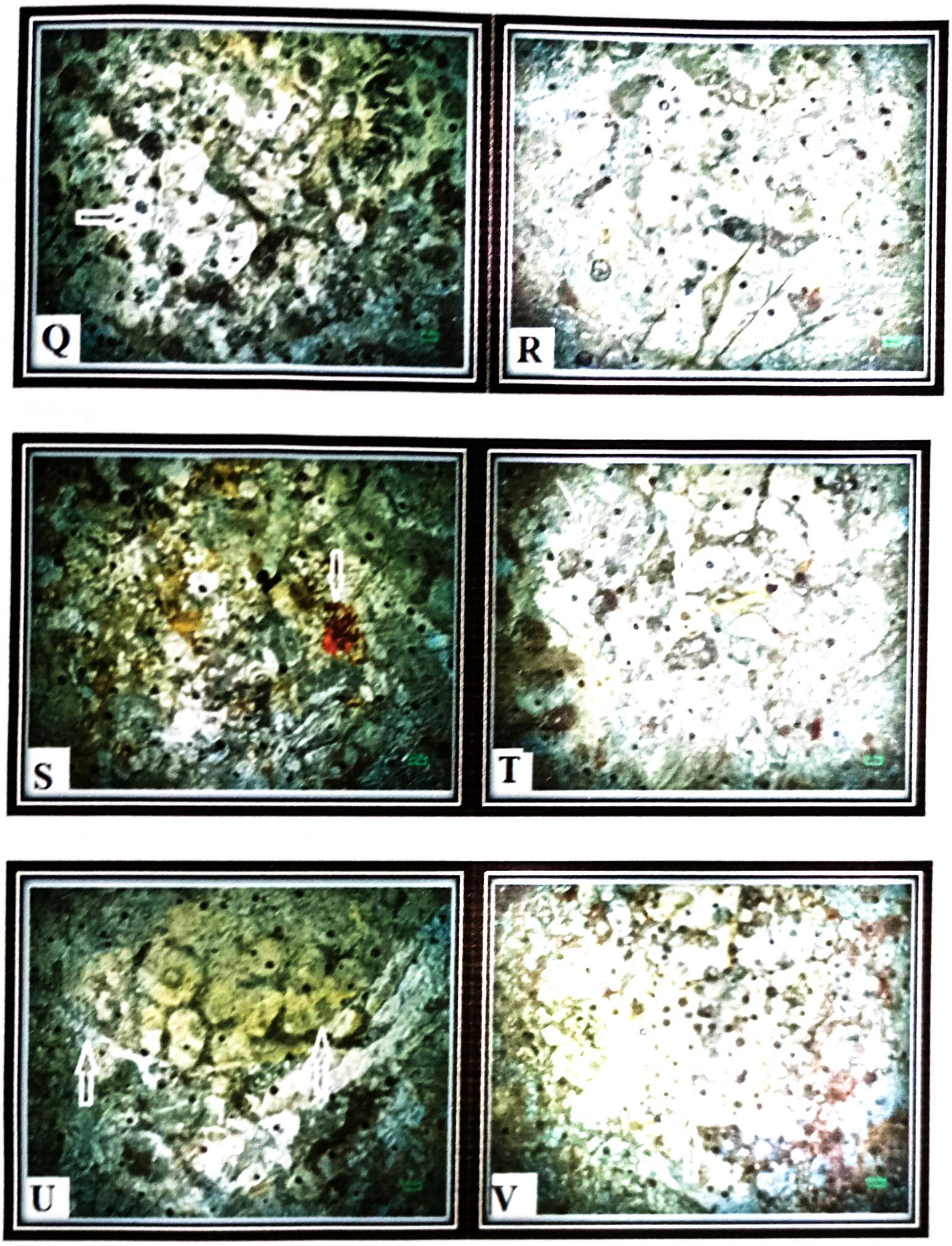


Fig.4.4 Photomicrograph showing (Q) fossils gastropods, (R) foruminifera, (S) iron leaching and calcite fracturing, (T) crinoids fossil, (U) bioturbation and (V) bryozones.

4.2 Depositional Model

A facies model is generalized summary of given depositional system (Walker 1992). The information required for this summary is taken from local case studies of modern and ancient examples. The facies model should act as norms for the purposes of comparison, as a frame work and guidelines for the future observations, as a predictor of new geological situations, and as an integrated basis for the system as that represents. Sensitive and predictive facies models are important in the exploration of Hydrocarbon and limestone resources (Flugel,2004).

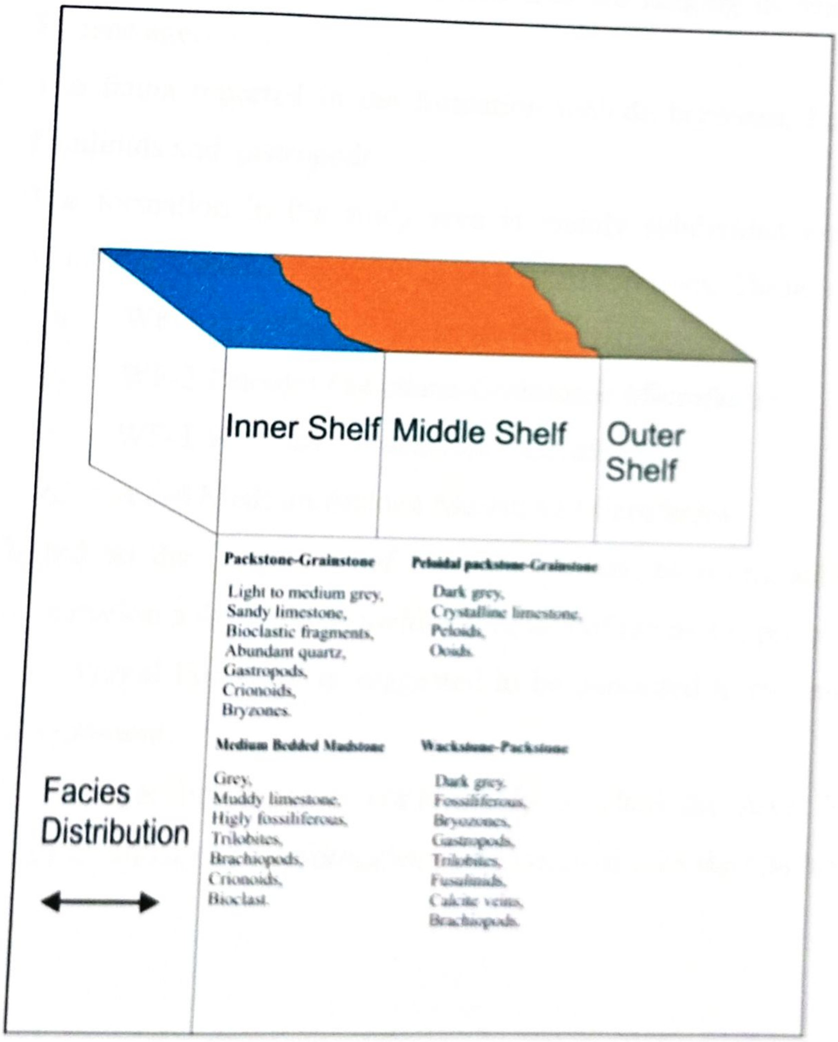


Fig. 4.5 Depositional Model

CONCLUSIONS

In this study a detailed facies analysis of Wargal Formation from the key stratigraphic sections of Western Salt Range have been documented. Based on thorough geological studies of the study area Nammal gorge section, Western Salt Range Pakistan, the following windings up is drawn;

- The Wargal limestone in the study section is comprised mainly of limestone.
- The rocks exposed in the studied area are ranging in from lower Permian to Eocene age.
- The fauna reported in the formation include bryzones, brachiopods, crinoids, fusulinids and gastropods.
- The formation in the study area is mainly subdivided into four microfacies, which are repeated vertically in the various sections. These microfacies are;
  - i. WF-1 Packstone-Grainstone Microfacies.
  - ii. WF-2 Peloidal Packstone-Grainstone Microfacies.
  - iii. WF-3 Wackstone-Packstone Microfacies.
  - iv. WF-4 Medium Bedded Mudstone Microfacies.
- Based on the integration of the outcrop data, biostratigraphic and microfacies information a dynamic depositional model of the unit is proposed.
- The Wargal limestone is suggested to be deposited in the inner to middle shelf environment.
- The Wargal limestone is conformably overlain the Amb Formation and the upper boundary of the formation is transitional with the Chiddru Formation.

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APPENDIX

COMPILATION OF MICROFACIES TYPES OF THE WARGAL LIMESTONE

Section Name	Sample No	Petrographic Features
Nammal Gorge Section	11, 12, 13	Packstone-Grainstone Microfaices WF-1 Light to medium grey, well preserved spares marine biolclastic fragments. Fine grained quartz present abundantly. The environment of deposition is shallow water.
	08	Peloidal Packstone-Grainstone Microfacies WF-2 Dark grey color, fine crystalline limestone. Peloidal have varied origin and environmental associations. The environment of deposition is middle shelf.
	02, 03, 04, 05, 06, 07, 09, 10	Wackstone-Packstone Microfacies WF-3 Dark grey fosssiliferous limestone. High diversity of fauna like crinoids, gastropods, bryozones and peloids etc inidcates middle shelf environment.
	01	Medium Bedded Mudstone Microfacies WF-4 Greyish color muddy limestone of high fossiliferous, calcite viens are clearly observed. The diagenetic fabric of facies includes iron leaching and calcite fracture. The environment of deposition is inner shelf