

PALAEOENVIRONMENTS, DIAGENESIS, AND
GEOCHEMICAL STUDIES OF THE DUNGAN FORMATION
(PALAEOCENE), EASTERN SULAIMAN RANGE, PAKISTAN.

Thesis submitted for the Degree of
Doctor of Philosophy
at the University of Leicester

by

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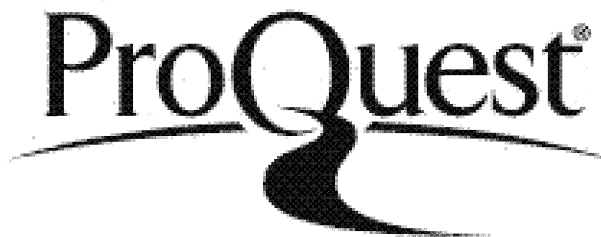
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Palaeoenvironments, Diagenesis, and Geochemical Studies of the Dungan Formation (Palaeocene), Eastern Sulaiman Range, Pakistan.

Nazir Ahmad

Abstract

The Sulaiman Range is located on the northwest margin of the Indian Plate. It forms the middle part of the Indus basin, and has been termed the Sulaiman sub-basin. The Indus basin is filled with a thick sequence of Mesozoic and Cenozoic sediments.

The Dungan Formation is Palaeocene in age and comprises a 98 m thick predominantly carbonate sequence which extends about 200 km from north to south along the Sulaiman Range. The Formation is characterised by different microfacies. Petrographic studies revealed the following microfacies; peritidal carbonate, inner lagoon, oolitic, outer lagoon, rhodolith platform, nummulitic, larger foraminiferal, and planktonic foraminiferal. All these facies can be interpreted broadly within a homoclinal, windward carbonate ramp model.

The cementation history has been investigated by petrography of stained thin sections, cathodoluminescence microscopy, XRD, electron microprobe, SEM (in back scattered mode), XRF, and carbon and oxygen stable isotope analysis to reveal trace element contents and their variation in the diagenetic cements. The diagenesis of the formation starts from the marine phreatic environment, characterised by micritization and peloidal cements. These cements are of high Mg-calcite, and low in Fe and Mn. They do not show luminescence. The active fresh water phreatic zone may involve leaching in the zone of solution, neomorphism, isopachous bladed cement around the oolites and foraminifera, syntaxial overgrowth cement on echinoderm fragments, and interlocking crystals of equant calcite that coarsen towards the pore centres (drusy cement). The neomorphic spars having irregular boundaries and are cloudy and patchy. They are also low in Fe and Mn, and non-luminescent. The isopachous bladed cements are low in Mg and high in Fe and Mn and show orange luminescence. The syntaxial overgrowth cements are low Mg-calcite. They show bright zoned luminescence, indicating different zones of Fe and Mn concentration. The drusy cement is also low Mg-calcite, and shows dull to orange luminescence indicating the high concentrations of Fe and Mn as compared to marine cement. The oxygen isotopic values of this cement type are low when compared to the whole rock. Vug and mould porosities are developed in the freshwater vadose zone, which are filled by sparry calcite cement. The shallow burial environment is marked by compaction of skeletal grains, stylolites and fractures. The fractures show two generations. The early fracture fills cements are non ferroan and show bright zoned luminescence. The later fracture fills cements are ferroan and non-luminescent. The oxygen isotope values of non-ferroan cement filling fractures are more negative when compared with that of ferroan cement filling fractures, which may be formed in shallow burial environments by formation water.

Table of Contents

	Page
Abstract	I
Table of Contents	II
List of Figures	V
List of Tables	VII
Acknowledgements	VIII
Chapter One Introduction	
1.1. Aim of the Study	2
1.2. Location of the Study Area	2
1.3. Field Work and Sampling	5
1.4. Method of Study	5
1.5. Structure of the Thesis	7
1.6. Previous Work	8
1.6.1. Sulaiman Range	8
1.6.2. Ramp Mode	10
1.6.3. Diagenesis	12
Chapter Two Regional Geology of Sulaiman Range	
2.1. Introduction	14
2.2. Regional Tectonic Setting	17
2.3. Indus Basin	18
2.4. Sulaiman Range	21
2.4.1. Sulaiman Foredeep	22
2.4.2. Sulaiman Foldbelt	22
2.5. History of the Area	25
Chapter Three Stratigraphy of Sulaiman Range	
3.1. Introduction	29
3.2. Wulgai Formation	31
3.3. Shirinab Formation	31
3.3.1. Loralai Limestone Member	32
3.3.2. Anjira Member	33
3.4. Chiltan Limestone	35
3.5. Sember Formation	38
3.6. Goru Formation	39
3.7. Parh Limestone	40
3.8. Mughal Kot Formation	41
3.9. Fort Munro Formation	42
3.10. Pab Sandstone	43
3.11. Dungan Formation	44
3.12. Ghazij Formation	46
3.13. Kirthar Formation	48
3.13.1. Habib Rahi Limestone Member	49
3.13.2. Domanda Shale Member	49
3.13.3. Pir Koh Limestone Member	49
3.13.4. Drazinda Shale Member	50
3.14. Nari Formation	50
3.15. Vihowa Formation	52
3.16. Litra Formation	53
3.17. Chaudhwan Formation	54

Chapter Four	Field Relation and Lithology of Dungan Formation	
4.1. Introduction		56
4.2. Lithology of Raghasar Section		56
4.3. Lithology of Zinda Pir Section		63
4.4. Lithology of Rakhi Nala Section		71
4.5. Comparative Studies of Sections		79
Chapter Five	Petrography of Dungan Formation	
5.1. Introduction		81
5.2. Limestone Classification		81
5.3. Carbonate Grains		82
5.3.1. Skeletal Allochems		82
5.3.1.1. Benthonic Foraminifera		83
5.3.1.2. Calcareous Algae		90
5.3.1.2.1. Calcareous Red Algae		90
5.3.1.2.2. Calcareous Green Algae		95
5.3.1.3. Bryozoa		96
5.3.1.4. Echinoderms		98
5.3.1.5. Molluscs		99
5.3.1.6. Corals		100
5.3.1.7. Planktonic Foraminifera		100
5.3.2. Non Skeletal Allochems		102
5.3.2.1. Ooids		102
5.3.2.2. Intraclasts		102
5.4. Non Carbonate Grains		103
5.5. Cement Types		103
5.5.1. Peloidal Cement		103
5.5.2. Neomorphic Spar		104
5.5.3. Isopachous Bladed Cement		105
5.5.4. Drusy Cement		105
5.5.5. Syntaxial Overgrowth Cement		106
5.6. Matrix		106
5.7. Porosity		108
5.8. Compaction and Pressure Solution		108
5.9. Microfractures		109
5.10. Veins		109
5.11. Rock Types		111
Chapter Six	Facies and Palaeoenvironments of Dungan Formation	
6.1. Introduction		112
6.2. Microfacies		112
6.2.1. Peritidal Carbonate Facies		113
6.2.2. Inner Lagoonal Facies		114
6.2.3. Oolitic Facies		116
6.2.4. Outer Lagoonal Facies		119
6.2.5. Rhodolith Platform Facies		122
6.2.6. Nummulitic Facies		128
6.2.7. Larger Foraminifera Facies		137
6.2.8. Planktonic Foraminiferal Facies		140
6.3. Depositional Model and Palaeoenvironments		141
Chapter Seven	Geochemical Studies	
7.1. Introduction		148
7.2. Samples and Methods		149
7.2.1. Field Samples		149
7.2.2. Laboratory Treatment		149
7.3. Methods and Techniques		150
7.3.1. X-Ray Differentiation Analysis		150

7.3.2. Electron Microprobe Analysis	150
7.3.3. X-Ray Fluorescence Analysis	150
7.3.4. Stable Isotope Analyses	152
7.4. Results and Interpretation	159
7.4.1. Whole Rock Mineralogy	159
7.4.2. Residual Mineralogy	159
7.4.3. Mineral Chemistry	162
7.5. Whole Rock Geochemistry	167
7.6. Results and Interpretation	168
7.6.1. Major Elements Geochemistry	168
7.6.2. Trace Element Geochemistry	181
7.6.3. Isotope Geochemistry	189
7.6.3.1. Carbon Isotopes	191
7.6.3.2. Oxygen Isotopes	193
7.7. Palaeotemperature	199
Chapter Eight Diagenesis and Diagenetic History of Dungan Formation	
8.1. Introduction	201
8.2. Diagenesis	201
8.3. Marine Diagenesis	202
8.3.1. Micritization	204
8.3.2. Peloidal Cement	205
8.4. Freshwater Diagenesis	207
8.4.1. Neomorphic Spar	208
8.4.2. Dissolution	211
8.4.3. Cementation	212
8.4.3.1. Isopachous Bladed Cement	214
8.4.3.2. Drusy Cement	216
8.4.3.3. Syntaxial Overgrowth Cement	219
8.5. Shallow Burial Diagenesis	220
8.5.1. Compaction	220
8.5.2. Pressure Dissolution	222
8.5.2.1. Dissolution Seams	222
8.5.2.2. Stylolites	222
8.5.3. Fractures and Veins	224
8.5.3.1. Early Fractures	224
8.5.3.2. Later Veins	225
8.6. Diagenetic History of Dungan Formation	227
Chapter Nine Conclusions	
9. Conclusions	229

List of Appendices

Appendix 1. Details of method used for staining thin sections.	231
Appendix 2. Details of method used for cathodoluminescence microscopy.	232
Appendix 3. Details of method used for XRD.	233
Appendix 4. Details of method and percision used for electron microprobe.	234
Appendix 5. Details of method and percision used for XRF.	236
Appendix 6. Details of method and percision used for stable isotope.	238
Appendix 7. Table A6.1. Point count data of thin sections.	239
Appendix 8. Table A7.1. Electron microprobe analysis of Dungan Formation.	244

References

References	255
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List of Figures

	Page
Chapter One Introduction	
1.1. Index map of Project Areas	3
1.2. Topographic location of the Project Areas	4
Chapter Two Regional Geology of Sulaiman Range	
2.1. Regional Tectonic Setting of Pakistan	15
2.2. Tectonic map of Sulaiman Foldbelt	16
2.3. Regional Tectonic map of Pakistan	19
2.4. Tectonic Features of Pakistan	23
Chapter Three Stratigraphy of Sulaiman Range	
3.1. Various Geological Provinces of Pakistan	30
3.2. Stratigraphic Sequence of Sulaiman sub-basin	34
3.3. Geological map of Sulaiman sub-basin	36
Chapter Four Field Relation and Lithology of Dungan Formation	
4.1. Lithologic log of Raghasar section	59
4.2. Outcrop photographs of Raghasar section	61
4.3. Lithologic log of Zinda Pir section	65
4.4. Outcrop photographs of studied sections	68
4.5. Lithologic log of Rakhi Nala section	73
4.6. Outcrop photographs of studied section	77
Chapter Five Petrography of Dungan Formation	
5.1. Photomicrographs illustrate petrography of Dungan Formation	84
5.2. Photomicrographs illustrate petrography of Dungan Formation	87
5.3. Photomicrographs illustrate petrography of Dungan Formation	91
5.4. Photomicrographs illustrate petrography of Dungan Formation	94
5.5. Cathodoluminescence microscopy petrography of Dungan Formation	97
5.6. Cathodoluminescence microscopy petrography of Dungan Formation	101
5.7. Photomicrographs illustrate petrography of Dungan Formation	107
5.8. Plot shows various rock types within the Dungan Formation	110
Chapter Six Facies and Palaeoenvironments of Dungan Formation	
6.1. Photomicrographs illustrate different facies in Dungan Formation	117
6.2. Photomicrographs illustrate different facies in Dungan Formation	121
6.3. Figure shows depth and abundance percentage of coralline algae	125
6.4. Figure shows depth distribution of different foraminifera	133
6.5. Photomicrographs illustrate different facies in Dungan Formation	136
6.6. Figure showing the lithology and facies types in Dungan Formation	143
6.7. Figure showing ramp profile and distribution of facies in Dungan Formation	144
6.8. Block diagram of proposed ramp model facies	146
Chapter Seven Geochemical Studies	
7.1.A. Detection limit for major elements	151
7.1.B. Detection limit for trace elements	151
7.2. XRD traces of calcite	160
7.3.A. XRD trace of residue	161
7.3.B. XRD trace of residue	161
7.4. Mineralogy of carbonate skeletal grains	163
7.5.A. Comparison of Sr content in recent and Dungan Formation sediments	164

7.5.B. Comparison of Mg content in recent and Dungan Formation sediments.....	164
7.6. Correlation plots of major elements.....	171
7.7. Correlation plots of major and trace elements	172
7.8. Correlation plots of major and trace elements	173
7.9. Scattered plot showing the luminescent and non-luminescent grains.....	177
7.10. Correlation plots of trace elements	185
7.11. Correlation plots of trace elements	186
7.12. Scattered plot of carbon oxygen isotope values	192
7.13. Variation of $\delta^{18}\text{O}$ values of Dungan's marine and freshwater sediments.....	194
7.14. Plot showing the diagenetically altered and unaltered sediments	196
7.15. Correlation chart of Sr and $\delta^{18}\text{O}$	198
7.16. Correlation chart of $\delta^{18}\text{O}$ and percentage of foraminifera	198
Chapter Eight Diagenesis and Diagenetic History of Dungan Formation	
8.1. Figure illustrates different diagenetic zones	203
8.2. Photomicrographs illustrate different diagenetic features	206
8.3. Photomicrographs illustrate different diagenetic features	209
8.4. Photomicrographs illustrate different diagenetic features	213
8.5. Photomicrographs illustrate different diagenetic features	215
8.6. Photomicrographs illustrate different diagenetic features	217
8.7. Photomicrographs illustrate different diagenetic features	221
8.8. Photomicrographs illustrate different diagenetic features	223
8.9. Figure illustrates the proposed diagenetic history of Dungan Formation.....	226

List of Tables

	Page
Chapter Six Facies and Palaeoenvironments of Dungan Formation	
6.1. Thin section point count data	115
Chapter Seven Geochemical Studies	
7.1. XRF analyses of major and trace elements	153
7.2. Electron microprobe analyses of carbonate grains	166
7.3. XRF analyses of major elements in different facies	169
7.4. Electron microprobe analyses of carbonate grains in different facies	179
7.5. XRF analyses of trace elements in different facies	183
7.6. Carbon and oxygen isotope values of different facies	190

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Chapter One

INTRODUCTION

Rationale

This thesis describes and interprets the facies development and diagenetic history of Palaeogene carbonate rocks (the Dungan Formation) from the Sulaiman Range, Central Pakistan.

Palaeogene carbonates form the most significant hydrocarbon reservoirs in Pakistan. This is partly because carbonate sedimentation was fairly widespread, particularly in Central Pakistan. Remarkable facies changes all across the Indus Basin represent widespread carbonate platforms, ramps and shale basins with selective barred and silled basins. Very few sedimentological works have been carried out so far, particularly in Sulaiman Range. In 1952, after the discovery of a giant gas field in Sui (Sulaiman Range) by Pakistan Petroleum Limited (PPL), the area attracted organisations to study the region. As a result some oil companies entered in the region with their commercial and economic interest. Pakistan Petroleum Limited (1952-1960), Oil and Gas Development Corporation (1975-1985), Pakistan Shell Oil Company (1958-59) and then as Pakistan Shell Petroleum Development (1980-1981) focused their activities in the Sulaiman Range, although detailed sedimentological work was not carried out. Their main aim was to study the stratigraphy, tectonics and petroleum geology of the region. All the information which they collected was secret

and unpublished. Very few academic works had been carried out in the area due to limited field facilities and the tribal customs.

1.1. Aims of Study:-

The study has been conducted with the following aims:

- To provide a detailed petrography which will help a better understanding of carbonate classification, diagenesis, diagenetic history, and palaeoenvironments.
- To establish the microfacies within the Dungan Formation.
- To reconstruct the palaeoenvironmental model on which these facies can be interpreted.
- To evaluate the diagenesis and the diagenetic history of the formation on the basis of petrographical and geochemical analysis.

1.2. Location of the Study Area:-

The area described in the present investigation is located from north to south along the eastern part of Sulaiman Range (Figure, 1.1). It lies between lat. $29^{\circ} 57' 44''$ and $31^{\circ} 37'$ N, and long. $70^{\circ} 02' 30''$ and $70^{\circ} 30'$ E, and is covered by a part of topographic sheet Nos. 39I, 39J and 39K (Figure, 1.2). It covers almost 200 km. distance from north to south. The area is along the boundary of Punjab and Baluchistan; and North West Frontier Province and Baluchistan provinces (Figure, 1.2). The northern part of the study area lies in the province of North West Frontier Province and the southern part in the province of Punjab (Figure, 1.2). The entire area under investigation lies in the

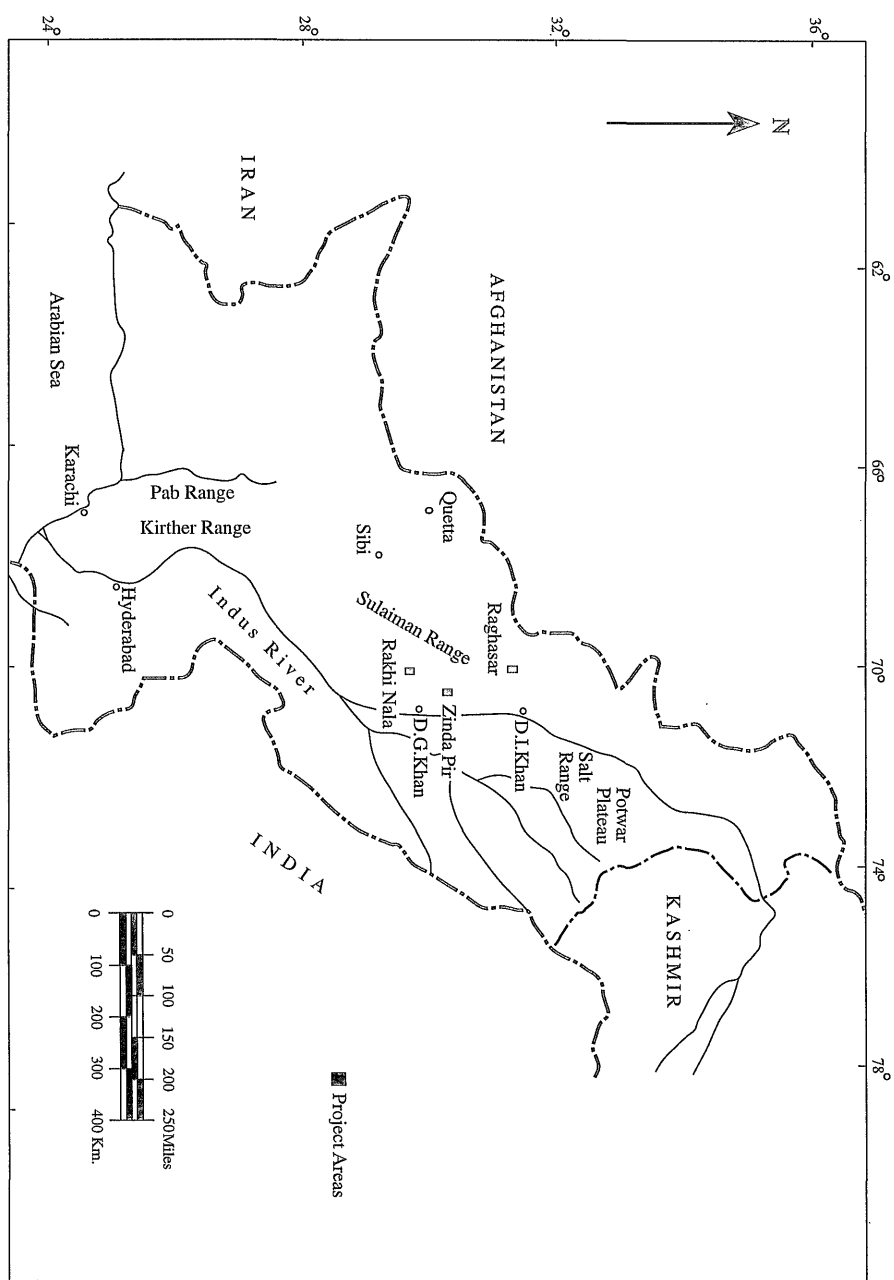


Fig. 1.1. Location map of the Project Areas.

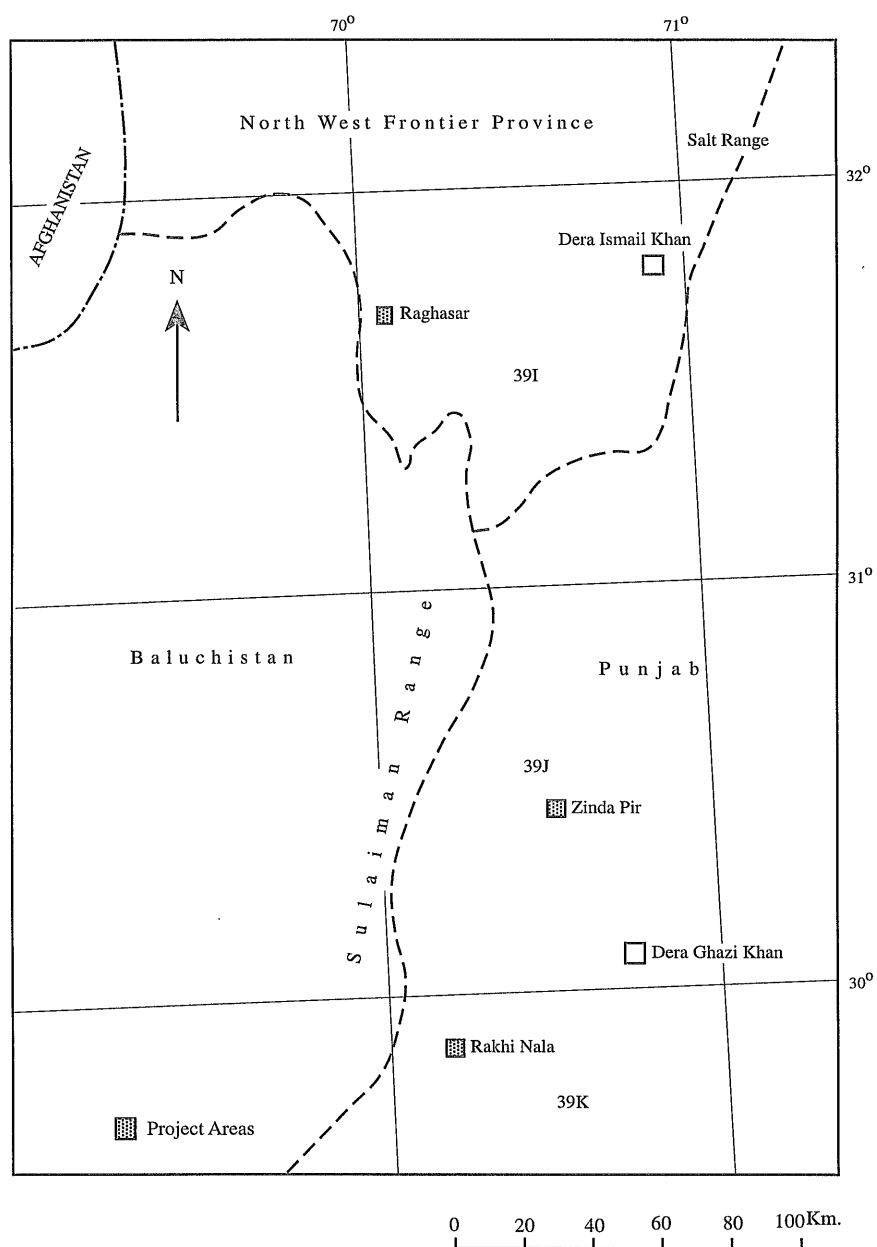


Fig. 1.2. Map showing the topographic locations of the project areas.

tribal area of Dera Ismail Khan and Dera Ghazi Khan. The location of the project area is shown in Figures 1.1 and 1.2.

1.3. Field Work and Sampling:-

The field work on which this investigation is based was carried out in three stages, began in Dec. 1992 and continued intermittently until May 1993. Three sections were selected to collect the samples. The selection of these sections were taken in a way to get the maximum coverage of the facies changes vertically and laterally from north to south. In first stage the northern part of the area is covered, in second stage the central part of the area is covered, and the southern part of the study area is covered in last stage. The entire area is exposed very well. Streams and roads cut the rocks and as a result excellent outcrops are seen. More than 160 samples were taken from all the three sections on the basis of bio and lithologic changes. The physical characteristics of the rocks, their bedding trend and character, and sedimentary structure within the strata have observed during the field excursion. All samples were collected from these three outcrops.

1.4. Method of Study:-

The samples are used to prepare the thin sections in order to interpret the carbonate classification, microfacies, and the environments of deposition. They were studied using binocular microscope and optical microscope. Thin sections were stained

according to the techniques of Dickson (1966), which is modified from that of Friedman (1959).

A total of 132 thin sections from the samples collected from three localities were used in the present study. A large petrographic microscope was used for thin section study for such details as skeletal and non-skeletal allochems. Carbonates were classified according to schemes of both Folk (1959), and Dunham (1962). Cement types, porosity distribution and types, diagenesis, and diagenetic history were also examined. Point counts (1000 per slide), were made for the thin sections (see appendix 7) in order to determine the percentage of allochems. The percentage thus obtained formed the basis for numerous petrographic plots.

Polished thin sections were used for cathodoluminescence microscopy, and the carbon coated thin sections were used for scanning electron microscopy and electron microprobe analysis. The cathodoluminescence microscopic studies helped to determine the cement stratigraphy, and the better recognition of growth stages in void-filling calcite cement, the delineation of vein calcite which is seen in optical continuity with the host rock, and for the better discernment of fossils in altered carbonates (Sipple and Glover, 1965). The scanning electron microscope to identify the skeletal allochems particularly the foraminifera. The electron microprobe was used to analyse the chemistry of the skeletal allochems, cement, and veins.

Ground powders from the samples were used for x-ray diffraction analysis to determine the mineralogy of the whole rock, and x-ray fluorescence analyses to establish the whole rock chemistry of the major oxides and trace elements. All these techniques were performed in Leicester University. The picked grains and ground

powder was also used for carbon oxygen stable isotope analyses. This technique was carried out at NERC Isotope Geosciences Laboratory, Keyworth.

1.5. Structure of the Thesis:-

The whole study is carried out in two sections. The first deals with the facies and the palaeoenvironments, and the second with the diagenesis and diagenetic history of the Dungan Formation.

Chapter Two describes the major tectonic elements and tectonic history of Pakistan particularly with structural features and tectonic activities in the Sulaiman Range. It also includes the development of the Indus Basin, Sulaiman sub-basin and sub-Sulaiman foredeep.

Chapter Three. This chapter deals with the stratigraphy of the Sulaiman Range, which includes the stratigraphy in the Sulaiman foldbelt and Sulaiman foredeep. It comprises the lithologic characteristics, type localities, fauna and flora, the thickness of the formation, and their relationship to the overlying and underlying formations.

Chapter Four. This chapter explains the geological observations made during the geological field excursion. It includes the lithologic variations and sedimentary structures within the Dungan Formation. The thickness of individual beds their styles, and their relationship to overlying and underlying units are also described in this chapter.

Chapter Five. This chapter deals with the petrographic work done under binocular microscopy, optical microscopy, scanning electron microscopy and cathodoluminescence microscopy. Folks (1962) and Dunham's (1962) classification of limestones are adopted to describe the petrography of Dungan Formation.

Chapter Six. In this chapter an attempt has been made to establish the microfacies within the Dungan Formation, on the basis of the observations described in chapter four and the observations taken from the preceding chapter. It also includes the palaeoenvironmental model on which all these facies can be interpreted.

Chapter Seven. This chapter comprises the results and the interpretation of geochemical characteristics of the facies of the Dungan Formation, including data on major and trace elements (XRF), oxides of Ca, Mg, Fe, Mn, Sr, and Ba of the skeletal allochems, cement and veins (EMP), the mineralogy of the whole rock (XRD), and carbon oxygen stable isotope values.

Chapter Eight. In this chapter an attempt has been made to reconstruct the diagenesis and the diagenetic history of the Dungan Formation, on the basis of the observations studied in chapter five and the results of the preceding chapter.

Chapter Nine. In this chapter all the information deduced from these investigations are summarised and further work has been recommended to study more sections.

1.6. Previous Work:-**1.6.1. Sulaiman Range:-**

The earliest references, regarding the geology of Sulaiman province are by Steward (1860), Vercher (1867), and Griesbach (1884). Blandford (1883), Oldham (1890), and La Touche (1893) did early reconnaissance work in the Sulaiman Range (as cited by Eames, 1952). Paleogeographic and stratigraphic studies were done on Cretaceous and Paleocene rocks of the Sulaiman Range by Davies (1939) and Pinfold (1939). Eames, (1952) worked out the basic stratigraphy in the Fort Munro and Zinda Pir structures in the eastern Sulaiman Range. The Hunting Survey Corporation, carried out major reconnaissance mapping (1:253,000 scale), using aerial photographs supplemented with field checks (Jones, 1961). Abdel Gawad (1971) and Rowlands (1978) interpreted the shape and gross structure of the Sulaiman lobe with the help of satellite images. Hemphill and Kidwai (1973) mapped the northern part of the Sulaiman Range at the scale of 1:250,000 and recognised some strike-slip and thrust faults. Shah (1977) renamed the stratigraphic unit of the area according to the new stratigraphic nomenclature (accepted by the Stratigraphic Committee of Pakistan). Sarwar and DeJong (1979) interpreted the arcuate shape of the Sulaiman lobe. Gansser (1979), Abbas and Ahmad (1979), Allemann (1979) and Asrarullah et al. (1979) have described the various features of the Zhob valley ophiolites. Banks and Warburton (1986) proposed a passive-roof duplex model to explain the frontal portions of the Sulaiman and Kirthar ranges. Wells (1984), Waheed, Wells and Ahmad, (1988) carried out sedimentological and paleocurrent studies in the northern part of the Sulaiman Range. Ahmad (1987) and Malik et al. (1988) discussed the

petroleum potential and prospects of the Sulaiman foredeep. Raza, et al. (1989) gave the hydrocarbon prospects of the Sulaiman sub-basin. Lillie et al. (1989) and Jadoon et al. (1989) have explored the possibility of the presence of thin transitional or oceanic crust beneath the Sulaiman Range. Humayon et al. (1991) interpreted the structural style and tectonic shortening of the eastern Sulaiman foldbelt and the foredeep. A great deal of work regarding the stratigraphy, palaeontology, and economic geology has been done on the Sulaiman Range by Geological Survey of Pakistan, and Hydrocarbon Institute of Pakistan. Oil and Gas Development Corporation and other oil companies contributed in the field of stratigraphy and structure by geophysical prospecting. The conclusions of most of the work were available for this present investigation.

1.6.2. Ramp Model:-

In most of the early studies on carbonate rocks, description of fossils, lithology and position in the stratigraphic sequence were emphasized. Little was known about modern carbonate facies patterns. Studies of the recent carbonates during the 1950s and 1960s however, led to the establishment of model depositional environments which could be used as analogues for ancient carbonate environments. The late 1960s and early 1970s have been devoted mainly to studies of carbonate diagenesis, since most of the recent carbonate environments of the world are no longer virgin territory. A range of carbonate depositional models were developed based largely on modern analogues from the Bahama, the Florida Shelf, and Yucatan (Bathurst 1975; Wilson 1975). The term shelf environment is commonly used to describe nearly all ancient

neritic carbonates, and in some instances reefs are designated, a priori, as shelf-margin buildups. However, the typical shelf model is not adequate to explain many limestone facies patterns such as those on the Campeche Bank (Pleistocene to Holocene), the Persian Gulf (Holocene) and many others (Ahr 1973).

Major carbonate bodies built away from land and with very gentle regional slopes are commonly termed ramps. The concept of ramp was given by Ahr 1973, defining "a sloping surface connecting two levels". The carbonate ramp model is a sloping topographic surface on which carbonate facies are deposited while subject to open ocean conditions from the surf zone to depth of hundreds of metres. The growing facies, however, will be deposited near the surf zone and the adjacent mainland. The ramp model displays facies patterns which are opposite to the shelf model in lateral relationship. That is, in the ramp model, grainstone and packstone facies are the landward facies, and the wackestone and mudstone facies are mainly the seaward facies. Read 1982, and 1985, classified ramps into homoclinal and distally steepened ramps on the basis of their profile. He also identified the difference of facies patterns in these ramps. Buxton and Pedley (1989), worked on Cenozoic ramps in Mediterranean and presented a ramp model for Tethyan Tertiary carbonates. The Tethyan ramps are particularly widespread and extend tens of hundreds of kilometers along strike and occupy tens of kilometers of slope. Many studies have dealt with Cenozoic ramp associations and sequences, and have demonstrated the diversity of biotal and sediment detail but without ascribing them to the ramp model (Buxton and Pedley, 1989). They also described the characteristic features of biofacies and their pattern which can be interpreted on the Tethyan Tertiary carbonate ramp models. These down ramp biofacies are suggested as being commonly present in Cenozoic ramps and

typical of Palaeogene and Neogene ramps. They also concluded that the ramp model is applicable in geographically disparate regions such as in the Caribbean and in the western palaeomediterranean. They concluded that the ramp model may be of major value in basin analysis and especially in hydrocarbon exploration where ramps can provide important migration routes from basin to platform reservoir. Burchette and Wright (1992), subdivided ramps on environmental basis into inner ramp, mid ramp, outer ramp, and basin. They discuss the different facies fitted in these subdivisions, and the tectonic setting of the ramp models.

1.6.3. Diagenesis:-

Diagenesis includes obvious processes such as cementation to produce limestones and dissolution to form cave systems but it also includes more subtle processes such as the development of microporosity and changes in trace elements and isotope signatures. Studies of limestone diagenesis involve trying to identify the original mineralogy of the various cements, their significance in terms of pore-fluid chemistry and diagenetic environments and the relative timing of precipitation and any alteration. The manner in which the grains themselves are preserved is also important. Such studies involve optical petrography, cathodoluminescence, scanning electron microscope examination, and geochemical analysis for isotope and trace element signatures. Some of the relevant previous references include, Ginsburg (1957); Bathurst (1958, 1959, 1975); Keith and Weber (1964); Friedman (1964, 1975); Folk (1965, 1974); Land (1967, 1970); Matthews (1967, 1968); Bricker (1971); Tucker (1973); Tucker and Kendall (1973); Milliman (1974); Hudson (1975, 1977); Meyers (1978, 1980); Dickson and

Coleman (1980); Allan and Matthews (1977) ; and Longman (1980). The compilations of some related useful papers include Roehl and Choquette (1985); Schneidermann and Harris (1985); Schroeder and Purser (1986); Choquette and James (1988) and Tucker and Bathurst (1989).

Chapter Two

REGIONAL GEOLOGY OF SULAIMAN RANGE

2.1. Introduction:-

The Himalayan orogenic belt is the world's largest active continental convergent zone extending westward from Burma through northern India and Nepal into Pakistan (Gansser, 1981); as a result of underthrusting of the Indian craton beneath its own sedimentary cover, several fold-and-thrust belts have formed (Figure 2.1). These belts are more than 100 km wide along a series of lobes in Pakistan (Salt, Sulaiman, and Kirthar Ranges), in contrast to India and Nepal, where the width of the fold and thrust belt is less than 50 km (Figure 2.1). Lillie et al., 1987; Leathers, 1987; Baker et al., 1988; Jaume and Lillie, 1988; and Pennock et al., 1989; studied the structural style of the Salt Range/Patwar Plateau in detail. Humayon, Lillie, and Lawrence, 1991; and Jadoon, Lawrence, and Lillie, 1992; studied the structural style of the Sulaiman Range. The broad Sulaiman foldbelt is developed by transpression as a result of the left-lateral strike-slip motion along the Chaman fault zone and southward thrusting along the western boundary of the Indian subcontinent (Figure 2.1 and 2.2) (Sarwar and DeJong, 1979; Lawrence et al., 1981; Fareh et al., 1984; Quittmeyer et al., 1984). The frontal part of the Sulaiman foldbelt is seismically active (Quittmeyer et al., 1979, 1984), however, the stratigraphy is not disrupted by any thrust faults that break the surface (Figure 2.2).

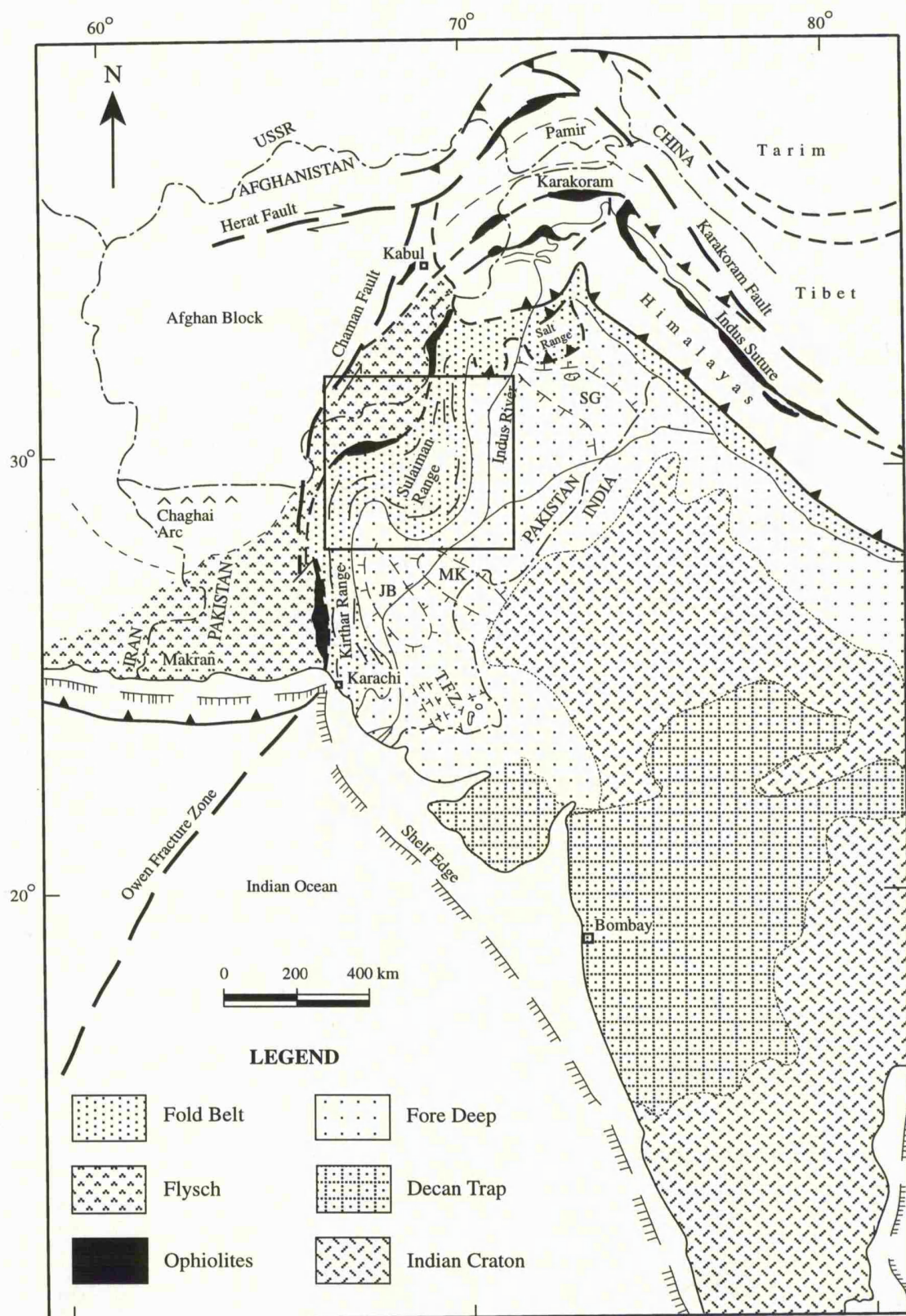


Fig. 2.1:- Regional tectonic setting of Pakistan (modified from Stonely (1974), Powell (1979), and Kazmi and Rana (1982)), showing the position and lobate shape of the Sulaiman Range on the western edge of the Indian subcontinent. (The abbreviations are TFZ, Talhar fault zone; JB, Jaccobabad basement high; MK, Mari-Kandkot basement high; SG, Sargodha basement high)

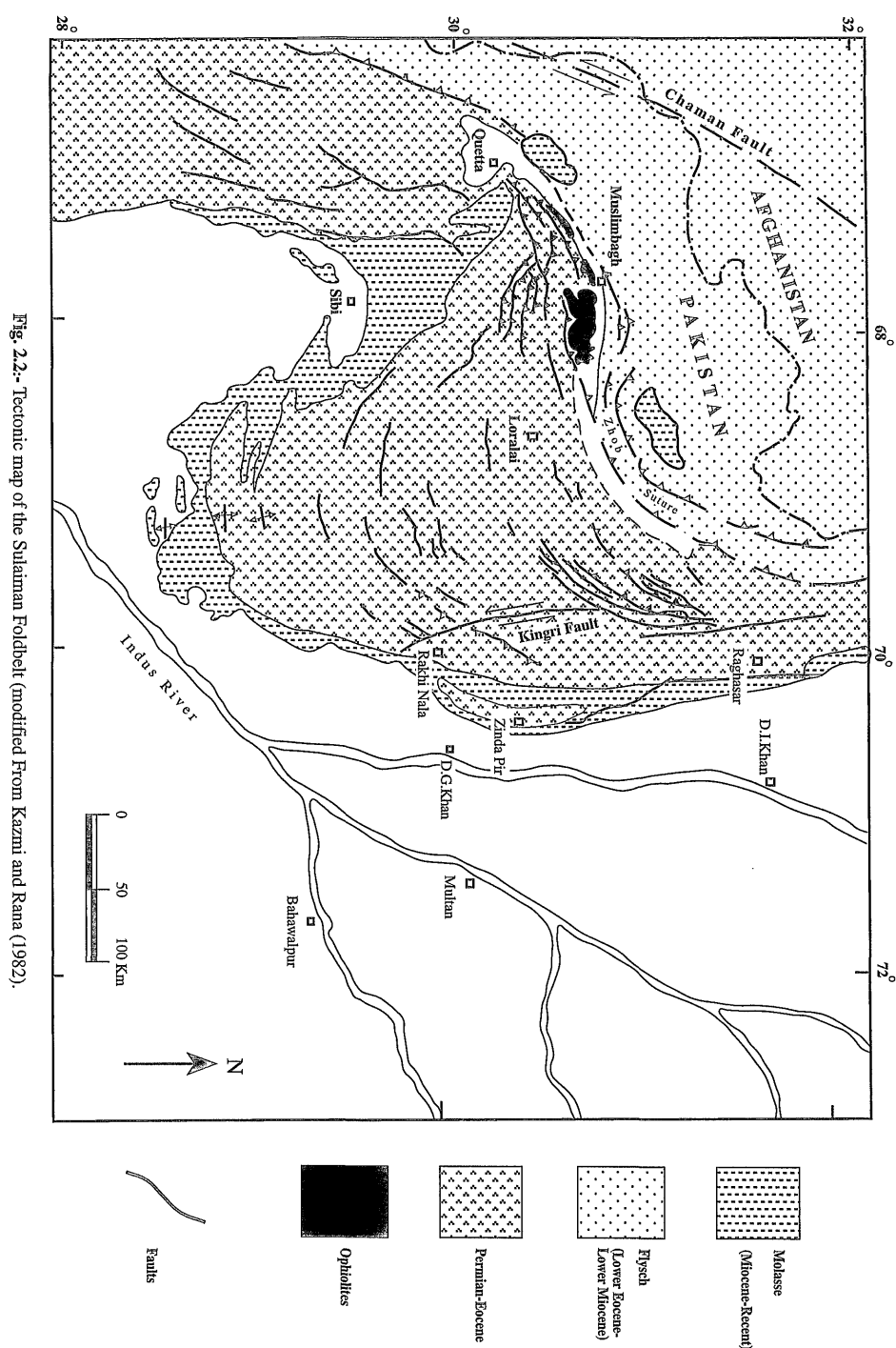


Fig. 2.2:- Tectonic map of the Sulaiman Foldbelt (modified From Kazmi and Rana (1982).

2.2. Regional Tectonic Setting:-

The Indian subcontinent is interpreted as having separated from Australia and Antarctica about 130 Ma and migrated northward, closing the Tethys sea. After consumption of Tethyan oceanic crust along a north dipping subduction zone, continental crust of the Indian plate collided with Asia about 50 Ma (Powell, 1979). This collision has resulted in the rise of the Himalaya, along with the development of several folded thrust belts that now flank the northern and western margins of the Indian plate (Figure 2.1). In Pakistan, the northern boundary of the plate remains a convergent boundary (i.e. in the area of the Salt Range and Potwar Plateau), while oblique collision with the Afghan block formed the Sulaiman and Kirthar Ranges in a transpressional zone on the northwest and west, respectively (Yeats and Lawrence, 1984), (Figure 2.1).

The western boundary of the Sulaiman Range is demarcated by a suture zone through the Zhob valley (Figures 2.2), which consists of a discontinuous belt of ophiolite (Abbas and Ahmad, 1979; Gansser, 1979; Farah et al., 1984) and Mesozoic sedimentary rocks interrupted by numerous faults, unconformities, and facies changes (Jones, 1961; Wells, 1984). This suture is not active; instead, the Chaman strike-slip zone, to the west, connects the northern Himalayan convergence zone with the Makran convergence zone in the south, where oceanic crust of the Arabian plate is being subducted (Farah et al., 1984). The eastern and southern boundaries of the Sulaiman Range are marked by broad folds abutting alluvial deposits of the Indus River System, which flows through the active Himalayan foredeep (Figure 2.1).

2.3. Indus Basin:-

According to Sokolove and Shah, (1965) the areas of Pakistan are located within two geotectonic elements i.e, the ancient Pre-cambrian platform and the young Alpine folded area, known as Himalayan Alpine Belt (Figure 2.1). To the northwest of the Indian Shield, the areas of Pakistan, were parts of a sedimentary basin and were occupied by a S-shaped geosynclinal trough which existed from late Pre-cambrian times.

Before the commencement of the Himalayan orogeny in the Tertiary period i.e, prior to early Paleocene and during the Jurassic times, a general flooding of the entire areas of Pakistan occurred which resulted in the deposition of massive, oolitic and pelletaloid limestones, radiolarian limestones and argillaceous sediments. The principal movements within the geosyncline were isostatic rather than the orogenic. The isostatic movement resulted in the development of geanticlinal belts that formed longitudinally in the central part of geosyncline from middle to late Mesozoic times and divided it into subsidiary depositional basins with separate tectonic and sedimentary history. These were the Foreland Indus Basin towards the east and Hinterland Baluchistan Basin towards the west, separated by the Axial Belt (Hunting Survey Corporation, 1961).

Axial Belt can be traced from the Arabian Sea, west of Karachi to the Pak-Afghan border, north of Fort Sandeman and is now exposed as an intensively folded thrust and intruded zone.

In the basin architecture of Pakistan Zubari and Dubois (1962), have proposed that the

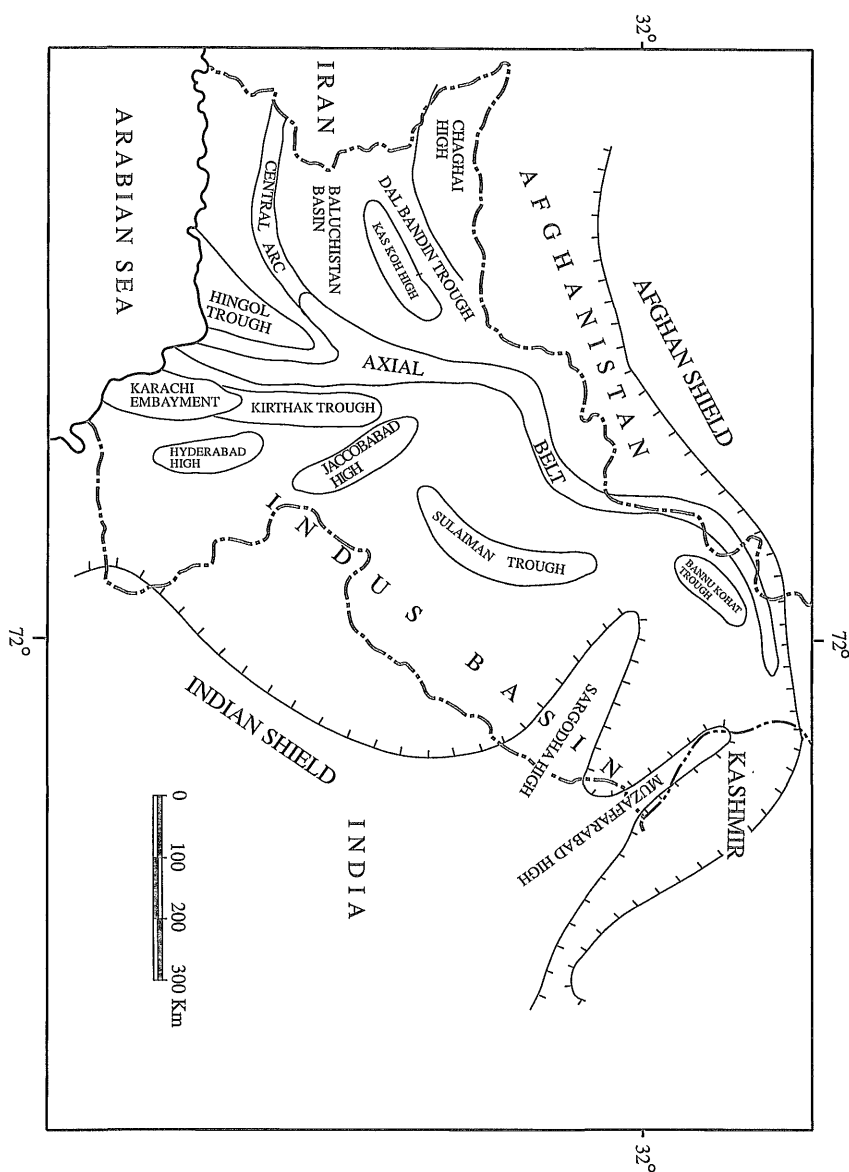


Fig. 2.3:-Regional Tectonic map of Pakistan, after H. Rahman, 1963.

development of two basins took place with the incursion of the "Tethys Sea" during early Paleozoic times that formed a great structural trough. In this trough, the deposition of at least 15,240 metres. of sediments took place in water of shallow to moderate depths, extending over an area of about 5,12,000 square km. The Indus Basin is commonly referred to as a "Calcareous Zone" where the shallow water limestones, shales and sandstones were deposited. In the Baluchistan Basin which is generally known as "Arenaceous Zone" on the other hand sand, shale and flysch deposits were laid down.

The irregular ridges of Indian Shield that extend northwestward into the Indus Basin seem to be the most important and prominent tectonic element in the Indus Basin. Three such positive blocks extend through Muzaffarabad, Sargodha and Jaccobabad (Fig. 2.2) which acted as barriers in the shelf or neritic parts of the Indus Basin in different geological ages and thus subdivided the basin into three recognisable provinces, namely, the Potwar Bannu, the Sulaiman and the Kirthar Provinces, from north to south respectively. In each province, a general southeast to northwest sloping shelf gave place to a trough (Figure 2.3) on the eastern side of the Axial Belt (Rahman, 1963).

In the middle Miocene, during a severe phase of Himalayan orogeny, these positive blocks acted as resistant buttresses against the softer sediments that were being pushed towards the Indian shield and as a result gave rise to the syntaxial bend in the fold mountain axes. The folds gathered together and attained maximum intensity at these bends on the Indian side of which, foredeeps were generated due to this corresponding depression of the resistant spur.

Renewed southward thrusting since late Oligocene-early Miocene constantly reworked the molasse strata migrating the Indus basin further east and south (Banks and Warburton, 1986; Waheed et al., 1988).

2.4. Sulaiman Range:-

Unlike the Salt Range/Potwar Plateau that is associated with the main zone of Himalayan convergence, the Sulaiman foldbelt is located along a zone of transpression in the northwestern part of the Indian subcontinent (Figure 2.1). The foredeep basin (Figure 2.4) to the east and south of the active Sulaiman lobe is formed mainly as a result of tectonic compression between the Indian plate and the Afghan block (Figure 2.3). The initial event of collision is manifested by the emplacement of the Muslimbagh ophiolite (Figure 2.2) between late Cretaceous and early Eocene times (Allemann 1979). An unconformity between Cretaceous and Palaeocene rocks in the Attock Cherat Ranges north of the Potwar Plateau (Yeats and Hussain 1987) extends all the way to the Loralai valley of the Sulaiman Range (Hunting Survey Corporation, 1961). The main structural elements in the Sulaiman foldbelt are east-west trending arcuate folds and faults which change to a north-south direction along the margin of the active foldbelt (Figure 2.2). Imbricate faults are visible at the surface only in the north (Hunting Survey corporation, 1961; Kazmi and Rana, 1982). They gradually disappear toward the frontal part of the foldbelt in the subsurface. Tear faults such as the Kingri fault, manifest neotectonic activity by the offset of fold axes, faults, uplifted and tilted gravel beds, and major bends along the course of the streams (Abdel-Gawad, 1971; Rowlands, 1978).

2.4.1. Sulaiman Foredeep:-

Structurally, the Sulaiman foredeep (Figure 2.4) is a broad syncline with a very gentle, undisturbed eastern limb and a steeper western limb. The eastern limb has monoclinal dips of 1° to 2.5° and is over 200 km wide. In the eastern portion of this monocline, several salt-cored anticlines have been formed (unpublished report of Pakistan Shell Petroleum Company, 1980). The average thickness of the Salt Range Formation in this area is about 500 m, with 100 to 200 m of salt section. Thickness increases in the core of anticlines due to the flow of the salt from beneath adjacent synclines. The monoclinal structure of the Sulaiman foredeep extends 25 km west of the Indus River, where it is separated from the foldbelt by a syncline (Humayon et al., 1991). The depth of the basement beneath this syncline is about 8 km. West of the synclinal axis, basement reflections extend off the bottom of the time sections and therefore cannot be traced beneath the Sulaiman foldbelt (Humayon et al., 1991).

2.4.2. Sulaiman Foldbelt:-

The overall structure of the eastern Sulaiman Foldbelt (Figure 2.4) is different from that of the central part of the Sulaiman lobe. A sharp contrast in structural trends exists across a left-lateral strike-slip fault known as the Kingri fault (Hunting Survey Corporation, 1961). The trends of the structures are mainly east-west, more or less perpendicular to tectonic transport direction, near the fault on the west. However, structural trends are N-S to NNE-SSW and quite oblique to the tectonic transport

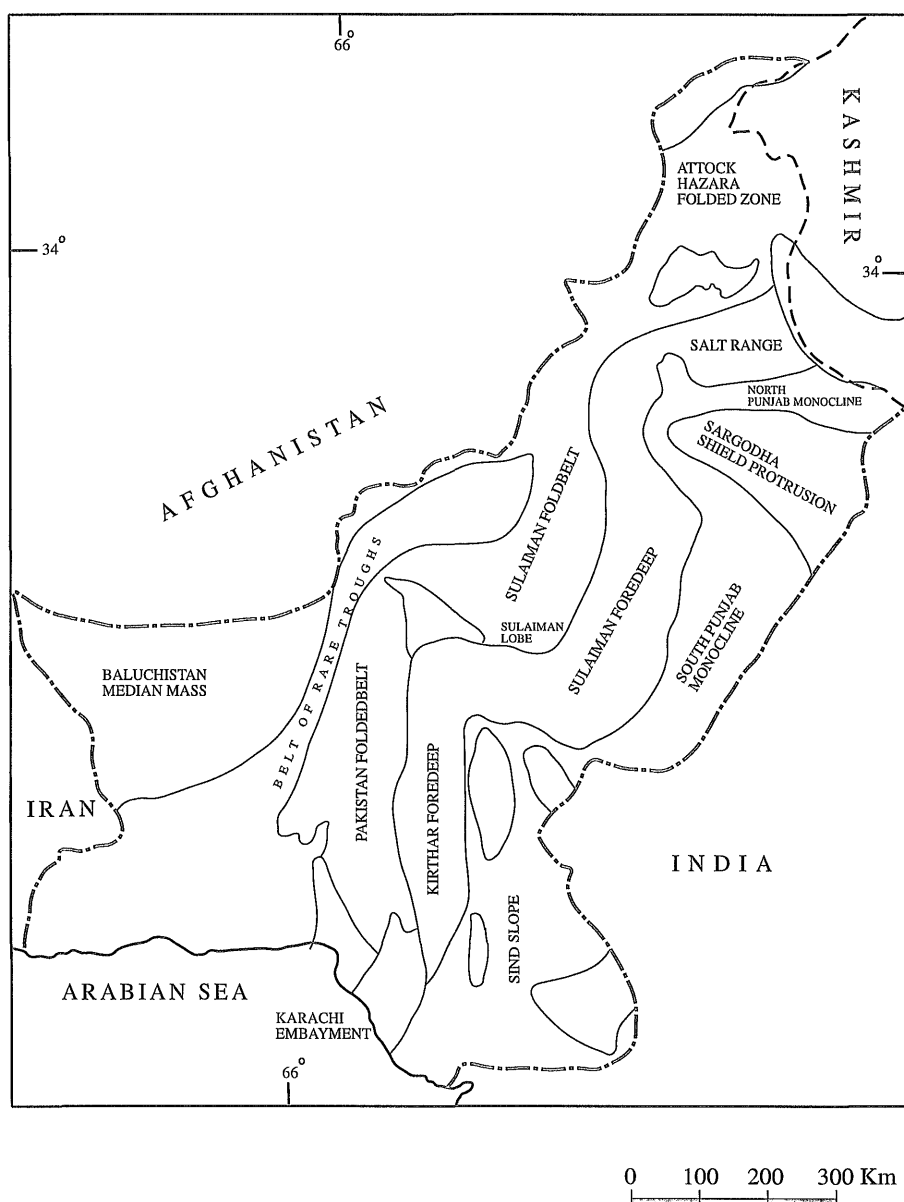


Fig. 2.4:- Tectonic Features of Pakistan modified after Sokolove and Shah (1965).

direction on the east side of the fault. It appears that the central Sulaiman lobe has moved further, in a thin-skinned manner, than the eastern part. Low topographic slope and broad concentric folds near the southern deformational front (Jadoon et al., 1990) contrast with higher topographic slope and tighter folds near the eastern deformation front (Humayon et al., 1991), consistent with this idea. The further movement of the central Sulaiman lobe appears to be accommodated by left-lateral motion along several strike-slip faults (including the Kingri fault), and by the formation of a passive roof duplex (Jadoon et al., 1990; Humayon et al., 1991) in the eastern Sulaiman lobe.

The deformation front of the Sulaiman foldbelt shows foreland-dipping molassic strata throughout its length, and no thrust appears on the surface. This suggests that blind thrusts are present in the cores of the frontal folds of the Sulaiman foldbelt, as is the case in the Rocky Mountains of Canada (Thompson, 1981). A similar situation exists in the frontal part of the eastern Salt Range/Potwar Plateau, where blind thrusts are present in the cores of anticlines (Pennock et al., 1989). This is in contrast to the central and western Salt Range, where the lowermost detachment (Salt Range thrust) appears on the surface (Lillie et al., 1987).

Rocks from the Sulaiman foldbelt (Figures 2.2 and 2.4) can be divided into three main groups to emphasize their tectonic significance. From south to north these units are;

- (1) Late Miocene to Recent molasse deposits;
- (2) Permian to Eocene, Shallow marine shelf to deep marine rocks (Kazmi and Rana, 1982); and
- (3) Late Eocene to early Eocene Khojak Flysch (Lawrence and Shahid, 1990).

The Muslimbagh ophiolite in the Zhob valley represents pieces of oceanic crust thrust over Maestrichtian shelf strata (Abbas and Ahmad, 1979). The Sulaiman foldbelt with

such a thick sedimentary section yet with relatively high Bouguer gravity anomalies is interpreted to overly an extended crust (Lillie et al., 1989; Jadoon et al., 1989).

2.5. History of The Area:-

A Permian to Pleistocene sequence of rocks, with few breaks, is exposed at the surface or drilled in the Sulaiman Range (Shah, 1977). Sedimentary rocks older than Permian are thought to be in the subsurface (Banks and Warburton, 1986), but this has not been confirmed by drilling. The youngest rocks, of Pleistocene age, are present in the foothills along the eastern and southern edge of the Sulaiman Range (see Figure 3.3). Surface exposures are generally older towards the interior, with the oldest rocks exposed near the northwestern part of the range (see Figure 3.3). Although the oldest rocks exposed are Permian in age, they are present only in the form of isolated outcrops near Kalat, Wulgai, and Ghazaband. Drill hole data within 200 km of the Sulaiman deformation front show the presence of a late Precambrian evaporite sequence beneath the foredeep (Humayon et al. 1991). Thinning and truncation of Cambrian strata in the northern part of the Salt Range/Potwar Plateau and in the western part of the Sulaiman foredeep suggest that the platform was gently dipping to the east during the Cambrian. There is a significant stratigraphic break between Middle Cambrian and Early Permian rocks. Deposition of Permian tillitic boulder beds and fluvial sandstones indicates marginal basin conditions during the Early Permian, which gave way to marine conditions during the Late Permian. The presence of these Late Permian limestones in the western part of the Sulaiman foldbelt and continuation of Permian reflectors (with westerly dip) on seismic lines near the deformational front

show that the platform had already started to tilt toward the west/northwest during the Late Permian (Humayon et al. 1991).

A Mesozoic section of more than 8000 m in the Sulaiman Range, consisting mainly of carbonate rocks and deepwater shales, indicates shallow to deep water marine conditions (Figures 3.2 & 3.3). However, in the eastern part of the Sulaiman foredeep, the Mesozoic strata are relatively thin and show a facies change from marine limestones to a near-shore sandstone and shale sequence in the Jurassic (Jones, 1961, and OGDC unpublished reports). The Mesozoic sedimentary assemblages are the response to the evolution of a passive (Atlantic type) continental margin (Malik et al., 1988); this margin is still intact to the south, on the west coast of India. Basin studies by Biswas (1982) and refraction studies by Naini and Talwani (1983), along with other geophysical evidence from gravity, magnetic and reflection studies, also suggest that this margin is a rifted continental margin. Paleocurrent studies by Waheed, Ahmad and Wells (1988) in the eastern Sulaiman foldbelt suggest preorogenic, west facing, open marine shelf during the Late Cretaceous.

The present investigations involve the Palaeogene rocks of the Sulaiman Range. The Cenozoic sequence is very thick and includes 1700 to 3700 metres of marine sedimentary rocks. The Palaeocene-Eocene rocks comprise sandstone and shale, foraminiferal limestone (Dungan Formation, on which this investigations is based), marine shales and foraminiferal limestone and shale.

During the Paleocene and Eocene, deposition was marine but involved shallow water shelf limestone facies. Palaeocurrents also change from westward in the Late Cretaceous to more eastward in the Paleocene/Eocene (Waheed et al., 1988), possibly reflecting the emplacement of Zhob suture ophiolites and initial deformation of the

western margin of India in the area of Baluchistan. At about the same time (53 Ma), a sharp decrease in the rate of northward movement of India (from 15 cm/year to 5 cm/year) also suggest the initial collision of India with the Kohistan-Chitral island arc terrane (Powell and Conaghan, 1973; Quittmeyer et al., 1979).

The main collisional tectonics responsible for the development of the Sulaiman foldbelt, in response to which the Sulaiman foredeep was formed, started during the middle Eocene. Marine sedimentation, which remained restricted in the southern part of the Sulaiman foldbelt and foredeep area during the Oligocene, ceased dramatically during the Miocene. From the Miocene onward, continental environments prevailed, as shown by the thick molasse deposits of more than 8000 metres in the Sibi Trough area (Movshovitch and Malik, 1965). This great thickness of Siwalik Group rocks represents high uplift rates of the Himalayan source area (0.8 to 1.0 m/1000 year [Zeitler et al., 1982]) and high subsidence and sedimentation rates in the foredeep (0.8 to 1.0 m/1000 year [Mehta, 1980; Barndt et al., 1978]).

The stratigraphic setting described above suggests that the area now underlying the Sulaiman foldbelt and foredeep was a part of the stable craton (Gondwana) from late Proterozoic to late Paleozoic. Breakup of Gondwana started in early Mesozoic; the passive margin on the western margin of the Indian subcontinent was formed during middle to late Mesozoic. The northern margin of the subcontinent (Himalaya-Salt Range/ Potwar Plateau) experienced a head-on collision with Asia, while the northwestern margin (Sulaiman and Kirthar Ranges) collided with the Afghan block in an oblique fashion during the Oligocene to Recent. The Mesozoic margin appears to be in an early stage of collision in the Sulaiman Range, in contrast to the area north of

the Salt Range/Potwar Plateau, where the passive margin appears to have been completely deformed as a result of head-on collision.

Chapter Three

STRATIGRAPHY OF SULAIMAN RANGE

3.1. Introduction:-

The Sulaiman Range (Figs. 2.1 and 3.1) is located on the northwestern margin of the Indian Plate. It forms the middle part of the Indus basin (Fig. 3.1), of Triassic to Tertiary age, and has been termed the Sulaiman sub-basin. The Kirther Range lies to the south, the Salt Range to the north (Fig. 3.1) and the Punjab Plain to the east. On west it is bounded by the marginal zone of the Indian Plate (Fig. 3.1) against the Himalayan orogen.

The sub-basin exclusively consists of thick sedimentary rocks with some breaks in the succession (Fig.3.2). The dominant lithology is arenaceous, with argillaceous intercalation and subordinate limestone. In the sub-basin, rocks from Triassic to Tertiary are exposed and they are in excess of 7000 metres (Fig.3.3). The Triassic rocks comprise shale and limestone. The Jurassic strata are of limestone shale and shallow marine limestone. The Cretaceous sequence is marine and, in ascending order, composed of shale, siltstone, limestone, marl and sandstone. The Cainozoic sequence is very thick and includes 1700 to 3700 metres of marine sedimentary rocks. The Paleogene rocks comprise sandstone, shale and foraminiferal limestone. The Paleogene is unconformably overlain by a thick section of Neogene fluvial clastics.

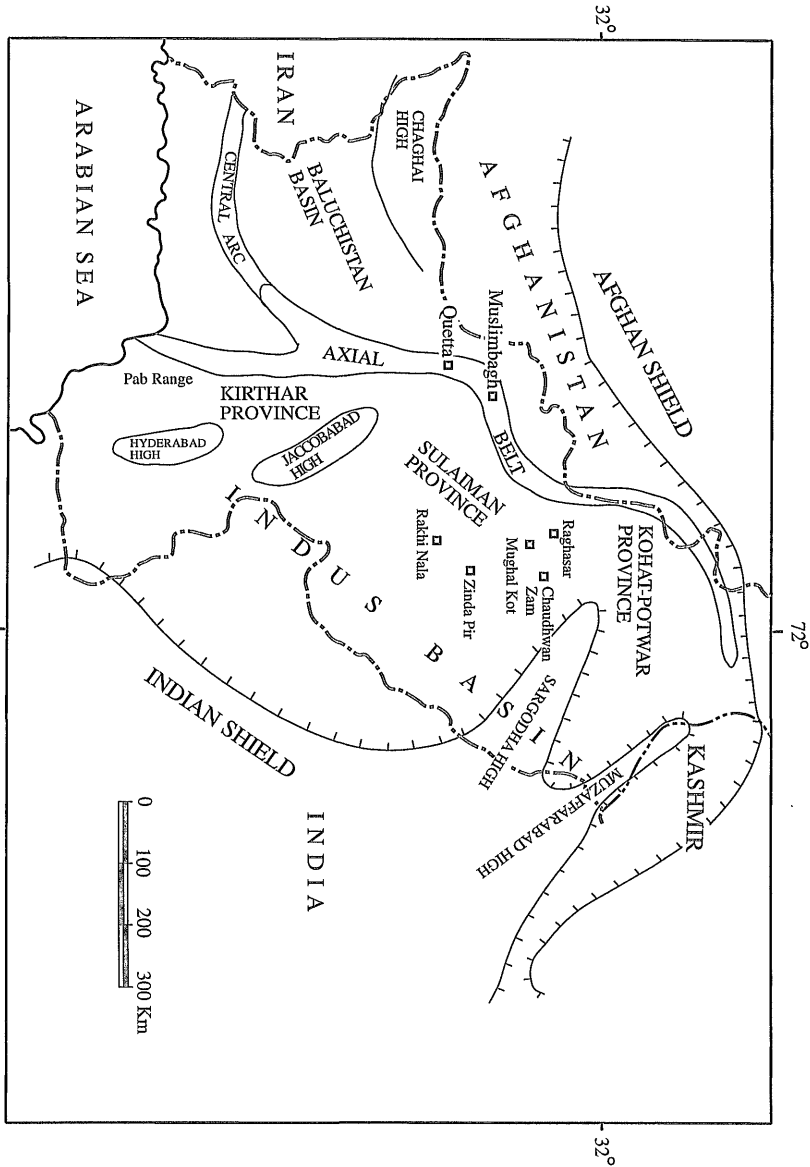


Fig. 3.1.- Various Geological Provinces of Pakistan (modified after H. Rahman, 1963).

3.2. Wulgai Formation:-

William (1959) gave the name of Wulgai Formation for the Triassic rocks after the village of Wulgai near Muslimbagh (Fig. 3.1), and the name was accepted by the stratigraphic committee of Pakistan (Shah, 1977).

According to Sokolov and Shah (1965) the total thickness of the Wulgai Formation is 985 m. They divided the formation into three units. The lower unit is dark grey to black and greenish clayey shale and mudstone with subordinate limestone. The limestone is black and fine-grained. The thickness of the unit ranges from 300 to 500 m. The middle unit is interbedded with shale, limestone, and sandstone. The limestone is dark grey to black, fine to medium grained and includes some sandy limestone beds. The mudstone and shale are dark grey, nodular, laminated and sandy with carbonaceous inclusions. The sandstone is yellow, fine grained, calcareous and poorly sorted, with ferruginous concretions and containing fragmentary brachiopods and bivalves. The thickness of the middle unit is 200 m. The upper unit has shale, marl and limestone of black, dark grey and greenish-grey colour. The limestone is crystalline. The marly beds contain ammonoids. The thickness of the unit is 300 m. The upper contact of the formation with the Shirinab Formation of Jurassic age is transitional. The presence of ammonoids such as *Halorites*, *Jovites*, *Pararcestes*, *Arietocelites*, and the bivalve *Halobia* in the upper part and of *Columbites* in the lower part, indicate an Early to Late Triassic age.

3.3. Shirinab Formation:-

The stratigraphic committee of Pakistan gave the name of Shirinab Formation (Shah, 1977) to the lower division of the Jurassic rocks of Vredenburg (1909) namely, "Stratified limestone, sometimes interbedded with richly fossiliferous dark calcareous shale", the lower half ("thin bedded limestone and shale") of the 'Sulaiman limestone group' of Williams (1959) and Woodward (1959), the three formations, namely Anjira Formation, Loralai limestone and Spingwar Formation of Williams (1959), and the upper part of the Windar and Alozai groups of Hunting Survey Corporation (1961).

The Shirinab Formation consists of interbedded limestone and shale which grades downward into a dominant shale lithology of Triassic age and is overlain transitionally by the Chiltan limestone. The Shirinab limestone is thin to medium bedded, grey to dark grey and black. It is finely crystalline to fairly coarse-textured, with shaly, oolitic, pelitic and pisolitic interbeds. Argillaceous limestone is present at different levels and is generally associated with shale. The lower part locally includes sandstone intercalations. The associated shale is of grey to dark grey colour but occasionally orange-yellow, green and red varieties are also present. The shale is calcareous and ranges from soft flaky to hard fissile and platy.

The formation may be divided into three members depending on the increase or decrease of the shale in the generally thin to medium bedded limestone. In the Sulaiman Range the lower member has not been differentiated from other parts of the formation. Only two members may be recognised in the area.

3.3.1. Loralai Limestone Member:-

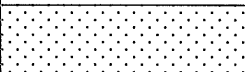
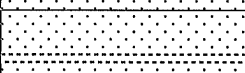
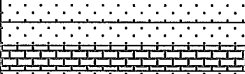
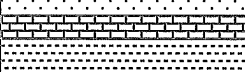
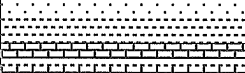
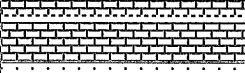
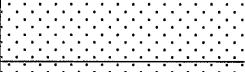
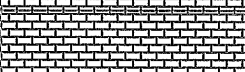
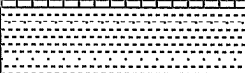
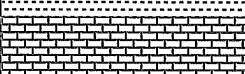
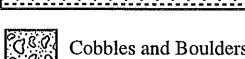
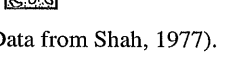
Loralai Limestone Member is predominantly of thin to medium bedded grey, dark grey and black limestone. Shale is very subordinate and is present as thin partings at different levels. The limestone is generally fine grained, but oolitic, pisolitic and pelleted beds in the upper part. This member is widely developed in the Loralai district where it forms prominent hills.

3.3.2. Anjira Member:-

Anjira Member is dark grey, thinly bedded limestone, softer argillaceous limestone and calcareous shale. The limestone is generally fine textured, sub-lithographic.

The Shirinab Formation in its type area is estimated to be 2250 m thick. Fossils recorded from different parts of Sulaiman and Kirthar provinces and Axial Belt (see Fig. 3.1) indicate an Early Jurassic age, but the upper part may extend into the Middle Jurassic.

The fossils reported from Murree Brewery section near Quetta include the following (Cox in Hunting Survey Corporation, 1961); *Montlivaltia* sp., *Coroniceras* sp., *Terebratula* sp., *T. juravica*, *T. andleri*, *Rhynchenella* cf. *R. lua*, *Entolium* sp., *Chlamys* cf. *C. prisca*, *Lima* (*Plagiostama*) cf. *L. deslongchampsii*, *Nucula* sp. and *Gryphaea* sp. In addition of the above fauna, *Arietites* cf. *A. bisulcatus* of Sinemurian age has been reported (Holland, 1909, Arkell, 1956) from Shirinab Valley. Near the Natrani River in Lasbela, *Phylloceras*, *Juraphyllites*, *Lytoceras*, *Dactylioceras*, *Porpoceras*, *Protogrammoceras* and *Polypilectus* have been recorded (Arkell, 1956). At a lower level in Kalat and Lasbela (Porali River) *Bouleiceras* and *Fuciniceras*, with

Age			Formation	Lithology	
C A I N O Z O I C	QUATER NARY		PLEISTO CENE	Chaudhwan formation	
	T E R T I A R Y	N E O G E N E	PLIOCE NE	Litra Formation	
				Vihowa Formation	
		MIOCE NE	Unconformity		
			Nari Formation		
	P A L E O G E N E	EOCENE	Kirthar Formation		
			Ghazij Formation		
		PALEO CENE	Dungan Formation		
Unconformity					
M E S O Z O I C	CRETACEOUS			Pab Sandstone	
				Fort Munro Formation	
				Mughal Kot Formation	
				Parh Limestone	
				Goru Formation	
				Sembar Formation	
	JURASSIC			Unconformity	
				Chiltan Limestone	
				Shirinab Formation	
	TRIASSIC			Wulgai Formation	

 Shale

 Sandstone

 Limestone

 Pebbles

 Cobbles and Boulders

 Shale
  Sandstone
  Limestone
  Pebbles
  Cobbles and Boulders

Fig.3.2:- The stratigraphic sequence of the Sulaiman sub-basin (Data from Shah, 1977).

abundant *Spiriferina* and *Weyla ambongoensis* have been reported. From the lower part of the Loralai Limestone Member the following fossils have been recorded (Hunting Survey Corporation, 1961) *Entolium* sp. cf. *E. hehli*, *Pectinula* sp. cf. *P. cancellata*, *Arnioceras* sp. and *Harpoceras madagascariense*.

The presence of *Bouleiceras* establishes a good correlation with the Shinawari Formation of the Kohat-Potwar Province (Upper Indus Basin) as well as the adjoining countries of Madagascar and Saudi Arabia. These fossils indicate Early Jurassic age of the lower part of Shirinab Formation.

3.4. Chiltan Limestone:-

The name Chiltan Limestone (introduced by Hunting Survey Corporation, 1961) is derived from the Chiltan Range, southwest of Quetta (Fig. 3.1). Prior to Hunting Survey Corporation (1961) and Williams (1959), the Pakistan Shell Oil Company used the term Chiltan Formation in their unpublished reports for the upper division of their two-fold lithological classification of the Jurassic rocks of the Lower Indus Basin. The Chiltan Limestone is accepted here to represent similar thick bedded limestone referred to by Vredenburg (1909) as "massive limestone", by Williams (1959) and Woodward (1959) as "Takatu limestone" and upper part of "Sulaiman limestone group". The stratigraphic committee of Pakistan accepted the name of Chiltan Limestone (Shah, 1977) after the name given by Hunting Survey Corporation, (1961).

The Chiltan Limestone is massive, thick bedded, dark limestone, but shows colour and texture variations within one section and in different areas. The colour varies from black, dark grey, grey, light grey, brownish grey, bluish grey to occasionally white. Pisolitic limestone beds are present locally. The texture varies from fine-grained, sub-

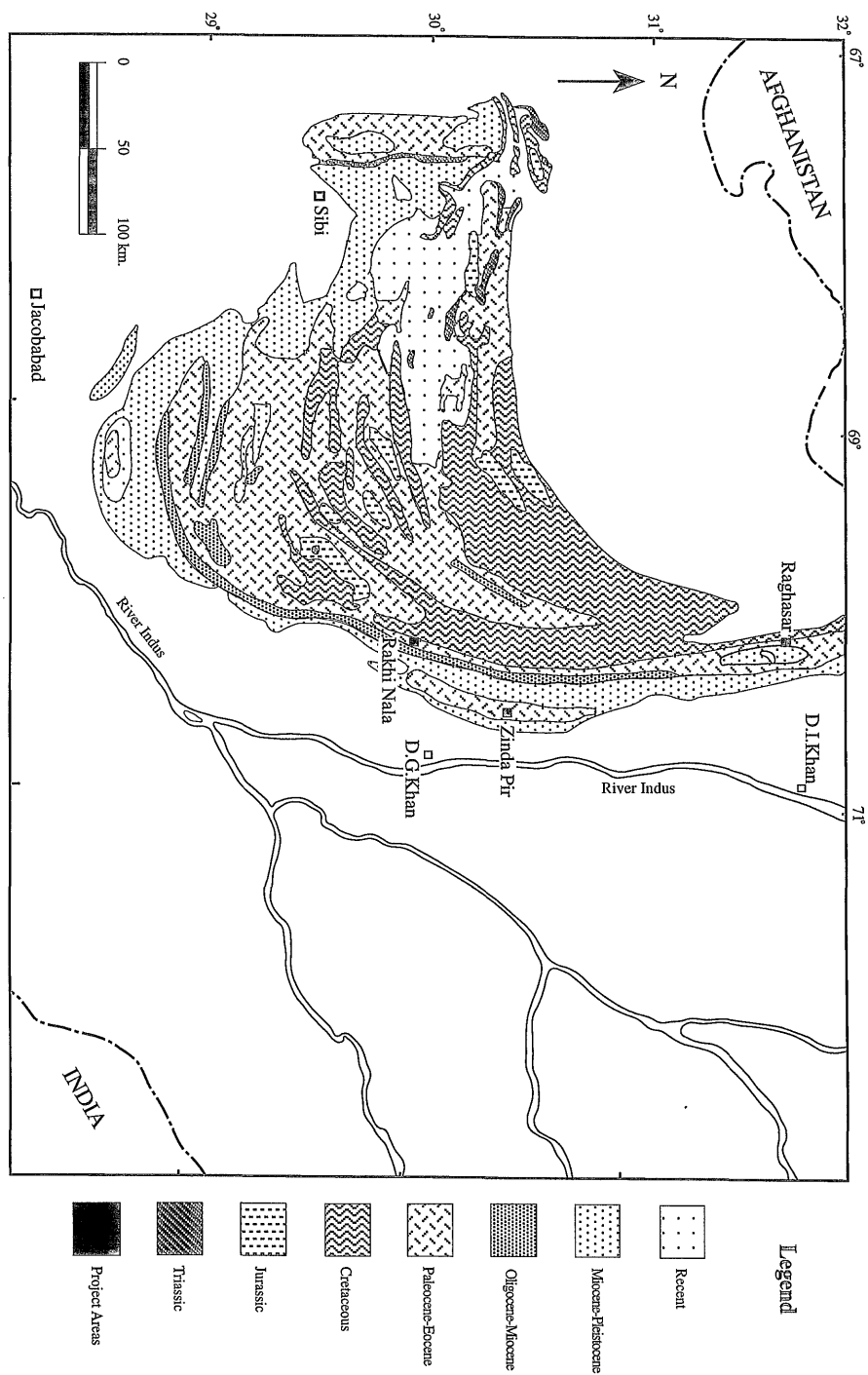


Fig. 3.3:- Generalized geological map of the Sulaiman sub-basin (modified after Bakr and Jackson, 1964).

lithographic to oolitic, reefoid and shelly. Veins and nodules of black or rusty weathering chert are present locally. The Chiltan limestone is widely distributed, forming prominent high mountains like Koh-e-Maran, Koh-e-Siah, Chiltan, Murdar Ghar, Takatu, Khalifat and Zardah. Most of these mountains are resistant cores of the anticlines. Hunting Survey Corporation estimated a thickness of 1,818 m in the region of Quetta and Dhanasar.

The Chiltan Limestone has not yielded identifiable fossils though poorly preserved fragmentary remains are found occasionally. Its stratigraphic position above the Shirinab Formation of Early Jurassic age and below the Sember Formation of Neocomian to Late Jurassic suggest the age to be mainly Middle to Upper Jurassic. In parts of the Lower Indus Basin the Chiltan Limestone and the overlying Mazar Drik Formation are not developed and the Upper Jurassic to Lower Cretaceous rocks directly overlies the Shirinab Formation. Hunting Survey Corporation (1961) regarded the Chiltan Limestone doubtfully as a lateral massive development of the Loralai limestone (part of Shirinab Formation), and like Williams doubtfully considered the age to be Middle to Late Jurassic. Following Arkell (1956) and Vredenburg (1909) the age of their "massive limestone" (Chiltan Limestone) is mainly Middle Jurassic on the basis that the overlying Mazar Drik Formation has yielded a definite early Callovian-late Bathonian fauna. In that case it must all be Middle Jurassic.

Chiltan Limestone has a disconformable contact directly with the overlying Sember Formation of mainly Early Cretaceous age whereas the lower contact with the Shirinab Formation is gradational. The Chiltan Limestone may be correlated with the Samana Suk Formation of the Kohat-Potwar Province of Upper Indus Basin (Shah, 1977).

3.5. Sember Formation:-

The name Sember Formation was introduced by Williams (1959), after Sember Pass in the Marri hills, to include the lower part of the “Belemnite Beds” of Oldham (1892) and the “Belemnite Shales” of Vredenburg (1909). The “Belemnite Beds” of Oldham also included the overlying Goru formation and the Parh limestone. Hunting Survey Corporation (1961) did not recognise this formation as a separate unit but included it in the lower part of their “Parh Series” (implying undivided Cretaceous) or “Parh Group” (undifferentiated “Belemnite Shale” and Parh limestone). The stratigraphic committee of Pakistan accepted the name of Sember Formation (Shah, 1977) after Williams (1959).

The Sember Formation consists of black silty shale with interbeds of black siltstone and nodular rusty weathering argillaceous limestone beds or concretions. Glauconite is commonly present which gives the greenish hue to the weathering colour. In the basal part pyritic and phosphatic nodules and sandy shales are developed locally. The thickness in the type section is 133 m but the formation thickens to 262 m in the Moghal Kot section (Fig. 3.1) north of the Sulaiman Range and has been reported to be much thicker in the subsurface (Williams, 1959).

The lower contact of the Sember Formation with the underlying Chiltan Limestone is disconformable while the upper contact is generally gradational with the Goru Formation. The formation is reported to contain foraminifers, but the most common fossils are the belemnites *Hibolithes pistilliformis*, *H. subfusiformis* and *Duvalia* sp. From the Winder River in Lasbela, Nuttall (in Arkell, 1956) reported fragments of *Virgatospinctes denseplicatus* and *V. cf. V. subquadratus*, but their stratigraphic

position is not known. The *Hibolithes spp.*, though regarded as early Neocomian (Berriasian-Valanginian), may not be restricted to this age as comparable species from the Salt Range and Trans-Indus ranges have been found to be associated with Late Jurassic ammonites (Fatmi, 1968, 1972). The age of the formation, though mainly Neocomian, most likely extends into the Late Jurassic. The Sember Formation is correlated with the Chichali Formation of the Kohat-Potwar Province.

3.6. Goru Formation:-

The name Goru Formation was introduced by Williams (1959) for rocks included by Oldham (1892) in the upper part of his "Belemnite Beds". Hunting Survey Corporation (1961) included these strata in the "Parh Group". The stratigraphic committee of Pakistan accepted the name of Goru Formation (Shah, 1977) after Williams (1959).

The Goru Formation consists of interbedded limestone, shale and siltstone. The limestone is fine grained, thin bedded, light to medium grey and olive grey in colour. The interbedded shale and siltstone are grey, greenish grey and locally maroon in colour. The shale varies greatly in proportion and in places is the dominant rock type. Limestone is dominant in the lower and upper parts of the formation.

The Goru Formation is widely distributed both in the Kirthar and Sulaiman provinces. It is 536 m thick in the type locality.

The lower contact with the Sember Formation is conformable, though locally an unconformity has been reported by Williams (1959). The upper contact with the Parh limestone is transitional and is placed at the last shale interbed. The formation contains

foraminifers and belemnites (*Hibolithes spp.*). Fritz and Khan (1967) describes the following foraminifers from Bangu Nala in Quetta region: *Globigerinelloides algeriana*, *G. breggiensis*, *G. caseyi*, *Ticinella roberti*, *Gavelinella lorneiana*, *Rotalipora ticinensis*, *R. appenninica*, *R. brotzeni*, *R. reicheli*, *Praeglobotruncana stephani* and *Planomalina buxtorfi*. The age of the formation is assessed mainly as Early Cretaceous. The Goru Formation may be correlated with the Lumshiwai Formation of the Kohat-Potwar Province.

3.7. Parh Limestone:-

The term "Parh" was introduced by Blanford (1879) for the rocks of Parh Range. The name was later applied by Vredenburg (1909) to a prominent white limestone in his Cretaceous succession. William (1959) redefined it as a limestone formation between the Goru and Mughal Kot Formations. The stratigraphic committee of Pakistan renamed the formation as Parh Limestone (Shah, 1977) after Blanford, (1879).

The Parh Limestone is a lithologically very distinct unit. It is hard, light grey, white, cream, olive green, thin to medium bedded, lithographic to porcellaneous, argillaceous occasionally platy to slabby limestone, with subordinate calcareous shale and marl intercalations. The porcellaneous nature and the conchoidal fracture distinguish it from other limestone units. In the lower part an impersistent, maroon coloured limestone bed is developed near the contact with the Goru Formation. The formation is widely distributed in the Sulaiman Province (Lower Indus Basin) and parts of the Axial Belt. In the type area the thickness is 268 m but varies from 300 to 600 m in other areas.

The lower contact of the Parh Limestone with the underlying Goru Formation and the

upper contact with the overlying Mughal Kot Formation are conformable. The formation is rich in foraminifers (*Globotruncana spp.*) and is dated as Late Cretaceous. The foraminifers include *Globotruncana ventricosa*, *G. lapparenti*, *G. sigali* and *Pseudotextularia elegans* (Gigon, 1962). The formation is correlated with the part of Kawagarh Formation of the Kohat-Potwar Province.

3.8. Mughal Kot Formation:-

The stratigraphic committee of Pakistan gave the name of Mughal Kot Formation (Shah, 1977) to the “Mughal Kot” of Williams (1959), minus the “Fort Munro Member”, the “Inoceramus clays”, “bedded clays” and lower part of the “Orbitoides limestone and shale” of Eames (1952). Hunting Survey Corporation (1961) did not identify the formation as a distinct entity but included it in the lower part of their “Pab sandstone”.

The formation comprises dark grey, calcareous mudstone and calcareous shale with intercalations of quartzose sandstone and light grey argillaceous limestone. The sandstone is well developed in the northern part of the Sulaiman Province only. Some yellow to greenish yellow marl and shale beds are present in the upper part of the formation in the southern part of the Sulaiman Province, (northeast of Pui). In the Kirthar Province, grey, silty and calcareous shale is more abundant than the calcareous mudstone or marl. The Mughal Kot Formation is best developed in the Sulaiman Province. It is 1,170 m thick in the type section.

The formation unconformably overlies the Parh Limestone throughout most of its extent. However the area around the type section, the contact is apparently

conformable. The formation is conformably overlain by the Fort Munro Formation with a transitional contact in most of the areas. Williams (1959) reported *Omphalocyclus* sp. and *Orbitoides* sp. and assigned a Maestrichtian age to the formation. Marks (1962) reported *Siderolites* cf. *calcitrapoides*, *Orbitoides tissoti minima* and *O. tissoti compressa* from Rakhi Nala (Fig. 3.1) (Sulaiman Province) and assigned a late to middle Campanian age to the upper part of the unit, which might extend up to early late Campanian. On the basis of this evidence, a Campanian to early Maestrichtian age is assigned to the formation. The formation is correlated with the middle part of the Kawagarh Formation of the Kohat-Potwar Province.

3.9. Fort Munro Formation:-

The formation represents the "Limestone with *Hippurites*" of Blanford (1878) "the *Hemipneustes* Limestone" of Vredenburg (1909), the upper part of the "*Orbitoides* Limestone and Shale" of Eames (1952), and the "Fort Munro Limestone Member" of Williams (1959). Hunting Survey Corporation (1961) included the unit in their "Pab Sandstone" in the Sulaiman Province and Axial Belt but differentiated it as "*Hemipneustes* Limestone" in the Kirthar Province. The stratigraphic committee of Pakistan upgraded the Fort Munro limestone member of Williams (1959) to the Fort Munro Formation (Shah, 1977).

In the northern Sulaiman Province the formation typically consists of limestone. The formation is dark grey to black, very hard, thickbedded, commonly sandy in the upper part and argillaceous in the lower part. In the southern part of the Sulaiman Province, the formation is dominantly light grey to yellow grey, medium hard, argillaceous

limestone which is slightly nodular in the lower part, where yellow to greyish yellow marl and calcareous shale are intercalated. The limestone is sandy in the upper part where some shale and brown-weathering sandstone are intercalated. The formation is widely exposed in the Sulaiman Province, parts of the Kirthar Province and the Axial Belt. The unit is 100 m thick at the type section.

The formation conformably overlies the Mughal Kot Formation throughout its extent with a transitional contact, and is conformably overlain by the Pab Sandstone with a transitional contact. Williams (1959) reported *Omphalocyclus macropora* and *Orbitoides spp.*, and assigned a Maestrichtian age to the formation. Hunting Survey Corporation (1961) reported *Actinosiphon punjabensis*, *Orbitoides media*, *Siderolites sp.* etc., and assigned a Maestrichtian age to the formation. Marks (1962) assigned a middle or late Campanian to the unit in Rakhi Nala on the basis of *Orbitoides tissoti minima*, found at its base and the upper part of underlying unit. From the above it is reasonable to assign late Campanian to early Maestrichtian age to the formation. The formation may be correlated with the upper part of the Kawagarh Formation of Kohat-Potwar Province.

3.10. Pab Sandstone:-

The term Pab Sandstone was introduced by Vredenburg (1909), after the name of Pab Range (Fig. 3.1) in the Kirthar Province, and the name was accepted by the stratigraphic committee of Pakistan (Shah, 1977), after Vredenburg (1909).

The formation typically consists of quartzose sandstone which is white, cream or brown, weathers yellow brown, medium to coarse grained, thick bedded to massive,

and shows cross stratification. Some marl and argillaceous limestone, similar to that of the Parh Limestone are found intercalated. Subordinate shale is dark grey and calcareous in the Pab Range, brown and sandy in the Lakhi Range and pale grey, white, pale green and maroon. The formation is widely developed in the Sulaiman and Kirthar Provinces and Axial Belt. Its thickness varies considerably and is 490 m at type section but pinches out northward to complete absence in parts of Marri Bugti hills (south of the Sulaiman Province). Further north, it thickens to 450 m in the Fort Munro anticline, but again further north it thins to about 240 m in the west of Mughal Kot (Fig. 3.1) (north of the Sulaiman Province).

The formation conformably overlies the Fort Munro Formation and is unconformably overlain by the Dungan Formation in the Sulaiman Province. Vredenburg (1908) reported *Orbitoides (Lepidorbitoides) minor* of early Maestrichtian age from the lower part of the formation in Rakhi Nala. Williams (1959) recorded a mixed benthonic-pelagic assemblage of foraminifers of Maestrichtian age from the type locality. Hunting Survey Corporation (1961) reported two collections, one of them of "Senonian-Maestrichtian" and the other of "probably Maestrichtian" ages. On the basis of these data a Maestrichtian age is assigned to the formation. The Pab Sandstone is correlated with the Moro Formation of the Kirthar Province, and the upper sandy member of the Kawagarh Formation of Hazara (Kohat-Potwar Province).

3.11. Dungan Formation:-

The name "Dungan Limestone" was introduced by Oldham (1890) to replace the "Alveolina Limestone" of Griesbach (1881). It includes the "Lower Rakhi Gaj Shale",

“Zinda Pir Shale” and “Zinda Pir Limestone (lower part)” of Eames (1952) and “Dungan Group” (excluding Moro Formation), “Dab Formation” and “Karkh Group” of Hunting Survey Corporation (1961). Williams (1959) redefined the terms as “Dungan Formation” and the name was approved by the stratigraphic committee of Pakistan (Shah, 1977).

The Dungan Formation dominantly consists of nodular to massive limestone with subordinate shale, marl, sandstone and limestone conglomerates. The limestone is dark grey to brown and creamy white, and weathers brown, grey and buff yellow. The dark blue grey, brown and olive shale which weathers grey or green becomes dominant in the southern Sulaiman Range. Beds of limestone conglomerates also occur which grade into nodular and massive limestone. The conglomerate is usually composed of pebbles and cobbles of grey and brown limestone and marl, embedded in a matrix of soft, ash grey calcareous shale. Occasionally brownish green, coarse grained, calcareous sandstone beds are interlayered with shale. The Dungan Formation is mainly developed in the Sulaiman Province. It is about 300 m thick, though its thickness changes rapidly from place to place.

The lower contact of the Dungan Formation is unconformable in most of the localities and “marks one of the major unconformities of the basin” (Williams, 1959). The upper contact with the Ghazij Formation is conformable. A rich fossil assemblage including foraminifers, gastropods, bivalves and algae are recorded by Davies (1941), Khan and Haque (in Lexique, 1956), Hunting Survey Corporation (1961), Latif (1964), and Iqbal (1969). Foraminifers are generally abundant and most of them belong to *Fasciolites*, *Nummulites*, *Coskinolina*, *Dictyoconoides*, *Discocyclina*, *Linderina*, *Lockhartia*, *Operculina*, *Miscellanea*, *Globorotalia*, and *Cibicides* genera. Species

like *Miscellanea miscella*, *M. stampi*, *Nummulites nuttalli*, *N. thalicus*, *N. sindensis*, *Assilina dandotica*, *Kathina selveri*, and *Lockhartia tipperi* indicate a Paleocene to Early Eocene age. The algae such as *Distichoplax sp.*, *Lithothamnium sp.*, *Mesophyllum sp.*, reported from this formation confirm that age. The formation is correlated with the Ranikot Group and the Rakhshani Formation of Axial Belt, and the Hangu-Patala sequence of the Kohat-Potwar Province.

3.12. Ghazij Formation:-

It represents the “Ghazij Group” of Oldham (1890), “Shales with Alabaster, Rubbly limestone, Green and Nodular Shales, Ghazij Shales, Upper Rakhi Gaj Shales and Zinda Pir Limestone (upper part)” of Eames (1952) the “Chat beds” of Nagappa (1959), and the “Ghazij Shales”, “Tiyon Formation” and upper part of “Gidar Dhor Group” of Hunting Survey Corporation (1961). Williams (1959) redefined it as “Ghazij Formation” and the stratigraphic committee of Pakistan agreed with the name of Ghazij Formation (Shah, 1977) after Williams (1959).

The upper part of the formation is differentiated into two members in different parts of the Sulaiman Province, the Baska shale and Alabaster member, and the Marap conglomerate member. The Baska shale and Alabaster member is dominant in the eastern and southeastern parts of the Sulaiman Province, whereas the Marap conglomerate is present in subordinate amounts in western Sulaiman Province.

The formation consists dominantly of shale with subordinate claystone, sandstone, limestone, conglomerate, alabaster (gypsum) and coal that becomes abundant locally. In the Kirthar and Sulaiman provinces, the formation consists of pale greenish grey or

brown shale and white or light grey limestone that increases in proportion upward. The shale is calcareous, hard, flaky and in places grades into marl and limestone. The limestone is thin to thick bedded and weathers yellowish white or chalky white. Subordinate greenish grey or brown sandstone, which is calcareous and grades into arenaceous limestone, is also present locally. In the upper part of the formation green or greenish grey shale with beds, nodules and veins of alabaster is present that represents the Baska shale and Alabaster member. In parts of the Sulaiman Province, the formation consists of olive, brown, maroon, purple and yellow shale and green, grey or brown sandstone with interbeds of arenaceous limestone and some conglomerate. The shale is earthy or hard, blocky, flaky and in places gypsiferous. The sandstone is coarse grained to pebbly, thick bedded, cross-stratified and carbonaceous where associated with coal. The coal generally is dark lignite or poor grade bituminous type.

The Marap conglomerate member consists of poorly sorted and well rounded pebbles and boulders of grey, white and pink limestone, green shale, marl and sandstone derived from the underlying strata which are as old as the Shirinab Formation. Some shale, sandstone and rare limestone are also interbedded and these are similar in lithology to the rest of the formation.

The formation is widely developed in the Sulaiman Province, parts of the Kirthar Province and Axial Belt. It is 590 m thick at the type section, maximum thickness of about 3,300 m has been recorded at Mugal Kot (Fig. 3.1) and about 1,220 m at Zinda Pir (Fig. 3.1). The Baska shale and Alabaster member is 190 m thick at the type section. The Marap conglomerate member is about 910 m thick at its type locality.

The formation conformably overlies the Dungan Formation in Sulaiman Province. In the Sulaiman and Kirthar Provinces, it is conformably overlain by the Kirthar Formation. The fossil fauna includes foraminifers, gastropods, bivalves, echinoids and algae (Eames, 1952; Hunting Survey Corporation, 1961; Latif, 1964; Iqbal, 1969). The foraminifers include *Coskinolina* cf. *C. balsilliei*, *Lockhartia* cf. *L. hunti* var. *pustulosa*, *Assilina sublamina*, *Flosculina globosa*, *Dictyoconus indicus*. Among the bivalves *Cardita mutabilis*, *Corbula* (*Bicorbula*) *subexarata*, *Anomia* sp., *Parinomya* sp. and others are abundant. The formation is assigned as Early Eocene age. The formation is correlated with the Laki Formation in parts of the Kirthar Province and with the Chharat Group of Kohat-Potwar Province.

3.13. Kirthar Formation:-

It represents the “Spintangi Limestone “ of Oldham (1890), the “Kirthar” of Noetling (1903), and “Bhahui Limestone” of Hunting Survey Corporation (1961) and the stratigraphic committee of Pakistan renamed it as Kirthar Formation (Shah, 1977) after Noetling (1903).

The Kirthar Formation consists of interbedded series of limestone and shale with minor marl. The limestone is light grey, cream coloured or chalky white, weathers in grey, brown or creamy colours. It is thick bedded to massive, in places nodular, and occasionally contains algal and coralline structures. The shale is calcareous, olive, orange yellow, grey, soft and earthy. In some parts of the Sulaiman Province milky white gypsum beds, up to 6 m thick, are present. The Kirthar Formation is divisible into four easily distinguishable members.

3.13.1. Habib Rahi Limestone Member:-

This member consists of pale grey, buff and brown limestone that weathers white or pale brown and is fine grained, platy to thin-bedded, dominantly argillaceous and in a few places grades into marl. There are nodules and thin, discontinuous beds of chert in the upper part, where the limestone emits a fetid smell from a freshly broken surface. The basal bed of the member is rich in *Assilina*. The upper part of the member at few places is rubbly and massive, the middle is thickbedded and the lower is massive. The thickness ranges from 15 to 150 m.

3.13.2. Domanda Shale Member:-

This member consists predominantly of brown, greenish grey and chocolate coloured claystone and silty shale, which are in places gypsiferous, with grey and brown, fine to medium grained, thick bedded to massive, calcareous sandstone, grey siltstone and greyish brown limestone. The thickness of this unit ranges from 4 to 300 m.

3.13.3. Pir Koh Limestone and Marl Member:-

This member consists of intergrading limestone and marl that are light grey to chalky white, buff to brown, weathering white, thin bedded and in a few places contain thin beds of chert. This unit is highly fossiliferous. The thickness is 10 to 175 m.

3.13.4. Drazinda Shale Member:-

This member consists of brown, grey and chocolate claystone and silty shale, which in places passes into siltstone. Some calcareous shale and marl are present in the lower part. Subordinate grey sandstone and buff or olive grey limestone also occur in places. Some gypsum stringers are also present, especially in the upper part. The thickness of this unit is 15 to 450 m.

The Kirther Formation is distributed widely in the Sulaiman Province. It is 650 m thick in Zinda Pir section (Fig. 3.1) and 600 m thick in the Rakhi Nala section (Fig. 3.1). The formation transitionally overlies the Ghazij Formation. The upper contact of the formation is unconformable with the Nari Formation. The formation is rich in fossils. According to Hunting Survey Corporation (1961) the fauna are *Lepidocyclina dilatata*, *Nummulites fichteli*, *N. intermedius*, *N. beaumonti*, *N. gizehensis*, *Dictyoconoides cooki*, *D. vredenburgi*, *Actinocyclina alticostata*, *Assilina cancellata*, *A. rota*, *A. irregularis*, *A. laminosa*, *Coskinolina balsilliei*, *Pellatispira madaraszii*, *Corbula (Varicorbula) pseudopisum*, and *Discors soriensis*. On the basis of these fossils the age of the formation is considered to be Early to Late Eocene.

3.14. Nari Formation:-

The name Nari was introduced by Blanford (1876) after the River Nari in the Kirthar Range. The Nari Formation represents the "Nari Series" of Blanford (1876), "Nari Formation" of Williams (1959), and the lower parts of the "Sibi" and "Urak" groups of

Hunting Survey Corporation (1961). The stratigraphic committee of Pakistan renamed the formation as Nari Formation (Shah, 1977) after the name of Nari series of Blanford (1876).

The formation consists of red, grey, and green claystone and subordinate amounts of siltstone and sandstone. The siltstone is varigated, friable, and ferruginous; the sandstone is white, brownish yellow, subangular to subrounded, fine grained, friable, calcareous in places, and commonly ferruginous. In different places hard ferruginous sandstone and conglomerates beds crop out at or near the top of the formation. In the northern part of Sulaiman Range, southwest of Domanda Post, varigated claystone in the upper part is somewhat silty and contains thin carbonaceous beds, sulfur stains, and root fragments. Gypsiferous claystone, ferruginous beds of ripple-marked crossbedded sandstone, and varigated siltstone crop out in the lower part. The formation has widespread distribution in the Kirthar and Sulaiman Provinces. It is 1,400 m thick at type locality and 300 m thick at Mughal Kot (Fig. 3.1).

The lower contact with the underlying Kirthar Formation and the upper contact with the overlying Vihowa Formation are unconformable. The fauna of foraminiferas, coral, molluscs, echinoids, and algae has been recorded by Duncan and Sladen (1884-1886), Vredenburg (1906-1909), Nuttall (1925-1926), Hunting Survey Corporation (1961), Pascoe (1963), Khan (1968), and Iqbal (1969). These includes foraminifera; *Nummulites intermedius*, *N. vascus*, *N. fichteli*, *N. clipeus*, *Lepidocyclina* (*Eulepidina*) *dilatata*, Bivalvia: *Crassatella sulcata*, *Venus* (*Ventricola*) *multilamella*, *V. (Antigona) peepera*; Gastropoda; *Scaphander oligoturritus*, *Lyria anceps* and *Tritonsium* (*Saia*) *indicum*. Pascoe (1963) concluded that the formation corresponds approximately to the Stampian of Europe and ranges from Rupelian to Chattian.

Hunting Survey Corporation (1961) assigned an Oligocene age to the formation, with some upper strata being Early Miocene in age. Khan (1968) assigned a Rupelian to early Aquitanian age to the formation, basing his deduction on a comparative study of the larger foraminifers. The upper part of the formation may be correlated with Murree Formation of the Kohat-Potwar Province.

3.15. Vihowa Formation:-

The term “Vihowa Formation” was introduced by Hamphill and Kidwai (1973) after the village Vihowa Rud in the Sulaiman Range. It represents the lower part of the Siwalik Group in the Sulaiman Range. The stratigraphic committee of Pakistan recommended the name of Vihowa Formation (Shah, 1977) after Hamphill and Kidwai (1973).

The Vihowa Formation consists of grey and brown sandstone and subordinate amounts of red and brownish-red sandy siltstone. The sandstone consists of subangular, medium, and coarse grains and is massive, thick bedded and cross bedded. The sandstone contains abundant scattered pebbles in the upper part, clay material and ferromagnesian mineral grains in the middle part, and abundant secondary calcite in the middle and lower parts. Very coarse grained sandstone and pebble conglomerate near the base contain abundant derived fossils fragments, mostly of foraminifera.

The lower contact of the formation with the underlying Nari Formation is unconformable where as the upper contact with the overlying Litra Formation is gradational. The formation is 427 m thick at Chaudhwan Zam (Fig. 3.1) (north of Sulaiman Province), and 697 m thick at type locality. La Touche (1893) reported

reptilian bones and teeth between Parwara and Landai village (north of Sulaiman Province) in a somewhat pebbly band near the base of the formation. Williams (1959) reported reworked mammalian bone fragments and fragments of foraminifera in the formation. On this basis Pliocene age has been assigned to the formation. Vihowa Formation is believed to be equivalent with the Chinji Formation of the Kohat-Potwar Province.

3.16. Litra Formation:-

The term "Litra Formation" was introduced by Hamphill and Kidwai (1973) after the Litra Nala in the Sulaiman Range. It represents the middle part of the Siwalik Group in the Sulaiman Range. The stratigraphic committee of Pakistan accepted the name of Litra Formation (Shah, 1977) after Hamphill and Kadwai (1973).

The Litra Formation consists of friable light grey and brown, strongly cross-bedded sandstone that is fine and medium grained, thick bedded, massive, and silty and clayey in places. The grains are angular to subrounded. Some beds are coarsely micaceous and garnetiferous. Few beds contain abundant well-preserved burrows. The conglomerates are gritty and consists of rounded to subrounded pebbles and cobbles of sandstone, limestone, quartzite, brown chert and yellow quartz. The polished pebbles of chert and translucent quartz are quite attractive. The conglomerate beds are common particularly in the upper and middle parts of the formation. Apart from making certain horizons they are also found in lenses. The conglomerates are embedded in a coarse-grained sandstone matrix and become increasingly common

towards the top. Throughout the Sulaiman Range the Litra Formation forms steep ridges and cliffs.

The lower contact of the Litra Formation with the underlying Vihowa Formation and the upper contact with the overlying Chaudhwan Formation are transitional. The Litra Formation is 1685 m thick at Chaudhwan Zam (Fig. 3.1) (north of the Sulaiman Range), and at type locality it is 1697 m thick. Williams (1959) assigned a late Pliocene age to the formation on the basis of certain reworked foraminifera, and mammalian teeth and bone fragments. The Litra Formation is believed to be equivalent with the Nagri and Chinji Formations of the Kohat-Potwar Province.

3.17. Chaudhwan Formation:-

The term “Chaudhwan Formation” was introduced by Hamphill and Kidwai (1973) after the Chaudhwan Zam (Fig. 3.1) in the Sulaiman Range. It represents the upper part of the Siwalik group in the Sulaiman Range. The name of Chaudhwan Formation was accepted by the stratigraphic committee of Pakistan (Shah, 1977) after Hamphill and Kadwai (1973).

The Chaudhwan Formation consists mostly of hard massive, thick bedded conglomerates and sandstone which are interstratified. The conglomerates are composed of boulders, cobbles, and pebbles of limestone, quartzite, and sandstone embedded in a medium and coarse-grained sandstone matrix. Subordinate amounts of brown and grey sandstone, siltstone, and claystone crop out in the middle part of the formation in the Chaudhwan Zam section (north of Sulaiman Range). The sandstone is subangular, fine to medium and coarse grained, and commonly crossbedded. Locally,

sandstone and siltstone beds contain abundant burrows. The formation contains a greater proportion of sandstone, siltstone, and claystone in the Rakhi Nala section (Fig. 3.1) (southern part of the Sulaiman Range) than in the Chaudhwan Zam (Fig. 3.1) area, where massive conglomerate is the predominant rock type. Throughout most of its outcrop areas, the Chaudhwan Formation forms steep, commonly impassable, cliffs. The contact with the overlying surficial deposits of Indus and Bannu Plains is commonly indistinct. The contact with the underlying Litra Formation is transitional. The Chaudhwan Formation is 1485 m thick at Chaudhwan Zam (Fig. 3.1). The conglomerates of the formation indicate subjection of some degree of diastrophism that occurred during late Pliocene or Pleistocene. So the formation is most probably Pleistocene. Chaudhwan Formation is believed to be equivalent to the Dhok Pathan Formation, and the upper part of the Nagri Formation of Kohat-Potwar Province.

Chapter Four

FIELD RELATIONS AND LITHOLOGY OF DUNGAN FORMATION

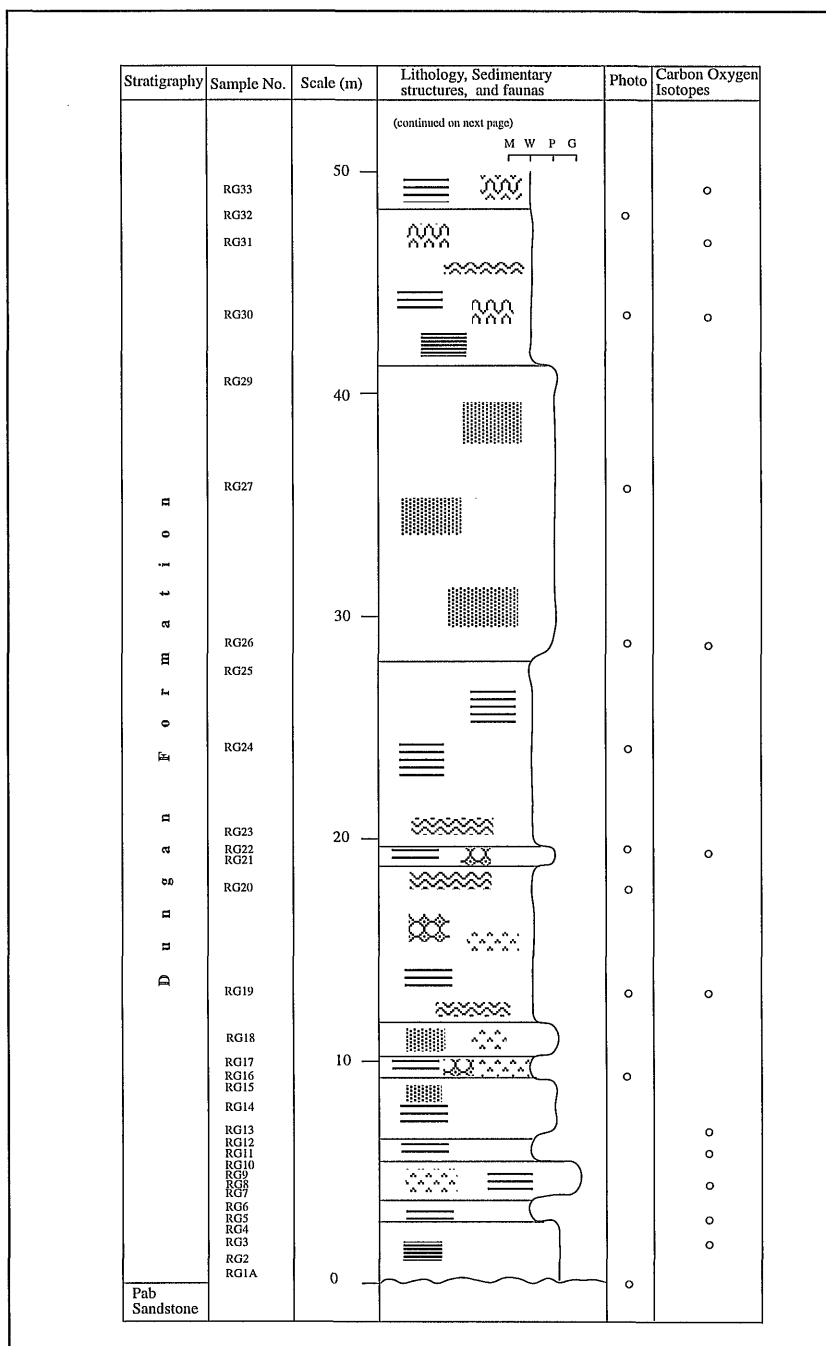
4.1. Introduction:-

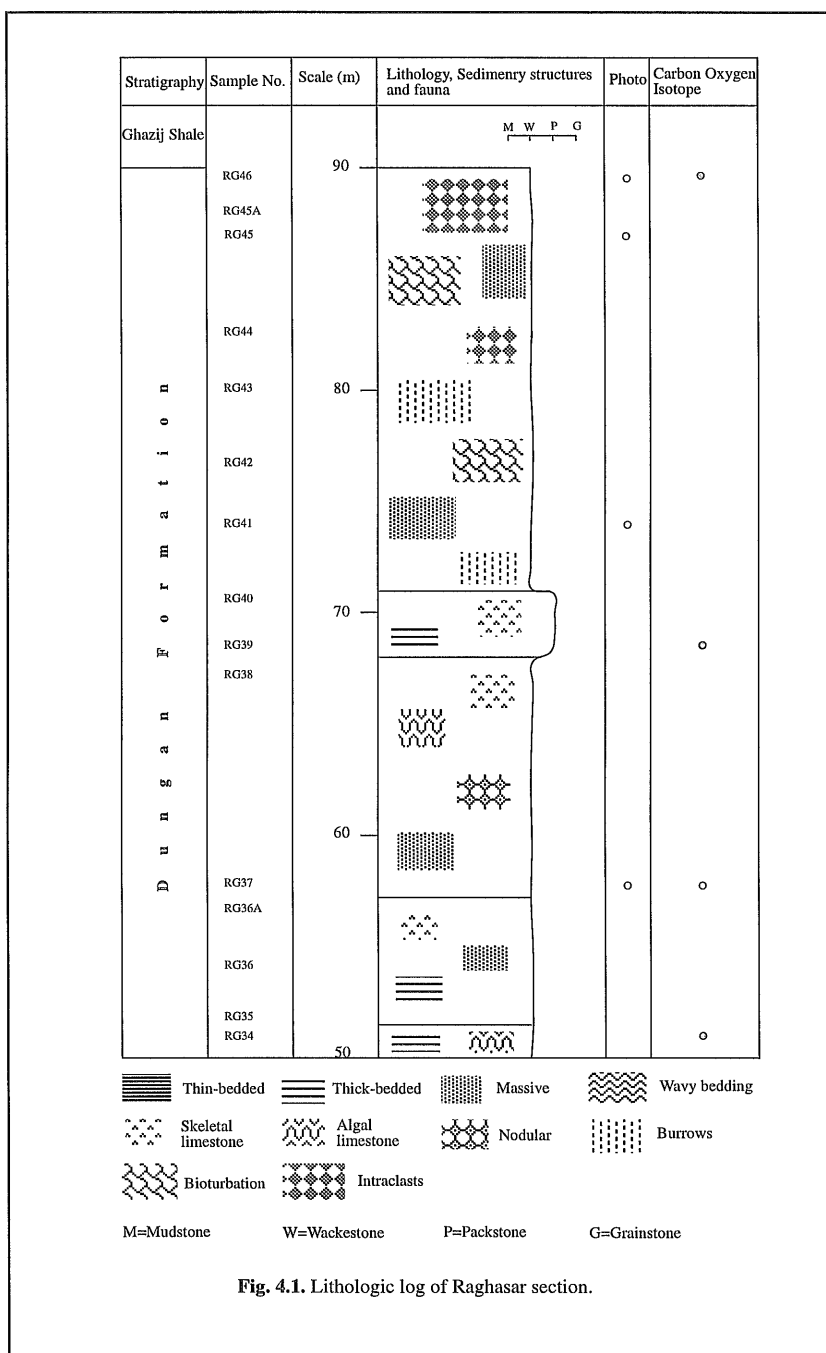
This chapter deals with the lithology of the Dungan Formation. The Dungan Formation is composed predominantly of limestone. Dunham's classification of limestone (1962), is adopted to describe the lithology in the field. The Dungan Formation is a widespread unit extending from north to south along the eastern flank of the Sulaiman Range. The general strike is north-south and dipping towards east. The lithology of the formation in the study area has been described from the outcrops. Three sections have been selected for the collection of samples extending from north to south, namely Raghasar, (lat. 29° 57' 44"; long. 70° 05' 38") Zinda Pir, (lat. 30° 24', long. 70° 30') and Rakhi Nala, (lat. 31° 37', long. 70° 02' 30") (see Fig. 3.3.).

4.2. Lithology of Raghasar Section:-

In this section the Dungan Formation is grey to dark grey coloured, hard, finely crystalline, and thick bedded to massive limestone. The general strike is N10°E and it dips towards east at 66°. The formation is 90 metres thick in this section, which further subdivided into 18 units on the basis of different lithologic characteristics, observed in the field (Fig. 4.1).

The 1st unit is 2.8 metres thick, coarse grained, medium bedded (20 to 30 cm) sandy packstone. The sand grains are badly sorted and decrease upwards. It has a wavy contact with the underlying formation (Pab sandstone) (Fig. 4.2A). Four samples are taken from this unit (RG 1A, RG 2, RG 3 and RG 4). The next unit is fine grained thick bedded (1.0 metre) wackestone. The bedded planes are planar, the upper and lower contacts are planar and sharp. Two samples are taken from this unit, one near the base (RG 5) and second near the top (RG 6). The 3rd unit is coarse grained thick-bedded (0.5 to 0.8 metre thick) skeletal grainstone. The lower and upper contacts are sharp and planar. Four samples are collected from this unit, the first is taken near to the base (RG 7), second at the level of 0.60 metre (RG 8), third at the level of 1.0 metre (RG 9), and fourth at the level of 1.6 metres (RG10). The next unit is fine to medium grained thick bedded (1.0 metre) skeletal wackestone. The lower and upper contacts of this unit are sharp and planar. Two samples are collected from this unit (RG 11 and RG 12). The 5th unit is medium to coarse grained thick bedded to massive (0.8 to 1.2 metres thick) packstone. The lower and upper contacts are sharp and planar. It is 2.8 metres thick, and three samples are taken from this unit (RG 13, RG 14, and RG 15). The next unit is fine to medium grained, nodular, thick bedded (0.8 metre), skeletal, wackestone (Fig. 4.2B). The total thickness of this unit is 0.8 metre. Two samples are collected from this unit, one near the base (RG 16) and the other near the top (RG 17). The next unit is composed of medium grained, massive (1.5 metres thick), skeletal packstone. The lower contact is sharp and planar, where as the upper contact is sharp and slightly wavy. One sample (RG18) is taken from the upper part of the unit. The 8th unit is fine to medium grained, thick bedded to massive (70 to 1.50 metres thick), nodular skeletal wackestone. The skeletal grains are poorly sorted,





and the foraminifera decrease upwards. The size of nodules are small at the base which gradually increases upward. The lower and upper contacts are sharp and wavy. The thickness of this unit is 6.9 metres. Two samples are taken from this unit, one from the level of 1.2 metres (RG 19) and second at the level of 4.8 metres (RG 20). The next unit is coarse grained, thick bedded (0.8 metre thick), nodular packstone. The size of the nodules are bigger than the last unit. Few calcitic veins are found which are perpendicular to the bedding plane. The lower and upper contacts are sharp and wavy. It is 0.8 metre thick unit. Two samples are taken from this unit, one near the base (RG 21), and the other near the top (RG 22) of the unit. The 10th unit is fine to medium grained, thick bedded (.60 to 1.0 metre thick), wackestone. rill marks (Fig. 4.2C) and calcitic veins forming the en-echelon structure (Fig. 4.2E), are found in this unit. The thickness is 8.4 metres. The lower contact of the unit is slightly wavy and sharp where as the upper contact is sharp and planar. Three samples are collected from this unit, one near the base (RG 23), second from the middle (RG 24), and third near the top (RG 25) of the unit. The next unit is medium to coarse grained, massive (1.2 to 1.8 metres thick), packstone. The zebra calcite structures (Fig. 4.2D) are seen in this unit. Few calcitic veins of en-echelon types are also present. The thickness of this unit is 13.2 metres. The lower and upper contacts are sharp and planar. Three samples are taken from this unit, one near the base (RG 26), second from the middle (RG 27), and third near the top (RG 29) of the unit. The next unit is fine to medium grained, thin to thick bedded (.3 to 1.0 metre thick), algal wackestone. The lower and the upper contacts are sharp and planar, the bedding surfaces are slightly wavy within the unit (Fig. 4.2F). The thickness of this unit is 6.90 metres. Three samples are taken from this section, one from 2.10 metres (RG 30), second from 4.30 metres (RG 31), and

Fig. 4.2. A.

Field photograph (taken from the base) illustrates the uneven contact of Dungan Formation with the underlying Pab sandstone (Raghasar section), standing man is a scale.

Fig. 4.2. B.

Photograph (taken from RG 16) showing the closely spaced nodules and sedimentary boundinage in the lower part of the Dungan Formation in Raghasar section.

Fig. 4.2. C.

Photograph (taken from RG 24) illustrates the narrow, deep grooves rill marks in wackestone of Dungan Formation in Raghasar section.

Fig. 4.2. D.

Field photograph (taken from RG 26) illustrates the effect of differential solution weathering as a result of zebra calcite structure in wackestone of Dungan Formation in Raghasar section.

Fig. 4.2. E.

Photograph (taken from RG 25) illustrates the calcitic veins of en-echelon structure in the wackestone of Dungan Formation in Raghasar section. These veins are perpendicular to bedding surfaces.

Fig. 4.2. F.

Field photograph (taken from RG 30) illustrates thinly to thickly bedded carbonate wackestone of Dungan Formation in Raghasar section. The bedding surfaces are wavy.

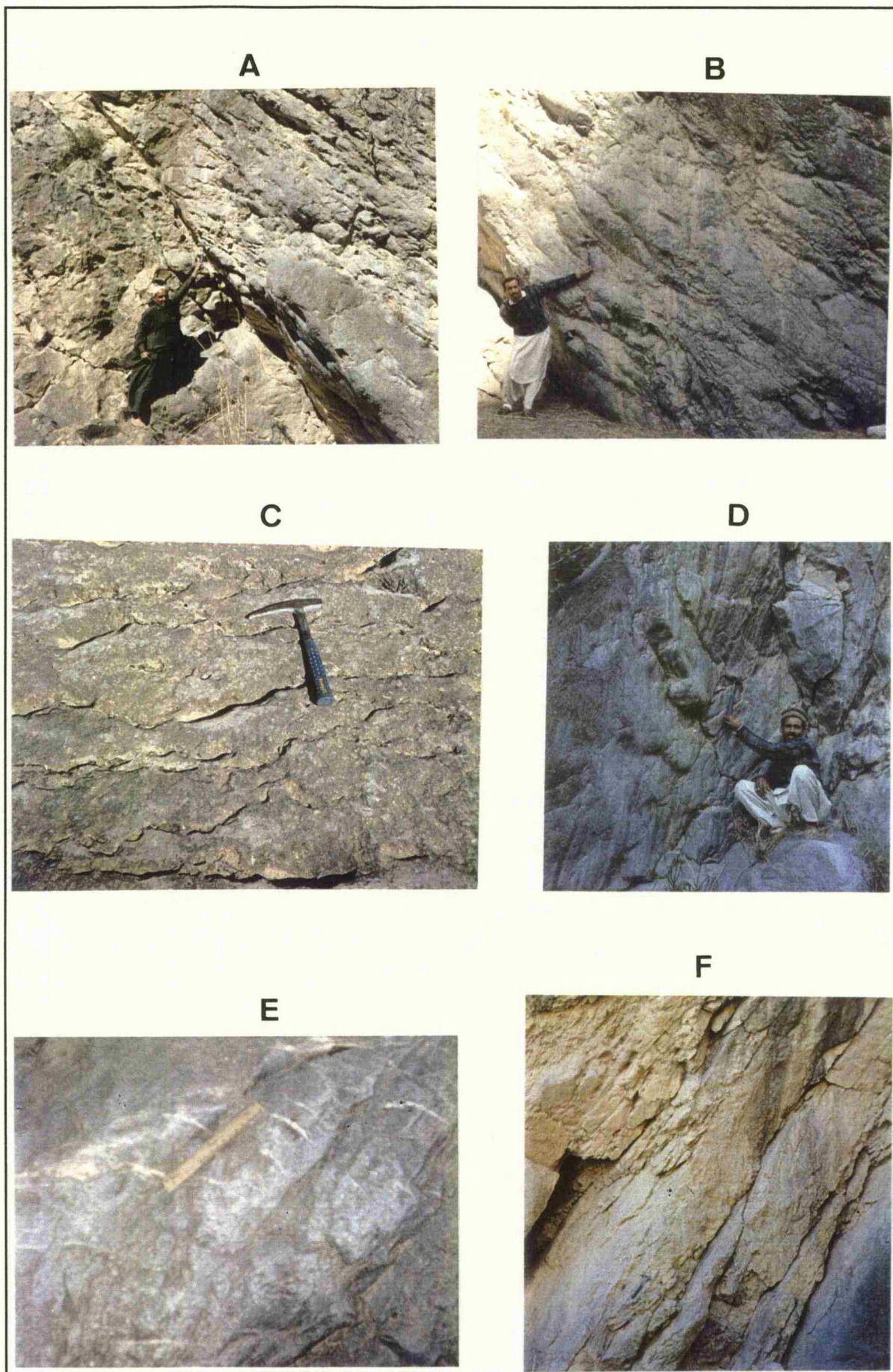


Fig. 4.2.

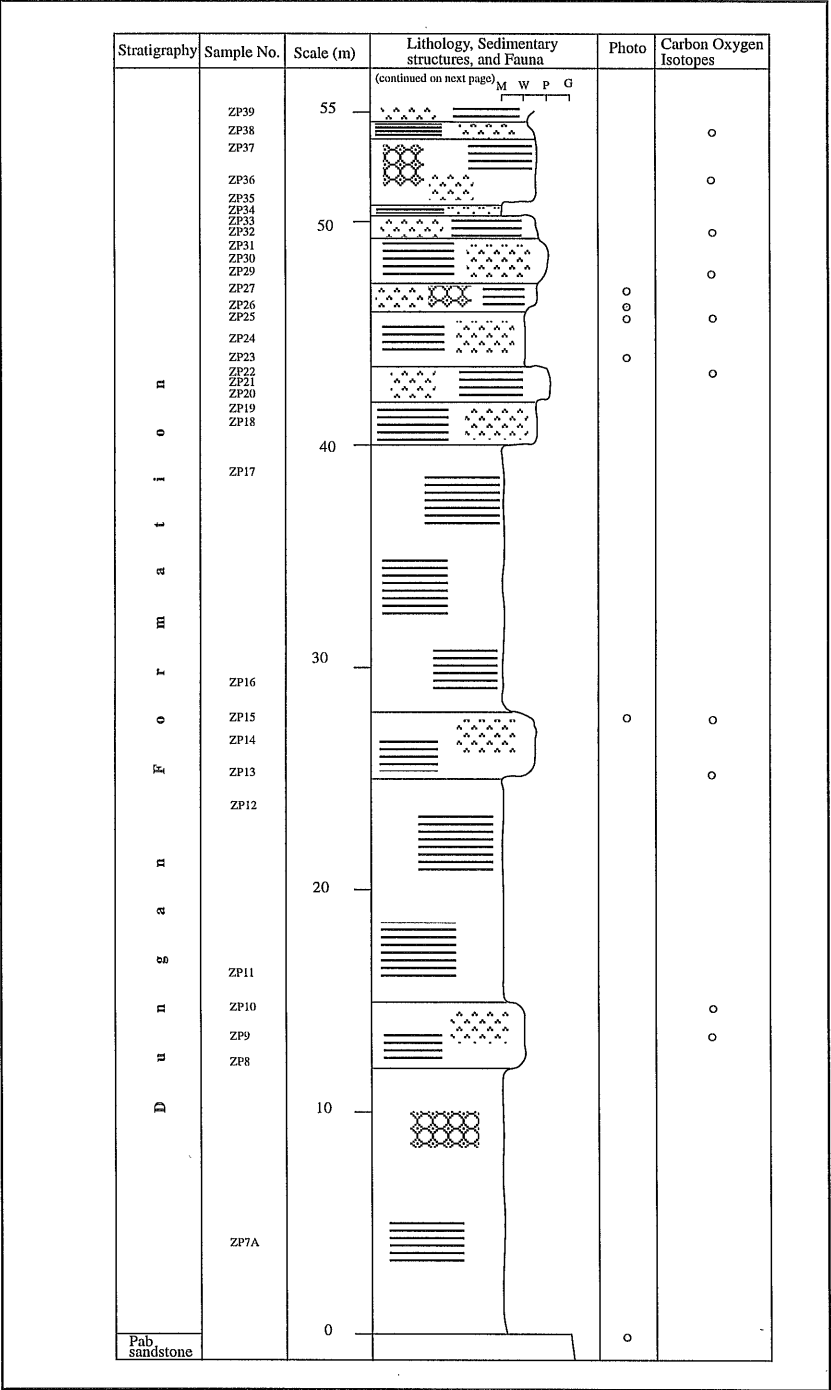
third from 6.80 metres (RG 32), from the base. The 13th, unit is fine to medium grained, thick bedded (.7 to 1.0 metre), algal wackestone. The lower and upper contacts are sharp and planar. The total thickness is 3.10 metres. Two samples are collected from this unit, one near the base (RG 33), and second from 3.0 metres from the base (RG 34). The next unit is fine grained, thick bedded to massive (8.0 to 1.5 metres thick), skeletal wackestone. The lower and upper contacts are planar and sharp. It is 5.70 metres thick unit. The foraminifera decrease upward. Three samples are taken from this part, one near the base (RG 35), second from 2.5 metres (RG 36), and third from 5.5 metres from the base (RG 36A). The 16th unit is fine to medium grained, massive (1.3 to 1.8 metres thick), nodular, algal wackestone. Due to solution weathering it shows the structure of zebra calcite. The thickness of this unit is 10.70 metres. Two samples are collected from this portion, one near the base (RG 37), and the second near the top (RG 38) of the unit. The next upper unit is medium to coarse grained, thick bedded (.8 to 1.0 metre thick), skeletal packstone (Fig. 4.4A). The foraminifera are very prominent, and can be seen with naked eyes, and they decrease upwards. The lower and upper contacts are planar and sharp. This unit is 2.8 metres thick. Two samples are taken from this part, one near the base (RG 39), and second near the top (RG 40). The topmost unit is fine to medium grained, massive (1.5 to 1.8 metres thick), wackestone. The lower and the upper part of this section shows bioturbation the top of the section also shows horizontal burrows, solution weathering (Fig. 4.4B) and the interclasts in the form of breccias (Fig. 4.4C) are occasionally present. The lower contact is sharp and planar, where as the top is slightly wavy. The total thickness of this unit is 18.7 metres. Seven samples are taken from this part, one is taken at the level of 3.0 metres (RG 41), the second at the level of 5.7 metres (RG

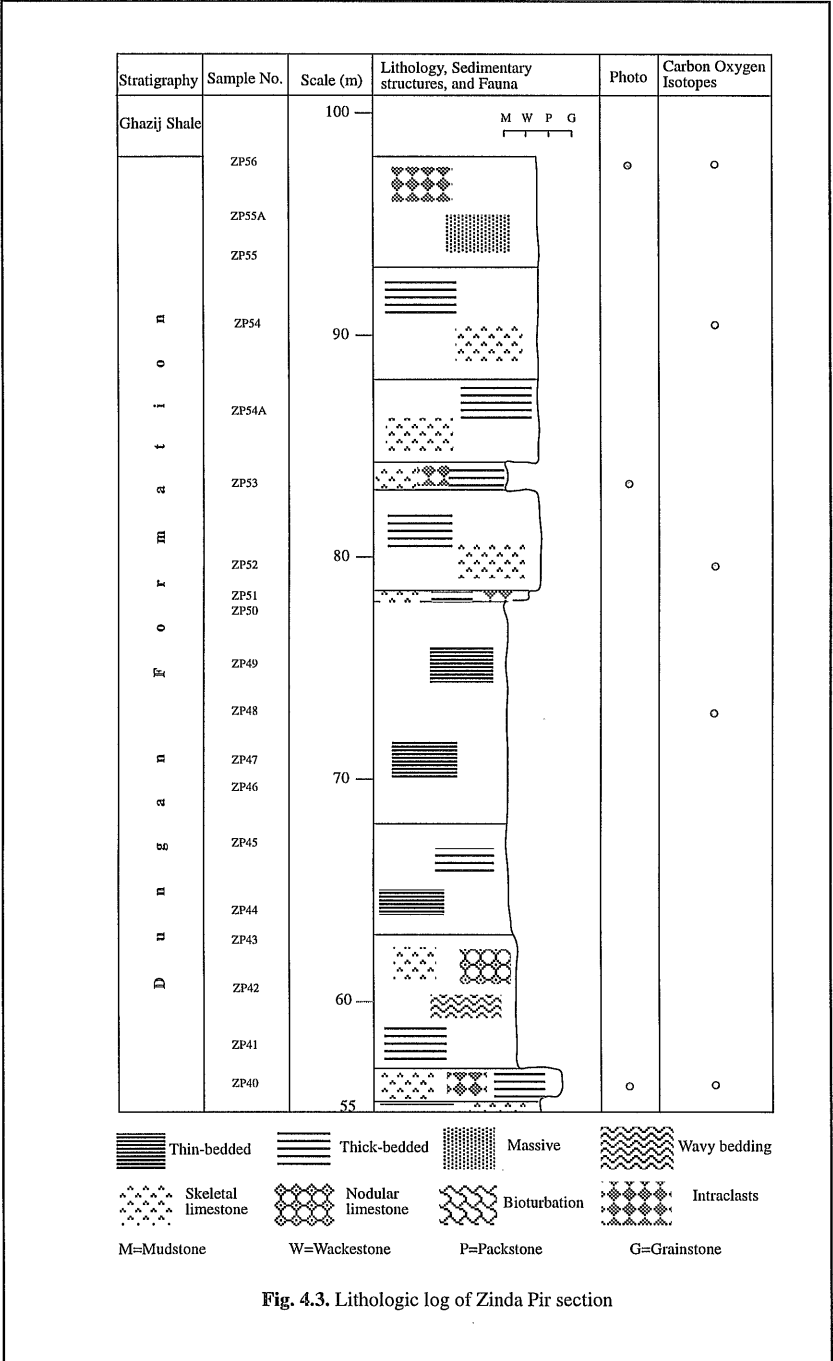
42), the third at the level of 9.2 metres (RG 43), the forth at the level of 11.7 metres (RG 44), the fifth at the level of 15.7 metres (RG 45), the sixth at the level of 17.1 metres (RG 45A), and the last at the level of 18.7 metres (RG 46) from the base.

4.3. Lithology of Zinda Pir Section:-

Zinda Pir lies at lat. $30^{\circ} 24' 00''$ and long. $70^{\circ} 30' 00''$. The Dungan Formation in this section is composed of grey to brownish grey, dark grey to black coloured limestone, with few grey to green coloured sandy/silty/shaly calcareous layers. The formation is rich in skeletal allochems. In this section the total thickness of Dungan Formation is 98 metres. The general strike is $N40^{\circ}E$ and is dipping towards east at 10° . On the basis of field observations the formation is subdivided into 26 units (Fig. 4.3).

The first unit is fine grained, thick bedded (.8 to 1.0 metre thick), nodular mudstone with siltstone. The lower contact with Pab Sandstone is planar. This part of formation is 12.0 metres thick, and its lithology is uniform from base to top. One sample is collected from the middle of the unit (ZP 7A). The upper next unit is fine to medium grained thick bedded (0.5 to 1.0 metre thick), skeletal wackestone. The lower and upper contacts are sharp and planner. The thickness of this unit is 3.0 metres. Three samples are taken from this part. one at a level of 0.5 metre (ZP 8), second at the level of 1.5 metres (ZP 9), from the base, and third from the top (ZP 10), of the unit. The next unit is fine grained, thick bedded (0.6 to 0.9 metre thick), mudstone with shale. It is 10.0 metres thick unit. Two samples are collected from this portion, one at the level of 1.0 metre (ZP 11), and second from 9.0 metres (ZP 12) from the base. The fourth unit is medium to coarse grained, thick bedded (1.0 metre thick), skeletal, wackestone





to packstone. The skeletal allochems are mainly foraminifera, which increase upward. The upper part is slightly nodular (minor), and also show the effect of weathering solution (Fig. 4.4E). The lower and upper contacts are sharp and planar. The bedding surfaces are also planar. The total thickness of this unit is 3.0 metres. Three samples are taken from this part, one at the level of 0.5 metre (ZP 13), the second at the level of 1.5 metres (ZP 14) from the base, and third from the top of the unit (ZP 15). The next unit is fine grained mudstone with siltstone and shale. The lower and upper contacts are sharp and planar. It is the repetition of unit three. The thickness of this portion is 12.0 metres. Two samples are taken from this part, one at the level of 1.0 metre (ZP 16) and the second at the level of 11.0 metres (ZP 17) from the base. The next unit is coarse grained, thick bedded (0.90 to 1.0 metre thick), skeletal wackestone/packstone. The lower and upper contacts are sharp and planar. The total thickness is 1.90 metres. One sample is collected from the middle of this unit (ZP 18). This unit is underlain by a 10 cm thick shale, one sample (ZP 19) of shale is collected from the middle of this unit. The 8th, unit is coarse grained, thick bedded (0.5 to 0.7 metre thick), skeletal, wackestone/packstone. It is relatively thin bedded to the underlying unit (6th). The foraminifera can be seen by the naked eye. This unit is well bedded and the bedding surfaces are planar. The lower and upper contacts are planar and sharp. The total thickness of this part is 1.6 metres. Three samples are taken from this part, one from the base (ZP 20), the second at the level of 1.0 metre (ZP 21), and the third from the top (ZP 22) of this unit. The next unit is fine to medium grained, thick bedded (0.50 metre thick), skeletal, wackestone. The foraminifera are more in lower and upper part as compared to the middle. This unit shows the effect of solution weathering and bioturbation (Fig. 4.4D). It is 2.5 metres thick unit. The lower contact

is sharp and planar, whereas the upper contact is irregular. Three samples are taken from this unit, one from the base (ZP 23), the second at the level of 1.0 metre (ZP 24), and third at the level of 2.0 metres (ZP 25) from the base. The next unit is 1.20 metres thick, fine to medium grained, thick bedded skeletal, wackestone/packstone. It is shaley at the base which gradually changes into nodular, fossiliferous limestone. It contains en-echelon veins which are transverse to bedding plane (Fig. 4.4F). Two samples are taken from this part, one from the base (the shaley part) (ZP 26), and the second near the top (ZP 27) of the unit. The 11th unit is medium grained, thick bedded (0.7 to 1.0 metre thick), skeletal packstone. It is highly fossiliferous, containing foraminifera. The lower and upper contacts are sharp and planar. The total thickness of this part is 2.0 metres. Three samples are collected from this unit, one from the base (ZP 29), the second at the level of 1.10 metres (ZP 30), and the third at the level of 1.80 metres (ZP 31) from the base. The next unit is medium grained, thick bedded (0.5 metre thick) skeletal packstone/wackestone. It is 1.0 metre thick unit, and has a planar bedding surfaces. Two samples are taken from this portion, one from lower bed (ZP 32), and the second from the upper bed (ZP 33). The next unit is calcareous shale, which is highly fossiliferous and is 0.50 metre thick. One sample is taken from this part (ZP 34). The 14th unit is medium to coarse grained, medium to thick bedded (0.3 to 0.5 metre thick), skeletal packstone/wackestone. The limestone becomes nodular upward. The total thickness of this part is 3.0 metres. The lower and upper contacts are sharp and planar. Three samples are taken from this part, one at the level of 0.30 metre (ZP 35), the second at the level of 1.30 metres (ZP 36), and third at the level of 2.65 metres (ZP 37) from the base. The next unit is medium grained, medium bedded (0.25 metre thick), skeletal wackestone/packstone. The thickness of this unit is 0.80

Fig. 4.4. A.

Photograph (taken from RG 39) illustrates thin to thick bedded wackestone of Dungan Formation in Raghasar section. The bedding surfaces are plane.

Fig. 4.4. B.

Photograph (taken from RG 41) illustrating the cavities left behind as a result of differential solution weathering in the wackestone/packstone of Dungan Formation in Raghasar section.

Fig. 4.4. C.

The field photograph (taken from the topmost surface of the Formation) illustrates the randomly oriented calcareous breccia in the upper part of the Dungan Formation in Raghasar section. The rock is a wackestone.

Fig. 4.4. D.

Field photograph (taken from ZP 23) illustrates the bioturbation in the wackestone (Dungan Formation) in Zinda Pir section. Hammer shows the scale.

Fig. 4.4. E.

Photograph (taken from ZP 13) showing the effect of differential solution weathering in skeletal wackestone/packstone of the Dungan Formation in Zinda Pir section. The skeletal grains are removed and the cavities are left behind.

Fig. 4.4. F.

Photograph (taken from ZP 27) shows the en-echelon structured calcitic veins in Dungan Formation (Zinda Pir section). The en-echelon veins are perpendicular to the bedding. Hammer indicates the scale.

A



B



C



D



E



F



Fig. 4.4.

metre. One sample (ZP 38) is collected from the middle of this unit. The next unit is fine to medium grained, thick bedded (1.0 metre thick), skeletal packstone/wackestone. It is slightly argillaceous and the skeletal allochems are mainly the foraminifera. The thickness of this portion is 1.0 metre. The lower and upper contacts are sharp and planar. One sample (ZP 39) is collected from the middle of the unit. The next unit is medium to coarse grained, thick bedded (individual bed 0.4 metre thick), skeletal packstone/grainstone. The rock is highly fossiliferous. Few intraclasts are also found. The total thickness of this part is 1.6 metres. The bedding surfaces are planar. The lower and the upper contacts are sharp and planar. One sample (ZP 40) is taken from the middle of this unit. The 18th, unit is fine to medium grained, thick bedded (0.8 to 1.0 metre thick), wackestone/mudstone. The weathering surfaces are argillaceous and on these surfaces very small foraminifera can be seen with the help of lens. The limestone is marly, nodular, and well bedded. The bedding surfaces are wavy. The thickness of individual beds decreases upward. The total thickness of this part is 6.0 metres. The lower and upper contacts are sharp. Three samples are taken from this part, one at the level of 1.0 metre (ZP 41), the second at the level of 3.5 metres (ZP 42), and third at the level of 5.5 metres (ZP 43), from the base. The next unit is fine grained, thick bedded (0.60 metre thick), mudstone. It is relatively thin bedded than the underlying unit. The limestone is marly, well bedded, and homogeneous throughout the unit. The lower and upper contacts are planar and sharp. This unit is 5.0 metres thick. Two samples are collected from this part, one at the level of 1.0 metre (ZP 44), and second at the level of 4.0 metres (ZP 45), from the base. The 20th, unit is fine grained, thin to medium bedded (0.05 to 0.20 metre thick), calcareous mudstone. The limestone is black coloured (fresh surface), marly and well

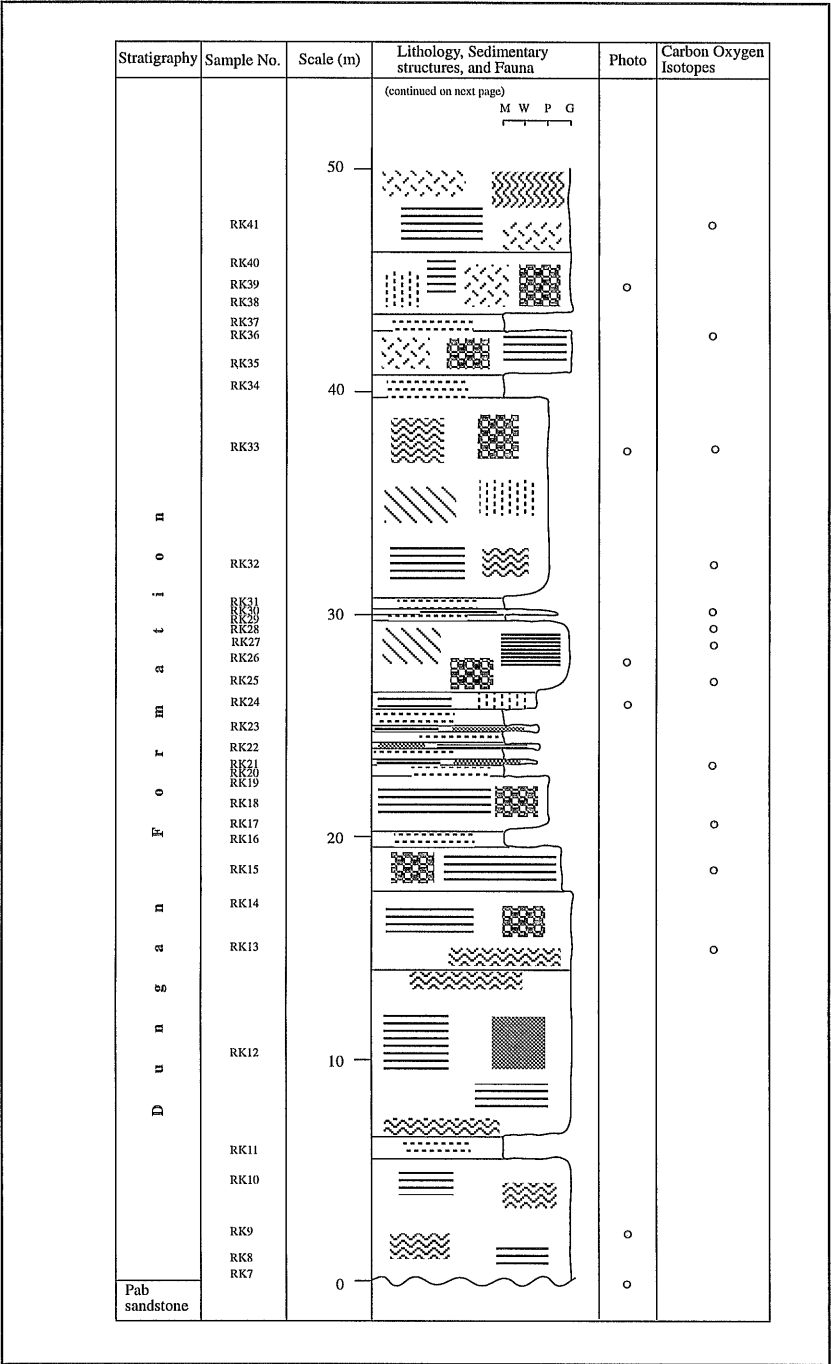
bedded. The lower part has locally chert nodules. The middle part has spary calcitic en-echelon veins (Fig. 4.6A). The lower and upper contacts are planar and sharp. The total thickness of this unit is 10.0 metres. Five samples are taken from this unit, one at the level of 1.5 metres (ZP 46), the second at the level of 2.7 metres (ZP 47) (chert nodule), third at the level of 5.0 metres (ZP 48), the forth at the level of 7.0 metres (ZP 49), and last at the level of 9.5 metres (ZP 50), from the base. The next unit is fine grained, thick bedded (0.5 metre thick), skeletal wackestone. It contains the intraclasts, and foraminifera. The lower and upper contacts are sharp and planar. One sample (ZP 51) is collected from the middle of the unit. The next unit is fine to medium grained, thick bedded (0.8 to 1.0 metre thick), skeletal wackestone/packstone. The limestone is well bedded and highly fossiliferous. The fossils are mainly foraminifera. One sample (ZP 52) is taken from the middle of the unit. The total thickness of the unit is 5.0 metres. The next unit is fine grained, thick bedded (0.5 metre thick), skeletal wackestone. It contains the intraclasts and foraminifera. One sample (ZP 53) is taken from this unit. The total thickness of this unit is 1.2 metres. The lower and upper contacts are planar and sharp. The next unit is again fine to medium grained, thick bedded (0.8 to 1.0 metre thick), skeletal wackestone/packstone. The limestone is well bedded and highly fossiliferous. One sample (ZP54A) is taken from this unit. The total thickness of this unit is 3.3 metres. The 25th unit is fine to medium grained, thick bedded (1.0 metre thick), skeletal packstone/wackestone. It contains the foraminifera which decrease upward. The lower and upper contacts are planar and sharp. The unit is 5.0 metres thick, and is homogenous throughout. One sample (ZP 54) is collected from the middle of the unit. The topmost unit is medium grained, massive bedded (1.2 to 1.7 metres thick) packstone/wackestone. It contains

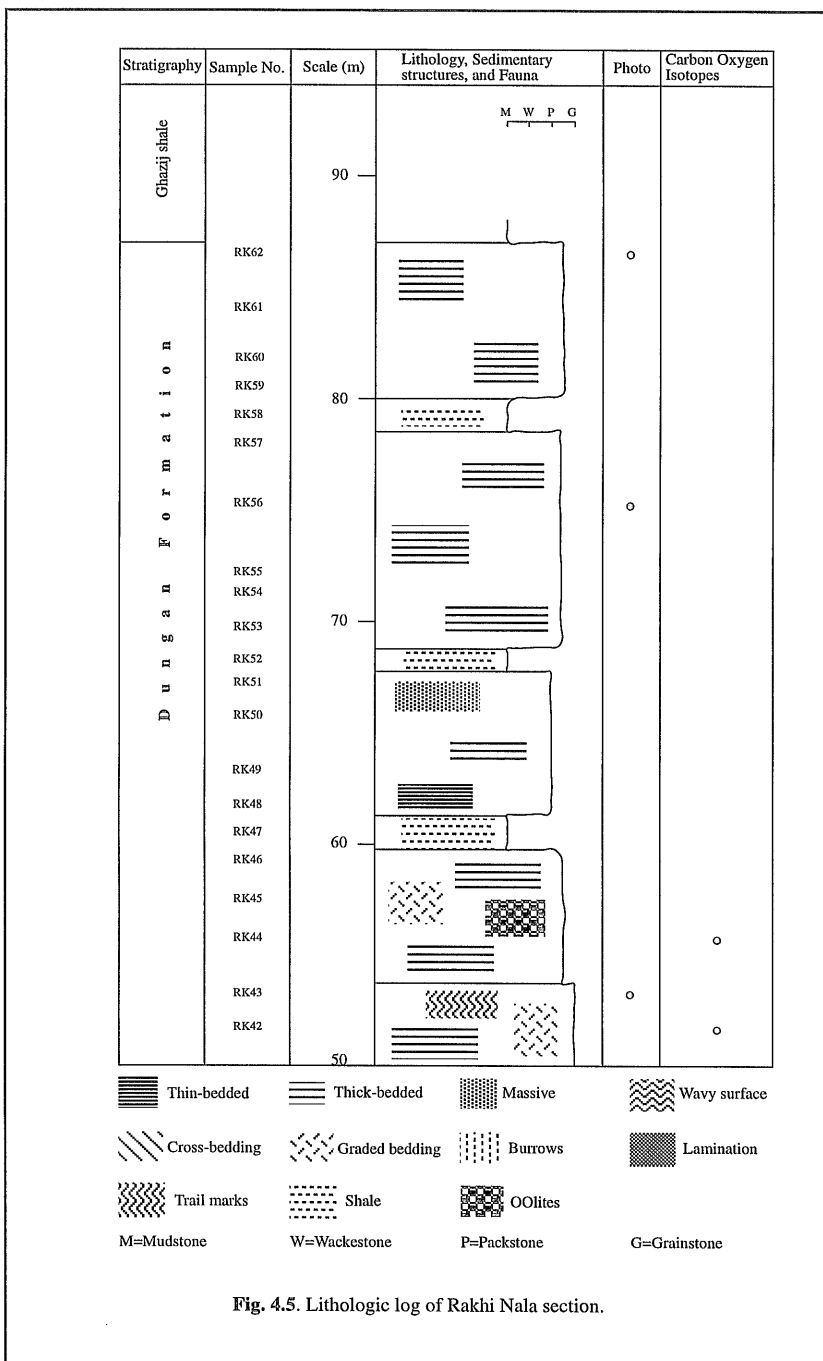
the intraclasts, conglomerates and shows kerren structures (Fig. 4.6B) near the top. The lower and upper contacts are sharp and planar. The thickness of this part is 5.0 metres. Three samples are taken from this part, one at the level of 1.0 metre (ZP 55), second at the level of 3.0 metres (ZP 55A), from the base and third from the top of the formation (ZP 56). The overlying formation is Ghazij shale.

4.4. Lithology of Rakhi Nala Section:-

Rakhi Nala lies at lat. $29^{\circ} 57' 44''$, long. $70^{\circ} 05' 38''$. The Dungan Formation is 87.5 metres thick in this section, and composed of limestone with subordinate sandstone, siltstone, and shale. The sandstone is olive, yellowish brown, grey and green soft, and fine to medium grained. The shale is olive, pale bluish grey, reddish brown and argillaceous. The limestone is brown grey to green in colour. The general strike is $N18^{\circ}E$ and dipping towards southeast at an angle of 35° . The formation is further subdivided into 29 units on the basis of field observations (Fig. 4.5).

The first unit is yellow brown sandstone with calcareous material. The sandstone shows variation in grain size from base to top in the form of cycles. The upper part is more calcareous as compared to the lower part. The unit is thick bedded (individual bed is 0.5 to 0.7 metre thick), and the bedding surfaces are uneven. The lower contacts with the underlying Pab sandstone is sharp and wavy. The upper contact with the overlying unit is sharp and planar. The total thickness of this portion is 5.6 metres. Four samples are taken from this unit, one from the base (RK 7), second at the level of 1.0 metre (RK 8), third at the level of 2.0 metres (RK 9), and fourth at the level of 4.5 metres (RK 10), from the base. The next unit is 1.0 metre thick, well laminated,





reddish brown shale. The lower and upper contacts are sharp and uneven. One sample (RK 11) is collected from the middle of this shaley part. The next unit is grey coloured, thick bedded (0.4 to 0.8 metre thick) calcareous sandstone, showing lamination. The total thickness of this part is 7.5 metres, and is homogeneous from base to top. The lower and upper contacts are sharp and wavy. One sample (RK 12) is taken from the middle of the unit. The forth unit is grey coloured, thick bedded (0.6 to 1.0 metre thick) packstone/wackestone. The lower contact is sharp and wavy, and the upper contact is sharp and planar. The thickness of this portion is 3.5 metres. Two samples are taken from this unit, one at the level of 1.0 metre (RK 13), and second at the level of 3.0 metres (RK 14), from the base. The next unit is grey to green coloured, thick bedded (0.8 metre thick) packstone/grainstone. The lower and upper contacts are plane and sharp. This unit is 2.0 metre thick and is homogeneous from bottom to top. One sample is collected (RK 15) from the middle of the unit. The next unit is 0.60 metre thick bluish grey shale/siltstone, and is well laminated. The lower and upper contacts are sharp and planar. One sample is taken (RK 16) from the middle of the shale. The 7th unit is grey to green coloured, thin to thick bedded (0.2 to 0.7 metre thick), packstone/wackestone. The lower and upper contacts are plane and sharp. The total thickness of this part is 2.5 metres. Three samples are taken from this part, one near the base (RK 17), second at the level of 1.2 metres (RK 18) from the base, and third from the top (RK 19) of the unit. The next unit is olive grey coloured shale. It is 0.40 metre thick, and has a sharp and plane contacts with lower and upper units. One sample (RK 20) is taken from the middle of the shale. The next unit is grey, coloured medium bedded (0.2 metre thick), wackestone/packstone, showing lamination (Fig. 4.6E). The lower and upper contacts are sharp and planar. The thickness of this

portion is 0.2 metre. One sample (RK 21) is taken from the middle of the unit. The 10th unit is grey coloured thin bedded (0.10 metre thick) wackestone/packstone. It shows fine lamination within the bed. This unit is 0.10 metre thick. One sample (RK 22) is brought from this portion. This unit is separated from the underlying unit by a 0.60 metre thick olive grey shale. The next unit is grey coloured thin bedded (0.10 metre thick) packstone/grainstone. It shows lamination within the bed. This unit is 0.10 metre thick. One sample (RK 23) is collected from this part. This unit is separated from the underlying unit by a 0.50 metre thick olive grey shale. The next unit is grey coloured thick bedded (0.70 metre thick) grainstone/packstone. The bedding surface contains the horizontal burrows. The lower and upper contacts are sharp and planar. This unit is 0.70 metre thick. One sample (RK 24) is taken at the level of 0.2 metre from the base. This unit is separated from the underlying unit by a 0.80 metre thick olive grey shale. The 13th unit is dark grey coloured, thin to medium bedded (0.3 to 0.5 metre thick) packstone/grainstone, showing trough type of cross-bedding (Fig. 4.6D). The lower and upper contacts are sharp and planar. The thickness of this unit is 3.2 metres. Four samples are collected from this part. one near the base (RK 25), the second at the level of 1.5 metres (RK 26), the third at the level of 2.2 metres (RK 27), and the forth at the level of 3.0 metres (RK 28). The next unit is bluish grey coloured shale. It is 0.30 metre thick, and has a sharp and plane contacts with lower and upper units. One sample (RK 29) is taken from the middle of the shale. The next unit is dark grey coloured, thin bedded (0.20 metre thick), packstone/grainstone. The lower and upper contacts are plane and sharp. The thickness of this unit is 0.20 metre. One sample (RK 30) is taken from this part. The next unit is 0.60 metre thick bluish grey coloured shale. The lower and upper contacts

are sharp and plane. One sample (RK 31) is taken from the middle of the shale. The 17th unit is grey coloured, thick bedded (0.6 to 0.9 metre thick) packstone. Trough cross-bedding are found in this unit. The lower and upper contacts are plane and sharp. The bedding surfaces are slightly uneven, and in the upper part of this unit horizontal burrows are present. The total thickness of this unit is 9.0 metres, and it is homogeneous from bottom to top. Two samples are collected from this part, one at the level of 1.5 metres (RK 32), and second at the level of 7.0 metres (RK 33), from the base. The next unit is 1.0 metre thick bluish grey coloured shale. The lower and upper contacts are sharp and plane. One sample (RK 34) is taken from the middle of the shale. The next unit is yellowish brown thick bedded quartzose grainstone. The grain size increases upward. The lower and upper contacts are plane and sharp. The total thickness of this part is 2.30 metres. Two samples are collected from this part, one at the level of 0.50 metre (RK 35) and the second at the level of 2.0 metres (RK 36) from the base. The 20th unit is yellowish brown thick bedded (0.4 to 0.6 metre thick) quartzose grainstone. The grain size decreases upward. The beds are lenticular and show burrows. The lower and upper contacts are plane and sharp. The total thickness of this part is 2.60 metres. Three samples are collected from this part, one at the level of 0.50 metre (RK 38) the second at the level of 1.2 metres (RK 39), and the third at the level of 2.2 metres (RK 40) from the base. This unit is separated from the underlying unit by a 0.80 metre thick, pale bluish grey shale. One sample is taken (RK 37) from this shale. The next unit is grey to green coloured, thick bedded (0.6 to 1.0 metre thick) quartzose grainstone/packstone. The grains are coarser at the base and relatively finer at the top, and there is the alternations of coarser and finer grains. The upper part of the unit shows the trailing marks on the bedding plane (Fig. 4.6F).The

Fig. 4.6. A.

Photograph (taken from ZP 50) illustrates the late calcite veins in the topmost surface of the Dungan Formation in Zinda Pir section. The veins are transverse to the bedding.

Fig. 4.6. B.

Photograph (taken from ZP 56) showing the effect of differential solution weathering in wackestone (Dungan Formation) in the Zinda Pir section. The soft particles have been removed and developing the kerren structure.

Fig. 4.6. C.

Photograph (taken from RK 32) showing the massive bedding in the lower part of the formation in Rakhi Nala section. Scale stick is 1.5 metres long.

Fig. 4.6. D.

Photograph (taken from RK 25) showing the normal cross bedding in the grainstone part of the Dungan Formation in Rakhi Nala section.

Fig. 4.6. E.

Photograph (taken from RK 21) illustrates the lamination within the thick bedded packstone/grainstone of the Dungan Formation in Rakhi Nala section.

Fig. 4.6. F.

Photograph (taken from RK 43) illustrates the trail marks on the bedding surface of the Dungan Formation in Rakhi Nala section.

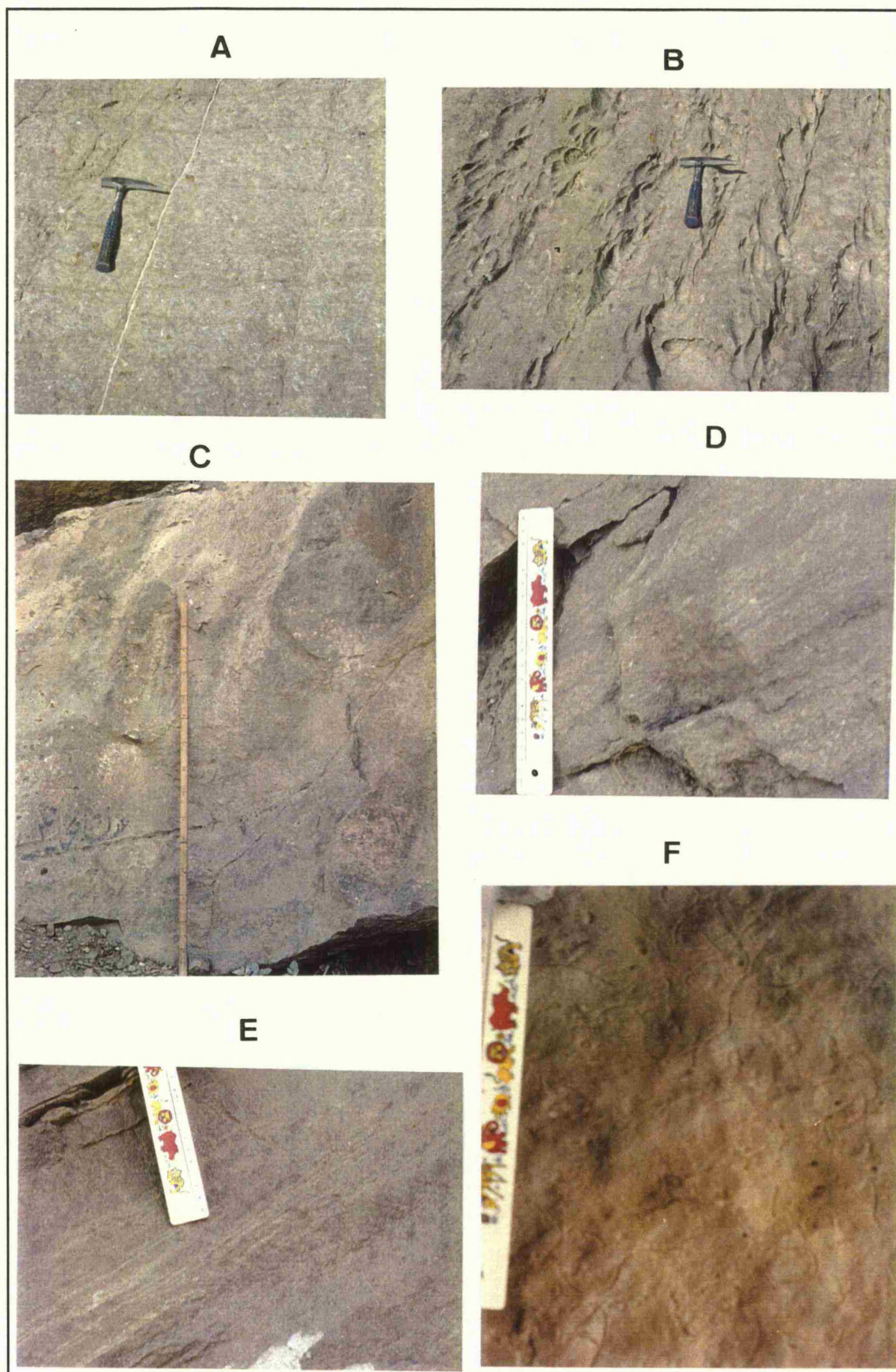


Fig. 4.6.

lower and upper contacts are plane and sharp. The total thickness of this part is 7.5 metres. Three samples are collected from this portion, one at the level of 1.0 metre (RK 41), second at the level of 5.5 metres (RK 42), and third at the level of 7.0 metres (RK 43) from the base. The next unit is grey coloured, thick bedded (0.6 to 0.9 metre thick) packstone/grainstone. It is relatively fine grained at the base, coarse grained in the middle, and then fine grained at the top. The lower and upper contacts are plane and sharp. The total thickness of this unit is 6.0 metres. Three samples are taken from this part, one at the level of 2.0 metres (RK 44), which is fine grained, the second at the level of 3.8 metres (RK 45), which is coarse grained, and third at the level of 5.6 metres (RK 46), from the base, which is fine grained. The 23rd unit is yellowish brown, grey coloured, medium to thick bedded (0.3 to 1.0 metre thick) quartzose packstone. The thickness of the beds increases upward, and the topmost beds are very thick. The grain size remains more or less same throughout the unit. The lower and upper contacts are plane and sharp. The thickness of this unit is 6.5 metres. Four samples are collected from this part, one at the level of 0.5 metre (RK 48), the second at the level of 2.0 metres (RK 49), third at the level of 4.5 metres (RK 50), and fourth at the level of 6.0 metres (RK 51). This unit is separated from the underlying unit by a pale bluish grey shale. The thickness of the shale is 1.50 metres. One sample is taken (RK 47) from this shale. The next unit is yellowish brown, coloured, soft thick bedded (0.6 to 1.0 metre thick) calcareous sandstone. It is sandy in the lower and upper parts, and argillaceous in the middle part of the unit. The lower and upper contacts are plane and sharp. The total thickness of the unit is 9.8 metres. Five samples are collected from this part, one at the level of 1.0 metre (RK 53), second at the level of 2.5 metres (RK 54), third at the level of 3.5 metres (RK 55), the fourth at the level of 6.5 metres (RK

56), and fifth at the level of 9.5 metres (RK 57), from the base. This unit is separated from the underlying unit by 1.0 metre thick pale bluish grey shale. One sample (RK 52) is taken from this shale. The topmost unit is olive, yellowish brown, coloured, soft thick bedded (0.6 to 1.0 metre thick) calcareous sandstone. The lithology is homogeneous throughout the unit. The lower and upper contacts are sharp and planar. The total thickness of the unit is 7.0 metres. Four samples are taken from this part, one at the level of 0.5 metre (RK 59), second at the level of 1.70 metres (RK 60), third at the level of 4.0 metres (RK 61) and fourth at the level of 6.5 metres (RK 62), from the base. This topmost unit is separated from the underlying unit by a shale and overlain by the Ghazij shale (Eocene age). The underlying shale is olive pale bluish grey and argillaceous. The thickness of shale is 1.5 metres, and one sample (RK 58) is collected from the middle of the shale.

4.5. Comparative Studies of the Sections:-

The Rakhi Nala section is predominantly grainstone and packstone. The clastic material is in abundance in this section. The beds are thick and show lenticular and trough cross-bedding. Lamination, burrows, and fenestral structures are occasionally present. The fossils fauna are rare. The quartz grains are unicrystalline, ill sorted and subrounded to subangular. All these features show that the area was near the shore.

The Raghasar section is mainly the wackestone and packstone. It is dominantly carbonate, and is thin to thickly bedded. The beds occasionally show nodular structure, bioturbation, solution weathering in the form of zebra calcite, and storm

structures are fairly present. The fossils are mainly the algae and foraminifera. These features indicate the shallow marine environments.

The Zinda Pir section is composed mainly of wackestone, mudstone, with few packstone. It is mainly the carbonate with few shales. The carbonates are occasionally marly, and the shales are carbonaceous. The bedding characteristics are thin to thick bedded, occasionally nodular. Bioturbation and solution weathering are fairly present. The calcitic veins are commonly present in the middle part of the section. The fossils are mainly the foraminifera and can be seen with naked eyes. The shales are highly fossiliferous. These features indicate the shallow marine environments but near to the basin.

Chapter Five

PETROGRAPHY OF DUNGAN FORMATION

5.1. Introduction:-

This chapter deals with the petrography of the Dungan Formation, the studies are based on the stained thin sections under binocular microscope, reflected light microscopy, polished thin sections under cathodoluminescence microscopy and scanning electron microscopy on back scattered mode. A compromise system has been used (based on both Folk, 1959, 1962, and Dunham, 1962) to describe the composition, texture and the framework of the Dungan Formation.

5.2. Limestone Classification:-

Two classification systems are commonly used each with different emphasis. These systems are given by Folk (1959, 1962) and Dunham (1962).

Folk Classification:- Folk's classification (1959, 1962) is based mainly on depositional texture and especially on matrix type. He distinguished three components, the allochems (particles or grains); the matrix, chiefly micrite (equivalent to clay in sandstone); and cement, chiefly drusy sparite. An abbreviation for the allochems (bio-skeletal grains; oo-ooids; pel-peloids; and intra-intraclasts) is used as a prefix to micrite or sparite whichever is dominant.

Dunham Classification:- Dunham's classification is based on the depositional texture of the limestone. The fundamental criterion of subdivision is the nature of the framework of the sediments. He classified limestones into: grainstone, grains without matrix (grain supported); packstone, grains in contact with matrix (grain supported); wackestone, coarse grains floating in a matrix, grains are more than 10%, (mud supported); and mudstone, micrite with few grains, grains are less than 10%, (mud supported).

In the present study both type of classifications are used to describe the composition, texture and the types of grains present in the thin sections of the Dungan Formation.

5.3. Carbonate Grains:-

Carbonate grains, broadly the main component of the limestone, are called the allochems. There are two main types of allochems, the skeletal and non-skeletal. The Dungan Formation contains both types of carbonate allochems.

5.3.1. Skeletal Allochems:-

The skeletal allochems of a limestone are formed by carbonate-secreting organisms. In the Dungan Formation these organisms (in order of abundance) are the benthonic foraminifera, algae, bryozoa, echinoderms, molluscs, corals and planktonic foraminifera. The present studies show that the skeletal allochems are the main component of the carbonates of the Dungan Formation.

5.3.1.1. Benthonic Foraminifera:-

The benthonic foraminifera present in the Dungan Formation are *Coskinolina*, *Miliolids*, *Rotalia*, *Lockhartia*, *Miscellanea*, *Ranikothalia*, *Nummulites*, *Assilina*, *Operculina*, *Discocyclina*, *Alveolina*, *Athenocyclina* and *Actinosiphon* (Davies, 1941; Hunting Survey Corporation, 1961; Latif, 1964; Iqbal, 1969a and many others).

Miliolids:-

They are abundantly present in the studied thin sections of Rakhi Nala and Raghasar areas. Their walls are of porcellaneous texture which gives shiny and smooth appearance. The test is made up of randomly oriented micrite grains. In thin section they appear dark in plane polarized light. The walls are composed of high-Mg calcite and the chambers are filled by sparry calcite cement (Fig. 5.1A). Under cathodoluminescence microscopy the micritic wall are non-luminescent whereas the chamber fill cement shows orange luminescence (Fig. 5.5C) in some cases.

Coskinolina:-

Very few *Coskinolina* foraminifera are present in the few studied thin sections of Rakhi Nala and Raghasar areas. Their walls are of simple agglutinated forms, consisting of a single layer composed of particles. In thin sections the walls appear dark in plane polarized light. Both uniserial and biserial *Coskinolina* are present in the formation. The chambers are filled by non-ferroan sparry calcite cement (Fig. 5.1B).

Lockhartia:-

Fig. 5.1. A.

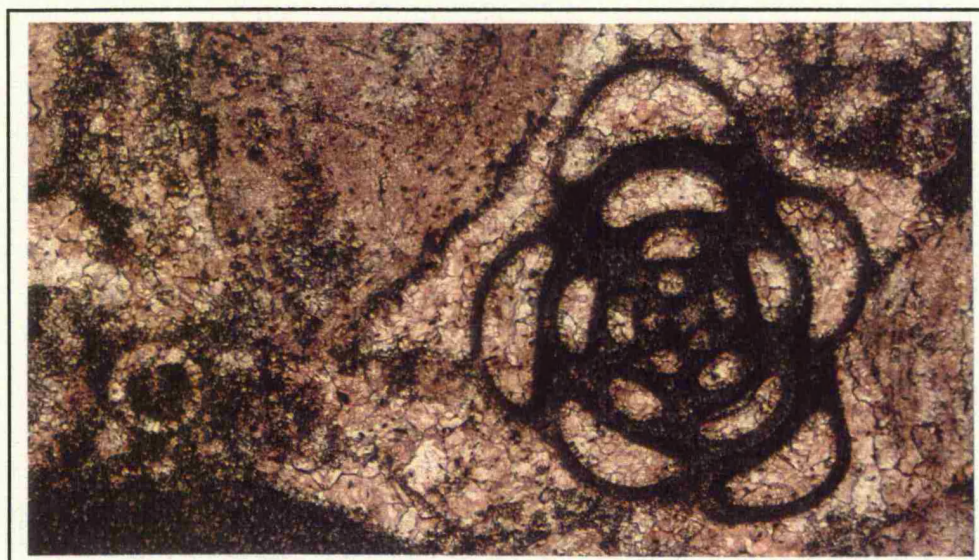
Thin section photomicrograph from sample RG13, showing miliolid foraminifera with micritic wall structure and the chambers are filled by non-ferroan sparry calcite cement.

Fig. 5.1. B.

Thin section photomicrograph from sample RG4 illustrating biserial *Coskinolina* with micritic wall structure and the chambers are filled by non-ferroan sparry calcite cement.

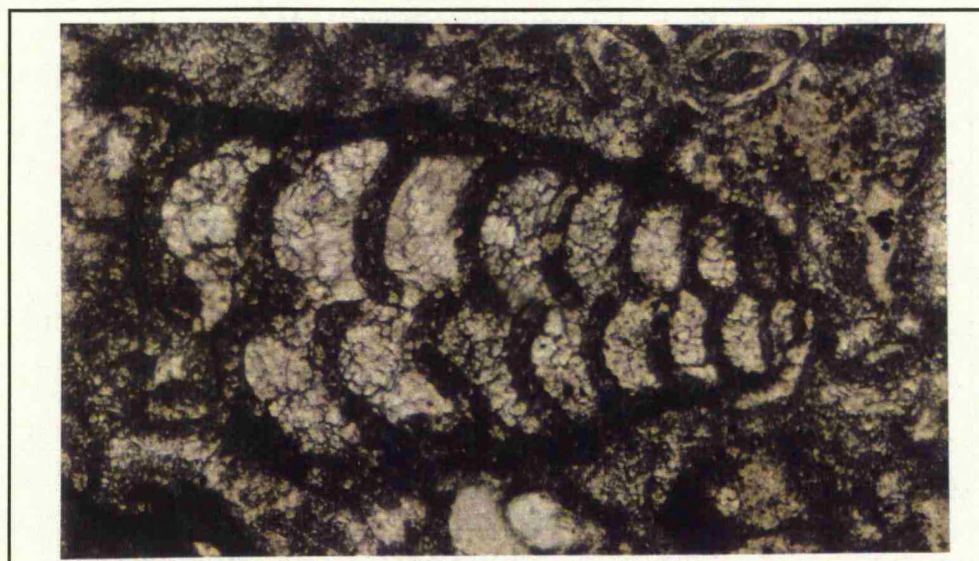
Fig. 5.1. C.

Thin section photomicrograph from sample RG21, showing foraminifera (*Lockhartia*), the walls are thick and have a radial fibrous structure, the fibres being aligned at right angle to the test wall. The chambers are filled by sparry calcite cement.



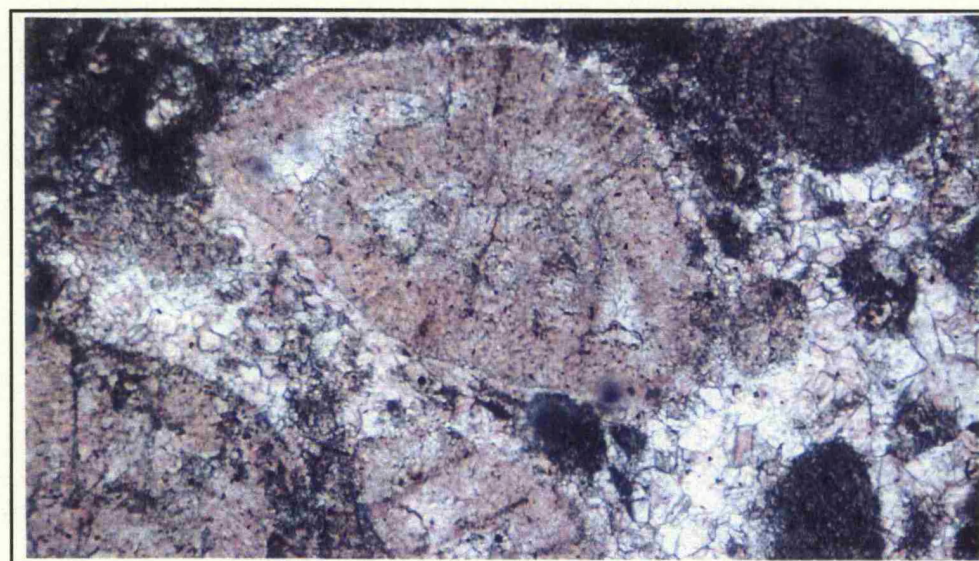
A

200μm



B

200μm



C

200μm

Fig. 5.1.

This genus of foraminifera is very common in most of the studied thin sections of Raghasar and Zinda Pir areas. Their wall structure is of hyaline texture which is characterized by fine and coarse perforation, and is originally composed of high-Mg calcite. The high-Mg calcite walls of foraminifera may become ferroan after diagenesis whereas low-Mg calcitic walls are not (Richter and Fuchtbauer, 1978). In thin section the walls appear light coloured in plane polarized light, and the chambers are filled mainly by sparry calcite cement, and few by micrite (Fig. 5.1C). Under cathodoluminescence microscopy in some cases the walls show orange luminescence and the chamber fill cement are non-luminescent whereas in some cases the walls are non-luminescent and the chamber fill cement shows orange luminescence (Fig. 5.5B).

Miscellanea:-

This genus is commonly present in few thin sections of the studied areas of Raghasar and Zinda Pir. It is lenticular to subspherical, the walls are of hyaline texture which show the coarse perforation and is composed of high-Mg calcite. In thin sections the walls appear light coloured in the plane polarized light, and the chambers are filled mostly by non-ferroan sparry calcite cement. In some cases they are filled partially by ferroan and partially by non-ferroan sparry calcite cement. In few thin sections the walls of the foraminifera are also ferroan (Fig. 5.2A).

Ranikothalia:-

Very few foraminifera of this genus are present in a few of the studied thin sections of the Zinda Pir area. They are mostly present as fragments, very few are in a complete form. The wall structure of this genera is of hyaline texture which is

characterized by perforation and is composed of high-Mg calcite. In thin sections chamber walls appear light coloured in plane polarized light. The chambers are filled mostly by the non-ferroan sparry calcite cement, and few are partially by non-ferroan sparry calcite cement and partially by micrite. *Ranikothalia* are planispiral and the whorls are 4/5 in A form (Fig. 5.2B).

Nummulites:-

This genus of benthonic foraminifera is very commonly present in most of the studied thin sections of the Zinda Pir section. They are present mostly in a complete form along with broken fragments. The wall structure of this genera is of hyaline texture which is characterized by minute perforations and is composed of both low-Mg calcite and high-Mg calcite. In the thin sections the walls appear light coloured in plane polarized light, and show extinction under cross polarized. In a few cases the wall are ferroan (Fig. 8.6C). The chambers are filled mostly by non-ferroan sparry calcite cement. In a few cases the chambers are filled by ferroan sparry calcite cement, and in few cases they are partially filled by ferroan and partially by non-ferroan sparry calcite cement (Fig. 5.2C). *Nummulites* are planispiral and have many whorls. Under cathodoluminescence microscopy the walls of few *Nummulites* show orange luminescence and the cement filled in chambers is non-luminescent (Fig. 5.5A). Similarly in few cases the cement filled in chambers show orange luminescence and the walls are non-luminescent.

Assilina:-

This genus is commonly present in most of the thin sections of the Zinda Pir section. It is planispiral and has a tight coil with many whorls. The wall structure of this genera is

Fig. 5.2. A.

Thin section photomicrograph from sample ZP15, showing foraminifera. The wall are thin and the chambers are filled partially by sparite and partially by micrite.

Fig. 5.2. B.

- a) Thin section photomicrograph from sample Zp15, showing *Ranikothalia* foraminifera. The wall are thick and fibrous, and the chambers are filled partially by sparry calcite and partially by micrite.
- b) *Alveolina* foraminifera with micritic wall and the chambers are filled by sparry calcite cement.

Fig. 5.2. C.

Thin section photomicrograph from sample ZP40, showing *Nummulites*, *Assilina*, *Operculina*, *Discocyclina* and *Athecocyclina*. The *Nummulites*, *Assilina* and *Operculina* have a thick fibrous wall structure, and the chambers are filled partially by sparry calcite cement and partially by micrite. *Discocyclina* and *Athecocyclina* have radial chambers, filled by sparry calcite cement.



A

1000μm



B

1000μm



C

1000μm

Fig. 5.2.

of hyaline texture, characterized by perforations and is composed of high-Mg calcite. In thin sections the walls are light coloured in the plane polarized light. The chambers are filled mainly by non-ferroan sparry calcite cement, and occasionally by ferroan and non-ferroan sparry calcite cement (Fig. 5.2C). Under cathodoluminescence microscopy the walls of few *Assilina* show orange luminescence and the cement filled in chambers are dead. Similarly in a few cases the cement filled chambers show orange luminescence and the walls are non-luminescent.

Operculina:-

This type of genus is commonly present in most of the thin sections of the Zinda Pir section. Specimens are planispiral and have a moderately tight coil with three quarters of their whorls in A form. The wall structure of *Operculina* is hyaline with minute perforations. The walls are composed of both high-Mg calcite and low-Mg calcite. The chambers are filled mainly by non-ferroan sparry calcite cement (Fig 5.2C) and in few cases they are filled partially by sparite and partially by micrite. Under cathodoluminescence microscopy the walls of some *Operculina* show orange luminescence (Fig 5.5A) and the cement filled chambers are non-luminescent. Similarly in some cases the cement filled in chambers show orange luminescence and the walls are non-luminescent.

Alveolina:-

Very few foraminifera of this genus were observed in thin sections of the Zinda Pir area. The wall structure of *Alveolina* is porcelainous which gives a shining and smooth appearance under plane polarized light. It is micritic and in thin section it appears dark

in plane polarized light. The walls are composed of high-Mg calcite. The chambers are filled by non-ferroan sparry calcite cement (Fig. 5.2B).

Discocyclina:-

This type of genus is commonly present in many of the thin sections of the Zinda Pir area and in some thin sections of the Raghasar area. The genus is present both in complete form and in the form of broken fragments. It is circular in plane and discoidal (Fig. 5.2C). The radial chamberlet walls of equatorial chambers are in adjacent annuli usually alternating, the wall structure is of hyaline texture characterized by perforations. The walls are composed of both low-Mg calcite and high-Mg calcite. After diagenesis the high-Mg calcitic wall texture becomes ferroan (Fig. 8.8C) whereas the low-Mg calcitic wall does not (Richter and Fuchtbauer, 1978). In thin sections the walls appear light coloured in the plane polarized light. The chambers are filled by non-ferroan sparry calcite cement. Under cathodoluminescence microscopy the cement filled in chambers of some specimens show orange luminescence. Similarly the walls of the *Discocyclina* show orange luminescence in some specimens (Fig. 5.6A).

Athecocyclina:-

This genus of foraminifera is commonly present in some thin sections of the Zinda Pir area. Specimens are present mostly in the form of broken fragments, some are present in a complete form. Tests are circular in plan. The radial chamber walls are more or less absent. The wall structure of *Athecocyclina* is of hyaline characterized by minute perforations. These walls are composed of low-Mg calcite. In thin sections the walls

appear light coloured in plane polarized light (Fig. 5.2C). The chambers are filled by non-ferroan sparry calcite cement.

Actinosiphon:-

Very few foraminifera of this genera are present in thin sections of the Zinda Pir area. Mostly they are present in a complete form very few are in broken fragments. The embryonic chambers are bilocular, and are completely surrounded by a ring of about eleven peribryonic chambers. The equatorial chambers are irregular radial row, each with a large median intercameral foramen. The wall structure of the *Actinosiphon* is hyaline, characterized by minute perforations which are composed of low-Mg calcite. In thin sections the walls appear light coloured in plane polarized light.

5.3.1.2. Calcareous Algae:-

The calcareous algae present in the carbonates of Dungan Formation are mainly the red calcareous algae along with few green calcareous algae. The genera of red calcareous algae are the *Archaeolithothamnium*, *Lithothamnium*, *Mesophyllum*, *Lithophyllum*, and *Jania* and the genera of green algae are *Trinocladus*, *Clupeina* and *Acicularia* (Davies, 1941; Khan and Haque, 1956; Hunting Survey Corporation 1961).

5.3.1.2.1. Calcareous Red Algae:-

Archaeolithothamnium:-

Fig. 5.3. A.

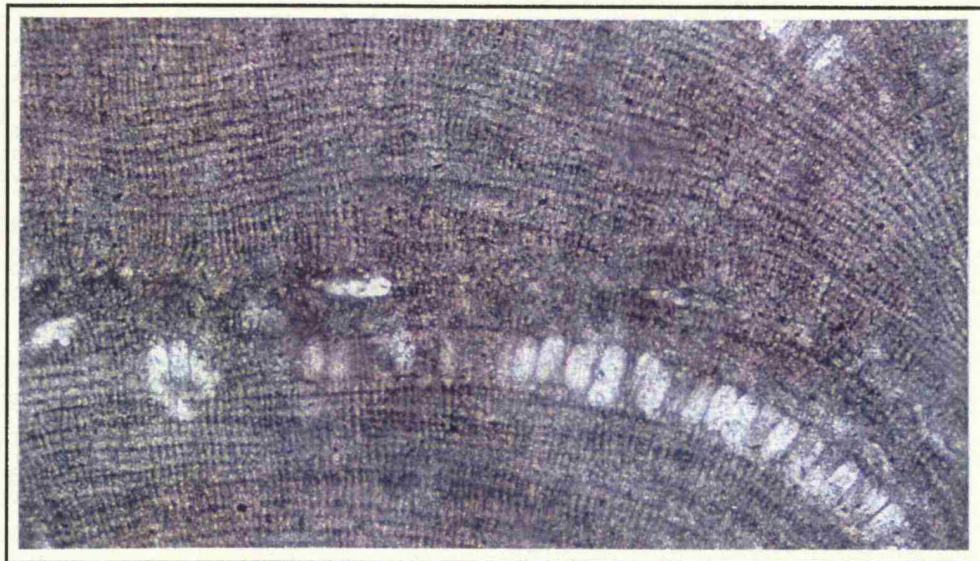
Thin section photomicrograph from sample RG 7, showing algae *Archaeolithothamnium*, the perithallial tissue containing rows of individual Sori.

Fig. 5.3. B.

Thin section photomicrograph from sample RG 24, illustrating *Lithothamnium* algae, in the form of rhodolith structure.

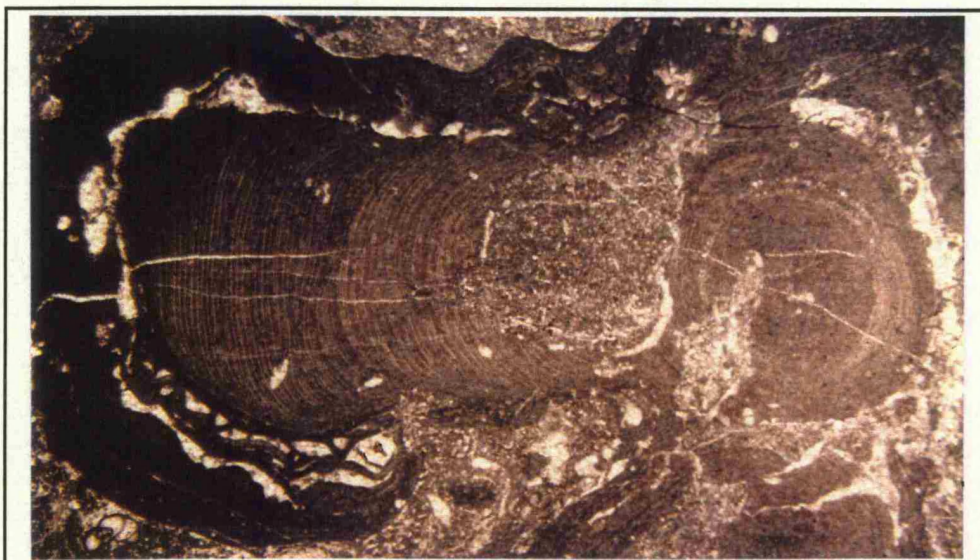
Fig. 5.3. C.

Thin section photomicrograph from sample RG 10, showing *Lithophyllum* algae, the thick perithallial and hypothallium is coaxial.



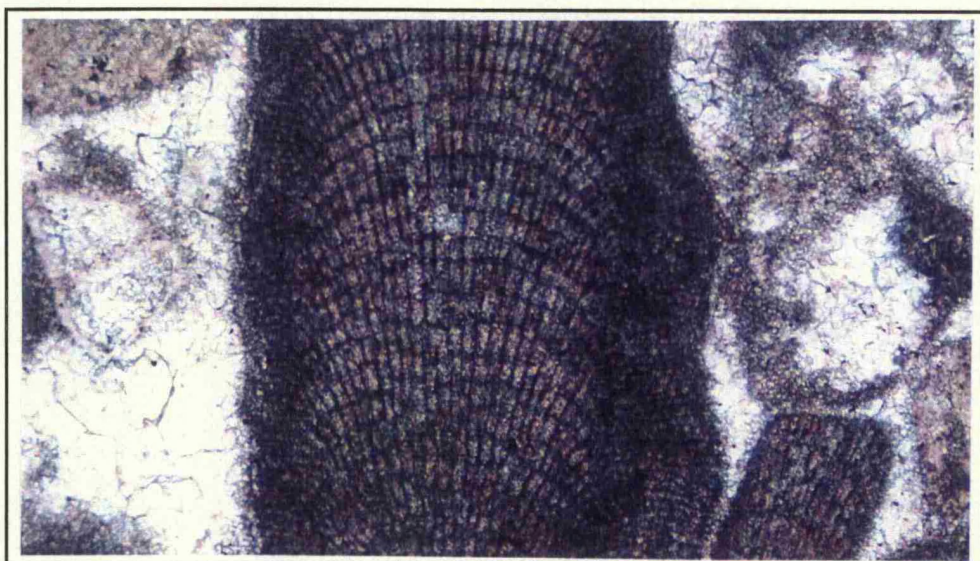
A

200 μ m



B

1000 μ m



C

200 μ m

Fig. 5.3.

This genus of red calcareous algae is very commonly present in most of the thin sections of Raghasar area, moderately in Zinda Pir area. In the Raghasar area most of the algae are in a complete forms along with few fragments, where as in Zinda Pir section they are mainly in the form of fragments. In the Raghasar area this genus of algae mainly adopts a rhodolithic structure. The structure is formed of individual layers of cells, each of which can be differentiated into hypothallus and perithallus. The hypothallium is multilayered, developing parallel to the substrata. The perithallial tissue is generally thick and composed of regular rows of cells. The sporangia are not in conceptacles but occur loose in rows (Fig. 5.3A), this is a distinctive characteristic of this genera. In thin section the tissues appear dark and micritic under plane polarized light. The conceptacles appear light and spary calcitic under plane polarized light. In some cases the rhodoliths are encrusted by bryozoa. Under cathodoluminescence microscopy in several cases the tissues of the algae show orange luminescence (Fig. 5.6B).

Lithothamnium:-

This genus is abundantly present in most of the studied thin sections of Raghasar and few in Zinda Pir and Rakhi Nala sections. In the Raghasar area they are present mainly as complete rhodoliths. In the Zinda Pir section they are mostly in the form of broken fragments, and particularly in the Rakhi Nala section they are present in the form of very small fragments. The tissues are composed of numerous layers of cells which can be differentiated into hypothallus and perithallus. The hypothallium is multilayered, but non coaxial, developing parallel to the substrata. The perithallium is usually thick and composed of regular layers of cells (Fig. 5.3B). The sporangia occur in multipored

conceptacles. The hypothallium and the perithallium appear dark and micritic under plane polarized light in thin section whereas the conceptacles are light coloured and sparitic under plane polarized light. In the Raghasar area few *Lithothamnium* are encrusted by bryozoa. Under cathodoluminescence microscopy in a very few cases the hypothallium and perithallium of the algae show orange luminescence.

Mesophyllum:-

Mesophyllum is commonly present in most of the thin sections of Raghasar area, and in a few thin sections of the Zinda Pir area. In the Raghasar area specimens are preserved well in both complete and fragmental forms. In the Zinda Pir area they are mostly preserved as fragments. In this type of algae the tissues can normally be differentiated into hypothallus and perithallus. The multilayered hypothallium is parallel to the substrata and characteristically coaxial. The perithallium is thick and distinctly layered. The conceptacles are multipored and relatively larger. In thin sections the tissues appear micritic and dark under plane polarized light. The conceptacles are light coloured and sparitic under plane polarized light.

Lithophyllum:-

This genus of red algae is moderately common in most of the thin section of the Raghasar area. They are mainly in a complete sheet-like form although fragments also occur. The tissues are normally differentiated into a hypothallium and perithallium. The hypothallium is coaxial and the perithallial tissue is thick and composed of regular layers of cells. In a few cases the coaxial hypothallium is surrounded by a thinner marginal perithallium (Fig. 5.3C). The conceptacles have a single aperture. In thin

Fig. 5.4. A.

Thin section photomicrograph from sample Rg 11, illustrating the alga *Jania*, having dichotomously branched thallus.

Fig. 5.4. B.

Thin section photomicrograph from sample ZP 55 showing different genera of green algae, such as *Clypecina*, *Trinocladus* and *Acicularia*.

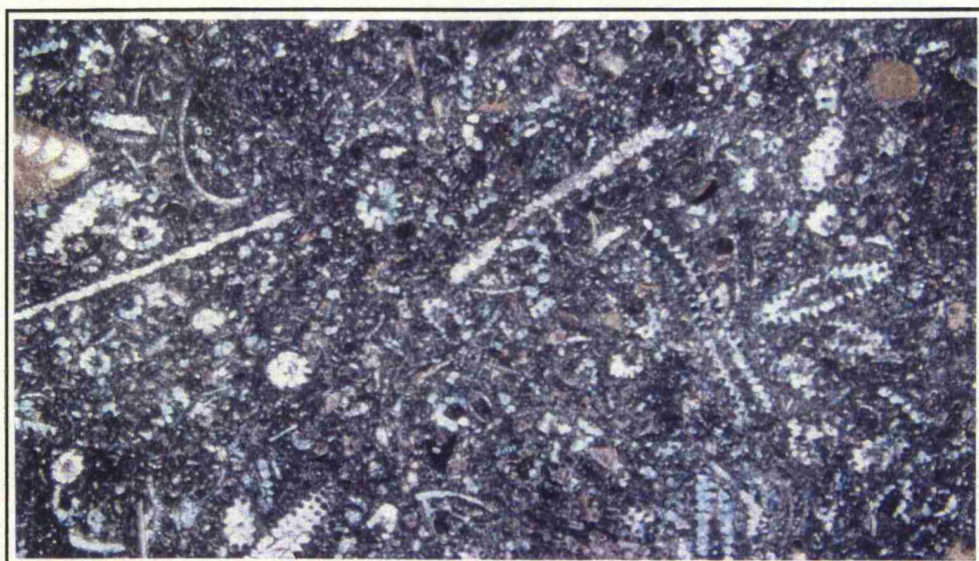
Fig. 5.4. C.

Thin section photomicrograph from sample RG 5 showing a) echinoderm fragment having syntaxial overgrowth cement, b) molluscs fragments having micritic envelopes around them and they are filled by sparry calcite cement.



A

1000μm



B

1000μm



C

1000μm

Fig. 5.4.

sections the hypothallus and perithallus appear as micrite and are dark under plane polarized light. The conceptacles are light coloured and sparitic under plane polarized light. Under cathodoluminescence microscopy occasionally the tissues of the algae show orange luminescence.

Jania:-

Very few calcareous algae of this genus are present in few thin sections of Raghasar area. They are mostly present in the form of fragments, very few are in a complete form (Fig. 5.4A). The *Jania* develops dichotomously branched thallus made up of cylindrical segments. Medullary filaments are surrounded by a thin zone of cortical filaments. The cells of the medullary filaments are typically wedge-shaped and successive rows of cells join along irregular lines. The conceptacles occur in axial positions. In thin sections the tissues appear dark and micritic under plane polarized light. The conceptacles are sparitic and light coloured under plane polarized light.

5.3.1.2.2. Calcareous Green Algae:-

Clypeina:-

This genus of calcareous algae belongs to family dasycladaceae. This type of algae are rarely present in few of the thin sections of Raghasar area. They are present both in complete and fragmental forms. Specimens look like a bowl-shaped disc which corresponds to the whorls of primary branches (Fig. 5.4B). The central stem is moderately large and sporangia occur in the lower ends of the branches. The stem and branches appear dark and micritic in thin section under plane polarized light. The

sporangia are light coloured and sparitic under plane polarized light and show extinction under cross polarized.

Trinocladus:-

This genus also belongs to dasycladaceae family. Very few *Trinocladus* algae are present in thin sections of Raghasar area. They are mostly present in the form of fragments. Specimens have a cylindrical thallus with moderately large central stem. Primary branches, occurring in regular whorls, give rise to secondary branches and these in turn to clusters of tertiary branches. The primary branches are thick, widen outward and probably contain the sporangia (Fig. 5.4B). In thin sections the stem and branches appear dark and micritic under plane polarized light.

Acicularia:-

This genera of calcareous algae belongs to family dasycladaceae. Specimen are rarely present in very thin sections of Raghasar area. They are mostly present in the form of fragments. The plant appears like a disc which is made up of radially arranged rays that contain spherical sporangial cavities. These rays or fragments may result from the disaggregation of the apical disc (Fig. 5.4B). In thin section the disc and the rays appear dark and micritic under plane polarized light. The sporangial cavities are light coloured and sparitic under plane polarized light, and show extinction under cross polarized.

5.3.1.3. Bryozoa:-

Fig. 5.5. A.

Thin section cl photomicrograph from sample ZP 40, illustrating the dull luminescence of the walls of nummulites, the chamber are non-luminescent.

Fig. 5.5. B.

Thin section cl photomicrograph from sample RG 46, the wall and the chambers of the foraminifera showing orange luminescence.

Fig. 5.5. C.

Thin section cl photomicrograph from sample RG 46, the micritic wall of the foraminifera do not show luminescence, whereas the chambers are showing orange luminiscence.



A

400μm



B

200μm



C

200μm

Fig. 5.5.

Bryozoan colonies are very commonly present in most of the thin sections of Raghasar and Zinda Pir areas, and in few sections of Rakhi Nala area. The colonies (zoaria) are generally small about one centimeter in diameter and they appear as lacy networks, as thin encrustation on algae, as rows of small beads, and as spiderlike webs. The colonies have a cellular arrangement of zooecia and the thin calcareous walls are of a granular texture. The zooids are generally less than 0.5 mm in diameter and colonies may comprise several hundred individuals. The bryozoans are characterized by their cellular colonial structure with tubes and pores of various widths and parallel arrangements. The diameter of their chambers is intermediate between those of coral and red calcareous algae. The zooecium is calcareous and cylindrical or polygonal in shape. The bryozoa are composed of high-Mg calcite. A few bryozoa colonies encrust the red calcareous algae. In thin section the walls appear dark in plane polarized light. The chambers are generally filled by non-ferroan sparry calcite cement, but in a few cases they are partially filled by micrite and partially by sparry calcite cement. Usually the wall and the chambers are not show luminescence, but sometimes the sparry calcite cement in filled chambers show orange luminescence (Fig. 5.6C). Similarly in a very few cases the walls of the bryozoa colonies show a orange luminescence.

5.3.1.4. Echinoderms:-

The echinoderms are commonly present in most of the thin sections of the Rakhi Nala, Raghasar and Zinda Pir areas. They are mainly echinoids along with a few asteroids. The echinoderms are composed of high-Mg calcite in the form of plates or spines. Each plate or spine behaves as a single crystal of calcite when viewed under plane

polarized light and giving unit extinction under cross polarized. The echinoderms are in the form of plates (Fig. 5.4C), and they are generally have a syntaxial overgrowth cement (Fig. 5.4C). Under cathodoluminescence microscopy most of the echinoderm fragments which have the syntaxial overgrowth cement show zoned (orange thin lines and dead thick part) luminescence (Fig. 5.6B), whereas in a few cases the whole fragment show bright orange luminescence.

5.3.1.5. Molluscs:-

Molluscs fragments are abundantly present in most of the thin sections of Rakhi Nala, Raghasar, and Zinda Pir areas. They are mainly bivalves including oysters, and gastropods. The bivalve shells are originally composed of aragonite which after diagenesis recrystallized to a mosaic of sparry calcite. In thin sections they are randomly oriented. Original shell shapes are discernible by means of a fine coating or micrite “dust rim”. The oyster shells have a calcitic foliated structure with a mixed mineralogy, the outer layers are calcitic and the inner layers are aragonitic which dissolved during diagenesis and is later filled by sparry calcite cement (Fig. 5.4C). The dense structure of oysters makes them relatively resistant to fragmentation. They are well preserved in the rocks. The shells of aragonitic bivalves do not preserve their original structures. The entire shells have been dissolved leaving voids which are later filled by calcite spar. Under cathodoluminescence microscopy very few of the sparry calcite cement void infillings show orange luminescence, and the micritic wall does not show any luminescence. The gastropod shells are present only in a few thin sections. These shells are composed of aragonite and have a cross-lamellar structure. The

skeletal structure of gastropod is not preserved due to their original aragonitic composition which, after diagenesis, it is replaced by non-ferroan sparry calcite cement. Under cathodoluminescence microscopy they do not show any luminescence.

5.3.1.6. Corals:-

Very few corals are present in thin sections of Raghasar and Zinda Pir areas. The corals are mainly the *Scleractinia* and were originally composed of fine, fibrous aragonite which later is replaced by sparry calcite cement after diagenesis. The chambers are filled by sparry calcite cement. Coral colonial skeletons may be distinguished from bryozoa skeleton by their tendency to form large colonies, the larger size of the body cavities, the presence of nodes, spines and septa projecting into the body cavity and their relatively thick, uniform walls. In thin section the septa appear as micrite and dark under plane polarized light and the chambers (trabecular canals) light coloured because of sparry calcitic infilling (Fig. 5.7C). Under cathodoluminescence microscopy they do not show any luminescence.

5.3.1.7. Planktonic Foraminifera:-

The planktonic foraminifera are abundantly present in few of the thin sections of Zinda Pir area. They are mainly the *Globorotalia*, *Globotruncana* and *Globigerina* (Davies 1941; Hunting Survey Corporation 1961; Latif 1964; Iqbal 1969a). and have thinner test wall than the benthonic foraminifera, composed of low-Mg calcite. The walls appear dark, micritic under plane polarized light. The chambers are relatively large.

Fig. 5.6. A.

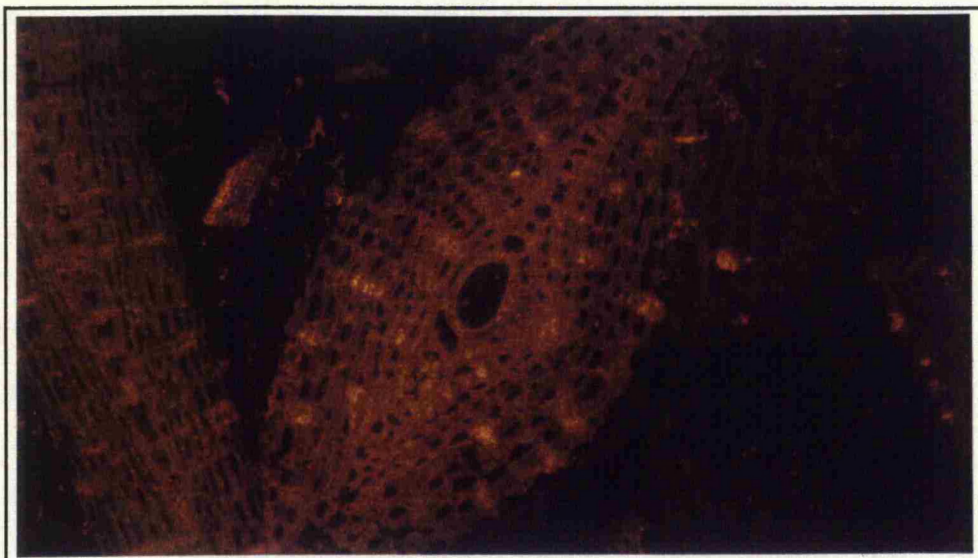
Thin section cl photomicrograph from sample ZP 40, the shell structure of *Discocyclus* shows orange luminescence and the sparry cement within the chamber is non-luminescent.

Fig. 5.6. B.

Thin section cl photomicrograph from sample RG 45, the network structure of the calcareous algae showing dull luminescence and the cement filling the structure is non-luminescent.

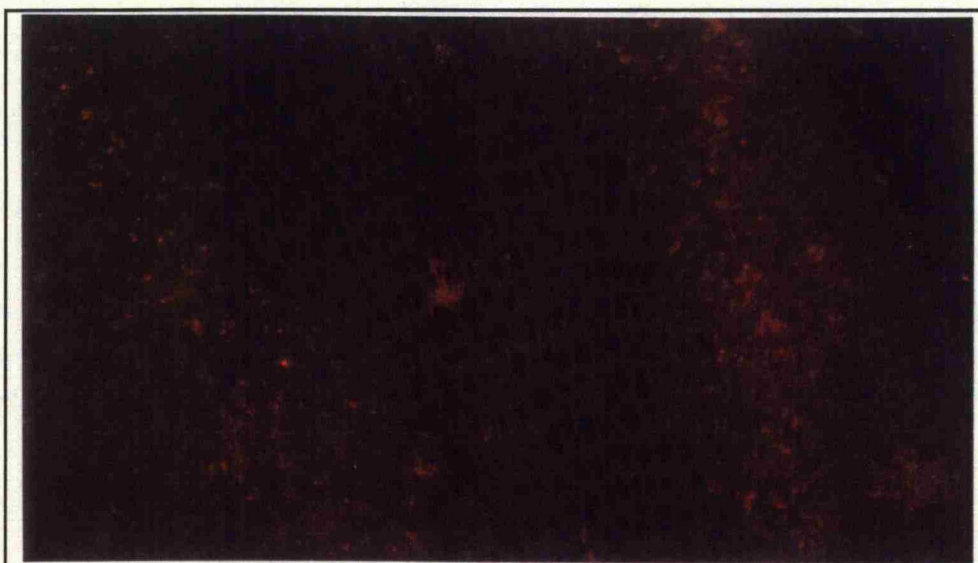
Fig. 5.6. C.

Thin section cl photomicrograph from sample RG 46, the walls of the bryozoa do not show luminescence, whereas the cement filling chambers show dull to orange luminescence.



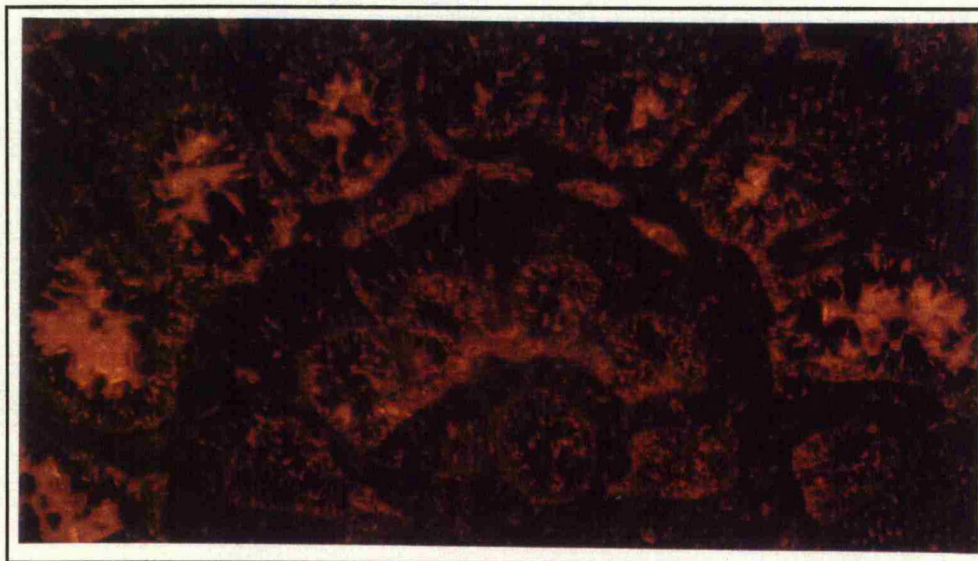
A

400μm



B

400μm



C

200μm

Fig. 5.6.

They are filled by non-ferroan sparry calcite cement (Fig. 6.5C). They appear as light coloured and sparry under plane polarized light, and show extinction under cross polarized. Under cathodoluminescence microscopy they do not show any luminescence.

5.3.2. Non-Skeletal Allochems:-

In the Dungan Formation the non-skeletal allochems are very few, consisting of ooids and intraclasts.

5.3.2.1. Ooids:-

In the studied area the ooids are found in 7/8 thin sections of the Rakhi Nala section only. The ooids are spherical to subspherical grains consisting multilaminar concentric lamellae. The nucleus generally is a foram or any other skeletal fragment or a quartz grain. The ooids are normally 0.3 to 0.5 mm. of diameter and do not show any fracture. They are well preserved and appear dark under plane polarized light. They are encircled by calcitic envelope, which shows orange luminescence (Fig. 8.4C).

5.3.2.2. Intraclasts:-

Very few intraclasts are found in thin sections of Zinda Pir and Raghasar areas. The intraclasts are of biomicrite of the same formation. In thin sections they are recognised

on the basis of sharp boundaries between the intraclasts and the primary part of the formation.

5.4. Non Carbonate Grains:-

In the Dungan Formation non carbonate grains are moderately common in most of the thin sections of Rakhi Nala area, but very few are present in the Raghasar and Zinda Pir areas. The non carbonate grains are mainly quartz grains, along with a few pyrite crystals. The quartz grains are uniaxial and medium to coarse grained, subangular to subrounded. They are characterized by low birefringence, lack of cleavage and twinning, and low positive relief, and show extinction under cross polarized. The pyrite are opaque in plane polarized light and in cross polarized, whereas it gives yellow shining appearance in the reflected microscopy.

5.5. Cement Types:-

This study established several different types of cement in Dungan Formation. These cement types are peloidal, neomorphic, isopachous bladed, drusy, and syntaxial overgrowth cements.

5.5.1. Peloidal Cement:-

This type of cement is found in some thin sections of Raghasar and Zinda Pir areas. In thin sections peloids appear dark with a little light coloured sparry calcite in between

them under plane polarized light. The micritic peloids are a subspherical bodies of 20 to 50 μm in diameter. They are composed of micrite of less than 3 μm . The microspar cement crystals are 5 to 8 μm in diameter and appear light coloured and cloudy. The peloids do not show fibrous structure. In other words it is a microcrystalline spary calcite cement with the micrite (in the form of peloids). The boundaries between the micrite and the microspar calcite are irregular. In modern carbonate sediments such type of cements are composed of high-Mg calcite (Scoffin, 1987). Under cathodoluminescence microscopy the peloids are non-luminescent.

5.5.2. Neomorphic Spar:-

This type of cement is present in several of the thin sections of Raghasar area. The neomorphism is the regrowth of fine grained spar (microspar, crystal size between 4 to 8 μm) in place of sparry calcite cement (crystal size between 10 to 50 μm) (aggrading neomorphism). Crystals are characterized by irregular intercrystalline boundaries, the irregular crystal size distribution, the gradational boundaries to areas of neomorphic spar and the presence of skeletal grains floating in coarse spar (Fig. 8.3B).

In general the development of the neomorphic spar takes place commonly on the margins of the large shell fragments of molluscs, which are originally composed of aragonite. They are now represented by relatively coarse mosaic of pseudospar (Fig. 5.4C). The crystals are characterized by irregular boundaries and great variations of size. The fabric of these crystals is very similar to that of sparry calcite cement, but it lacks the characteristic pore filling spar, and containing small patches of micrite. Under cathodoluminescence microscopy they do not show any luminescence.

5.5.3. Isopachous Bladed Cement:-

The isopachous bladed cement occurs in thin sections of Rakhi Nala, Raghasar, and Zinda Pir areas. It is in the form of crust or a thin uniformly fringe around the foraminifera and oolites with a uniform thickness (Fig. 8.4B). These fringes have grown outward into the pore space at right angle to the surface of the grains (foraminifera and oolite). Under plane polarized light they appear light coloured, and under cathodoluminescence microscope they show bright orange luminescence (Fig. 8.4C).

5.5.4. Drusy Cement:-

This type of cement is commonly present in most of the studied thin sections of the Rakhi Nala, Raghasar and Zinda Pir areas. This cement fills mainly the intergranular pore spaces and the intragranular spaces (i.e. the chambers of foraminifera, bryozoa, and corals). The drusy mosaic cement is composed of anhedral crystals of small longitudinal or prismatic calcite. The size of the crystal increases towards the centre of the pore (Fig. 8.8B). The cement is mainly non-ferroan, but in few cases it is ferroan as well. The boundaries between the crystals are usually sharp and irregular. The drusy cement is composed of low-Mg calcite. Under plane polarized light it appears light coloured, and shows extinction under cross polarized. Under cathodoluminescence microscopy most of the drusy cement show a dull luminescence, but in a few cases this cement shows orange luminescence.

5.5.5. Syntaxial Overgrowth Cement:-

The syntaxial overgrowth cement occurs in most of the thin sections which contain echinoderm fragments. Large single crystals developed on echinoderm fragments, in optical continuity with the calcite of the echinoderm. They can be distinguished from the allochems in the thin sections under plane polarized light, but under cross polarized they extinguish as a single crystal. The rim or overgrowth cements usually consists of non-ferroan clear crystals (Fig. 8.6A).

Evamy and Shearman (1965) were able to resolve the successive stages of the development of syntaxial sparry calcite overgrowth around echinoderm fragments by staining techniques. They traced the distribution of ferrous iron in the calcite crystal and identified iron free and variably iron bearing zones. They found that the calcite of the echinoderm debris and of the inner parts of the overgrowths remain unstained. Under cathodoluminescence microscope these zones are clearly established. The iron free zones are non-luminescent whereas the iron bearing zones are showing orange to dull luminescence on the basis of iron enrichment (Fig. 8.6B).

5.6. Matrix:-

The matrix is a material in which the grains (allochems) are embedded. This is fine grained, and composed of high-Mg micro crystalline calcite. It is present in most of the studied thin sections of Rakhi Nala, Raghasar, and Zinda Pir areas. It ranges from 0%

Fig. 5.7. A.

Thin section photomicrograph from sample RG 26, the geopetal sediment filling the pore space within the rhodolith. Micrite fills the lower part of the cavity while sparry calcite fills the upper part.

Fig. 5.7. B.

Thin section photomicrograph from sample ZP 20, showing the stylolite solution zone, dark lines are solution interfaces with concentration of insoluble minerals (especially clay minerals). These lines pass around the skeletal grains.

Fig. 5.7. C.

Thin section photomicrograph from sample ZP 14, a) the calcite vein which cuts the structure of foraminifera. The vein is mainly non-ferroan, b) Scleractinian coral showing septa (central dark line with surrounding trabecular structure) and the partially filling chambers by calcite cement.



A

1000 μ m



B

1000 μ m



C

1000 μ m

Fig. 5.7.

of the total rock to 89.2%. Under plane polarized light it appears dark. Under cathodoluminescence microscopy the matrix does not show any luminescence.

5.7. Porosity:-

In the studied thin sections of Rakhi Nala, Raghasar, and Zinda Pir areas the porosity is mainly secondary which includes mouldic, vug, and fracture. The mould (Fig. 8.3C) and vug porosities are formed by solution of grains, after through leaching by meteoric ground water, and fractures are formed through tectonic movements and pressures. All these porosity types are filled by non-ferroan sparry calcite cement, with some ferroan calcite cement. Under cathodoluminescence microscopy the calcite cement of the pores does not show any luminescence.

5.8. Compaction and Pressure Solution:-

Compaction refers to any process that decreases the bulk volume of rocks. This includes mechanical processes that decrease the bulk volume of single grains (grain deformation) or that cause closer packing of grains (re-orientation) and pressure solution which decreases the volumes of grains and of cement minerals.

The effects of compaction are seen in thin sections from the Zinda Pir area in the form of mechanical process and pressure solution. The skeletal grains in these sections show slight deformation in their shapes and have a concavo-convex contacts between them. This shows the weak compactional effect on them (Fig. 5.7B). The other sections of

Rakhi Nala and Raghasar areas do not show any significant compactional effect on the grains.

Similarly the effect of pressure solution is seen in most of thin sections of the Zinda Pir area in the form of dissolution seams and stylolite structures. In other sections of Rakhi Nala and Raghasar areas they are not significantly present. The dissolution seams are seen in a few thin sections of argillaceous carbonate rocks. They are smooth, undulose seams of insoluble residue which lack the distinctive suture of stylolite (Fig. 5.7B).

The stylolite are thin zones of discontinuity within rocks, and are developed locally due to the pressure solutions. In thin sections they appear like zig-zag sutures; in general of conical projections with intervening depressions. The stylolites are of low peak amplitude, (about 1 mm.), and are parallel to bedding. The seams of stylolites are filled by dark insoluble material (may be clays).

5.9. Microfractures:-

The microfractures are seen in most of the thin sections of all the three areas. They are generally small in width and length. The width is 0.2 to 0.5 mm. and few centimetres long. They are randomly present and most of them are parallel to each other but some are intersecting. They are mainly filled by non ferroan sparry calcite cement. Under cathodoluminescence microscopy they show zoned luminescence.

5.10. Veins:-

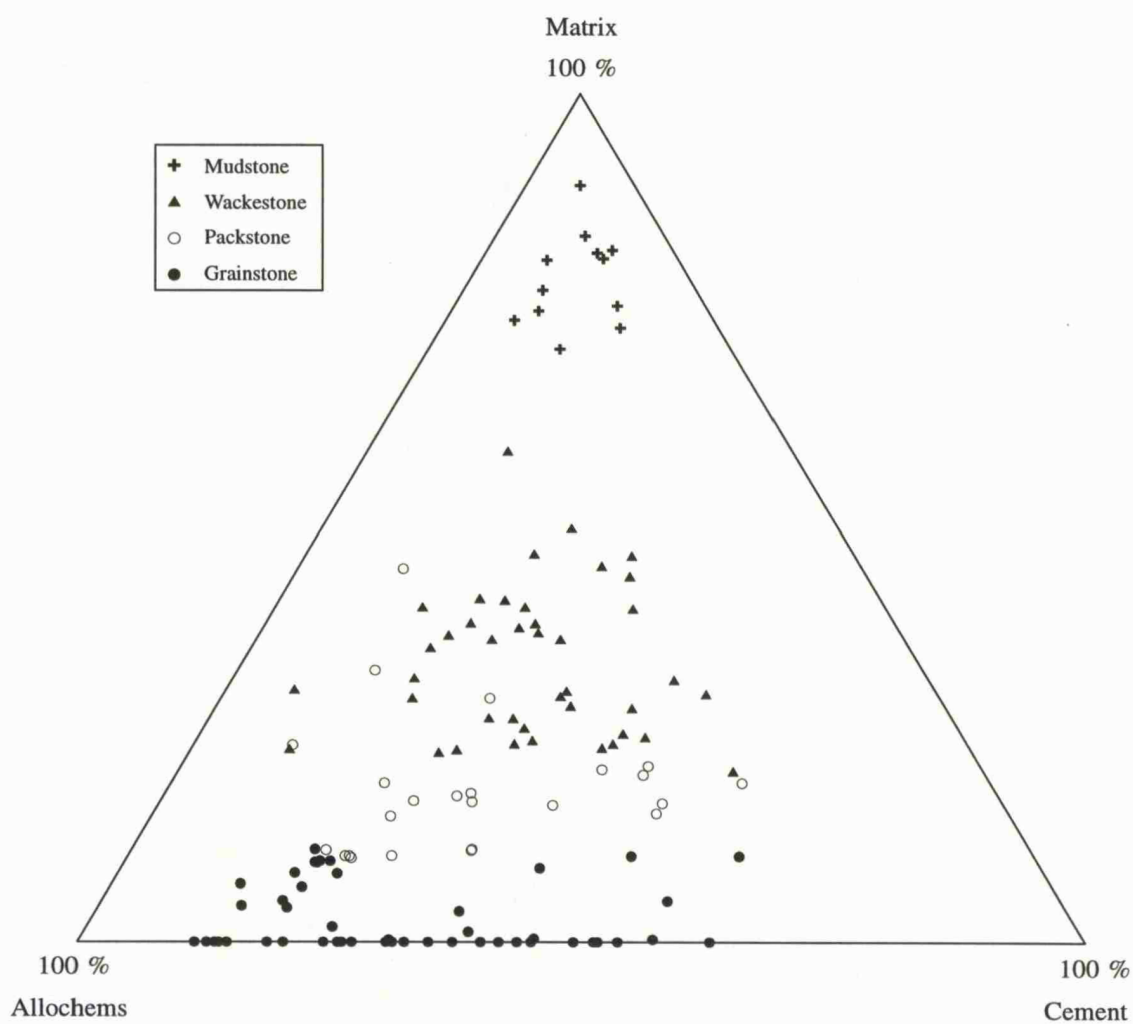


Fig. 5.8: Plot of various rock types identified within Dungan Formation, superimposed on Dunham's (1962) classification of limestones.

The veins are found in some thin sections of Rakhi Nala, Raghasar, and Zinda Pir areas. The veins are wider and larger than the microfractures. They are generally 0.2 to 10 mm. in width and ranging up to several centimetres in length. Most of the veins are perpendicular to the bedding, intersect the host rock allochems (Fig. 5.7C), and have a sharp boundaries with them. These veins run parallel to each other, some of them are perpendicular and intersect the others. Most of the veins are filled mainly by non-ferroan sparry calcite cements, whereas some are filled by ferroan sparry calcite cement, which intersect the non-ferroan sparry calcitic veins (Fig. 5.7C). The vein filling calcite crystals are anhedral to subhedral in shape.

5.11. Rock Types:-

On the basis of petrographic studies, the Dungan Formation is classified into four types of limestones (Fig. 5.8) (Dunham's classification, 1962).

Mudstones in which the grains (skeletal and non-skeletal allochems) are 10% on average, the rock is mud supported, the matrix is 78%, and the cement (spar) is 11% of the total rock. Wackestones in which the grains (skeletal and non-skeletal allochems) are 38% on average, the rock is mud supported, the matrix is 33%, and the cement (spar) is 29% of the total rock. Packstones in which the grains (skeletal and non-skeletal allochems) are 42% on average, the rock is grain supported, the matrix is 18%, and the cement (spar) is 40% of the total rock. Grainstones in which the grains (skeletal and non-skeletal allochems) are 67% on average, the rock is grain supported, the matrix is 3%, and the cement (spar) is 30% of the total rock.

Chapter Six

FACIES AND PALAEOENVIRONMENTS OF DUNGAN FORMATION

6.1. Introduction:-

This chapter documents the different depositional facies of the studied interval of the Dungan Formation, and their inferred environments of deposition. These were revealed from a detailed study of more than 130 stained and unstained thin sections by binocular microscope and reflected light microscopy. These samples were collected from three localities (Raghasar, Zinda Pir and Rakhi Nala) (details in chapter four), which lie approximately 60 to 120 kilometres apart from each other (Fig. 1.1). Collectively, the facies are considered to represent deposition through time on a homoclinal windward ramp.

6.2. Microfacies:-

Eight microfacies are recognised within the Dungan Formation, in the study area. They include Peritidal Carbonate facies, Inner Lagoonal facies, Oolitic facies, Outer Lagoonal facies, Rhodolith Platform facies, Nummulitic facies, Larger Benthonic Foraminiferal facies, and Planktonic Foraminiferal facies. These facies are interpreted on the basis of petrographic evidence (as studied) in chapter five.

6.2.1. Peritidal Carbonate Facies (F 1):-

This facies is mainly encountered in the Rakhi Nala section (Fig. 3.3) in the southern part of the Sulaiman Range. It is characterized by medium to coarse grained grey, grey brown coloured quartz arenite with a sparry calcite cement, which is thick bedded (0.7 to 1.0 metre thick) and shows planar cross bedding. The quartz grains are unicrystalline, well sorted medium grained and subangular to subrounded in shape. Most of the allochems are unidentifiable however, a few echinoid fragments (0.1%) are identified in this facies.

Interpretation:-

The peritidal carbonates are typical grainstone sediments and are commonly form sheet-like grainstone units, reflecting the tendency of high-stand ramp shoreface sediments to migrate or prograde rapidly (Burchette and Wright, 1992). Peritidal carbonates are generally associated low-energy tidal zones, they may accrete from the shorelines of land areas, and from around islands (Ebanks 1975; Pratt and James 1986). The peritidal carbonates show bedding dipping at a low angle off-shore (surf-swash deposit) and on-shore from deposition on the backsides of beach berms. On-shore directed cross-bedding is produced by shoreface megaripples and wave-ripple, cross-lamination also occur. Burrows may occur in the low intertidal shoreface part (Tucker and Wright, 1990). The presence of well sorted subangular to subrounded quartz grains, and the thick and planar cross-bedding of the unit indicate deposition of this facies close to shore. On these basis it is interpreted to have been deposited in a warm water near shore located below the supratidal zone at the depth of 3-5 metres.

6.2.2. Inner Lagoonal Facies (F 2):-

This facies is also encountered in the Rakhi Nala section (Fig. 3.3). It is composed of dark grey to grey coloured quartz arenite with a sparry matrix. Beds are thin to thick bedded (individual bed is 0.2 to 1.00 metre thick), and show planar and trough cross-bedding. The quartz grains are poorly sorted, subangular to subrounded. The sediments are poor in skeletal grains of benthonic foraminifera (0.8% mean), with bivalves (1.0% mean) and echinoids fragments (0.7% mean) (Table 6.1). The foraminifera include miliolids and agglutinated forams. Quartz grains are frequently present (Fig. 6.1A). A few scattered pyrite crystals with dark brown to black insoluble residues (probably organic matter) are also present.

Interpretation:-

A wide range of compositions of carbonate sands (Milliman, 1974) and carbonate mud (Flügel, 1982) is present in lagoons. The lagoonal sediments are fine grained and sandy, sediments are confined principally to tidal inlets. Sediment blown from barriers may be scattered throughout the lagoonal area, and characterised by current ripples and internal small scale cross-bedding that may dip in either a landward or in a seaward directions. The sand is generally horizontal laminated, but it may display ripple cross-lamination. The faunas that inhabit lagoonal environments are highly variable depending upon the salinity conditions, but are generally characterised by low diversity.

Table. 6.1. Thin section data of the Dungan Formation to illustrate mean, standard deviation, maximum, and minimum values obtained by point counting.

Facies	1	1	1	1	2	2	2	2
No. of Samples	9	9	9	9	15	15	15	15
	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.
Algae	0	0	0	0	0	0.1	0.2	0
Foraminifera	0	0.1	0.4	0	0.8	0.6	2.4	0
Echinoderms	0.1	0.3	0.8	0	0.7	0.8	2.6	0
Molluscs	0	0	0	0	1	1.2	4	0
Bryozoa	0	0	0	0	0.3	0.4	1.2	0
Coral	0	0	0	0	0.1	0.1	0.4	0
Total Allochems	2.6	2.3	6.8	0	5.2	3.8	15.4	1
Oolites	0	0	0	0	1.8	2.4	5.6	0
Cement	17.8	7.6	34.8	11.6	32.6	15.6	57	12.8
Matrix	0	0	0	0	2.9	5.7	18.8	0
Non-carbonate	79.6	7.7	87.2	65.2	57.5	18.6	83.2	29.2
Facies	3	3	3	3	4	4	4	4
No. of Samples	11	11	11	11	10	10	10	10
	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.
Algae	0.1	0.1	0.4	0	1.8	4.7	15	0
Foraminifera	0.9	0.4	1.6	0.4	3.1	3	8	0.4
Echinoderms	2.2	2.3	8	0.4	6.4	4.6	16.8	2
Molluscs	2.6	3.4	11.2	0	5.7	3.7	10.8	0.6
Bryozoa	1.1	1.7	5.6	0	2.4	5.2	17	0
Coral	0.3	0.4	1.2	0	0.3	0.4	1	0
Total Allochems	14	10.1	31.4	3.2	30.7	7.4	41	16.8
Oolites	17.4	10.9	34	6	1.3	2	5	0
Cement	32.7	6.3	43.6	22.4	43.5	11.1	62.8	22.4
Matrix	2.1	6	20	0	11.6	15.8	40.2	0
Non-carbonate	33.8	9.5	48.4	21.8	12.8	11.1	27.8	0
Facies	5	5	5	5	6	6	6	6
No. of Samples	31	31	31	31	29	29	29	29
	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.
Algae	20.1	9.2	39.2	2.8	11.7	9.7	36.4	1.2
Foraminifera	10.4	9.3	33	0.4	30.8	23.1	70	0.2
Echinoderms	5.1	2.8	12.4	0.8	4	3.4	14.4	0.6
Molluscs	0.3	0.3	1	0	0.2	0.3	1.2	0
Bryozoa	3.1	2.7	9	0	2.4	4.1	21.6	0
Coral	0.5	1.3	5	0	0.5	1.4	6.8	0
Total Allochems	39.5	10.2	67.6	24.6	50.4	15.4	76.6	22.2
Oolites	0	0	0	0	0	0	0	0
Cement	35.3	14.3	60.8	6.8	26.4	6.9	42	14.6
Matrix	25.2	10.3	45.6	4.8	22.8	12.9	48.6	4.8
Non-carbonate	0.1	0.2	0.8	0	0.4	0.7	3.2	0
Facies	7	7	7	7	8	8	8	8
No. of Samples	13	13	13	13	12	12	12	12
	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.
Algae	4.8	4.9	17.2	1.2	0	0.1	0.4	0
Foraminifera	56.3	20.9	77.6	6.6	9.4	5.1	17	3.4
Echinoderms	2.6	1.8	5.4	0.4	0.7	0.7	2.6	0
Molluscs	0.3	0.3	1	0	0.3	0.3	0.8	0
Bryozoa	0.5	0.5	1.8	0	0.1	0.2	0.8	0
Coral	0	0.1	0.4	0	0	0	0	0
Total Allochems	64.9	17.9	80.4	23.6	11	4.9	19.6	5.4
Oolites	0	0	0	0	0	0	0	0
Cement	20.3	5.3	33.4	12.8	10.8	3.8	17.8	5.4
Matrix	14.2	16.5	57.6	1.8	77.8	5.4	89.2	69.6
Non-carbonate	0.6	0.6	2	0	0.5	0.4	1.2	0

Under very arid conditions, lagoonal sedimentation may be characterised by deposition of evaporites, which are mainly gypsum, but may include some halite and minor dolomite, under less hypersaline conditions, carbonate deposition prevails, particularly in lagoon developed by barrier. Deposition in such lagoons may consist carbonate sparite and associated skeletal grains, although oolites may form in more agitated parts of the lagoon.

This facies probably represents the subtidal deposit of a lagoon formed under reducing conditions. The dark grey colour is due primarily to the presence of organic and pyrite. The environment in which this facies was deposited was probably calm or with little agitation. It is likely that during calm periods the water within the sediment became stagnant and eventually reducing hence pyritic. Consequently this facies is interpreted as having been deposited in the lagoon environments above the fair weather wave base at the depth of 5-10 metres.

6.2.3. Oolitic Facies (F 3):-

This facies is also found in the southern part of the Sulaiman Range, in the Rakhi Nala section (Fig. 3.3). It is represented by oolitic packstone (oolite 6 to 34.0%) (Fig. 6.1B) dark grey to grey, brown olive colour and containing scattered quartz grains. The unit is thick bedded (0.5 to 0.9 metre thick), sometimes liminated. Fenestrae structures are also present. The skeletal allochems are benthonic foraminifera (0.4 to 1.6%), fragmental infaunal bivalves and gastropods (0 to 11.2%) and echinoids (0.4 to 8.0%), with a few algal branch fragments (0 to 0.4%) (Table 6.1). The forams includes miliolids and small rotaliids. The ooids are spherical to oval in shape, 0.1mm to

Fig. 6.1. A.

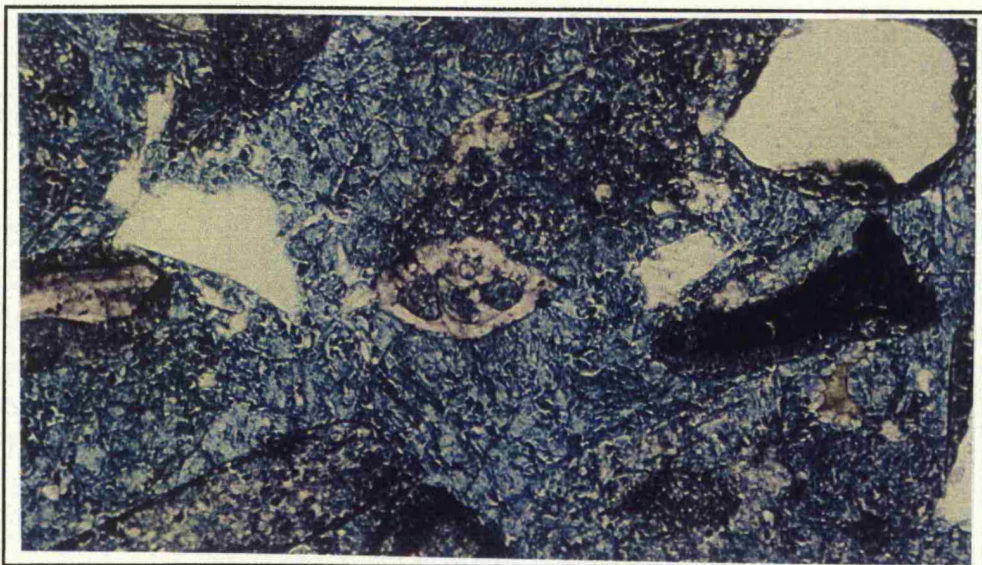
Thin section photomicrograph (from sample RK 21) represents the inner lagoon facies environments. The photograph shows the paucity of fossils, no matrix, and the cement is mainly ferroan calcite.

Fig. 6.1. B.

Thin section photomicrograph (from sample RK 13) represents the oolitic facies, the oolites are in abundance.

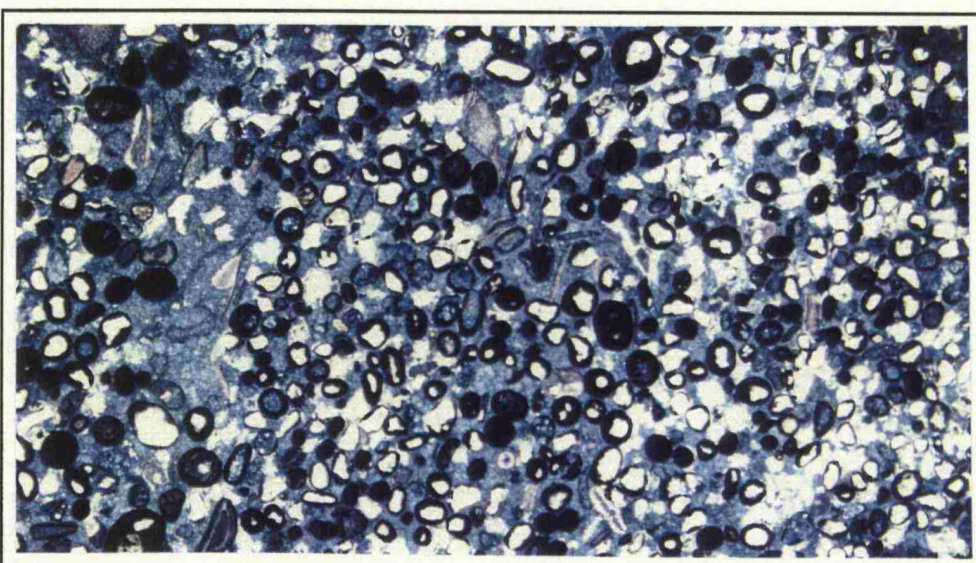
Fig. 6.1. C.

Thin section photomicrograph (from sample RK 25) of outer lagoon facies. The photograph shows the abundance of molluscs fragments with some echinoderm fragments.



A

200µm



B

1000µm



C

1000µm

Fig. 6.1.

0.2mm in diameter and their nuclei are the fragment of a molluscs, abraded foraminifera or the quartz grains. Scattered pyrite is present.

Interpretation:-

The characteristic set of depositional features e.g. (oolites, lamination and fenestrae) present and the general paucity of fossils provide important clues to the depositional environment of this facies. Laminations, whether thick or thin, are one of the most characteristic features of peritidal carbonate and are restricted to supratidal and upper intertidal conditions in modern tidal flats. They are found in similar positions in late Palaeozoic through Cenozoic sedimentary rocks (Shinn, 1982). The area under tidal margin conditions are more frequently exposed, and so are unsuitable to burrowers, thus there is little destruction of lamination. In subtidal and lower intertidal areas the laminations may not be preserved because of bioturbation.

Fenestral (birdseye) structures are most commonly associated with peritidal environments. Folk (1959) and Laporte (1967) suggested that fenestrae are associated with rocks deposited in very shallow water or in areas intermittently exposed at the time of deposition. Shinn (1968, 1982) noted that these features form in supratidal, intertidal and even subtidal sediments, but that they are not preserved in the lower intertidal and subtidal environments. They are commonly preserved in the upper part of the intertidal and increase in abundance through the transition of the supratidal.

Oolites are best developed in warm shallow water (tropical and subtropical) normally 0 to 4 metre deep. The sites of active oolite are shallow agitated waters, commonly of slightly higher temperature and salinity than normal open ocean water. According to

Scoffin (1987) oolites develop in shallow-water high energy zone though not necessarily at the margins of a platform, but may be on a gently sloping ramp or the inner part of the platform.

The paucity of fossils can also be used as a supporting indicator of the environment of deposition. All the evidence (oolites, lamination, fenestrae, and paucity of fossils) taken collectively it is highly indicative of intertidal origin at a depth of 5-8 metres.

6.2.4. Outer Lagoonal Facies (F 4):-

This facies is present in the Rakhi Nala and Raghasar sections (Fig. 3.3), the southern and the northern parts of the Sulaiman Range. It is characterized by dark grey and brown coloured packstone and wackestone. The biomicrite is medium to coarse grained, thick bedded (0.5 to 1.0 metre thick), and laminated. The beds occasionally show trough cross-bedding. Very few quartz grains are present. The skeletal allochems of this facies are predominantly echinoderms with molluscs, benthonic foraminifera and algae. Echinoid grains make up 2 to 16.8%. Molluscs (bivalves and gastropods) comprise 0.6 to 10.8%. They are replaced by non-ferroan sparry calcite cement. The forams (0.4 to 8%) are miliolids but agglutinating forams and rotaliids are also present. Coralline algae are also present (0 to 15%) (Table 6.1).

Interpretation:-

Lagoon sediments generally display greater textural and compositional variations. In part these variations reflect the wide range of environmental conditions within lagoons. Specifically, the texture and composition reflect the biological, hydrographic and

chemical regime within the depositional environment. These paraparameters, in turn, are influenced by climate, current systems and physical dimensions (such as depth and area) of the lagoon and the proximity to peripheral areas (Milliman 1974). Recent carbonate lagoons are different with respect to shape, sediments and water energy (Jordan, 1971). Lime muds with minor skeletal grains are found in low-energy coastal lagoons. The outer lagoons are characterised by abundant skeletal grains and deposited within a moderate to low energy environment. Lagoons with moderate energy contain skeletal sand as well as lime mud. Low energy lagoons are differentiated into those with predominately skeletal material (Flügel 1982). The open lagoons tend to contain sediments that are quite similar in composition to those found on the peripheral areas (Milliman 1974).

This facies probably represents the shallow subtidal zone. The presence of bivalves and gastropods which are totally dissolved and later on filled by sparry calcite cement and the presence of dark micritic envelope around them indicate the shallow environments. The presence of abraded forams, the algal and echinoids fragments also indicate the shallow marine environments. The composition and skeletal allochems are similar to the rhodolith platform facies.

The characteristic lithologic features such as lamination (thick bedded) and the absence of oolites indicate shallow marine low energy environment, probably inner lagoonal. The rotaliids are dominantly present at a depth of 20-45 metres (Reiss and Hottinger, 1984). By considering these characteristic features along with the presence of molluscs with occasional foraminifera, algae and echinoderm fragments it is suggested that this facies were deposited in a shallow subtidal environment at the depth of 8-35 metres.

Fig. 6.2. A.

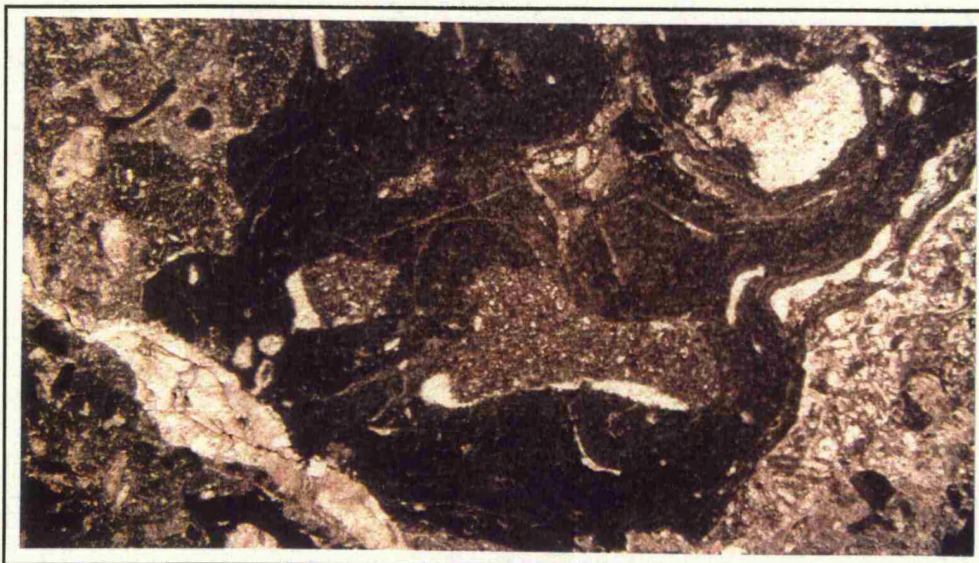
Thin section photomicrograph (from sample RG 26) of the rhodolith of the coralline algae, representing the rhodolith platform facies.

Fig. 6.2. B.

Thin section photomicrograph (from sample RG 11) showing the boring algae in the rhodolith platform facies.

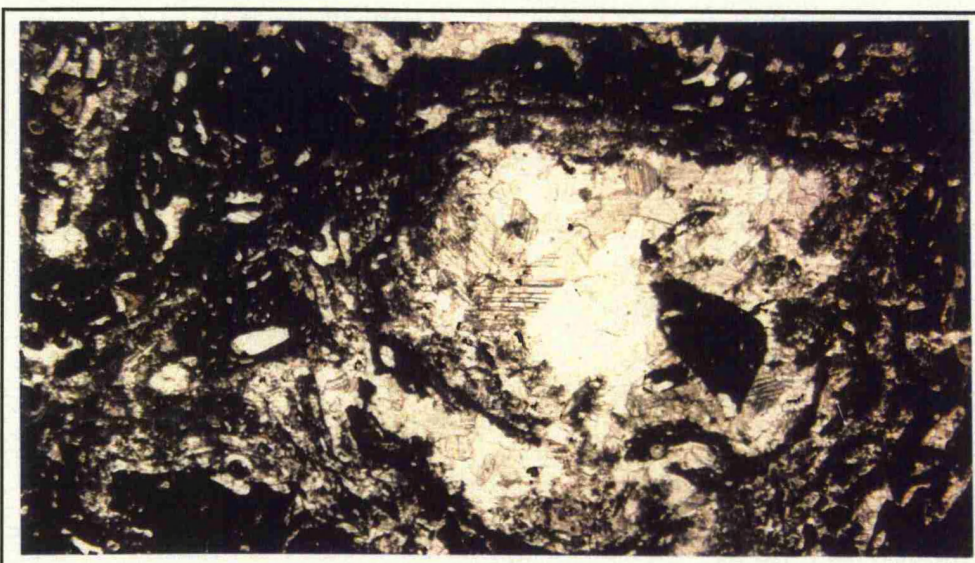
Fig. 6.2. C.

Thin section photomicrograph (from sample RG 43) illustrating the abundance of foraminifera with some algal fragments, representing the nummulitic facies.



A

1000μm



B

1000μm



C

1000μm

Fig. 6.2.

6.2.5. Rhodolith Platform Facies (F 5):-

This facies is found in the Raghasar section (Fig. 3.3), the northern part of the Sulaiman Range. It is represented by dark grey to brown and creamy white wackestone to packstone. These weather to brown, grey and buff yellow. These biomicrite are fine to medium grained, thick bedded to massive (individual bed is 1.0 to 1.8 metre thick) and are occasionally nodular. Bioturbation is common. The skeletal allochems present in this facies are predominantly algae, benthonic foraminifera, isolated coral heads, encrusting bryozoa, echinoderm fragments, and occasional mollusc fragments. The algae are mainly the red coralline (2.8% to 39.2%) (Table. 6.1). The main genera of red coralline algae (Fig. 5.4) are *Lithothamnium*, *Archaeolithothamnium*, *Lithophyllum*, *Mesophyllum*, *Lithoporella* and *Jania*, and the green algae are *Trinocladus*, *Neomeris*, *Clypeina* and *Acicularia*. These are very well preserved in thin section. Spheroidal and ellipsoidal structures of densely branched type Rhodoliths (Bosence, 1983a) are frequently present. Few of them are of large size (greater than 2cm in diameter). They are predominantly densely branched, spheroidal to ellipsoidal in shape (Fig. 6.2A). Coralline algal debris are commonly present in this facies. The rhodoliths are commonly abraded. Foraminifera (0.4 to 33%) are mainly rotaliids and miliolids but rotaliids are dominant. Corals comprise 0 to 5%. The echinoderms (0.8 to 12.4%) are dominantly echinoids with probable asteroids (starfish).

Interpretation:-

Red coralline algae are important rock builders, where the conditions are particularly favourable, as in clear, shallow, warm waters, rich in lime. These algae may grow rapidly and contribute appreciably to the formation of limestone.

The ecology of living crustose corallines has been summarized by Adey and Macintyre (1973). Principal factors controlling the distribution of corallinaceae are the temperature, depth, salinity, substrate type and energy.

According to Johnson,(1961), most of the Tertiary limestones in the Mediterranean region, the West Indies and around the islands of the tropical Pacific contain coralline algae. Algal foraminiferal limestone are especially abundant in the Cenozoic rocks of the Tertiary Tethyan Sea.

Rhodoliths are developed from crustose corallines in some unstable substrate environments (Bosellini and Ginsburg, 1971). A delicate balance between water motion and light conditions, which permits essentially continuous growth on all surfaces of the nodule, is required for rhodolith development. According to Adey and Macintyre (1973), branched species of *Lithothamnium* are the dominant rhodolith forms, although *Archaeolithothamnium* and *Lithophyllum* are also contributors to the construction of these kinds of algal structures.

Archaeolithothamnium and *Lithoporella* are common in rhodolith platform facies but are restricted to tropical and sub-tropical waters. *Mesophyllum* and *Lithothamnium* do occur in lower latitudes (warm water) regions in slightly deeper environments. According to Adey and Adey (1973), light is the primary factor controlling the depth distribution of coralline algae so these algae can not survive in very low intensity light conditions, consequently they are tropical of shallow water environments. *Jania* occur

widely in tropical and sub-tropical seas at shallow depths of less than 10 m., and in the intertidal zone in high energy regimes.

Montaggioni (1979) describes abundant rhodolith genera from depth of 25-60 metres on the fore reef slopes of the Mascarene Is. His studies shows that the rhodolith structures are constructed mainly by the *Lithophyllum*, and *Lithoporella* but with minor amounts of *Porolithon*, *Lithothamnium*, *Hydrolithon* and encrusting foraminifera. According to Adey and Boykin (in press) abundant rhodolith structures are developed by *Archolithothamnium*, *Lithothamnium*, and *Mesophyllum* in depths of 60 to 90 metres. The depth distribution of major genera in the Hawaii Archipelago are also discussed by Adey and Boykins (1982) (Fig. 6.3).

Rhodoliths have a wide variety of size, internal morphology and structure (Bosence and Pedley, 1982). Bosence 1976, 1983a, describes the classification of rhodoliths and illustrate spheroidal ellipsoidal and discoidal shapes with open to dense branched types. Bosence (1983b) also studied the ecology of the rhodoliths and concluded that rhodoliths may occur in a wide range of environments. The idea that rhodoliths indicate shallow warm water environment (Adey and Macintyre 1973) is not correct. The external morphology (shape and branch types) of rhodolith gives a good indicator of hydraulic energy.

Bosence and Pedley, (1982); and Bosence,(1983b), studied growth variations, morphology and the environment setting of rhodoliths, and concluded that the commonest shapes are ellipsoidal and spheroidal and these two classes show no obvious pattern of distribution. Discoidal forms are concentrated on sand, substrates. The branching density classes illustrate a close correlation with exposure of ripples. Their observations suggest that the ellipsoidal forms are more easily transported than

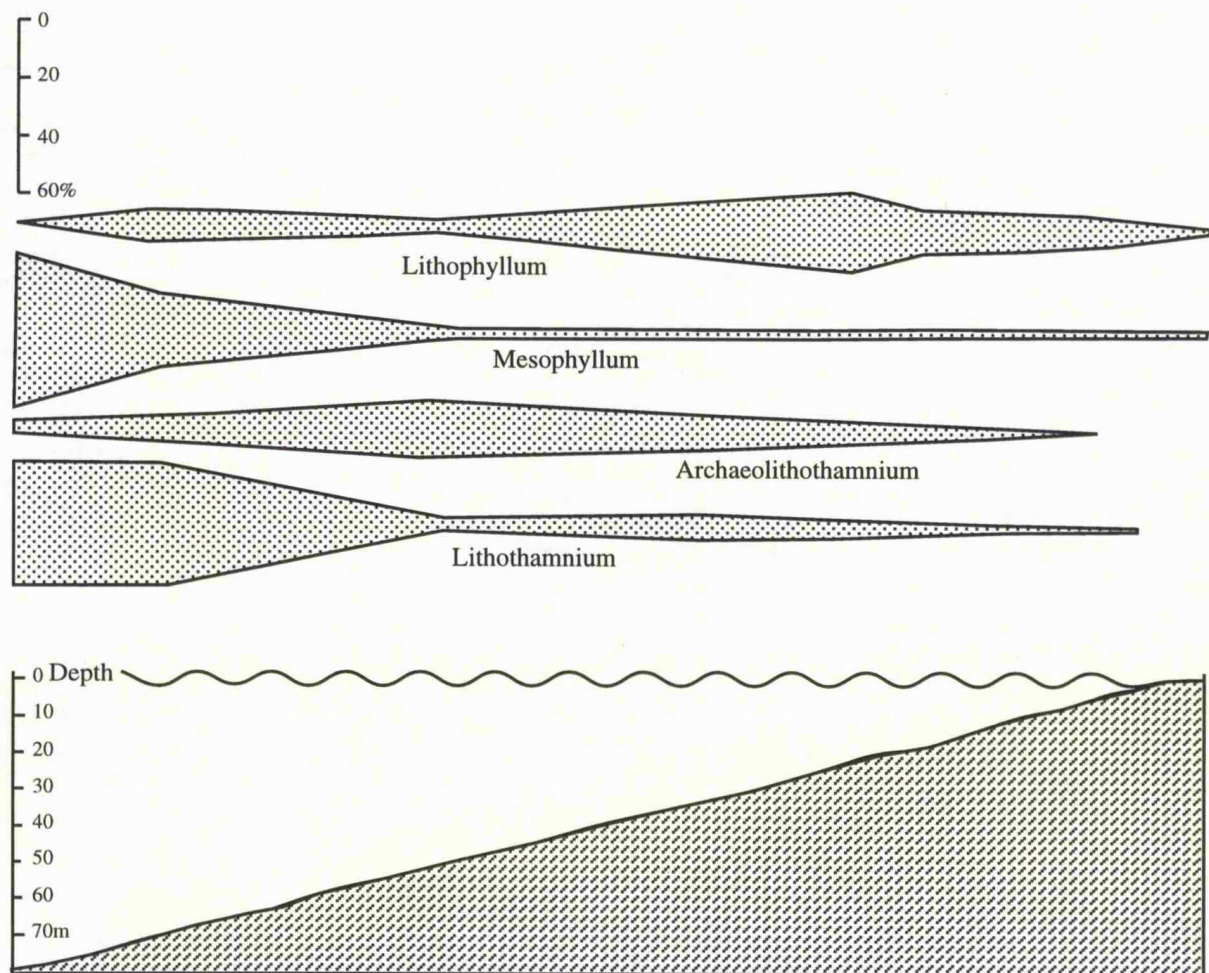


Fig. 6.3. Depth Distribution and percentage abundance of crustose coralline genera, (Modified after Adey and Boykins, 1982).

spheroidal form and that discoidal forms are the most stable. Open branched forms are found to be more stable than densely branched forms of the same shape and size.

The distribution of coralline algae is mainly controlled by temperature and light in marine setting (Adey 1966, 1970, Adey and McKibbin 1970; Adey and Adey 1973). Within the ecological restraints of light and temperature rhodolith occurrence will be controlled by substrate and hydraulic energy. To develop a rhodolith bed suitably sized grains for spore settlement must be present. However, once rhodoliths are established, future recruitment is probably by breakage and overgrowth of rhodoliths. An exposure of moderate hydraulic energy is required to overturn crests and branched growths of newly settled corallines which results in the concentric (crustose) and radial (branching) growths characteristics of rhodoliths (Bosence 1983b).

If the hydraulic energy is too high, then the rhodoliths are broken down into coralline gravels composed of branches and crusts. This erosion can be recorded within the rhodoliths which are smaller, densely branched or crusting with erosion surfaces are fractures (Bosence and Pedley, 1982). The densely branched and laminar rhodoliths are the result of frequent turning and high energy conditions. Apical abrasion occurred during turning appears to lead to intercalary branching or lateral filament growth below the apex. This results in branches joining laterally. Subsequent growth in higher energy environments may be recorded by concentric laminar growth. Bosellini and Ginsburg (1971) suggest that columar growth form from stabilized rhodoliths but Bosence and Pedley (1982) find columar growths on rhodoliths that have been turned and the columns may show the same lateral growth in response to apical abrasion.

According to Illing (1954), the two dasycladacean genera *Acicularia* and *Neomeris* occur on the Bahama Bank but are not common. A similar observation was made by

Cloud (1961) in the same area; it is stated that these algae inhabit tidal lakes. Johnson, (1961) summarized the ecology of Dasycladaceae, a group that occurs at depths ranging from low tidal down to 10 metres, but with the most luxuriant growth being confined to waters shallower than 5 or 6 metres (Johnson, 1960). Recent forms of this group are dominantly marine and are limited to tropical and warm temperature seas. In earlier observations Johnson (1957) concluded that these dasycladacean algae are present where the bottom is muddy or silty. The maximum depth at which they may occur is reported to be 30 metres (Cloud, 1952).

Many references note the occurrence of dasycladacean algae in ancient limestones. Newell et al. (1953) and Newell (1957) report them from the back-reef region immediately behind the Permian reef of the Guadalupe Mountain region. Schlanger (1963) considers the subsurface Eocene limestone of Eniwetok Atoll containing them to be shallow lagoon. Wolf (1965), from his work on the Devonian algal limestone of Australia, concluded that the favoured habitats of these algae are in protected pools, crevices, and local lagoons. According to Jamieson (1969) Devonian Dasycladaceae thrived best in shallow, calm muddy lagoonal areas subject to change in salinity and Eh (also Wray, 1969). Both the authors stress the role of this group as a sediment contributor. In the Eocene reefs of Northeast India, abundant skeletons of dasycladacean algae are present in limestones interpreted to have been formed from sediments deposited in the back-reef region close behind the reef core. From the above discussion it may be concluded that abundant dasycladacean algae indicate a shallow environment and a tropical to warm subtropical climate.

In this facies the foraminifera are dominantly rotaliids, which normally occur between 20 to 45 metres depth (Reiss and Hottinger, 1984).

On the basis of above discussion it is concluded that the coralline algae are deposited in a wide range of environments, and that their distribution was dependent on temperature, depth, salinity, substrate and hydraulic energy. This facies has both coralline algae such as *Lithothamnium*, *Archeolithothamnium*, *Lithophyllum*, *Mesophyllum*, and *Lithoporella* and Articulated coralline algae such as *Jania* with few green algae such as *Trinocladus*, *Neomeris*, *Clypeina* and *Acicularia*. Most of the coralline algae are densely branched, spheroidal and ellipsoidal in shape (rhodolithic growth form). All these algae and the rotaliids foraminifera occur in water of normal marine salinities and at shallow depth. By considering them collectively it is suggested that this facies is deposited in the shallow sub-tidal ramp environment at a depth of 40-70 metres, in a moderately open marine tidal situation.

6.2.6. Nummulitic Facies (F 6):-

This facies is encountered in the Raghasar and the Zinda Pir sections (Fig. 3.3), the northern and the eastern parts of the Sulaiman Range. It is characterized by dark grey to grey coloured wackestones and packstones. The bioclastic packstone is fine to medium grained, thick bedded (0.5 to 1.0 metre thick), and bioturbated. The skeletal allochems are predominantly benthonic foraminifera with red algae and isolated coral heads. Very few encrusting bryozoa (0 to 21.6%) (Table 6.1) and echinoderm fragments (0.6 to 14.4%) are present. The benthonic foraminifera are dominated by entire to fragmental *Nummulites*, with *Operculina*, *Assilina* and *Rotaliids* (*Lockhartia*, *Miscellanea* and *Ranikhothalia*) (Fig. 6.2C). The algae are mainly the red coralline developed as small rhodoliths fragments, particularly of *Lithothamnium*,

Archaeolithothamnium, *Lithophyllum*, *Mesophyllum*, and *Lithoporella*, *Lithothamnium* and *Mesophyllum* frequently are dominant. In this facies the coralline algae ranges from 1.2 to 36.4% of the total rock and the benthonic foraminifera are 0.2 to 70%.

Interpretation:-

Several authors have made attempts to explain the mechanisms governing nummulites distribution and accumulation in different geologic settings i.e. Arni (1965), Aigner (1983, 1985), Bernasconi et al (1984). Since nummulites are extinct assessment into sedimentological models and interpretation of the palaeoecological parameters i.e. water depth, salinity, and temperature, becomes rather uncertain, a point which complicates their interpretation in the stratigraphic record. Several comprehensive studies have, however, been done by a number of authors during the last three decades and different sedimentological models have been proposed which are of great importance in respect of understanding the depositional environments of nummulitic facies.

The following is a brief review of the different opinions of previous authors concerning deposition and accumulation of nummulitic facies.

Arni (1965) subdivided the nummulitic rock suite of Palaeogene of Libya into different facies related to bank formation and each nummulitic facies was distinguished from others by its own characteristic fossil assemblage e. g. the fore-bank setting is characterized by enrichment of fossil debris and the presence of *Assilina* and *Operculina*. The bank setting is associated with *Assilina*, *Operculina* and *Nummulites* and the back-bank setting is characterized by the dominance of *Alveolina* and

Orbitolites. According to his view during the deposition of nummulitic bank facies a submarine relief was formed almost as a consequence of the high biological productivity of the nummulites. He also interpreted the nummulitic bank facies in terms of insitu reworking phenomena and stated that the northern Africa continental platform was an ideal geological province for nummulitic facies developments. He did not, however, indicate the water depth of the formation of nummulitic bank but suggest a maximum depth corresponds to the wave base.

Fournie (1975) has studied the Tunisian nummulitic facies of the El Garia Formation and interpreted its depositional setting as outer platform. According to him, the water depth of the nummulitic bank ranges from wave base to the low tidal level. He also mentioned that this nummulitic bank became subject to reworking when it entered a high-energy environment as he recognized diagnostic sedimentary structures of cross-lamination type.

Aigner (1983), in his study of the Egyptian nummulitic facies of Mckattan Formation related the formation of the nummulitic bank to several factors which can be summarized as, "deposition of the nummulites on a pre-existing topographic high situated in the photic zone. Currents and wave action, lead to in situ reworking and mechanical or hydrodynamic concentration of the nummulitic shells with upward shallowing phenomena".

Bernasconi et al., (1984) on the basis of studies of the nummulitic bank and the seismic lines at the Bauri oil field, drew the conclusions that the nummulitic bank was deposited on a substratum consisting of restricted shallow platform packstones. The presence of petrographic structures typical of intertidal zone suggest that the banks were formed in a high-energy environment. During the growth of the nummulitic bank

it entered the intertidal conditions and become subject to reworking. The water depth of the formation of the banks could not have exceeded the wave-base.

Aigner (1985) has published a paper describing the major nummulitic biofabric types in the middle Eocene limestone of Cairo, Egypt. Based on the ratios of the smaller nummulites (A-forms) to the larger or (B-form), he classified the nummulitic biofabrics of the Cairo bank into four main assemblages and evaluated their hydrodynamic mechanism. The main characteristic of these biofabrics can be summarized as follow;

1- Relatively undisturbed assemblages: These are inferred when small nummulites dominates in matrix-supported lithologies. This nummulitic facies is very common in the back-bank environments.

2- Parautochthonous assemblages: The small nummulites are dominate with edge-wise imbrication of nummulites tests suggesting in situ reworking caused by a wave winnowing hydrodynamic mechanism.

3- Residual assemblage: This can be inferred when large nummulites are dominant and oriented parallel to bedding. The dominance of large nummulites suggest selective removal of the smaller ones.

4- Allochthonous assemblage: This can be inferred for layers composed entirely of small nummulites which suggest hydraulic sorting and separation of the bioclasts during lateral transport.

Gardiner, (1906) and Mc Kee et al., (1959), studied the depositional environment of *Operculina*. According to their study the *Operculina* has been reported from the deeper parts of lagoons where the water is quiet. Maxwell et al., (1961), reported them on channels on reef flats whereas Collins (1958); Jell et al., (1965); and Maxwell (1968), reported them on shelf areas. They also have been reported from the

subsurface reef limestones of Bikini (Cole, 1954), the Miocene reefs of Louisiana, where it is supposed to have lived in the sublittoral zones of the reef-flat environment (Squires and Sachs, 1957), and the Tertiary offshore carbonate bars of Libya along with *Nummulites* (Bebout and Pendexte, 1975). Both Henson (1950) and Schlanger (1963) state that *Nummulites* and *Operculina*, especially the larger one, lived in fore-reef shoal areas. On the other hand, Phleger (1960) grouped them with back-reef forms. Cushman et al., (1954) from their work on Bikini Atoll, report that these forms are rare in deeper water but are present in lagoons. Cloud et al., (1956) are of the view that they are associated with bank deposits.

Levin 1957, studied the depositional environment of *Miscellanea* (another species of nummulites). According to his studies, *Miscellanea* associated with *Lockhartia*, indicate a warm shallow water environment of deposition.

The nummulitid species are usually bottom dwellers throughout their life. They occur at depths of 20 to 130 metres (Reiss and Hottinger, 1984). The perforated nummulites are normally deposited at the depth of 60 to 70 metres, the *Alveolinids* occur below 60 metres. The distribution of foraminifera with depth is studied by a number of workers. Dario Sartorio and Sandro Venturini (1988) give a chart for the distribution of foraminifera with depth for the Tethys (Fig. 6.4).

The coralline algae (melobesiid algae to be more precise) are important not only as frame-builders but also sediment binders and sediment contributors (Cloud, 1952). Important genera of this group include *Archaeolithothamnium*, *Lithothamnium*, *Lithophyllum* and *Lithoporella*. There are numerous references to the different genera of crustose coralline algae in Recent reefs. Emery (1948); Tracey et al., (1948); Wells (1957); Chevalier, (1973); Doty, (1974); Litter and Doty, (1975), Maxwell et al.,

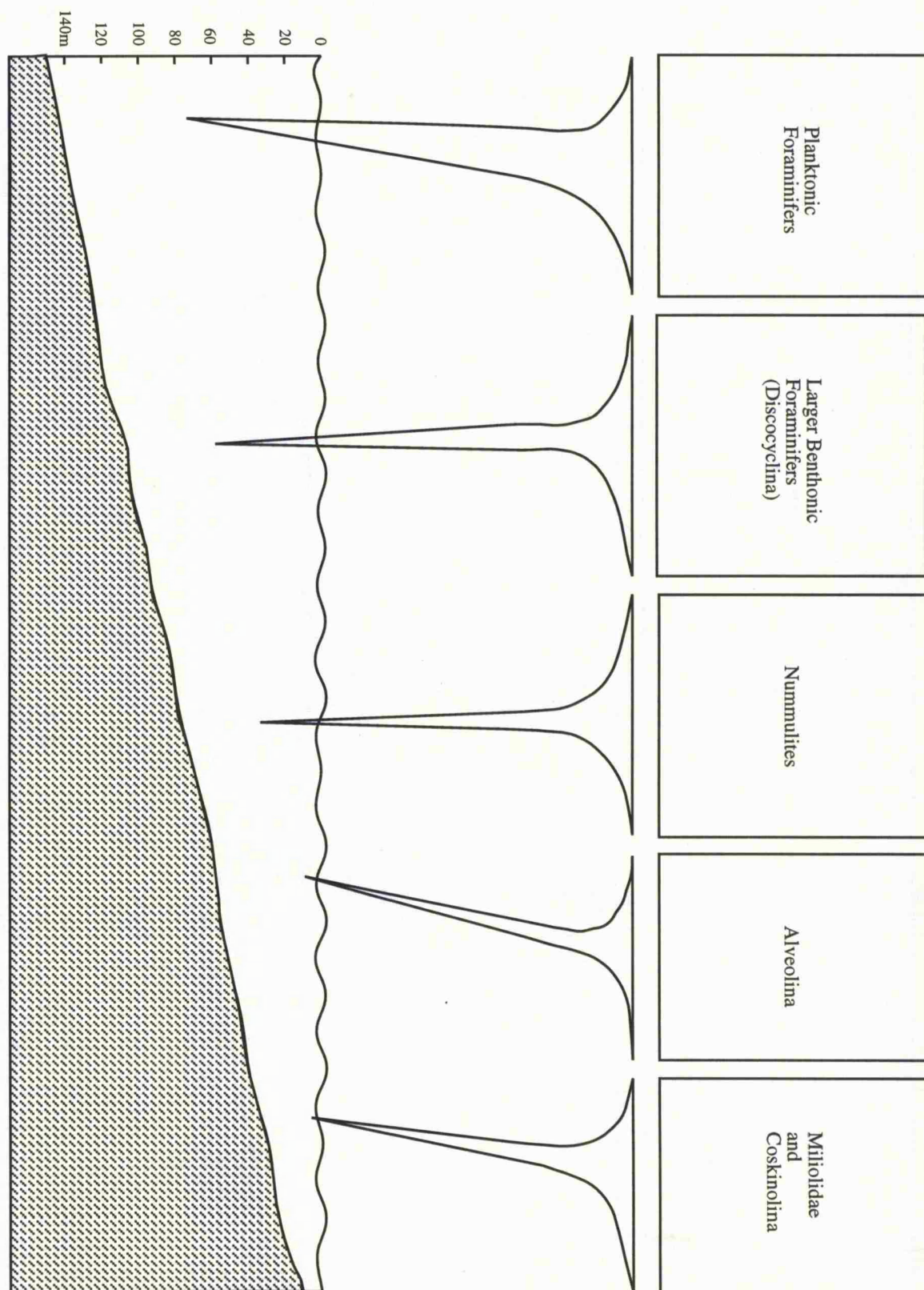


Fig. 6.4. Depth distribution of different types of foraminifera (modified after Sartorio & Venturini, 1988).

(1961); Maxwell et al., (1964); Lewis and Taylor (1966); Maxwell, (1968); Maiklem, (1968); Lewis (1969); Kendall and Skipwith, (1969); and Vasseur, (1974); all suggest the coralline algae occur mainly in the shallow water environments. Illing (1954) stated that crustose coralline algae (*Lithothamnium* and *Lithophyllum*) are quantitatively important on the Bahama Bank. Ginburg (1956) reported that they are abundant on reef edges and in areas immediately in front of reefs in Florida, but are not common in the back-reef region. In the same area *Lithothamnium* has been found to encrust dead corals. Coralline algae have been found to construct reef frame-works along with foraminifers (Garrett et al., 1971; Ginburg et al., 1971; and Jordan, 1973). Logan (1969) and Milliman (1973) record the presence of these algae (*Lithothamnium*, *Lithophyllum* and *Lithoporella*) from Yucatan shelf area off Mexico. From the Alacran reef-complex of the same region branching forms of *Lithothamnium* have been reported by Kornicker and Boyd (1962).

Johnson (1957), while discussing the paleoecology of algae occurring in the limestones of Spain and Mariana island, stated that coralline algae live at depths between tide level and 100 metres (in some cases up to 200 metres), but long-branching forms thrive within 10 to 15 metres. Later Johnson (1961) summarizes the ecologic distribution of coralline algae stating that, in general, they are widely distributed from cold temperate to warm tropical seas, they can live at depths ranging from the intertidal zone down to 156 metres, they grow on practically any surface, do not necessarily require strong light, can withstand strong current and surf action, and that they are euryhaline (also see Jamieson, 1969). This would indicate that the remains of coralline algae can not be effectively used for making palaeoenvironmental interpretations. This is not true, however. His discussion also shows that they are most

diverse (as regards species) and abundant in shallow, warm, strongly agitated tropical waters. Moreover, certain genera (e.g. *Archaeolithothamnium*) are confined to this particular environment. Though *Lithothamnium* is now found mostly in coolwaters, during the Late Cretaceous and the Eocene numerous species of this genus lived in the tropics and developed a variety of growth forms (Johnson, 1961, p.32). Adey and Macintyre (1973) have drawn attention to the same facts. They say that *Archaeolithothamnium* and *Lithoporella* are exclusively tropical genera; *Archaeolithothamnium* and *Lithophyllum* may grow in the intertidal zone, but the latter requires stronger light than the former.

The following conclusions can be drawn regarding the ecology of crustose coralline algae:

1. Limestones mostly constituted of skeletons of crustose coralline algae are deposited in a wide range of depth. High species diversity and abundance indicate a shallow, warm, tropical environment.
2. Coralline skeletons construct the main platform together with corals and foraminifers. They may construct alone by binding loose sediments into a coherent mass.
3. Their abundance increases towards the outer edges of the main platform.
4. They can grow on any surface.

In summary this facies has the coralline algae *Lithothamnium*, *Mesophyllum*, *Archaeolithothamnium*, and *Lithoporella* which can survive in deeper environments than the other genera of coralline algae. The nummulites are dominantly deposited below the depth of 60 metres.

Fig. 6.5. A.

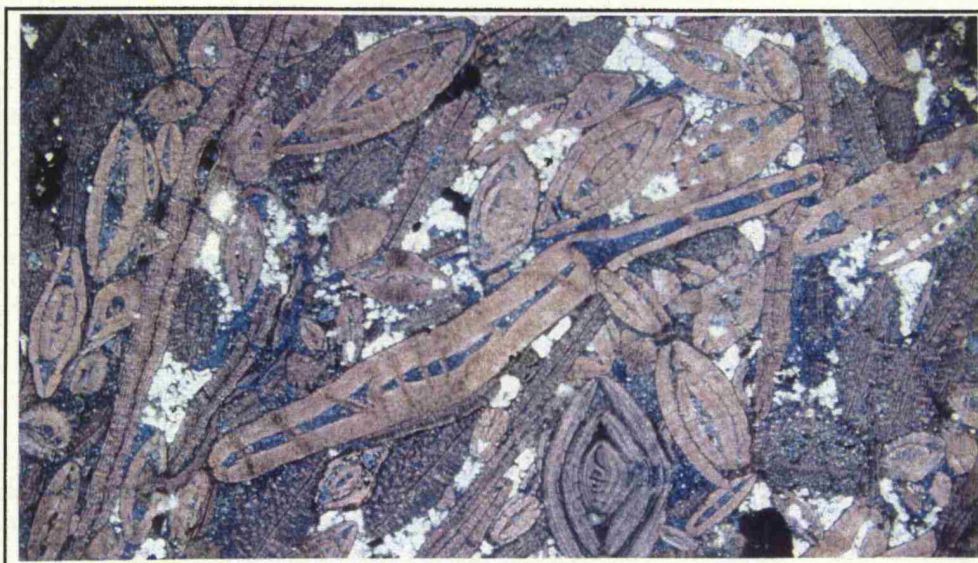
Thin section photomicrograph (from sample ZP 40) illustrating the abundance of larger foraminifera, such as *Discocyclina*, *Athecocyclina* and other larger nummulites represent the larger foraminiferal facies.

Fig. 6.5. B.

Thin section photomicrograph (from sample ZP 32) showing some larger foraminifera in complete form and the abundance of broken smaller nummulites, represents the larger foraminiferal facies in which the broken fragments of smaller nummulites are deposited as reworked sediments.

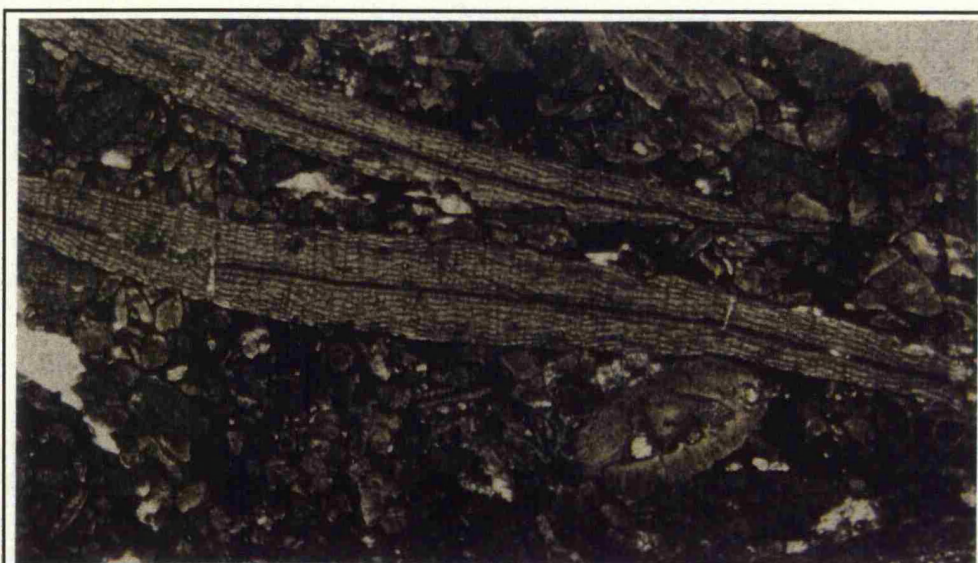
Fig. 6.5. C.

Thin section photomicrograph (from sample ZP 7A) showing the planktonic and the moulds of planktonic foraminifera, represents the planktonic foraminiferal facies.



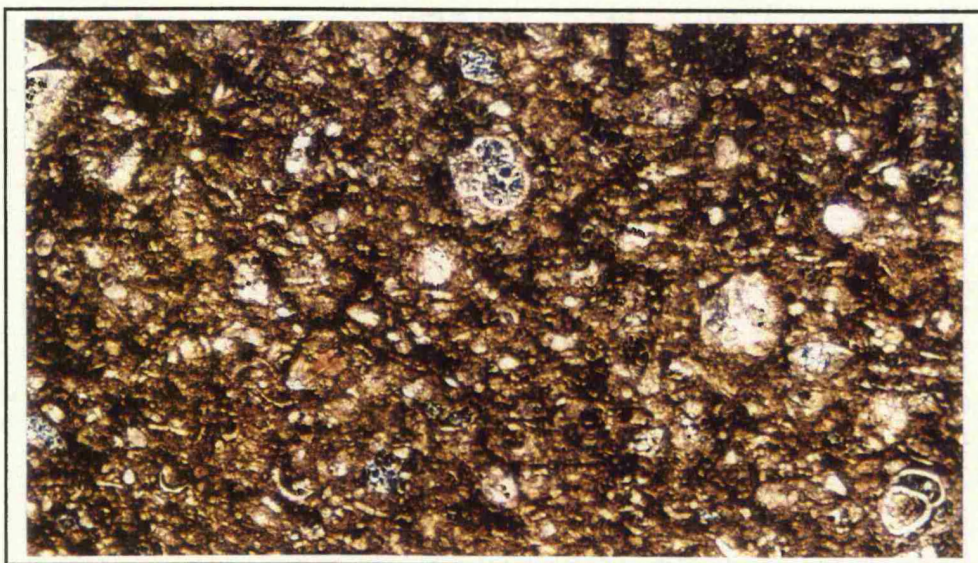
A

1000μm



B

1000μm



C

200μm

Fig. 6.5.

This facies has a large association of foraminifera; *Nummulites*, *Assilina*, *Operculina*, *Ranithokhalia*, *Miscellanea*, *Lockhartia*, along with the coralline algae (*Lithothamnium*, *Mesophyllum*, *Archaeolithothamnium*, and *Lithoporella*). The genera *Lithothamnium* and *Mesophyllum* are dominant in this facies and can survive in slightly low intensity light conditions and deeper environments as compared to other crustose coralline algae. By considering the presence of benthonic foraminifera and crustose coralline algae collectively this facies shows deposition in a shallow ramp environment at depths of 60 to 80 metres.

6.2.7. Larger Foraminifera Facies (F 7):-

This facies is encountered in the Zinda Pir section (Fig. 3.3), the eastern part of the study area. It is mainly characterized by grey to dark grey weathering buff, yellow coloured wackestone. The biomicrite is fine to medium grained, and the unit is thin to thick bedded (0.3 to 0.8 metre thick). Skeletal allochems are predominantly benthonic foraminifera (6.6 to 77.6%) (Table 6.1) with occasional planktonic foraminifera. Few bryozoa (0 to 1.8%), coralline algal (1.2 to 17.2%) and echinoid fragments (0.4 to 5.4%) are also present. The benthonic foraminiferas are mainly represented by larger *Nummulites*, *Discocyclina*, *Athecocyclina*, *Actinosiphon*, *Alveolina*, *Assilina*, and *Miscellanea* (Figs. 6.5A & B). Pressure solution phenomena are developed and mainly restricted to low amplitude, bedding parallel stylolites of simple type. The skeletal grains are slightly deformed which indicates the compactional effect on them. Some veins are also present which are filled by sparry calcite cement.

Interpretation:-

Ranikothalia (Fleury et al. 1985), a Palaeocene genus is worldwide in distribution in shallow water facies from Cuba through West Africa and southern Europe to Tibet and Borneo. *Alveolinids* are, in general, shallow water neritic forms (Reichel, 1964, p.505) and indicate a littoral and reefal facies. The recent *Alveolinella*, which may be regarded as the ecologic descendents of the Eocene genus "*Alveolina*", lives in tropical seas at depth of 10 to 80 metres. A study of the distribution of this genus in Recent reefs (Ghose, 1977), clearly shows that it lives in both fore-reef and back-reef zones. Henson (1950, pp. 230-231), also concluded that this genus was characteristic of reef areas with clear water having little or no deposition of clastic sediments. *Discocyclina* is supposed to be a typical fore-reef form (Henson, 1950). In addition, together with other foraminifers they formed bank and off-shore bar deposits (Cloud et al., 1956; and Bebout and Pendexter, 1975). Thus, it may be concluded that the paleoecology of *Discocyclina* is similar to that of *Nummulites*. Myers, (1943) suggests that the presence of *Discocyclina* indicates a deeper water environments.

According to Ghose (1977), *Heterostegina*, is a long ranging foraminifera (Eocene to Recent) and has obvious advantages from a paleoecological point of view. This genus is quite common in present day reef complexes of different parts of the world and has also been reported from ancient reef limestones. Ghose (1977) showed that it is an inhabitant of the quieter parts of the reef complex. *Cycloclypeus*, another genus of nummulite has been reported from the outer slopes of Bikini Atoll (Cushman et al., 1954) and from channels adjacent to the Great Barrier Reef (Maxwell, 1968), and is said to be tolerant of greater depth and lower temperature (Cole, 1957). Its occurrence has also been noted from subsurface reef limestones of Bikini (Cole, 1954) and

Eniwetok (Cole, 1957) atolls. The Tertiary limestone of Micronesia containing this genus are supposed to represent fore-reef detritus (Hanzawa, 1957). Consequently, the deeper environments appear to be the favourable habitats of *Cyclocypeus*. Buxton and Pedley 1989, studied the evolution and changes in ramp associated foraminiferal distributions. Their studies showed that in Palaeocene-Eocene times *Nummulites*/*Assilina*, *Asterocyclina*, and *Discocyclina* are present in the deeper environment which are replaced by *Spirocypeus* in the Oligocene and by *Heterostegina* and *Cyclocypeus* by Miocene time.

According to Bandy (1964) the foraminifera with chamberlets such as *Sorites*, *Heterostegina* and *Cyclocypeus*, attain their greatest abundance between depths of about 20 and 80 metres. They live on the deeper anchored types of seaweed. A few variations are reported in deeper waters as, for example, *Amphisorus*, occurs abundantly in the Red Sea at the depth of 941 metres (Said, 1949). The genus *Alveolinella*, is also present in depth of 20 to 80 metres in the region of the Sulu Sea. It is stenohaline restricted to the tropical waters, and generally is associated with the larger discoidal forms which have chamberlets.

Nummulites, *Assilina*, *Lockhartia*, *Ranikothalia*, and *Alveolina* generally are broken in this facies, only the *Discocyclina*, *Actinosiphon* and *Athecocyclina* with few *Nummulites* are completely preserved (Fig. 6.5A). It is concluded that the *Discocyclina*, *Actinosiphon* and *Athecocyclina* with few *Nummulites* grew and were preserved *insitu*. Most of the *Nummulites*, *Assilina*, *Lockhartia*, *Ranikothalia* and *Alveolina* were originally deposited in a shallow ramp setting and then were transported into deeper ramp environments. On the basis of the paleoecology of

Discocyclina, *Athecocyclina* and *Actinosiphon* along with the *Nummulites* a deeper ramp environment with a depth of 70 to 100 metres is suggested for this facies.

6.2.8. Planktonic Foraminiferal Facies (F 8):-

This facies is encountered in the Zinda Pir section, the eastern part of the Sulaiman Range. It is characterized by dark grey to grey coloured mudstone interbedded with shale. The biomicrite is fine to medium grained and the unit is thin bedded (0.1 to 0.3 metre). The skeletal allochems are mainly planktonic foraminifera (3.4 to 17%) (Table 6.1) with rare larger benthonic foraminifera. The planktonic foraminifera are generally *Globogerina* and *Globotruncana*. The moulds of foraminifera are also present (Fig. 6.5C). Pressure solution phenomena are developed and mainly restricted to low amplitude, bedding parallel stylolites of simple type.

Interpretation:-

In modern marine settings, planktonic foraminifera become more abundant seaward. In the Arabian Gulf they occur in significant quantities only near the entrance of the Gulf in the Straits of Hormuz at a depth of over 100 metres (Hughes-Clarke and Keij, 1973). In the Gulf of Mexico, off Alabama and Mississippi, there is a sharp increase at a depth of approximately 60 metres. Their greatest abundance occurs in depths greater than 200 metres (Walton, 1964; Hunter, 1976) and above the calcite compensation depth.

Most planktonic foraminifera live within the upper 100 metres of the ocean. A few genera, such as *Globigerinoides* and *Globorotalia*, however, can live at depths greater

than 500 metres (Milliman, 1974). The distribution of planktonic foraminifera in ocean sediments depends upon the resistance of individual tests to solution. The more delicate and smaller foraminifera will dissolve faster than the more massive types (Berger, 1967, 1968; Ruddiman and Heezen, 1967). *Globorotalia* is the most resistant to solution (Parker, 1971) and therefore appears to be more common in bottom sediments.

As the delicate and smaller foraminiferas dissolve, their moulds are left behind, which later on filled by sparry cement.

This facies comprises mainly the planktonic foraminifera, *Globogerina* and *Globotruncana* and the casts of planktonic foraminifera which indicates the deep water environment. This facies includes mudstone interbedded with shale, and the units are thin bedded. These features are indicative of deep water environments. On this discussion it may be concluded that this facies was deposited in a deep water environment at depths of about 100 to 120 metres.

6.3. Depositional Model and Palaeoenvironments:-

On the basis of lithological and fossil associations, the studied Dungan Formation is interpreted as have been deposited in the carbonate ramp environments.

The ramp model as given by Ahr (1973), is "a sloping surface connecting two levels". There is no break in slope. According to him grainstone and packstone are landward facies and the sediments become muddy in the basinward direction.

Read (1982, 1985) elaborate the ramp model and describes two types of ramps. 1) The homoclinal ramp has a relatively uniform slope (1 to a few metres per kilometre) into

the basin and generally lacks significant sediment gravity flow deposits and slumps in deep water facies. It includes coastal clastics, cyclic lagoon and tidal flat carbonates, coal/evaporites. These pass seaward into nearshore ooid/peloid sands or skeletal sheets and buildups; deep ramp argillaceous lime wackestone/mudstone, containing open marine diverse biotas; and slope and basin, deep water pelagic muds or periplatform muds and shale interbeds. 2) The distally steepened ramp shows a marked increase in slope at the seaward edge of the deep ramp, and abundant slumps, slope breccias and turbidites. It includes coastal clastics, cyclic lagoon, tidal flat carbonate, ooid/peloid sand or skeletal sheet and buildups; deep ramp sub-wave base, nodular burrowed lime wackestone, mudstone, with open marine biota; may also have slumps, breccias and turbidites along basin margin; and even-bedded grey to black lime mudstone and lesser wackestone, may be argillaceous or shaly, laminated, unburrowed, abundant intraformational truncation surfaces, and contain slumps and breccias with clasts of slope facies. The facies reflect relatively high (several degrees) slopes into the basin.

Buxton and Pedley (1989) give emphasis to a ramp model for Tethyan Tertiary carbonate rocks. According to their study on Cenozoic carbonate rocks in Malta, Sicily, Tunisia and Antigua, they grouped the peritidal carbonates, lagoonal, unstratified (grainstone) barrier/beach facies, protected embayment (gastropod-seagrass) facies and rhodolith platform/pavement facies into the inner ramp. For the outer ramp they suggested the corallgal patch-reef belt, larger foraminifera (orbitoid) facies and planktonic foraminiferal facies.

Burchette and Wright (1992) described the carbonate ramp and subdivided it into inner, mid and outer ramp. The inner ramp is the zone above fair-weather wave base,

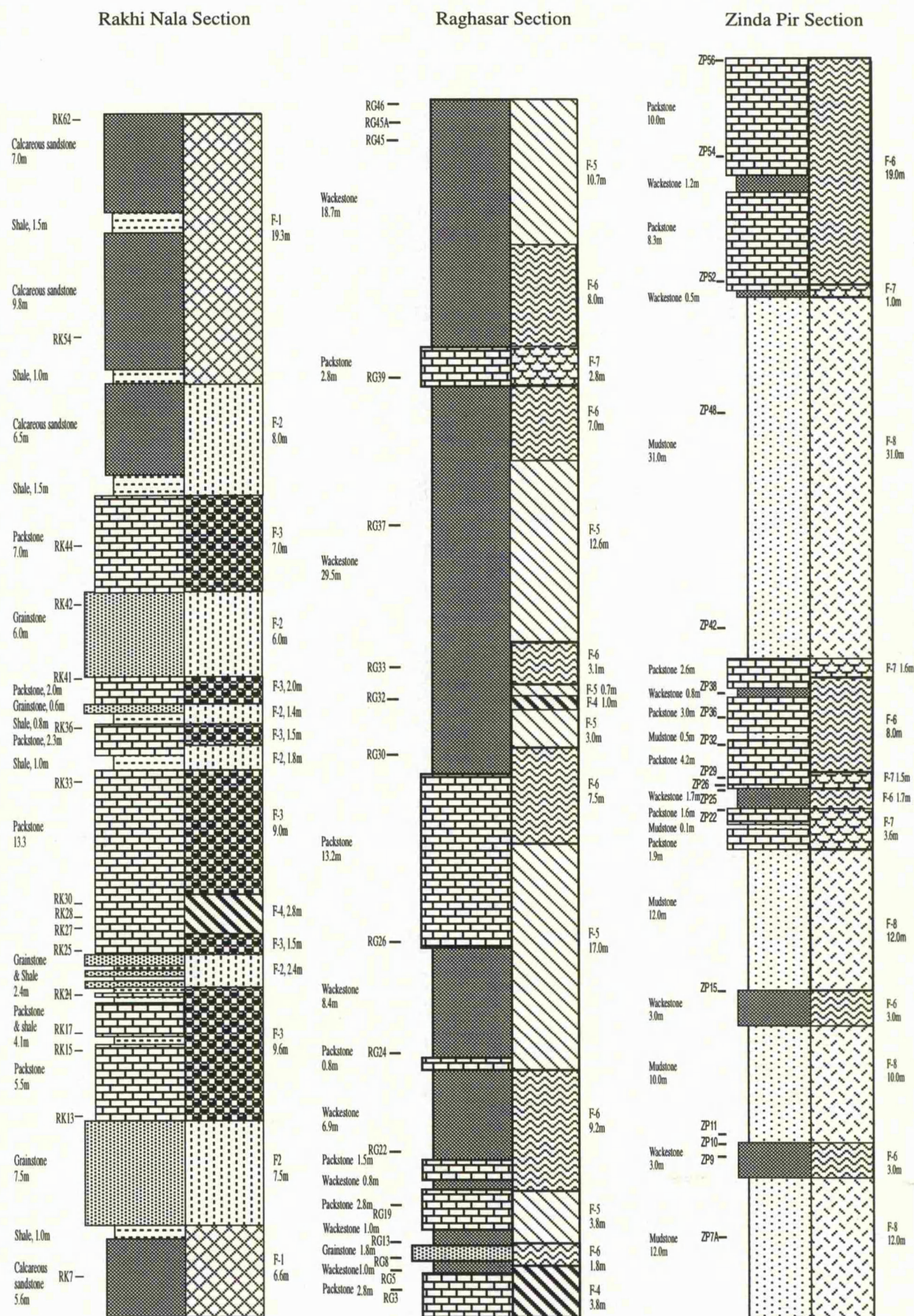


Fig. 6.6. Distribution of lithology and facies types in three studied sections of the Dungan Formation.

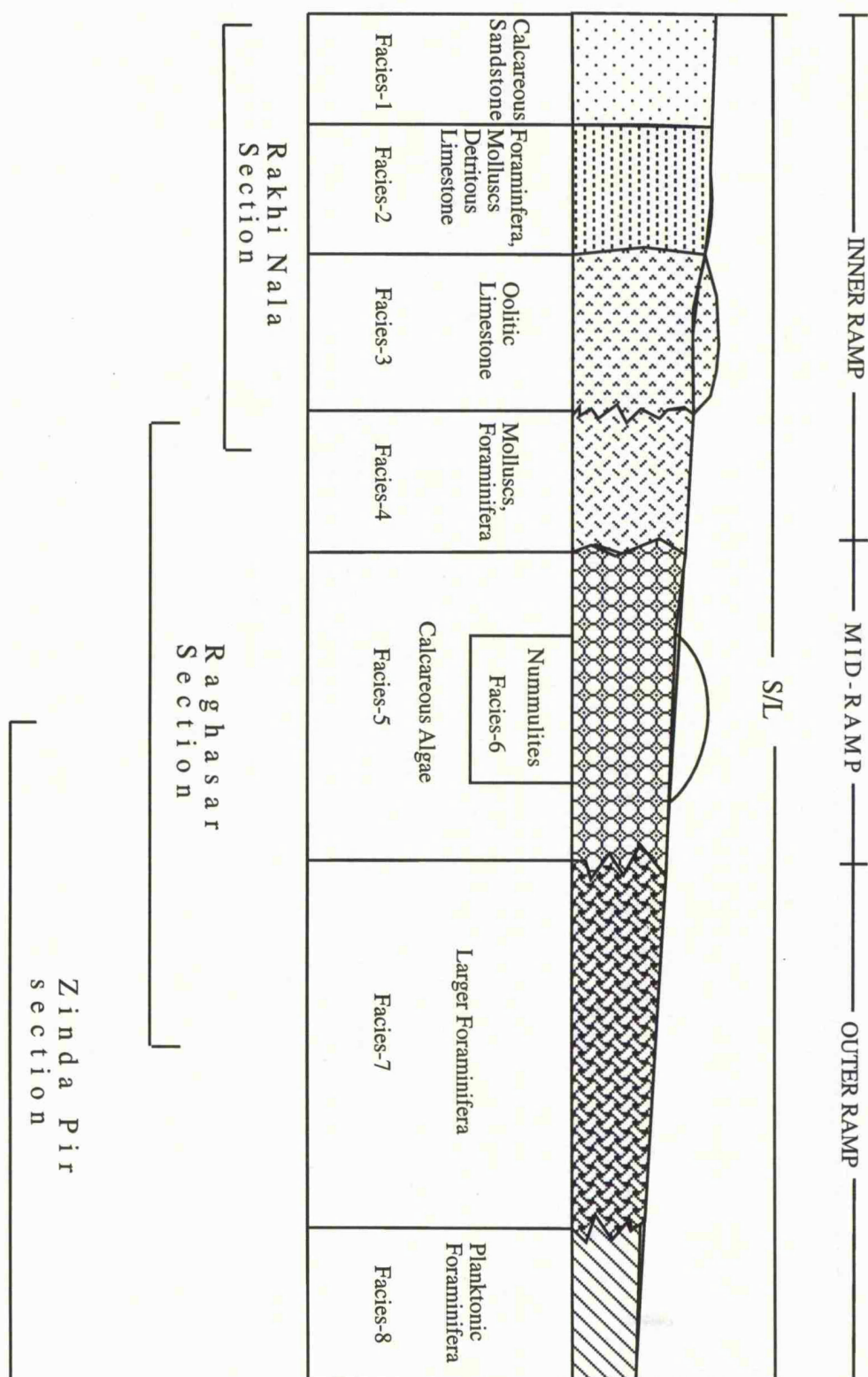


Fig. 6.7. Ideal Homoclinal Ramp Profile showing down-ramp distribution of facies in this study.

dominated by sand shoals or organic barriers and shoreface deposits and back-barrier peritidal areas. The mid ramp is the zone between fair-weather wave base and storm wave base. Sediments show evidence of frequent storm reworking. A variety of storm-related features typically occur, including graded beds and hummocky cross-stratification. Proximal-distal trends can commonly be recognised in ancient mid-ramp deposits (Aigner, 1984; Burchette, 1987; Faulkner, 1988). The outer ramp is the zone which extends from the depth-limit to which most storms influence the sea floor to the basin plain. Sediments show little evidence for direct storm reworking but a variety of storm related deposits, such as sparse, graded, distal tempestites may occur in the upper part (Aigner 1984; Calvet and Tucker, 1988). Their studies show that a wide variety of organisms have constructed mounds in mid and outer ramp environments, and that ramps develop mostly on cratonic interior basin margins, passive continental margins and foreland basins margins. The windward ramps are wave and storm dominated and have more grainstone facies in the inner ramp area. The leeward ramps show stronger progradation or even lower slope angles, with a tendency towards more tabular geometries, and less abundant grainstone than those in windward settings.

The present study shows the Dungan Formation has a lithofacies of peritidal carbonates, inner lagoon facies, oolitic and outer lagoon facies in the inner ramp environment (Fig. 6.7). The rhodolith platform and nummulites facies are the mid ramp facies. The larger foraminifera and planktonic foraminiferal facies represent the outer ramp facies (Fig. 6.7). The inner ramp facies show abundant grainstone and dominant sand shoal and high energy environments. The sediments may be removed from the coastal environment by longshore drift or wind deflation of beaches or shoal. The inner ramp facies also show oolitic units which may be assumed that the sediments removed by deflation from beach and shoal along the windward direction (Fig. 6.8). The mid

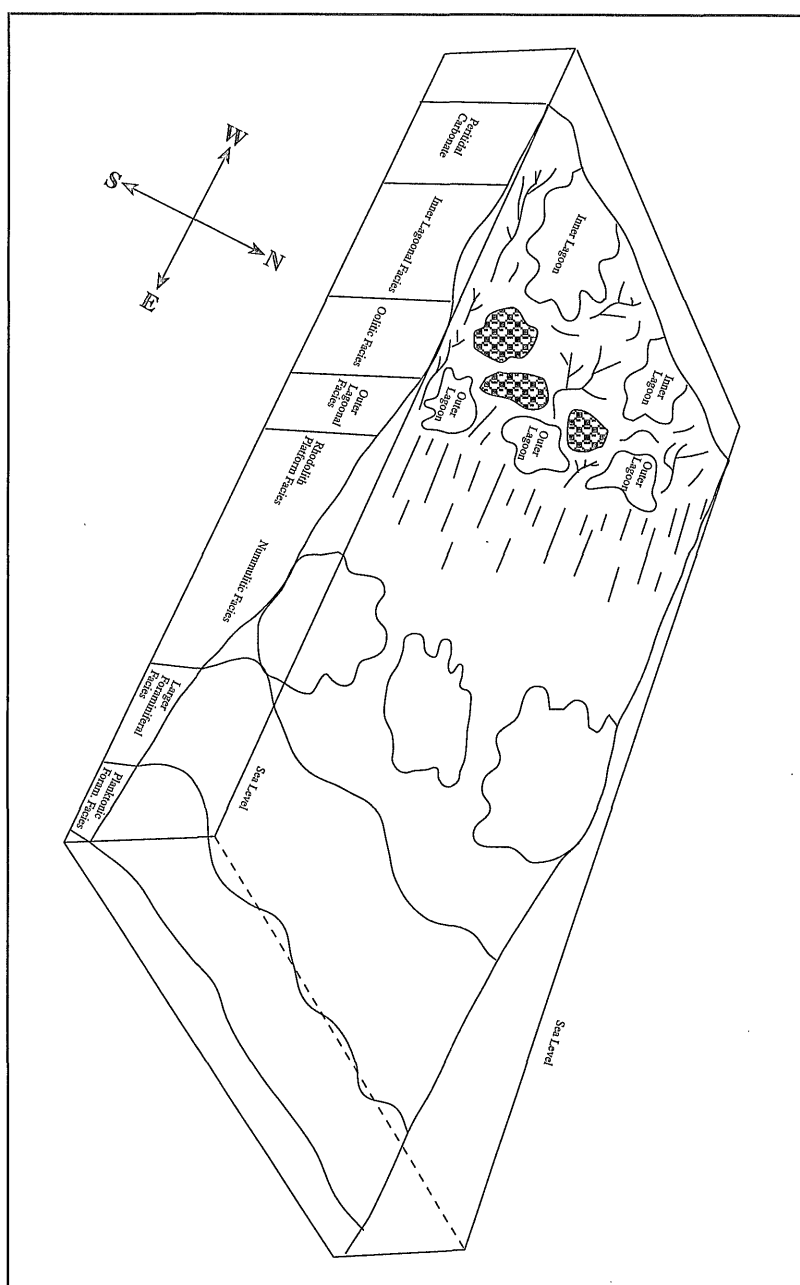


Fig. 6.8. Idealized block diagram of proposed homoclinal ramp model facies and sedimentary environment of eastern Sulaiman Range, Pakistan.

ramp facies are mainly thick-bedded to massive wackestones and packstones. They are bioturbated, slumps, and turbidites are rare in the mid ramp facies. The main skeletal allochems in this facies are red coralline algae and foraminifera. The red coralline algae are in the form of rhodoliths. As discussed above these rhodoliths include cool water (deeper) and shallower forms. In the higher latitudes they are in the shallow depth of cool water whereas in the low latitudes they shifted to the deeper depths (cool water). Similarly the presence of *Assilina*, *Operculina* and *Nummulites* in this facies show the deeper depth (as discussed in section 6.26). Consequently it is concluded that the mid ramp facies accumulated in depths of 50 to 80 metres (Fig. 6.8). The outer ramp facies are mainly thin bedded lime mudstone, interbedded with shale. Truncation surfaces are rare. Few breccias and reworked sediments are present. The skeletal allochems in outer ramp facies are mainly *Discocyclina*, *Athecocyclina*, larger *Nummulites*, and *Assilina*, and *Globogernia*, and *Globotruncana*. As discussed earlier, the presence of these foraminifera indicate the deeper environment of deposition. It is concluded the outer ramp facies accumulated in depths of 70 to 120 metres (Fig. 6.8). On the basis of this discussion it is concluded that these facies are deposited on a ramp with a slope of about 1°. The ramp is homoclinal, and the facies are deposited on the windward side of the ramp.

Cenozoic Ramps in Related Regions:-

Similar ramps to that described here are developed in Palaeocene rocks of Sirte basin Libya (Saleem, 1996), in Southeast Asia and in Oman (Bosence, personal commun.). Ramps are also widely distributed in Oligocene-Miocene rocks of S.W. Papua New Guinea (Pigram et al., 1989), and Mediterranean regions (Buxton and Pedley, 1989).

Chapter Seven

GEOCHEMICAL STUDIES

7.1. Introduction:-

This chapter deals with the results and interpretation of the geochemical investigations carried out on the sediments of the Dungan Formation. These include elemental analysis and the analysis of stable carbon and oxygen isotopes. The samples were analysed by x-ray diffraction for calcite and clay minerals, electron microprobe analysis to determine the chemistry of calcite present in different calcite grains and cements, and x-ray fluorescence analysis were used to determine the major elements (as oxides), and the trace element contents of the whole rock. Cathodoluminescence microscopic technique is used to compare with the iron and manganese concentrations in the Dungan Formation.

The geochemistry demonstrates a relationship between mineralogy and geochemical composition, and geochemical composition and the diagenetic events in the rocks studied. The first part of this chapter deals with the whole rock mineralogy and mineral chemistry determined by x-ray diffraction, and electron microprobe analysis; and the later part with the whole rock geochemistry determined by x-ray fluorescence and isotope geochemistry.

7.2. Samples and Methods:-

7.2.1. Field Samples:-

As described in chapter four, three sections had been studied thoroughly and more than 150 samples had been taken from these sections on the basis of lithologic variations. The sample numbering ascends from base to top of the formation. The letter denotes the section and the number designated the sample number, e.g. RG 7.

7.2.2. Laboratory Treatment:-

Each sample was crushed to about 1 cm. in diameter in a flypress; the flypress was cleaned after each sample crushing to prevent contamination. About 50 to 70 grams of the sample was ground to a fine powder in tungsten-carbide mill. This fine powder was used for the investigation of whole rock chemistry by x-ray fluorescence techniques. For whole rock mineralogy, about 10 gram of fine powder sample was micronised in the microniser, and kept them in the oven over night to become dry. This dried material was used for the analysis of whole rock mineralogy by x-ray diffraction techniques. Fine material picked by hand-drill from the fresh surface of the samples was used for the determination of stable carbon and oxygen isotopes. Carbon coated polished thin sections were used for the analysis of mineral chemistry of the carbonate grains and cements by electron microprobe techniques. The polished thin sections were used for the study of cathodoluminescence microscopy. The details of the procedure are described in appendix 2.

7.3. Methods and Techniques:-

7.3.1. X-Ray Diffraction Analysis:-

More than 50 samples were prepared for x-ray diffraction techniques. The analyses were carried out on a Philips PW 1729 x-ray diffractometer generator attached to PW diffractometer controlled by Sieronois Sie 1710 Software running on a Viglen 386 computer. The details of the procedure are described in appendix 3.

7.3.2. Electron Microprobe Analysis:-

Fifty polished thin sections were prepared for electron microprobe analysis. They are coated with carbon before performing the analysis. The analysis were carried out through Jeol Superprobe model JXA-8600S with an on-line computer for ZAF corrections and six major oxides (i.e., CaO, MgO, FeO, MnO, SrO, and BaO) were determined. The concentrations of oxides obtained are given in appendix 8 (Table A7.1). The details of procedure are described in appendix 4.

7.3.3. X-Ray Fluorescence Analysis:-

A total of ten major oxides (SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, and P₂O₅) were determined by using a Philips 1400 x-ray spectrometer and ARL 8420 spectrometer, each equipped with a rhodium anode x-ray tube. The detection limits are generally low, .01 for SiO₂; .0016 for TiO₂; .005 for Al₂O₃; .002 for Fe₂O₃; .002 for MnO; .011 for MgO; .003 for CaO; .016 for Na₂O; .002 for K₂O; and .002 for P₂O₅.

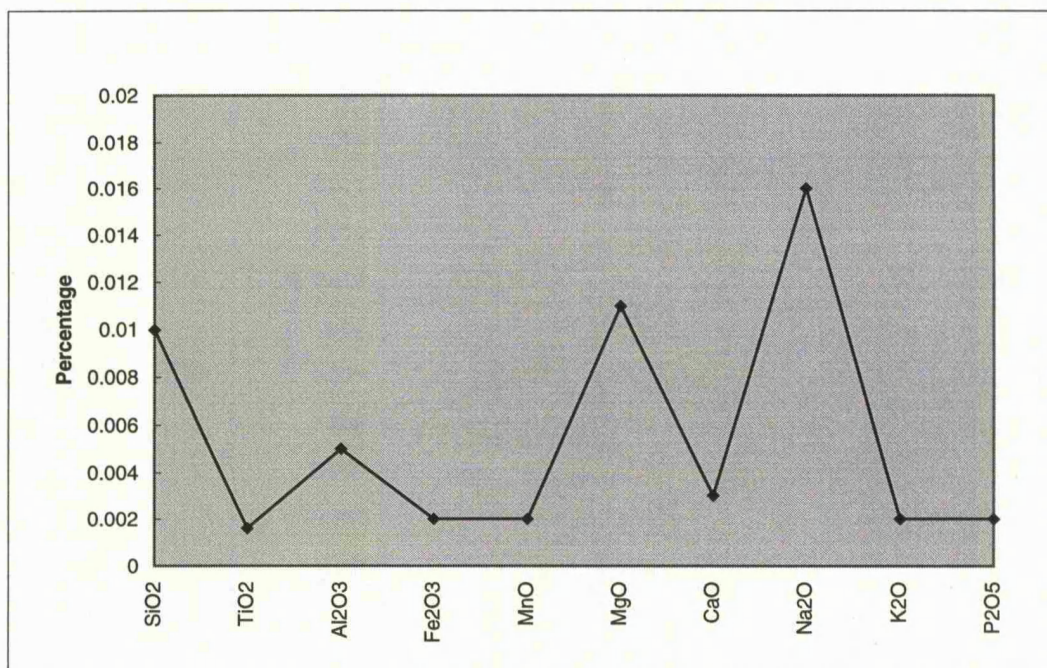


Fig.7.1A. Detection limit of XRF analysis for the major elements in percent.

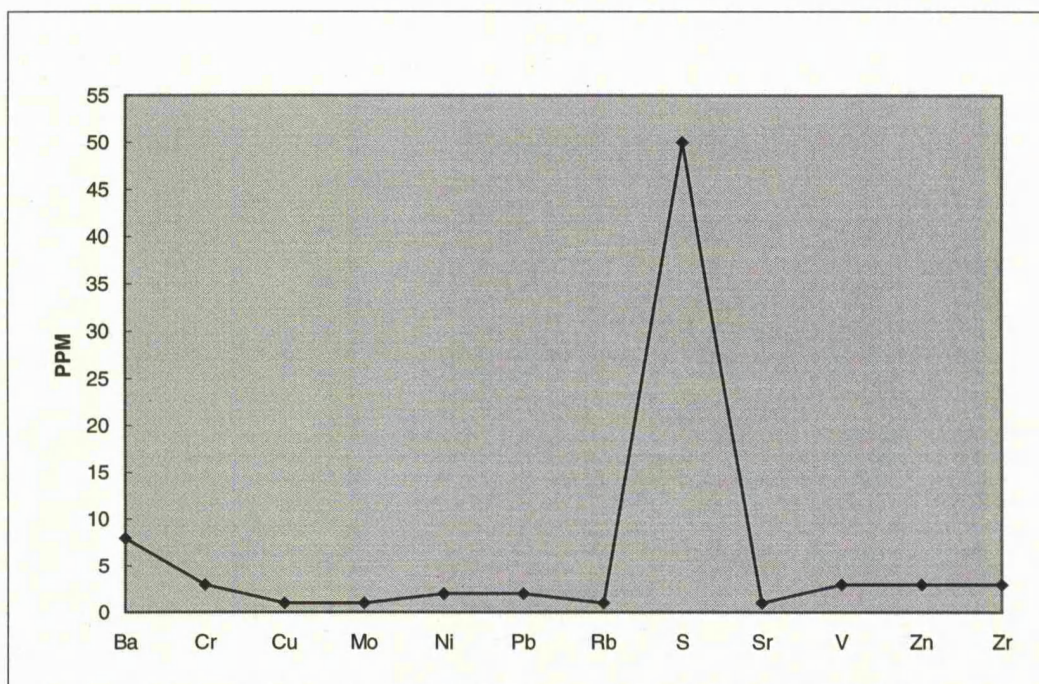


Fig.7.1B. Detection limit of XRF analysis for trace elements in ppm.

(Fig. 7.1A). However, the accuracy of the results is generally dependent upon the accuracy of calibrations used and the effect of mineralogical variations within the sample analysed. The analysis were performed on fused glass bead made up of 1.0 gram of 100 mesh dried rock powder and 5.0 gram of spectroflux (lithium tetraborate). All major oxides are reported in weight percent (wt.%). The compound compositions and concentrations obtained are given in Table 7.1. The details of the procedure are described in appendix 5.

A total of eleven trace elements (Ba, Cu, Mo, Ni, Pb, Rb, S, Sr, V, Zn, and Zr) were determined by using a Philips PW 1400/10 XRF spectrometer equipped with either a 3Kw rhodium anode tube on a tungsten anode tube. The detection limits are generally low, 8 for Ba; 3 for Cr; 1 for Cu; 1 for MO; 2 for Ni; 2 for Pb; 1 for Rb; 50 for S; 1 for Sr; 3 for V; 3 for Zn; and 3 for Zr (Fig. 7.1B). The trace element analysis were performed on the pressed powder pellets made up of 15.0 grams of 250 mesh rock powder and a small amount (20 to 25 drops) of Mowiol 88 (a solution of polyvinyl alcohol in a 1:5 mixture of methanol and distilled deionised water) as a binding material. The trace element data are reported in parts per million (ppm). The elemental concentrations obtained are given in Table 7.1. The details of the procedure are described in appendix 5.

7.3.4. Stable Isotope Analysis:-

Carbon oxygen stable isotope analysis of fifty selected samples were carried out at the NERC Isotope Geosciences Laboratory at Keyworth, by Dr. B. Spiro. Out of fifty samples, forty were of whole rock, two were of the drusy cement picked from the rock

Table. 7.1. Major and trace elements analyses of all samples of Dungan Formation analysed by x-ray fluorescence.

Sample No. Facies	RK53 F1	RK54 F1	RK55 F1	RK56 F1	RK57 F1	RK59 F1	RK60 F1	RK61 F1	RK62 F1	RK12 F2	RK21 F2
Major elements (%)											
SiO ₂	89.39	89.40	81.12	82.03	82.93	85.42	86.80	89.43	82.16	54.05	37.72
TiO ₂	0.33	0.25	0.48	0.20	0.17	0.41	0.20	0.36	0.24	0.24	0.23
Al ₂ O ₃	3.27	2.27	8.39	3.93	2.21	4.79	2.03	4.58	3.20	2.20	2.31
Fe ₂ O ₃	5.01	4.15	6.32	6.79	5.89	7.38	4.26	3.62	8.96	6.69	4.93
MnO	0.16	0.26	0.12	0.62	0.80	0.16	0.60	0.09	0.54	0.17	0.23
MgO	0.90	0.65	1.20	1.03	0.80	0.68	0.98	0.56	0.60	0.57	1.57
CaO	0.83	2.49	1.06	4.73	6.89	0.87	4.70	0.58	4.12	19.47	27.29
Na ₂ O	0.00	0.03	0.11	0.00	0.00	0.00	0.00	0.00	0.03	0.21	0.10
K ₂ O	0.11	0.13	0.90	0.24	0.13	0.26	0.19	0.32	0.38	0.41	0.09
P ₂ O ₅	0.03	0.05	0.04	0.04	0.05	0.06	0.10	0.03	0.08	0.11	0.40
Total	100.02	99.68	99.74	99.61	99.88	100.03	99.85	99.58	100.31	84.12	74.88
LOI	1.95	2.93	3.28	5.24	6.26	2.92	4.88	2.01	4.30	17.06	23.93

Trace elements in ppm

Ba	29	179	184	30	85	42	4	57	178	27	20
Cr	98	118	130	107	96	89	90	71	59	80	47
Cu	18	<1	3	2	3	3	<1	<1	6	1	6
Mo	<1	1	<1	<1	2	<1	<1	<1	2	1	<1
Ni	17	8	40	24	12	28	5	9	19	16	25
Pb	9	2	7	10	10	13	7	7	14	5	13
Rb	2	2	32	6	4	5	2	8	12	14	6
S	13	25	1002	46	115	25	241	129	183	979	2616
Sr	50	80	77	122	185	59	118	53	79	275	430
V	77	68	128	121	91	127	72	81	242	108	49
Zn	67	38	90	82	46	93	26	44	35	13	40
Zr	170	131	146	71	59	188	95	176	91	150	79

Sample No. Facies	RK22 F2	RK23 F2	RK24 F2	RK35 F2	RK38 F2	RK39 F2	RK40 F2	RK41 F2	RK42 F2	RK43 F2	RK48 F2
Major elements (%)											
SiO ₂	54.72	53.25	40.91	75.93	81.09	69.96	72.47	57.86	82.78	50.33	82.48
TiO ₂	0.12	0.15	0.56	0.44	0.89	0.47	0.23	0.17	0.23	0.15	0.15
Al ₂ O ₃	1.16	1.02	3.13	3.68	6.83	2.40	1.29	1.37	1.58	0.95	3.40
Fe ₂ O ₃	1.58	2.14	5.99	7.94	8.01	7.86	8.62	12.35	7.69	2.56	8.86
MnO	0.18	0.22	0.31	0.50	0.05	0.56	0.37	0.64	0.50	0.34	0.28
MgO	0.76	0.77	5.60	1.75	1.33	1.16	0.90	1.53	1.27	1.17	0.81
CaO	21.75	22.48	20.19	9.32	0.13	17.23	16.24	25.31	5.43	25.75	3.92
Na ₂ O	0.19	0.12	0.05	0.00	0.03	0.03	0.00	0.00	0.00	0.01	0.00
K ₂ O	0.11	0.04	0.51	0.27	0.67	0.28	0.15	0.14	0.19	0.13	0.27
P ₂ O ₅	0.09	0.19	0.10	0.13	0.06	0.40	0.13	0.28	0.14	0.12	0.04
Total	80.66	80.38	77.35	99.96	99.09	100.35	100.39	99.66	99.79	81.51	100.21
LOI	18.85	19.24	23.48	9.10	2.30	12.95	11.90	17.17	5.77	17.89	4.50

Trace elements in ppm

Ba	11	<8	31	72	159	134	30	42	35	23	163
Cr	20	34	139	72	132	75	44	53	41	34	61
Cu	6	5	7	2	5	2	3	4	<1	<1	2
Mo	2	<1	<1	<1	<1	2	<1	1	2	3	<1
Ni	6	6	26	45	56	8	14	17	25	4	23
Pb	6	10	5	8	13	11	9	14	10	5	4
Rb	5	2	15	11	22	13	4	8	7	5	10
S	1808	967	2749	1066	2697	689	256	535	408	368	1036
Sr	291	298	330	201	110	230	193	237	141	210	87
V	25	27	72	123	166	119	102	133	112	52	213
Zn	9	12	40	73	141	24	8	15	14	<3	48
Zr	70	96	533	149	509	505	184	105	145	116	70

Table. 7.1 (contd.)

Sample No. Facies	RK49 F2	RK13 F3	RK14 F3	RK17 F3	RK18 F3	RK19 F3	RK32 F3	RK33 F3	RK36 F3	RK44 F3	RK45 F3
Major elements (%)											
SiO ₂	81.91	34.68	39.39	18.09	42.28	27.08	44.69	44.17	57.15	60.51	43.78
TiO ₂	0.20	0.21	0.14	0.11	0.20	0.19	0.14	0.35	0.81	0.13	0.25
Al ₂ O ₃	6.00	2.51	1.13	0.97	2.37	1.40	1.12	3.13	7.42	1.31	1.93
Fe ₂ O ₃	8.83	6.91	2.75	3.66	5.64	5.23	5.37	10.82	19.65	8.58	3.20
MnO	0.15	0.29	0.40	0.30	0.24	0.28	0.36	0.50	0.24	0.77	0.41
MgO	1.03	1.01	0.89	1.73	1.11	1.49	0.90	1.33	1.76	1.12	1.22
CaO	1.90	28.48	28.94	40.48	25.37	33.20	24.91	20.33	11.81	27.16	26.57
Na ₂ O	0.00	0.10	0.10	0.23	0.10	0.04	0.01	0.02	0.02	0.01	0.04
K ₂ O	0.41	0.34	0.13	0.02	0.12	0.06	0.04	0.23	0.98	0.14	0.30
P ₂ O ₅	0.04	0.17	0.11	0.12	0.09	0.10	0.08	1.42	0.14	0.12	0.10
Total	100.46	74.70	73.97	65.70	77.51	69.07	77.61	82.30	99.98	99.84	77.80
LOI	3.56	24.87	25.24	32.23	22.41	29.33	21.88	18.71	10.77	16.68	22.12

Trace elements in ppm											
Ba	113	243	22	30	18	28	18	72	107	49	39
Cr	71	63	43	9	42	33	36	76	329	26	33
Cu	5	8	2	7	7	7	3	4	8	2	3
Mo	1	2	1	1	<1	1	<1	<1	2	2	1
Ni	44	28	22	16	28	19	17	46	75	11	11
Pb	6	11	9	2	<2	4	15	12	14	10	7
Rb	14	12	8	8	10	4	4	12	33	7	11
S	1734	1891	756	4846	2528	2919	649	704	1732	399	628
Sr	73	412	393	625	407	520	306	284	238	234	314
V	212	120	51	44	75	72	67	168	407	92	68
Zn	75	35	19	29	43	25	21	75	120	11	12
Zr	105	63	69	65	130	90	70	112	241	59	181

Sample No. Facies	RK46 F3	RK15 F4	RK25 F4	RK26 F4	RK27 F4	RK28 F4	RK30 F4	RG4 F4	RG5 F4	RG6 F4	RG32 F4
Major elements (%)											
SiO ₂	68.53	7.64	25.42	9.05	31.94	30.83	31.11	9.67	4.89	2.19	0.29
TiO ₂	0.32	0.07	0.11	0.06	0.12	0.25	0.34	0.02	0.01	0.02	0.00
Al ₂ O ₃	3.36	0.81	1.04	0.28	0.97	1.69	2.24	0.66	0.56	0.68	0.20
Fe ₂ O ₃	9.14	4.30	4.93	3.75	3.67	5.89	4.73	0.99	0.74	1.17	0.06
MnO	0.36	0.32	0.23	0.21	0.23	0.30	0.26	0.01	0.01	0.01	0.01
MgO	1.09	2.82	1.00	1.98	1.37	1.56	1.87	0.91	0.83	1.37	0.95
CaO	17.65	45.99	34.66	46.26	31.71	30.88	30.18	47.79	50.94	51.66	53.86
Na ₂ O	0.01	0.20	0.04	0.22	0.05	0.05	0.01	0.21	0.24	0.23	0.20
K ₂ O	0.20	0.08	0.07	0.05	0.06	0.07	0.15	0.12	0.10	0.14	0.01
P ₂ O ₅	0.14	0.14	0.13	0.13	0.63	0.09	0.06	0.04	0.09	0.06	0.03
Total	100.80	62.36	67.63	62.00	70.75	71.61	70.95	60.42	58.41	57.53	55.61
LOI	13.74	37.83	30.41	36.99	27.53	27.33	27.88	38.38	40.55	41.13	43.22

Trace elements in ppm											
Ba	150	51	57	12	<8	29	15	<8	<8	<8	<8
Cr	55	<3	33	26	41	40	78	51	45	72	<3
Cu	3	10	3	<1	1	3	30	4	6	<1	2
Mo	2	<1	2	<1	<1	<1	2	1	1	<1	2
Ni	41	12	14	13	8	18	29	19	17	8	<2
Pb	12	<2	7	7	7	9	11	6	11	10	4
Rb	8	9	7	4	5	7	9	8	7	10	6
S	1296	2611	708	875	986	1003	1470	1128	678	443	461
Sr	194	462	598	729	643	423	447	470	324	525	343
V	124	35	66	47	49	69	58	55	35	48	20
Zn	75	15	17	13	14	37	43	31	19	33	4
Zr	101	42	45	38	56	122	225	16	18	13	12

Table. 7.1 (contd.)

Sample No. Facies	RG7 F5	RG8 F5	RG10 F5	RG11 F5	RG12 F5	RG13 F5	RG14 F5	RG15 F5	RG18 F5	RG19 F5	RG20 F5
Major elements (%)											
SiO ₂	0.73	0.27	0.61	0.25	0.26	0.28	0.26	0.27	0.42	0.27	0.27
TiO ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al ₂ O ₃	0.35	0.19	0.31	0.18	0.19	0.18	0.19	0.19	0.26	0.21	0.19
Fe ₂ O ₃	0.32	0.09	0.13	0.06	0.07	0.05	0.04	0.02	0.07	0.06	0.12
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	1.07	1.15	0.95	1.09	0.94	0.81	0.80	0.86	0.83	0.91	1.08
CaO	54.27	55.13	54.98	55.18	55.31	55.64	55.40	55.53	55.33	55.35	54.92
Na ₂ O	0.18	0.21	0.20	0.19	0.20	0.25	0.21	0.25	0.22	0.22	0.22
K ₂ O	0.05	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01
P ₂ O ₅	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.10	0.03
Total	57.01	57.08	57.24	56.99	57.02	57.25	56.94	57.16	57.18	57.14	56.84
LOI	43.33	43.66	43.29	43.35	43.05	42.93	42.98	42.96	42.19	43.17	43.06

Trace elements in ppm

Ba	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8
Cr	13	<3	3	8	7	5	4	4	12	14	7
Cu	2	4	3	5	2	6	<1	2	3	5	6
Mo	1	2	<1	1	2	1	<1	1	<1	1	1
Ni	<2	<2	<2	3	<2	<2	<2	<2	4	<2	10
Pb	9	2	10	4	7	<2	7	4	13	<2	5
Rb	6	5	7	7	6	6	7	6	9	6	6
S	645	429	420	644	536	270	237	534	351	617	327
Sr	380	391	328	343	300	306	319	333	307	259	264
V	17	9	14	9	7	9	9	13	17	15	9
Zn	8	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Zr	13	13	16	7	4	14	7	15	15	12	7

Sample No. Facies	RG22 F5	RG23 F5	RG24 F5	RG25 F5	RG26 F5	RG29 F5	RG30 F5	RG31 F5	RG33 F5	RG34 F5	RG37 F5
Major elements (%)											
SiO ₂	0.39	0.41	0.49	0.62	0.34	0.38	0.50	0.39	0.52	0.49	0.27
TiO ₂	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Al ₂ O ₃	0.25	0.28	0.31	0.39	0.24	0.29	0.34	0.27	0.35	0.35	0.18
Fe ₂ O ₃	0.11	0.11	0.11	0.18	0.07	0.11	0.12	0.06	0.17	0.17	0.04
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	0.85	0.77	0.80	1.08	0.96	1.00	1.15	0.85	1.16	1.37	1.00
CaO	55.33	55.26	54.91	54.31	55.03	53.94	53.72	54.28	53.71	53.52	54.19
Na ₂ O	0.21	0.18	0.17	0.23	0.23	0.20	0.17	0.19	0.21	0.21	0.22
K ₂ O	0.02	0.02	0.03	0.05	0.02	0.02	0.03	0.02	0.04	0.04	0.01
P ₂ O ₅	0.02	0.06	0.03	0.10	0.03	0.05	0.10	0.03	0.06	0.04	0.04
Total	57.18	57.11	56.87	56.98	56.93	56.00	56.14	56.10	56.23	56.21	55.95
LOI	43.26	43.20	43.08	43.30	43.08	43.22	43.15	43.06	43.24	43.32	43.37

Trace elements in ppm

Ba	<8	<8	<8	<8	<8	<8	<8	<8	12	<8	<8
Cr	7	<3	6	8	<3	8	5	3	<3	5	3
Cu	4	3	3	4	3	3	4	8	3	2	1
Mo	<1	<1	1	2	<1	1	<1	<1	3	1	<1
Ni	4	8	3	2	<2	3	8	<2	3	3	<2
Pb	6	5	6	13	8	9	10	5	8	5	10
Rb	6	6	6	10	7	5	7	8	6	7	7
S	286	890	277	993	531	433	553	302	781	547	262
Sr	301	270	259	350	325	357	383	312	349	346	290
V	10	15	15	16	11	17	19	24	15	15	9
Zn	<3	<3	<3	5	<3	<3	<3	<3	<3	<3	<3
Zr	13	9	5	6	5	9	10	11	6	13	6

Table. 7.1 (contd.)

Sample No. Facies	RG38 F5	RG41 F5	RG42 F5	RG43 F5	RG44 F5	RG45 F5	RG46 F5	RG16 F6	RG17 F6	RG21 F6	RG27 F6
Major elements (%)											
SiO ₂	0.23	0.29	0.40	0.33	0.90	0.72	0.65	0.26	0.34	0.31	0.45
TiO ₂	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Al ₂ O ₃	0.17	0.22	0.27	0.23	0.57	0.45	0.26	0.19	0.22	0.21	0.27
Fe ₂ O ₃	0.03	0.06	0.06	0.04	0.19	0.32	0.25	0.01	0.07	0.06	0.12
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01
MgO	0.84	1.32	1.24	1.08	1.28	1.39	1.25	2.59	0.84	0.79	0.84
CaO	54.32	53.99	53.95	53.90	53.12	53.28	53.37	53.59	55.23	55.45	54.96
Na ₂ O	0.28	0.18	0.26	0.22	0.21	0.31	0.22	0.21	0.23	0.24	0.22
K ₂ O	0.01	0.01	0.02	0.01	0.09	0.03	0.02	0.01	0.02	0.02	0.03
P ₂ O ₅	0.02	0.04	0.04	0.03	0.06	0.07	0.13	0.02	0.03	0.05	0.05
Total	55.91	56.12	56.24	55.85	56.44	56.59	56.16	56.89	56.98	57.13	56.94
LOI	43.37	43.59	43.68	43.64	43.18	53.37	43.39	43.15	42.95	43.19	43.02

Trace elements in ppm

Ba	<8	<8	<8	<8	15	<8	<8	<8	<8	<8	<8
Cr	3	3	8	5	13	10	3	8	8	8	<3
Cu	1	4	5	2	3	6	2	3	3	4	3
Mo	<1	<1	2	1	1	1	1	3	3	<1	<1
Ni	<2	<2	<2	<2	6	5	<2	<2	3	<2	<2
Pb	9	<2	5	3	2	3	3	2	5	<2	8
Rb	5	6	6	5	8	6	7	7	5	8	6
S	292	529	526	496	947	795	932	481	410	294	516
Sr	225	314	308	280	307	285	315	319	317	299	304
V	9	8	14	9	14	14	9	13	12	6	19
Zn	<3	<3	<3	<3	<3	17	<3	<3	<3	<3	3
Zr	4	9	6	10	14	8	3	7	4	13	5

Sample No. Facies	RG35 F6	RG36 F6	RG36A F6	RG39 F6	RG40 F6	ZP10 F6	ZP13 F6	ZP15 F6	ZP18 F6	ZP23 F6	ZP25 F6
Major elements (%)											
SiO ₂	0.58	0.48	0.46	0.32	0.34	2.22	2.25	2.87	2.01	2.67	2.55
TiO ₂	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.02	0.03	0.04
Al ₂ O ₃	0.37	0.31	0.29	0.23	0.24	0.57	0.72	0.43	0.55	0.94	1.05
Fe ₂ O ₃	0.16	0.12	0.12	0.06	0.06	0.63	0.51	0.68	0.72	0.81	0.90
MnO	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
MgO	1.15	1.66	1.40	1.00	1.38	1.26	1.33	1.31	1.40	1.20	1.16
CaO	53.86	53.44	53.73	54.05	53.80	52.46	53.12	53.24	52.72	52.61	52.33
Na ₂ O	0.24	0.25	0.27	0.26	0.25	0.24	0.23	0.22	0.24	0.21	0.19
K ₂ O	0.04	0.03	0.02	0.01	0.02	0.05	0.07	0.03	0.05	0.09	0.10
P ₂ O ₅	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.06	0.06
Total	56.45	56.34	56.34	55.97	56.12	57.50	58.31	58.84	57.76	58.64	58.39
LOI	43.21	43.49	43.32	43.18	43.35	42.22	41.86	41.69	42.31	41.71	41.6

Trace elements in ppm

Ba	16	<8	<8	<8	9	<8	<8	<8	<8	<8	<8
Cr	11	9	5	5	5	7	<3	5	4	11	10
Cu	4	6	5	3	2	6	7	14	5	5	6
Mo	<1	2	1	<1	2	2	1	2	2	<1	<1
Ni	2	4	<2	<2	<2	2	6	29	3	5	5
Pb	4	4	5	9	<2	7	3	6	8	7	6
Rb	7	6	6	7	4	6	5	5	7	9	8
S	636	841	695	570	518	2408	4700	2751	2858	1978	3222
Sr	330	354	334	311	294	774	428	827	605	640	628
V	19	16	20	12	7	11	14	11	18	13	18
Zn	<3	3	<3	<3	<3	<3	<3	<3	<3	<3	11
Zr	5	11	9	18	14	17	13	11	17	16	13

Table. 7.1 (contd.)

Sample No. Facies	ZP26 F6	ZP27 F6	ZP31 F6	ZP32 F6	ZP33 F6	ZP35 F6	ZP52 F6	ZP53 F6	ZP55 F6	ZP9 F7	ZP19 F7
Major elements (%)											
SiO ₂	3.87	3.06	4.40	3.41	4.69	3.83	2.81	1.17	1.10	1.61	5.86
TiO ₂	0.08	0.08	0.14	0.12	0.20	0.15	0.02	0.00	0.01	0.02	0.08
Al ₂ O ₃	1.90	1.73	2.91	2.37	3.50	2.85	0.75	0.28	0.34	0.70	3.89
Fe ₂ O ₃	1.54	1.18	1.58	1.81	1.89	1.68	0.70	0.24	0.23	0.57	2.37
MnO	0.02	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.03	0.02	0.02
MgO	1.36	1.47	1.37	1.81	1.39	1.54	1.32	1.18	1.11	1.30	1.68
CaO	50.41	51.24	49.87	49.96	48.78	49.60	51.13	53.53	53.64	52.77	46.69
Na ₂ O	0.23	0.24	0.29	0.26	0.27	0.26	0.21	0.23	0.19	0.29	0.25
K ₂ O	0.23	0.16	0.27	0.15	0.14	0.11	0.17	0.01	0.01	0.07	0.30
P ₂ O ₅	0.15	0.20	0.26	0.13	0.18	0.11	0.12	0.04	0.02	0.03	0.64
Total	59.79	59.39	61.11	60.05	61.07	60.16	57.24	56.69	56.67	57.38	61.77
LOI	39.81	40.86	38.48	39.41	38.56	39.64	41.36	43.14	43.07	42.90	36.49

Trace elements in ppm

Ba	9	<8	31	75	211	13	49	19	25	<8	<8
Cr	24	18	30	33	34	35	39	<3	15	6	39
Cu	5	6	7	7	3	5	6	3	4	3	7
Mo	<1	<1	1	2	<1	<1	3	2	3	1	1
Ni	16	6	23	19	30	22	11	<2	6	<2	20
Pb	4	2	14	2	2	2	11	8	3	7	10
Rb	15	12	16	11	11	8	11	5	5	7	14
S	16162	10546	9726	4898	8776	3140	2349	1370	2793	2500	24374
Sr	657	553	614	633	649	741	534	833	685	728	792
V	31	30	59	52	62	59	20	9	28	14	44
Zn	28	24	39	19	29	28	14	<3	<3	<3	31
Zr	23	20	30	33	48	34	16	12	6	12	27

Sample No. Facies	ZP20 F7	ZP22 F7	ZP29 F7	ZP30 F7	ZP36 F7	ZP37 F7	ZP38 F7	ZP39 F7	ZP40 F7	ZP51 F7	ZP54 F7
Major elements (%)											
SiO ₂	5.08	4.18	5.61	5.36	4.00	3.72	9.14	6.97	2.87	2.69	1.99
TiO ₂	0.13	0.10	0.14	0.19	0.13	0.13	0.32	0.13	0.03	0.02	0.04
Al ₂ O ₃	2.72	2.45	3.36	3.39	2.62	2.31	4.15	3.04	0.77	0.56	0.84
Fe ₂ O ₃	2.05	1.65	2.81	2.17	1.48	2.20	3.81	2.80	0.77	0.71	0.54
MnO	0.02	0.03	0.02	0.03	0.03	0.04	0.02	0.02	0.03	0.01	0.03
MgO	1.83	1.73	1.38	1.93	1.67	1.81	2.09	1.99	1.86	1.08	1.53
CaO	47.57	49.80	47.61	47.39	50.12	50.06	45.02	47.57	41.13	52.40	51.65
Na ₂ O	0.26	0.29	0.24	0.29	0.29	0.25	0.32	0.27	0.17	0.17	0.21
K ₂ O	0.36	0.25	0.28	0.25	0.12	0.11	0.24	0.40	0.07	0.03	0.09
P ₂ O ₅	0.22	0.64	0.17	0.19	0.22	0.08	0.28	0.22	0.05	0.05	0.06
Total	60.23	61.11	61.62	61.18	60.68	60.71	65.40	63.41	47.74	57.72	56.98
LOI	38.53	39.50	37.56	38.22	39.56	39.53	35.62	37.39	35.32	41.36	42.09

Trace elements in ppm

Ba	15	<8	20	26	68	82	35	<8	81	<8	16
Cr	40	31	65	39	35	32	77	78	26	<3	13
Cu	15	8	8	12	5	5	10	57	143	10	2
Mo	<1	<1	1	2	2	2	3	1	3	3	1
Ni	18	15	39	24	25	20	29	27	2	10	5
Pb	3	5	3	9	7	4	10	4	4	<2	8
Rb	19	15	18	14	6	9	13	19	<1	6	7
S	10994	8635	16105	15675	1895	2041	1539	2034	35770	18839	3498
Sr	894	894	628	573	663	592	834	670	682	952	600
V	49	56	90	64	63	51	108	73	25	28	19
Zn	41	36	57	27	21	19	48	65	41	11	20
Zr	35	30	33	41	34	30	72	37	20	13	18

Table. 7.1 (contd.)

Sample No. Facies	ZP7A F8	ZP11 F8	ZP12 F8	ZP17 Sh F8	ZP41 F8	ZP42 F8	ZP43 F8	ZP44 F8	ZP45 F8	ZP46 F8	ZP48 F8
Major elements (%)											
SiO ₂	14.20	13.65	14.74	31.39	7.43	5.85	3.56	7.16	5.16	2.62	7.32
TiO ₂	0.36	0.32	0.36	0.97	0.09	0.08	0.03	0.08	0.04	0.01	0.01
Al ₂ O ₃	5.66	4.71	5.41	15.04	1.72	1.62	0.82	1.66	1.15	0.53	0.57
Fe ₂ O ₃	3.27	3.46	3.17	6.50	1.00	0.86	0.55	1.10	0.53	0.58	0.30
MnO	0.04	0.04	0.02	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.01
MgO	2.22	2.33	3.04	2.50	1.46	1.39	1.23	1.66	1.25	1.26	0.98
CaO	39.18	41.29	39.84	20.64	47.25	48.56	51.30	46.96	49.87	52.01	49.19
Na ₂ O	0.38	0.50	0.54	0.41	0.27	0.24	0.24	0.26	0.29	0.27	0.25
K ₂ O	0.69	0.54	0.68	1.66	0.16	0.13	0.07	0.14	0.08	0.05	0.06
P ₂ O ₅	0.08	0.08	0.09	0.16	0.11	0.13	0.09	0.11	0.10	0.38	0.15
Total	66.08	66.92	67.89	79.29	59.50	58.88	57.91	59.14	58.47	57.72	58.83
LOI	31.77	31.82	31.04	20.77	37.84	38.75	40.66	38.17	40.01	41.08	39.27

Trace elements in ppm

Ba	44	34	28	<8	9	18	14	52	<8	<8
Cr	45	57	61	32	30	16	31	25	<3	<3
Cu	7	6	11	10	12	5	6	10	9	7
Mo	2	2	<1	2	3	2	2	2	11	2
Ni	28	27	25	14	16	9	19	22	12	14
Pb	10	14	9	17	6	11	7	3	3	2
Rb	29	24	27	10	11	8	10	7	9	7
S	6116	15184	10298	8871	10339	11622	7331	4868	20857	8731
Sr	714	699	863	752	766	730	903	874	622	857
V	60	64	74	25	29	15	33	32	28	23
Zn	38	36	37	20	28	9	21	34	21	21
Zr	74	66	69	26	20	13	20	12	<3	12

Sample No. Facies	ZP49 F8	ZP50 F8
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Major elements (%)

SiO ₂	6.20	4.15
TiO ₂	0.02	0.02
Al ₂ O ₃	0.55	0.53
Fe ₂ O ₃	0.21	0.31
MnO	0.01	0.01
MgO	1.00	1.00
CaO	50.34	51.50
Na ₂ O	0.21	0.20
K ₂ O	0.04	0.04
P ₂ O ₅	0.04	0.04
Total	58.62	57.80
LOI	39.90	40.83

Trace elements in ppm

Ba	<8	10
Cr	<3	<3
Cu	9	7
Mo	2	2
Ni	8	9
Pb	<2	<2
Rb	7	10
S	7075	17175
Sr	869	864
V	7	18
Zn	10	11
Zr	12	12

by hand drill, and eight were of the veins present in the rock also picked by hand drill. The stable carbon and oxygen isotope values obtained are given in Table 7.6. The details of procedure are described in appendix 6.

7.4. Results and Interpretation:-

7.4.1. Whole Rock Mineralogy:-

More than 50 randomly oriented samples were analysed by XRD method for qualitative identification of minerals present in Dungan Formation. The minerals were identified from the tables given in International Centre for Diffraction Data (ICDD). Some representative traces are presented in Figure 7.2. The whole rock mineralogy of Dungan Formation is described by facies type.

In the inner ramp facies the minerals are quartz, calcite and clay minerals, in the middle ramp facies the mineral present is the calcite, and in the outer ramp facies the minerals are calcite and clay minerals. It is clear that the inner ramp facies are close to the shore and the quartz grains are transported from shore line to the depositional area. The middle ramp facies are pure limestone, and these facies represent the main “carbonate factory”. This limestone has mainly skeletal allochems of algae and benthonic foraminifera. The outer ramp facies are the deep water facies which are slightly argillaceous, so they show the presence of clay minerals with calcite.

7.4.2. Residual Mineralogy:-

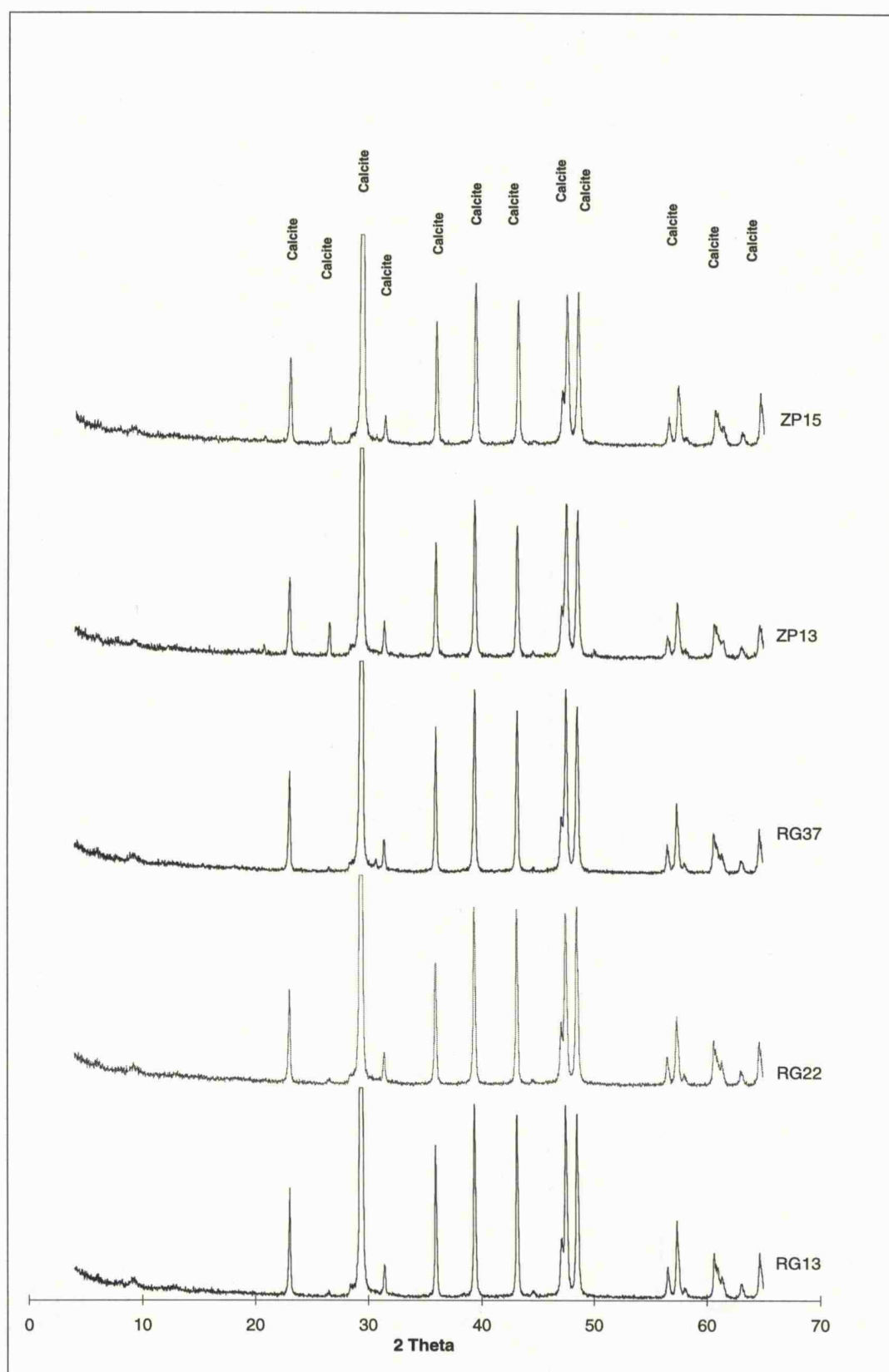


Fig. 7.2. XRD representative traces of some selected samples of Dungan Formation. All peaks are of calcite.

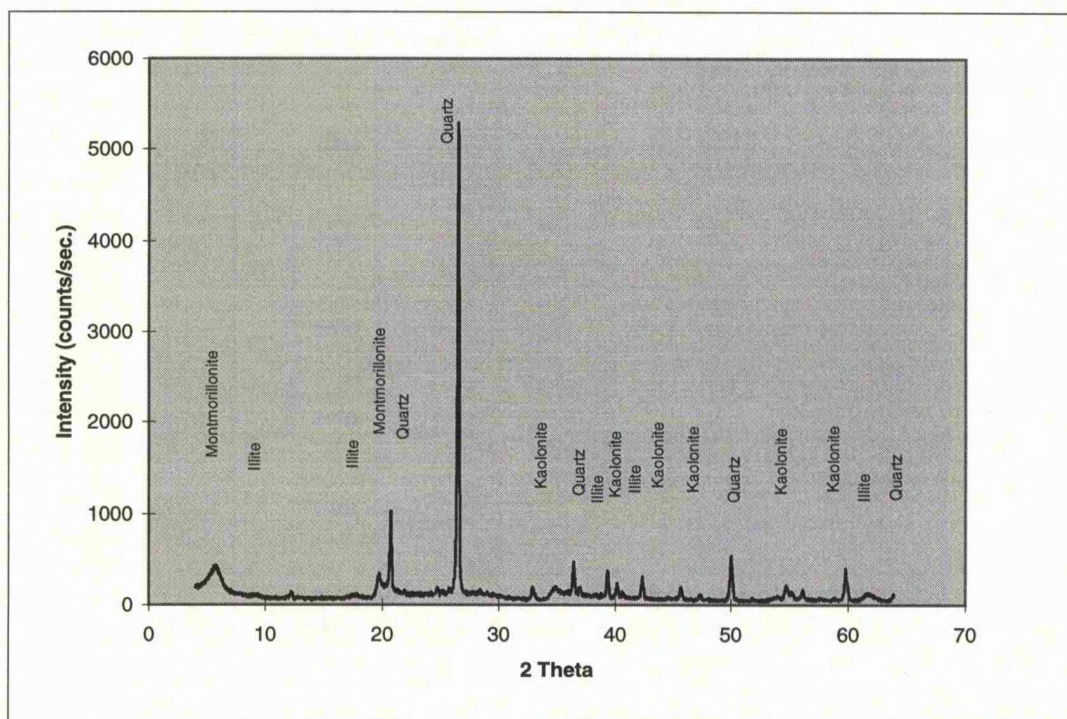


Fig. 7.3A. XRD trace of the residue sample, showing the concentration of clay minerals and quartz (sample ZP 45).

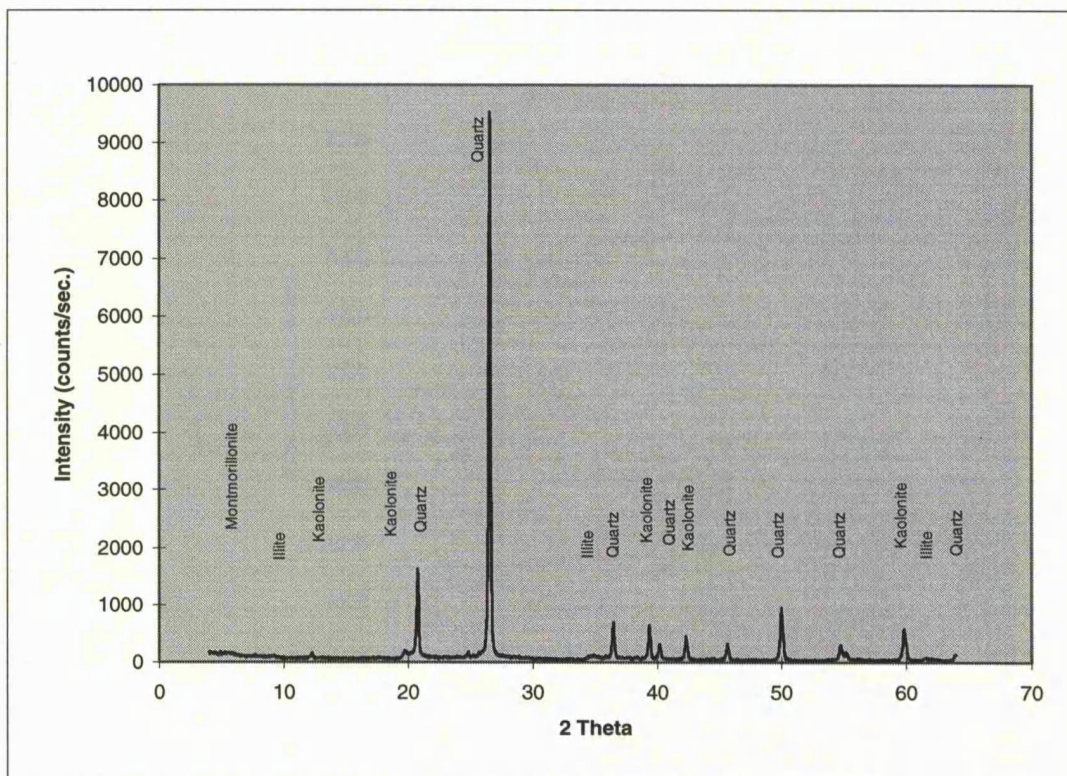


Fig. 7.3B. XRD trace of the residue sample showing the concentration of clay minerals and quartz, (sample ZP 50).

Nine samples which are the representative of facies 4, 7, and 8 are dissolved in 10% HCl to remove the carbonate. When the samples are free from carbonates, they are washed and dried overnight at 100 °C. These samples are analysed using XRD techniques. Similar to whole rock mineralogy, the residue confirms the presence of clay minerals (kaolinite, montmorillonite, and illite) in carbonates. Representative traces are shown in Figures 7.3 A & B.

7.4.3. Mineral Chemistry:-

Two calcium carbonate minerals aragonite and calcite predominate in modern carbonate sediments. Two types of calcite are recognised depending on magnesium content; low magnesium calcite, having less than 4 mole% MgCO_3 , and high magnesium calcite having more than 4 mole% MgCO_3 . The mineralogy of a modern carbonate sediment depends largely on the skeletal grains present in the sediments. The carbonate skeletons of organisms have a specific mineralogy or a mixture of mineralogies. The original mineralogy of the skeletal grains present in Dungan Formation is mainly high-Mg calcitic as shown in Figure 7.4, although the actual magnesium content of the calcite may vary, being partly dependent on water temperature. Since aragonite is metastable and in time high-Mg calcite loses its magnesium, all carbonate sediments are eventually converted to low-Mg calcite.

The mean values of oxides of Ca, Mg, Fe, Mn, Sr, and Ba of the skeletal allochems, and cement of Dungan Formation is listed in Table 7.2. The probe data shows the average mole% MgCO_3 of coralline algae, 2.01; bryozoa, 2.25; coral, 0.89; echinoids,

Organisms	Mineralogy			
	Aragonite	Low Mg-Calcite	High Mg-Calcite	Aragonite + Calcite
Calcareous Algae				
Red Algae			×	
Foraminifera				
Benthonic	○		×	
Planktonic		×		
Corals				
Scleractinian	×			
Bryozoa	○		×	○
Molluscs				
Bivalves	×	×		×
Gastropods	×			○
Echinoderms			×	

(After Tucker, 1981)

× = Common

○ = Rare

Fig.7.4. The mineralogy of modern carbonate skeleton grains. (During diagenesis, the mineralogy may be altered or replaced; in particular, aragonite is metastable and is invariably replaced by calcite, and in time, high Mg-calcite loses its Mg.

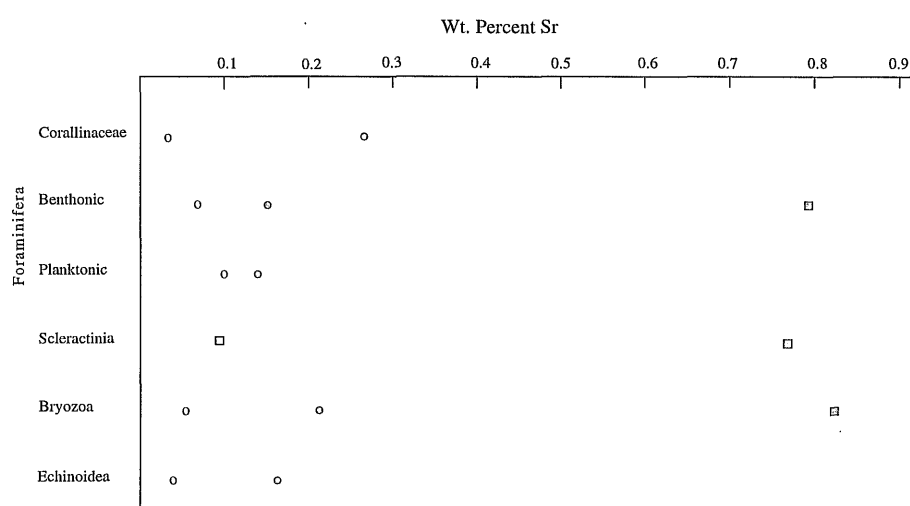


Fig.7.5A. Average Sr content in the various marine carbonate components. Solid squares represent values from aragonitic carbonates; solid circles, calcite and magnesian calcite, (Data from Milliman, 1974), and open squares represent present studied values from aragonitic carbonates; open circles, calcite and magnesium calcite.

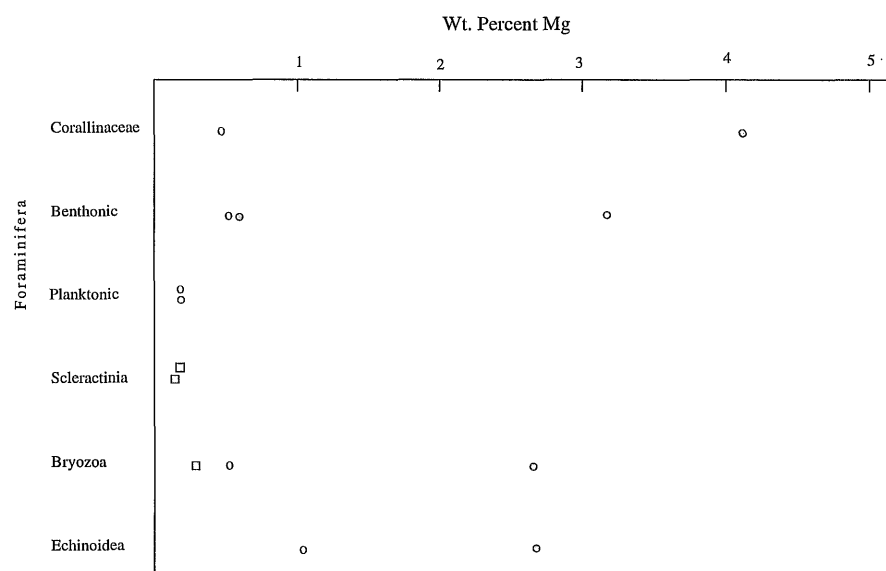


Fig.7.5B. Average Mg content in the various marine carbonate components. Solid squares represent values from aragonitic carbonates; solid circles, calcite and magnesian calcite, (Data from Milliman, 1974), and open squares represent present studied values from aragonitic carbonates; open circles, calcite and magnesium calcite.

4.34; benthonic foraminifera (non-ferroan), 2.08; benthonic foraminifera (ferroan), 2.37; and planktonic foraminifera 0.90.

Coralline algae are thought to be totally high magnesium calcite (Vinogradov, 1953; Goldsmith and others 1955; Thompson and Chow, 1956; Schmalz 1965; Keith and Weber 1965; and many others). Chave (1954) has done a lot of work on recent coralline algae of different areas and he found the wt. percentage of MgCO_3 from 8.0 to 21.0 at different water temperature ranges from 5.2 to 28.0 °C, the content of MgCO_3 increasing with temperature. The calcitic forms of calcareous algae such as *Lithothamnium* and *Lithophyllum*, contain a wide range of magnesium values, extending from 7.0 to almost 30.0 percent magnesium carbonate. As described in chapter five, the calcareous algae dominantly present in Dungan sediments are *Lithothamnium*, *Lithophyllum* and *Archaeolithothamnium*. Originally they were deposited as high magnesium calcitic and after diagenetic processes they lose their magnesium content and become stable at 2.0 mole% of MgCO_3 . The recent foraminiferal sediments collected at different localities show MgCO_3 from 0.33 to 16.0 at different water temperature ranges from 0 to 28 °C (Chave, 1955). From Bermuda eleven foraminifera were analysed and found to contain a range of magnesium carbonate from 10.8 to 15.2 percent. The benthonic foraminifera of Dungan Formation were originally high magnesium calcitic as shown by the recent foraminiferal sediment, but after diagenesis they lose their magnesium content and become stable at 2.2 mole% of magnesium carbonate. In the echinoids the magnesium contents of both the tests and the spines are different. The recent sediments of echinoids from Florida has a test with 10.2 percent magnesium carbonate and a spine with a very close 10.9 percent of magnesium carbonate. In the Dungan Formation the same is assumed, the echinoids

Table 7.2. Mean values of different carbonate grains present in Dungan Formation analysed by electron microprobe.

Grain No. of analyses	Algae 13	Bryozoa 6	Coral 3	Ech 19	F 24	FF 25	F(PL) 1
CaO	54.87	53.94	54.5	53.55	54.85	53.83	55.15
MgO	0.81	0.89	0.35	1.75	0.84	0.94	0.36
FeO	0.29	0.57	0.79	0.32	0.16	0.96	0.03
MnO	0.08	0.35	0.19	0.17	0.02	0.15	0.02
SrO	0.04	0.06	0.11	0.05	0.07	0.1	0.14
BaO	0.09	0.16	0.1	0.12	0.1	0.11	0.05
Total	56.18	55.97	56.03	55.96	56.05	56.09	55.74
CaCO ₃ %	97.93	96.26	97.26	95.58	97.9	96.08	98.42
MgCO ₃ %	1.69	1.87	0.74	3.66	1.75	1.97	0.75
Mol%MgCO ₃	2.01	2.25	0.89	4.34	2.08	2.37	0.9

Grain No. of analyses	C 207	CF 198	V 47	VF 43	Micrite 8
CaO	55.38	53.72	55.68	54.86	54.49
MgO	0.49	0.75	0.37	0.57	0.73
FeO	0.11	1.08	0.05	0.68	0.19
MnO	0.04	0.25	0.03	0.03	0.02
SrO	0.08	0.08	0.14	0.09	0.06
BaO	0.11	0.1	0.09	0.11	0.19
Total	56.2	55.97	56.36	56.35	55.69
CaCO ₃ %	98.84	95.87	99.38	97.92	97.25
MgCO ₃ %	1.02	1.56	0.76	1.2	1.52
Mol%MgCO ₃	1.21	1.9	0.9	1.43	1.83

$\text{CaCO}_3\% = \text{CaO} \times 100.09 / 56.08$; $\text{MgCO}_3\% = \text{MgO} \times 84.32 / 40.31$
 $\text{Mol\% MgCO}_3 = \text{Mol.MgCO}_3 \times 100 / (\text{Mol.CaCO}_3 + \text{Mol.MgCO}_3)$
 Ech=Echinoderm; C=Drusy Cement;
 F=Foraminifera; FF=Ferroan Foraminifera
 V=Veins; VF=Ferroan Veins.

CF=Ferroan Drusy Cement
 F(PL)=PlanktonicForaminifera

are originally deposited as high magnesium calcitic grains, and later on after diagenesis they lose their magnesium content and become stable at 4.34 mole% of magnesium carbonate. Due to the dense structure of echinoids they lose less magnesium as compared to algae. The bryozoa consists of calcite, aragonite or a mixture of the two, preliminary investigations indicate that the magnesium content of the calcite is above 4 percent. The bryozoa skeletal grains of Dungan Formation were originally of high magnesium calcitic which after diagenesis become stable at 2.25 mole% of MgCO_3 .

In summary all these skeletal grains are originally of high magnesium calcitic, after diagenesis (fresh water) they lose their magnesium content (Stehli and Hower, 1961), which established the new equilibrium with the fresh water and the drusy cement (non-ferroan) is formed with 1.2 mole% of MgCO_3 , and ferroan drusy cement with 1.90 mole% of MgCO_3 . The skeletal grains become stable at the present mole percentage of magnesium carbonate. From the data it is noted that the ferroan skeletal allochems, ferroan cement and ferroan veins have more mole% of MgCO_3 as compared to that of non-ferroan. It is similar to the findings of (Richter and Fuchtbauer, 1978), that the organisms having a skeleton originally of high magnesium calcite become ferroan during diagenesis, and the low magnesium calcite skeletons do not.

7.5. Whole Rock Geochemistry:-

The elements selected for study include magnesium, strontium, manganese, and iron. They have been chosen because of their ability to substitute for calcium in the carbonate lattice and their expected variability with mineralogical changes. Magnesium and strontium are common elements in the metastable carbonate minerals, magnesium

in Mg-calcite and strontium in aragonite and Mg-calcite. Hence these elements can be used as geochemical indicators of diagenetic trends.

Stehli and Hower (1961) studied the effects of diagenesis on the distribution of magnesium, strontium, barium, and manganese in Florida carbonates. They compared recent carbonate sediments in Florida with Pleistocene rocks from the same area. They found a reduction in the abundance of these elements from the recent to the Pleistocene.

Carbon and oxygen stable isotopes form the key to an understanding of the diagenetic sequence (Hudson, 1977 and many others). The stable isotopes indicate the effect of marine or freshwater alterations in the sediments, (Gross, 1964; Friedman, 1964).

7.6. Results and Interpretation:-

7.6.1. Major Elements Geochemistry:-

The whole rock chemical analyses by XRF are presented in Table 7.1. The mean, standard deviation, maximum and minimum of these analyses are presented by facies in Table 7.3. The major element oxides are reported on a 100% anhydrous basis and are in weight percent. Trace elements are given in parts per million.

Graf (1960) classifies the concentration of trace elements found in carbonate rocks as a function of the amount in solid solution in the carbonate minerals and of the kinds and amounts of detrital minerals present. A somewhat broader genetic classification of sedimentary rocks made by Krynine (1948) may considerably simplified the classification of trace elements in such rocks as a mixture of material carried in the basin of deposition in the solid state (detrital) and material entering the basin of

Table. 7.3. Mean, standard deviation, maximum and minimum values of major elements in different facies obtained by XRF analyses, with calculated Ca/Mg ratio.

Facies n	1 9 Mean	1 9 Std.	1 9 Max.	1 9 Min.	2 14 Mean	2 14 Std.	2 14 Max.	2 14 Min.	3 11 Mean	3 11 Std.	3 11 Max.	3 11 Min.
SiO ₂	85.41	3.47	89.43	81.12	63.96	15.95	82.78	37.72	43.67	14.54	68.53	18.09
TiO ₂	0.29	0.11	0.48	0.17	0.3	0.22	0.89	0.12	0.26	0.2	0.81	0.11
Al ₂ O ₃	3.85	1.98	8.39	2.03	2.67	1.83	6.83	0.95	2.42	1.85	7.42	0.97
Fe ₂ O ₃	5.82	1.74	8.96	3.62	6.72	3.01	12.35	1.58	7.36	4.81	19.65	2.75
MnO	0.37	0.27	0.8	0.09	0.32	0.17	0.64	0.05	0.37	0.15	0.77	0.24
MgO	0.82	0.22	1.2	0.56	1.44	1.24	5.6	0.57	1.24	0.3	1.76	0.89
CaO	2.92	2.27	6.89	0.58	15.46	9.46	27.29	0.13	25.9	7.63	40.48	11.81
Na ₂ O	0.02	0.04	0.11	0	0.05	0.08	0.21	-0.02	0.06	0.07	0.23	0.01
K ₂ O	0.29	0.25	0.9	0.11	0.26	0.18	0.67	0.04	0.23	0.27	0.98	0.02
P ₂ O ₅	0.05	0.02	0.1	0.03	0.16	0.12	0.4	0.04	0.23	0.39	1.42	0.08
Ca/Mg ratio	2.59	2.02	6.12	0.63	10.2	8.01	24.29	0.07	15.59	5.04	23.12	4.77

Facies n	4 10 Mean	4 10 Std.	4 10 Max.	4 10 Min.	5 29 Mean	5 29 Std.	5 29 Max.	5 29 Min.	6 24 Mean	6 24 Std.	6 24 Max.	6 24 Min.
SiO ₂	15.3	12.93	31.94	0.29	0.42	0.17	0.9	0.23	1.94	1.47	4.69	0.26
TiO ₂	0.1	0.11	0.34	0	0	0	0.02	0	0.04	0.06	0.2	0
Al ₂ O ₃	0.91	0.63	2.24	0.2	0.27	0.09	0.57	0.17	0.97	1.01	3.5	0.19
Fe ₂ O ₃	3.02	2.08	5.89	0.06	0.11	0.08	0.32	0.02	0.66	0.63	1.89	0.01
MnO	0.16	0.13	0.32	0.01	0.01	0	0.02	0.01	0.02	0.01	0.03	0
MgO	1.47	0.62	2.82	0.83	1.03	0.19	1.39	0.77	1.33	0.36	2.59	0.79
CaO	42.39	9.45	53.86	30.18	54.52	0.77	55.64	53.12	52.61	1.84	55.45	48.78
Na ₂ O	0.15	0.09	0.24	0.01	0.22	0.03	0.31	0.17	0.24	0.02	0.29	0.19
K ₂ O	0.08	0.04	0.15	0.01	0.02	0.02	0.09	0.01	0.08	0.07	0.27	0.01
P ₂ O ₅	0.14	0.18	0.63	0.03	0.04	0.03	0.13	0.02	0.07	0.07	0.26	0.02
Ca/Mg ratio	24.3	12.28	43.64	11.48	38.88	7.25	51.03	27.26	30.13	8.39	49.91	14.71

Facies n	7 13 Mean	7 13 Std.	7 13 Max.	7 13 Min.	8 13 Mean	8 13 Std.	8 13 Max.	8 13 Min.
SiO ₂	4.54	2.11	9.14	1.61	9.49	7.72	31.39	2.62
TiO ₂	0.11	0.08	0.32	0.02	0.18	0.27	0.97	0.01
Al ₂ O ₃	2.37	1.26	4.15	0.56	3.07	4.07	15.04	0.53
Fe ₂ O ₃	1.84	1.01	3.81	0.54	1.68	1.88	6.5	0.21
MnO	0.02	0.01	0.04	0.01	0.02	0.01	0.04	0
MgO	1.68	0.29	2.09	1.08	1.64	0.67	3.04	0.98
CaO	48.44	3.21	52.77	41.13	45.23	8.61	52.01	20.64
Na ₂ O	0.25	0.05	0.32	0.17	0.31	0.11	0.54	0.2
K ₂ O	0.2	0.12	0.4	0.03	0.33	0.47	1.66	0.04
P ₂ O ₅	0.22	0.2	0.64	0.03	0.12	0.09	0.38	0.04
Ca/Mg ratio	21.32	5.5	34.5	15.32	23.37	10.53	36.62	5.87

Major elements values are in weight %.

n=No. of Samples Std.=Standard Deviation

deposition in solution (non-detrital). Hirst and Nicholls (1958) point out that many impure limestones can be considered to consist of two distinct fractions, an essentially carbonate fraction, such as CaCO_3 , of non-detrital origin, and a detrital fraction made up of essentially of silicates, clay minerals or quartz. The presence of trace elements indicate the presence of detrital minerals.

The chemical composition varies remarkably between the facies. The plots are drawn against the mean values of major oxides in %; and against the mean values of major oxides in % and the mean values of trace elements in ppm (Fig. 7.6 to 7.10) of different facies present in Dungan Formation. The peritidal facies (inner ramp) are rich in SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 and MnO . The plots of Al_2O_3 against K_2O (Fig. 7.6 A); SiO_2 against TiO_2 (Fig. 7.6 B); TiO_2 against Fe_2O_3 (Fig. 7.6 C); SiO_2 against MnO (Fig. 7.6 D), and others show strong correlation. The plot of Al_2O_3 against K_2O (Fig. 7.6 A) presumably show that K and Al are both present in clays and in feldspars. The plot (Fig. 7.6 B) of SiO_2 and TiO_2 indicate the presence of quartz sand content and the heavy minerals (such as rutile). The plot of TiO_2 and Fe_2O_3 (Fig. 7.6 C) indicate the presence of quartz and feldspars. The plot of SiO_2 and MnO (Fig. 7.6 D) also indicates the presence of quartz sand. The plot (Fig. 7.7 E) of Fe_2O_3 versus V indicates the presence of quartz and argillaceous limestone. The plot of Fe versus Mn (Fig. 7.7 F) indicates the presence of quartz. The plot (Fig. 7.7 G) of SiO_2 versus Ba indicates the presence of quartz and shale. The plot of Mg against Sr (Fig. 7.7 H) indicate the presence of argillaceous shale. The plot of SiO_2 against V (Fig. 7.8 I) indicates the presence of quartz. The plot (Fig. 7.8 J) of SiO_2 versus Cr indicates the presence of detrital and clay minerals. The plot of MnO versus V (Fig. 7.8 K) indicates the presence of quartz sand and argillaceous limestone. Similarly the plot of TiO_2

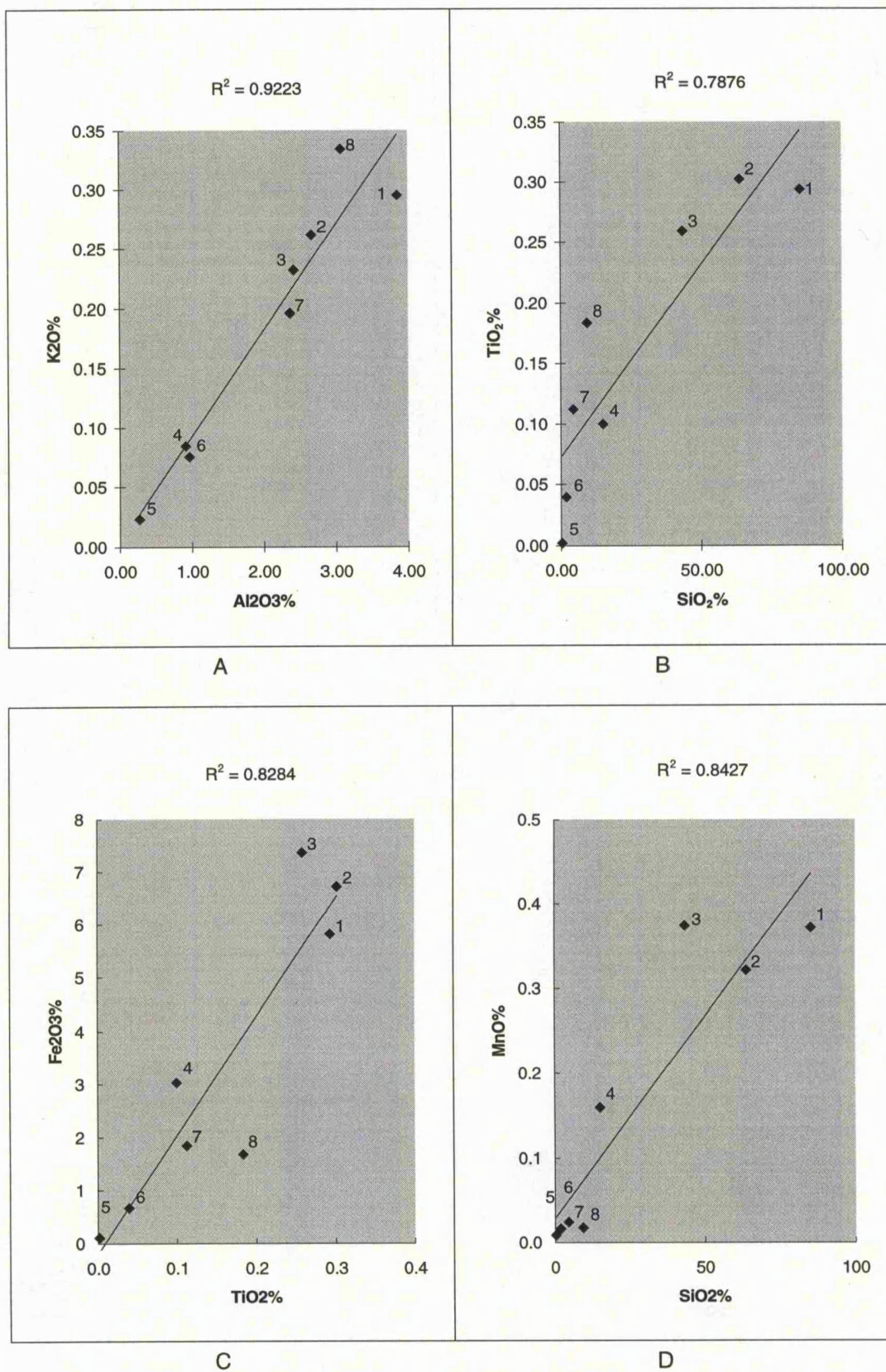


Fig. 7.6. Plots showing the relationship between the oxides of major elements in facies 1 to 8, present in Dungan Formation. A, between Al_2O_3 and K_2O ; B, between SiO_2 and TiO_2 ; C, between TiO_2 and Fe_2O_3 ; and D, between SiO_2 and MnO .

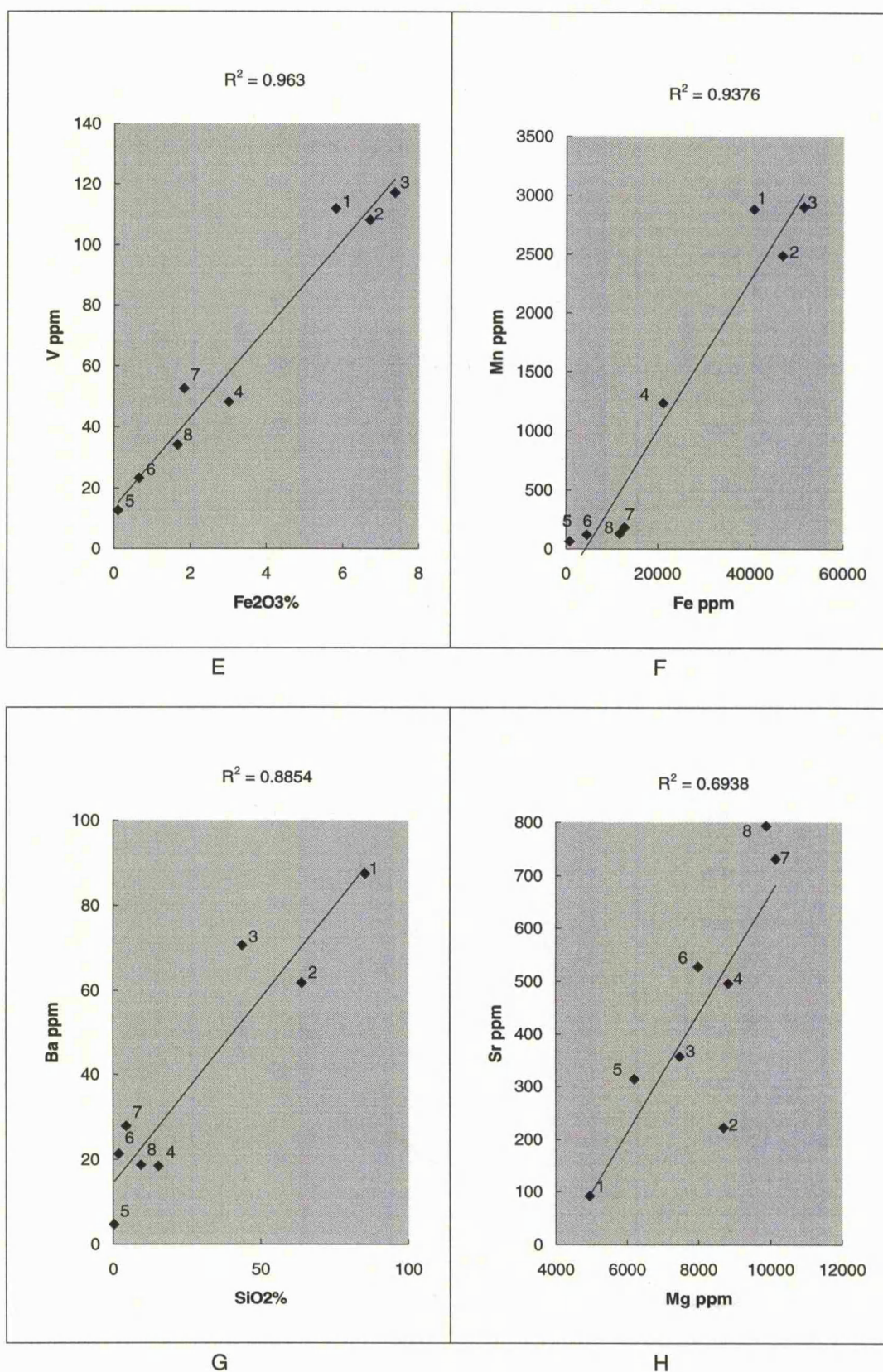


Fig. 7.7. Plots showing the relationship between the oxides of major elements in facies 1 to 8, present in Dungan Formation. E, between Fe₂O₃ and V; F, between Fe and Mn; G, between SiO₂ and Ba; and H, between Mg and Sr.

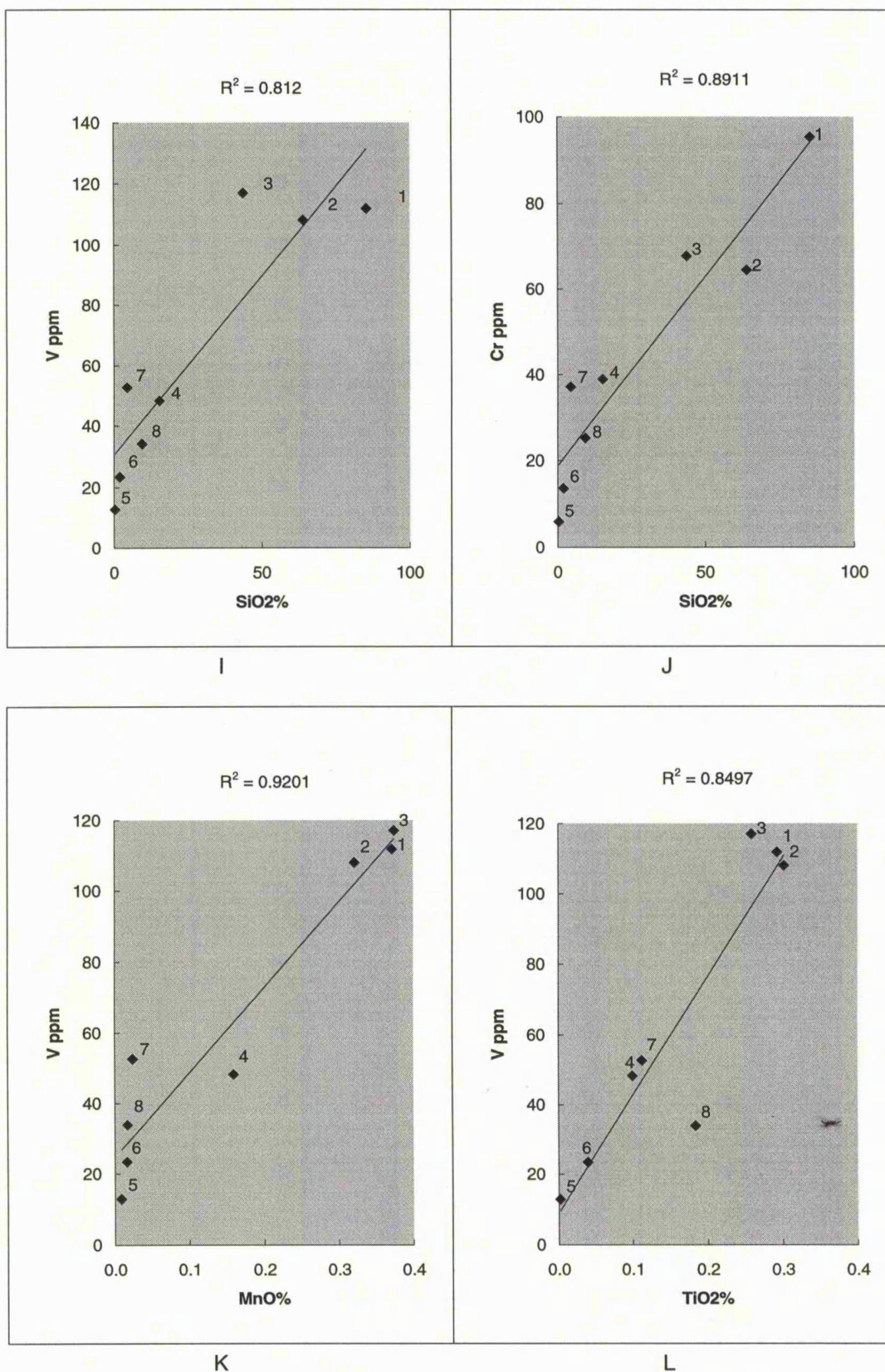


Fig. 7.8. Plots showing the relationship between the oxides of major and trace elements in facies 1 to 8, present in Dungan Formation. I, between SiO₂ and V; J, between SiO₂ and Cr; K, between MnO and V; and L, between TiO₂ and V.

versus V (Fig. 7.8 L) indicates the presence of heavy minerals (such as rutile) and the argillaceous limestone. These plots suggest, the inner ramp facies are rich in quartz, and low in carbonates and argillaceous material. It is also high in iron and manganese. The same observations are given by XRD. The middle ramp facies are low in SiO_2 , TiO_2 , and Al_2O_3 , and the outer ramp facies are low in TiO_2 but moderate in SiO_2 , Al_2O_3 and K_2O . The plot of Al_2O_3 against K_2O show the strong relation between them. The middle ramp facies are pure limestone, it is the main carbonate factory so they are poor in all these oxides. The outer ramp facies, which are deeper facies, are poor in TiO_2 , and moderate in SiO_2 , Al_2O_3 and K_2O . It suggests that outer ramp facies have more argillaceous than the inner and middle ramp facies, and very few detrital material. This observation is in agreement with XRD findings.

In summary the detrital material (quartz) is high in inner ramp facies, the middle ramp facies are the pure carbonate facies and the impurities are very low, and the outer ramp facies are the argillaceous carbonate.

Magnesium:-

Magnesium is sufficiently abundant in modern sediments (Fig. 7.5B) to be of major importance. Mineralogical and the trace element analyses show that the bulk of the magnesium is incorporated in high-Mg calcite, and a lesser amount in low-Mg calcite. From the conversion of high to low Mg-calcite, most of the magnesium is lost from the system. Early diagenesis reduces the magnesium level. The magnesium released by conversion of high-Mg calcite may ultimately contribute to dolomite formation, but it does not generally do so in the rocks in which it originates (Stehli and Hower, 1961). Three processes appear to be active in bringing the magnesium to an equilibrium state.

These are the removal of the magnesium from the fossils and deposition in the nearby matrix, i) as dolomite or some other magnesium mineral, ii) the reorganization of the material of the fossil to form two stable phases, low magnesium calcite and dolomite and, iii) the removal of magnesium from the rock by moving pore water.

Magnesium, originally deposited within the skeletons of living organisms, commonly remains within the rock throughout the processes of lithification and uplift. In many cases fossils of Cenozoic sediments contain magnesium still in its original form in solid solution with calcite (Chave, 1954a).

Clark and Wheeler (1922), Chave (1954b), Pilkey and Hower (1960), studied the magnesium distribution in carbonate rocks. These early studies involving distribution of calcite and magnesium in carbonate rock, investigated the role of their ratio in the precipitation of calcite and aragonite. This has been supported by other investigations which suggest a relationship between evaporite conditions and a low Ca/Mg ratio (Bordine 1965). The Ca/Mg ratio of carbonates corresponds to definite stability conditions during their formation and is thus of particular interest. Bordine (1965), showed an inverse relationship between Ca/Mg ratio and the insoluble material (clays and detrital sediments). In general if the Ca/Mg ratio is high, the residual material is low; and in low Ca/Mg ratio the residual material (clay and detrital material) is high (Bordine, 1965). The similar relationship is found in Dungan Formation. The distribution of Ca/Mg ratio in different facies of Dungan Formation is shown in Table 7.3. The mole% of MgCO_3 is high in inner ramp facies, low in middle ramp facies and moderate in outer ramp facies. In general magnesium content is considerably low in normal shallow marine conditions. In the inner ramp facies the mole% of MgCO_3 is high and the Ca/Mg ratio is low, which indicate more detrital material. In the middle

ramp facies the mole% of MgCO_3 is low and the Ca/Mg ratio is high, which indicates normal salinity and very few detrital materials. It is mainly the pure limestone. In the outer ramp facies the mole% of MgCO_3 is low and Ca/Mg ratio is moderate which indicates normal salinity conditions and slightly more residual material mainly clays than the middle ramp facies.

Iron and Manganese:-

Iron and manganese are generally present in low concentrations in sea waters, relative to fresh waters. Fresh water contain more soluble iron and manganese than does sea water (Friedman, 1969). The two elements tend to be picked up by carbonate precipitates during diagenesis. A plot of the concentration of Fe and Manganese present in facies 1 to 8 of Dungan Formation is made (Fig. 7.7 F). It shows a very strong correlation with a r^2 of 0.9376, as expected from the simple geochemistries of the two elements.

The trace element composition of freshwater cements found at shallow depths is controlled by the temperature, Eh, pH, and distribution co-efficients of precipitating waters. In well oxygenated ground waters ferric ions are common and thus iron is not incorporated into the cements (Evamy, 1969) and Manganese is precipitated preferentially to iron in near-surface oxygenated water (Meyers and Lahman, 1980), since Mn^{2+} is slightly more soluble in a wide range of Eh conditions than is Fe^{2+} (Garrels and Christ, 1965). Thus Mn^{2+} can occur in more oxidizing waters than Fe^{2+} leading to cements rich in Mn^{2+} but poor in Fe^{2+} . In waters from greater depths, oxygen is less common and in a reducing environment iron and manganese occur as divalent ions in solution which form ferroan and manganese-rich carbonate cements. In

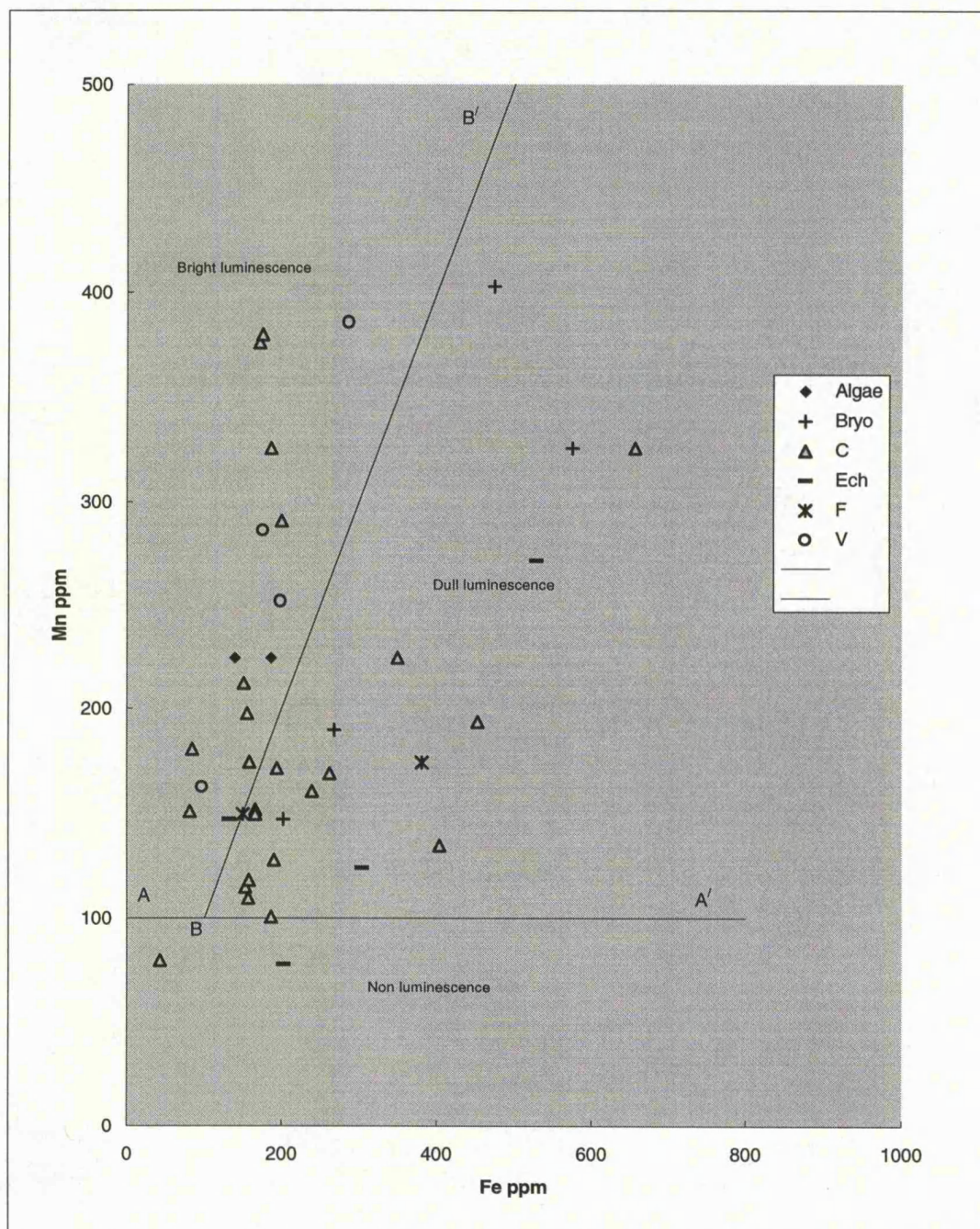


Fig. 7.9. Scatter plot of Fe against Mn, from microprobe analyses of different grains of the Dungan Formation, compared to cathodoluminescence intensity.

Bryo=Bryozoa; C=Cement; Ech=Echinoderms; F=Benthonic Foraminifera; V=Veins

(Data taken from Table 7.5)

high sulfide waters, iron is incorporated in pyrite giving preference to MnCO_3 in the carbonate. FeCO_3 forms in low HS^- waters. The present studies on the Dungan Formation show that the iron and manganese contents of the inner ramp facies are high as compared to the middle and outer ramp facies (see Table 7.3). In the inner ramp facies the detrital material are high as discussed above. The carbonate with admixed terrigenous debris have high iron and manganese content, but the manganese and iron is in silicate minerals and not in the carbonate fraction. In the middle ramp facies the iron and manganese contents are low which indicate the shallow fresh water diagenesis. In the outer ramp facies the concentration of iron and manganese are moderate which indicates the fresh water diagenesis under burial conditions.

As described above, iron and manganese have a strong correlation, because in inner ramp facies has more detrital material as compared to mid and outer ramp facies.

Cathodoluminescence microscopy:-

Cathodoluminescence has become an important tool for distinguishing the diagenetic events and for developing cement stratigraphies used in studying regional diagenetic pattern in carbonate stratigraphy (Dorobok, 1987, Goldstein 1988, Gover and Read 1983, Kaufman et al. 1988, Meyers 1978, Meyers and Lohman 1985, Niemann and Read 1988, and Oglesby 1976). The electron microprobe techniques has allowed quantitative measurements of Mn and Fe in luminescing calcite and dolomites. Fe and Mn are the important elements in activating and quenching the visible luminescence. According to Hemming et al. (1988), calcite with more than about 100 ppm manganese will luminescence even in the presence of moderate amount of iron. In the absence of detectable Fe, calcite with about 150 to 650 ppm manganese has moderate

Table. 7.4. Mean values of each grains for different facies obtained from electron microprobe analyses of Dungan Formation. All oxide values are in wt. percent.

Facies Grain No. of Analysis	4 Algae 3	5 Algae 10	3 Bryozoa 1	5 Bryozoa 4	6 Bryozoa 1	4 Coral 1	6 Coral 1	7 Coral 1
CaO	53.4	55.24	50.55	55.04	55.1	53.58	55.54	54.36
MgO	1.25	0.7	1.59	0.63	0.72	0.27	0.39	0.4
FeO	0.9	0.13	2.1	0.05	0.06	1.1	0.5	0.77
MnO	0.33	0.02	1.3	0.03	0.05	0.5	0.02	0.03
SrO	0.06	0.04	0.09	0.05	0.07	0.01	0.18	0.12
BaO	0.08	0.1	0.04	0.18	0.24	0.17	0.07	0.07
Total	56.02	56.23	55.67	55.99	56.24	55.63	56.71	55.76
CaCO ₃ %	95.3	98.59	90.23	98.24	98.34	95.63	99.13	97.03
MgCO ₃ %	2.61	1.47	3.32	1.32	1.5	0.55	0.81	0.84
Mol%MgCO ₃	3.15	1.73	4.19	1.57	1.78	0.68	0.96	1.02

Facies Grain No. of Analysis	3 Ech. 2	4 Ech. 3	5 Ech. 6	6 Ech. 8	5 F 5	6 F 7	7 F 12	3 FF 1
CaO	51.52	49.95	54.46	54.82	55.45	54.64	54.47	53.07
MgO	1.59	3.7	1.58	0.84	0.5	0.83	1.18	0.85
FeO	1.25	0.97	0.07	0.07	0.03	0.19	0.25	1.17
MnO	0.97	0.44	0.02	0.01	0.01	0.03	0.03	0.52
SrO	0.05	0.07	0.03	0.07	0.04	0.1	0.08	0.09
BaO	0.15	0.14	0.06	0.2	0.08	0.09	0.13	0.13
Total	55.52	55.27	56.22	56.02	56.11	55.88	56.15	55.82
CaCO ₃ %	91.96	89.15	97.19	97.85	98.97	97.52	97.22	94.71
MgCO ₃ %	3.33	7.75	3.3	1.76	1.04	1.75	2.47	1.77
Mol%MgCO ₃	4.12	9.35	3.84	2.08	1.23	2.08	2.93	2.18

Facies Grain No. of Analysis	4 FF 1	6 FF 8	7 FF 15	8 F(PL) 1	5 Micrite 5	6 Micrite 2	7 Micrite 1	3 Iso 2
CaO	52.35	54	54.31	55.15	54.8	54.31	53.61	54.25
MgO	1.37	0.73	0.96	0.36	0.6	0.85	0.98	0.59
FeO	1.99	1.02	0.63	0.03	0.15	0.23	0.25	0.64
MnO	0.43	0.05	0.03	0.02	0.01	0.02	0.03	0.37
SrO	0.07	0.1	0.1	0.14	0.04	0.12	0.06	0.09
BaO	0.04	0.09	0.14	0.05	0.17	0.23	0.24	0.14
Total	56.23	56	56.18	55.74	55.78	55.76	55.16	56.09
CaCO ₃ %	93.43	96.37	96.93	98.42	97.81	96.93	95.68	96.83
MgCO ₃ %	2.86	1.53	2.01	0.75	1.26	1.78	2.06	1.23
Mol%MgCO ₃	3.51	1.84	2.4	0.9	1.51	2.14	2.49	1.49

Table. 7.4. (contd.)

Facies	3	4	5	6	7	8	2	3
Grain	C	C	C	C	C	C	CF	CF
No. of Analysis	2	33	111	50	1	10	1	26
CaO	54.57	55.19	55.63	55.29	54.44	54.9	53.58	52.87
MgO	0.81	0.58	0.39	0.6	0.65	0.54	0.34	1
FeO	0.29	0.19	0.05	0.09	0.39	0.24	1.14	1
MnO	0.26	0.07	0.02	0.03	0.02	0.03	0.61	0.72
SrO	0.08	0.07	0.06	0.08	0.08	0.14	0.07	0.08
BaO	0.14	0.12	0.1	0.11	0.04	0.11	0.07	0.1
Total	56.15	56.22	56.26	56.19	55.61	55.95	55.8	55.76
CaCO ₃ %	97.39	98.5	99.29	98.68	97.16	97.98	95.63	94.37
MgCO ₃ %	1.69	1.21	0.81	1.25	1.36	1.13	0.71	2.08
Mol%MgCO ₃	2.03	1.44	0.96	1.48	1.63	1.35	0.88	2.54

Facies	4	6	7	5	6	6	7	8
Grain	CF	CF	CF	V	V	VF	VF	VF
No. of Analysis	29	89	53	41	6	41	1	1
CaO	53.4	54.34	53.98	55.8	55.46	54.79	54.2	55.81
MgO	1	0.56	0.6	0.32	0.46	0.53	0.8	0.49
FeO	1.13	1.08	1.1	0.06	0.02	0.66	1.12	0.33
MnO	0.28	0.04	0.05	0.02	0.04	0.03	0.05	0.01
SrO	0.1	0.08	0.09	0.17	0.08	0.09	0.12	0.08
BaO	0.1	0.09	0.1	0.07	0.14	0.13	0.09	0.01
Total	56.02	56.19	55.91	56.44	56.2	56.24	56.38	56.74
CaCO ₃ %	95.31	96.98	96.34	99.58	98.98	97.79	96.73	99.61
MgCO ₃ %	2.1	1.17	1.26	0.66	0.96	1.12	1.68	1.03
Mol%MgCO ₃	2.55	1.41	1.52	0.79	1.13	1.33	2.02	1.22

$\text{CaCO}_3\% = \text{CaO} * 100.09 / 56.08$; $\text{MgCO}_3\% = \text{MgO} * 84.32 / 40.31$
 $\text{Mol\% MgCO}_3 = \text{Mol.MgCO}_3 * 100 / (\text{Mol.CaCO}_3 + \text{Mol.MgCO}_3)$
 C=Drusy cement CF=Ferroan drusy cement
 F=Ferroan foraminifera F(PL)=Planktonic foraminifera
 V=Veins VF=Ferroan veins

Ech=Echinoderm F=Foraminifera;
 Iso=Isopachous cement O=Oolite

luminescence and those with manganese contents greater than about 700 ppm have bright luminescence. In the presence of detectable Fe, the amount of manganese required to impart moderate to bright luminescence increases with Fe content. Furthermore, Fe does not extinguish manganese activated luminescence up to about 10,000 ppm. Luminescence also depends upon the Fe/Mg ratio which they suggest (r) is in between 0.76 to 0.95.

The mean probe data of all the grains, cement and veins present in different facies (Table 7.4) show that in different facies the amount of manganese and iron varies, so some of them show luminescence and others not. The concentration of manganese in cement, veins and allochems are plotted against the iron concentration (Fig. 7.9). From the plot it is observed that the points below the line do not show luminescence, and the points above the line show luminescence. As the concentration of manganese increases the intensity of luminescence increases, if the Fe/Mg ratio is constant.

In summary those grains of the Dungan Formation that show luminescence are those which have the concentration of manganese greater than or equal to 100 ppm, and the Fe/Mg ratio is one or greater, in agreement with Hemming et al., (1988) and others. It is also clear from the graph that the grains which are near the line AA', meaning they are showing marine diagenesis whereas the cement and veins are above the line AA', which indicate fresh water cement. It is concluded that the sediments are deposited in shallow marine environments and subjected to freshwater environments for diagenesis.

7.6.2. Trace Element Geochemistry:-

The study of the variation in the trace element content of the Dungan Formation was made in an attempt to use these trace elements as facies indicators. The rock comprising the series of four main types, limestone, argillaceous limestone, arenaceous limestone, and calcareous shale, and they include eight lithologic facies.

As mentioned in section 7.6.1. Krynine (1948) gave classification of trace elements in sedimentary rocks as a mixture of material carried in the basin of deposition in the solid state (detrital) and material entering the basin of deposition in solution (non-detrital), and Graf (1960) classified the amount of trace elements in carbonate rocks as a function of the amount in solid solution in the carbonate minerals and of the kinds of detrital minerals and amounts present.

According to Hirst and Nicholls (1958) impure limestones consist of two distinct fractions, an essentially carbonate fraction, such as CaCO_3 , of non-detrital origin, and a detrital fraction made up of essentially of silicates, clay minerals or quartz. The presence of trace elements indicate the presence of detrital minerals. Keith and Degens (1959) investigated the difference in the trace element content of marine and non-marine shales. Potter, Shimp and Witters (1963) determined the modern and ancient marine and fresh-water argillaceous sediments on the basis of trace elements and found that Ba, Cr, Cu, Ga, Ni, and V are significantly more abundant in the marine than in the fresh water sediments.

In the present study the emphasis is given to the concentration of Ba, Cr, Ni, V, Pb, Zn, Zr, and Sr. The amount of concentration of these trace elements in the total rock samples are listed in Table 7.1. The average concentration of these elements in different facies are given in Table 7.5.

Table. 7.5. Mean, standard deviation, maximum, and minimum values of trace elements in facies 1 to 8 of Dungan Formation, analysed by x-ray fluorescence. All values are in ppm.

Facies n	1 9	1 9	1 9	1 9	2 14	2 14	2 14	2 14	3 11	3 11	3 11	3 11
	Mean	Std.	Max.	Min.	Mean	Std.	Max.	Min.	Mean	Std.	Max.	Min.
Ba	88	73	184	4	62	56	163	4	71	71	243	18
Cr	95	22	130	59	65	35	139	20	68	89	329	9
Cu	4	6	18	1	4	2	7	1	5	3	8	2
Mo	1	1	2	1	1	1	3	1	1	1	2	1
Ni	18	11	40	5	23	16	56	4	29	19	75	11
Pb	9	4	14	2	9	3	14	4	9	5	15	1
Rb	8	10	32	2	10	6	22	2	11	8	33	4
S	198	312	1002	13	1279	889	2749	256	1668	1345	4846	399
Sr	91	44	185	50	222	100	430	73	357	131	625	194
V	112	54	242	68	108	61	213	25	117	103	407	44
Zn	58	26	93	26	37	38	141	2	42	34	120	11
Zr	125	48	188	59	201	174	533	70	107	58	241	59

Facies n	4 10	4 10	4 10	4 10	5 29	5 29	5 29	5 29	6 24	6 24	6 24	6 24
	Mean	Std.	Max.	Min.	Mean	Std.	Max.	Min.	Mean	Std.	Max.	Min.
Ba	18	20	57	4	5	3	15	4	21	44	211	4
Cr	39	25	78	2	6	4	14	2	14	12	39	2
Cu	6	9	30	1	3	2	8	1	5	2	14	2
Mo	1	1	2	1	1	1	3	1	1	1	3	1
Ni	14	8	29	1	3	3	10	1	8	9	30	1
Pb	7	3	11	1	6	3	13	1	5	3	14	1
Rb	7	2	10	4	7	1	10	5	8	3	16	4
S	1036	635	2611	443	530	225	993	237	3443	4008	16162	294
Sr	496	129	729	324	314	39	391	225	528	187	833	294
V	48	15	69	20	13	4	24	7	23	17	62	6
Zn	23	13	43	4	2	3	17	2	9	12	39	2
Zr	59	67	225	12	9	4	16	3	16	11	48	4

Facies n	7 13	7 13	7 13	7 13	8 12	8 12	8 12	8 12
	Mean	Std.	Max.	Min.	Mean	Std.	Max.	Min.
Ba	28	30	82	4	19	17	52	4
Cr	37	24	78	2	25	22	61	2
Cu	22	39	143	2	8	2	12	5
Mo	2	1	3	1	3	3	11	1
Ni	18	11	39	1	17	7	28	8
Pb	6	3	10	1	7	5	17	1
Rb	11	6	19	1	13	8	29	7
S	11069	10681	35770	1539	10706	4797	20857	4868
Sr	731	129	952	573	793	90	903	622
V	53	28	108	14	34	21	74	7
Zn	32	18	65	2	24	11	38	9
Zr	31	15	72	12	28	26	74	2

n=No. of Samples

Std.=Standard Deviation

The clay minerals which are present in the detrital fraction of the rocks, contain trace elements in their lattice structures (Hirst, 1962, Nicholls and Loring 1962), and the concentrations of trace elements from this source will in general, increase in those rocks which have a higher content of detrital components. The differences in the trace element content of the various rock types and facies reflect the influence of the detrital fraction on their geochemistry. The influence of this fraction varies among the elements and has its greatest effect on the distribution of Ba, Cr, V, Zn, and Zr; least effect on Ni, and Pb; and most least effect on the distribution of Mo, Cu, and Rb.

The graphs illustrating the relationship between the trace elements of the total rock samples of different facies of the Dungan Formation are given in Figures 7.10 and 7.11. Ba versus V; Ba versus Cr; Ba versus Zn; Zn; versus V; Cr versus Zn; Cr versus V; and V versus Pb, all have a strong positive relationship. The plot of (Fig. 7.10 A) Ba against V indicates the presence of detrital material and argillaceous limestone. The plot of Ba versus Cr (Fig. 7.10 B) indicates the presence of quartz and shale. The plot of Ba versus Zn (Fig. 7.10 C) indicates the presence of shales. The plot of (Fig. 7.10 D) Zn against Ba indicates the presence of heavy minerals (such as rutile). The plot of Zn versus V (Fig. 7.11 E) indicates the presence of argillaceous limestone. The plot of Cr versus Zn (Fig. 7.11 F) indicates the presence of heavy minerals and shales. The plot of (Fig. 7.11 G) Cr against V indicates the presence of argillaceous limestone. Similarly the plot of V versus Pb (Fig. 7.11 H) indicates the presence of shale. As described above, these relationships show that these trace elements are higher in impure limestone (the detrital material is high) and less in pure limestone (the detrital material are low). In shale and argillaceous limestone the concentration of V, Ba, and

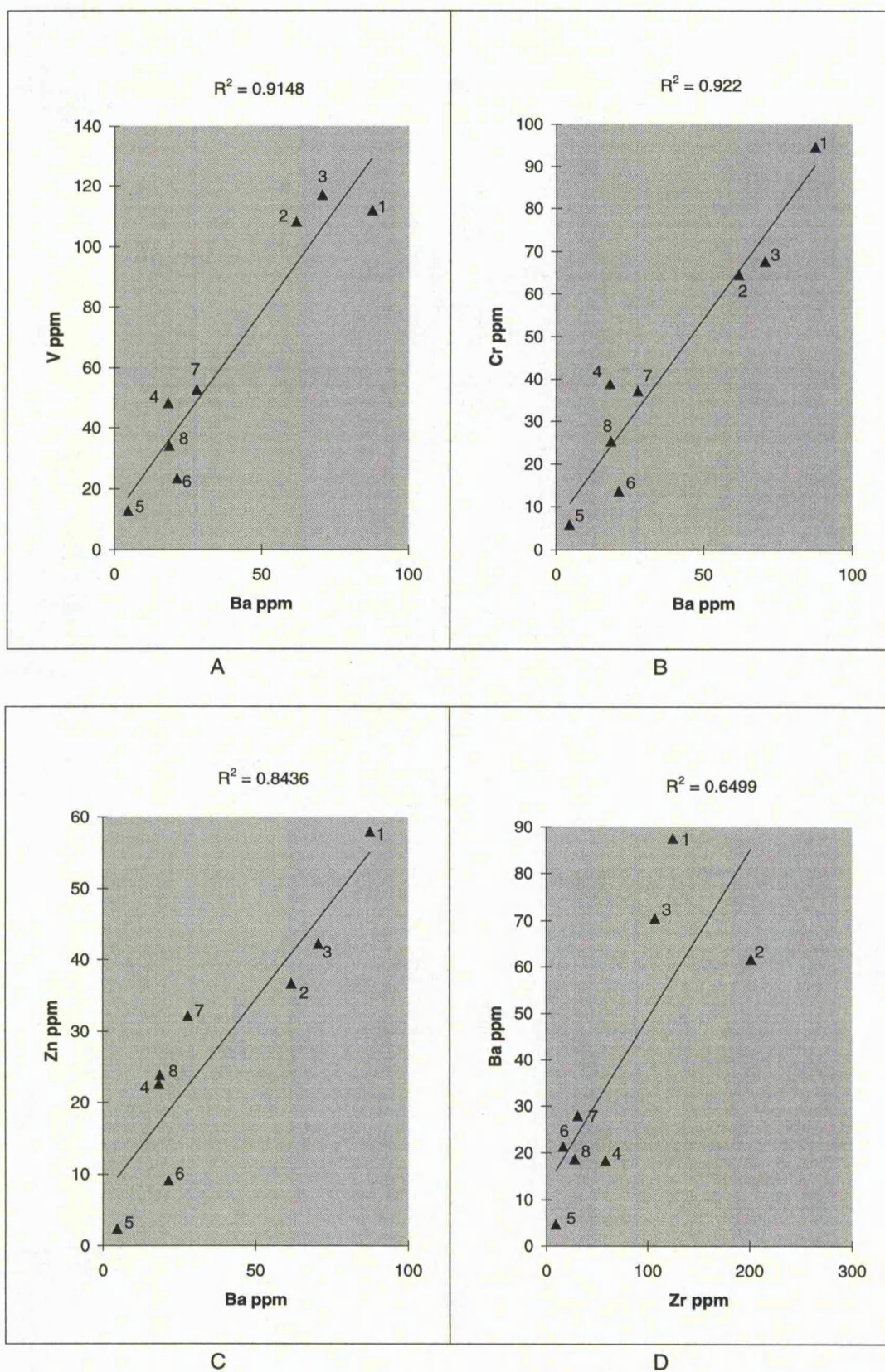


Fig. 7.10. Plots showing the relationship between the trace elements in facies 1 to 8, present in Dungan Formation. A, between Ba and V; B, between Ba and Cr; C, between Ba and Zn; and D, between Zr and Ba.

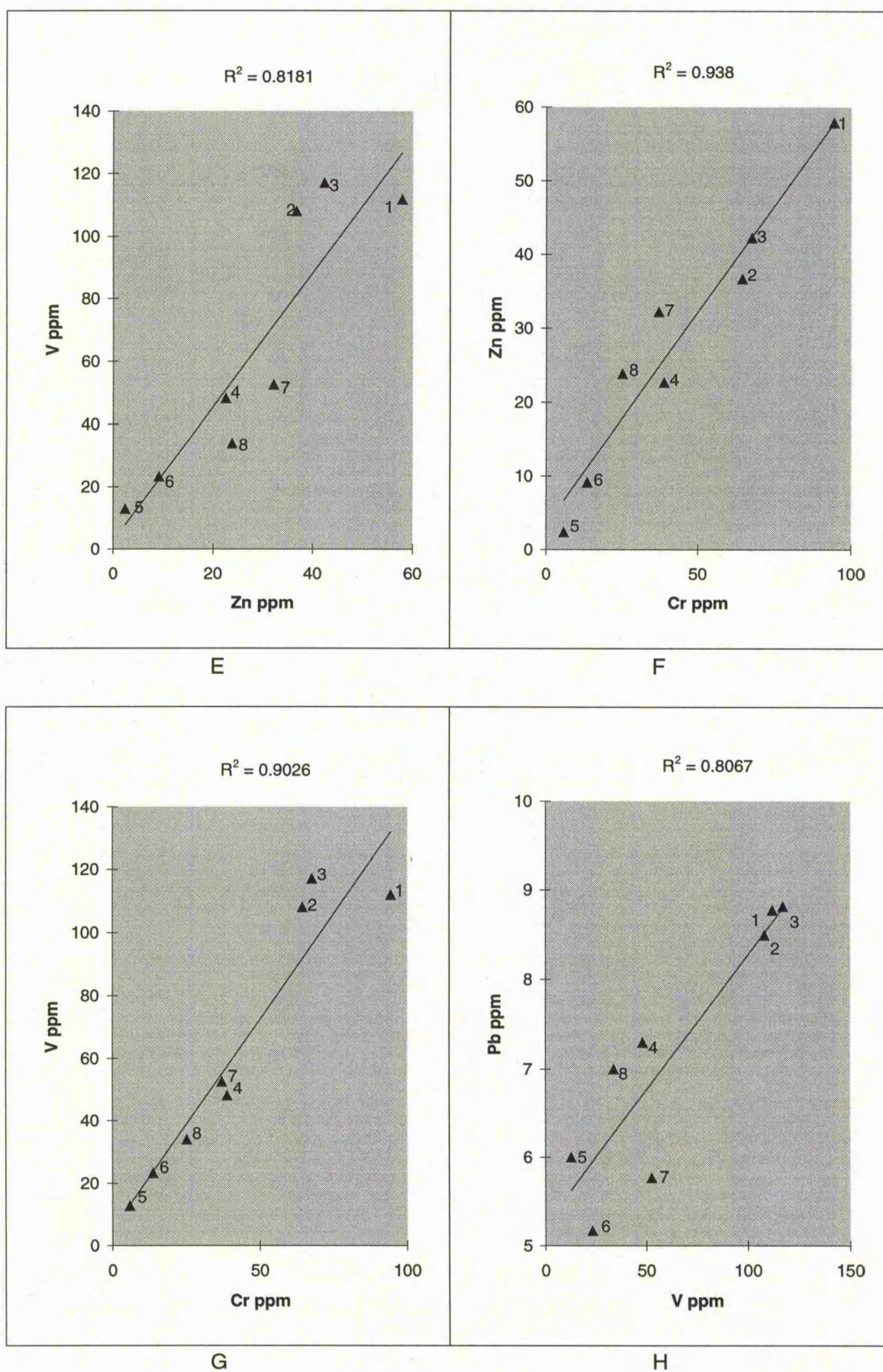


Fig. 7.11. Plots showing the relationship between the trace elements in facies 1 to 8, present in Dungan Formation. E, between Zn and V; F, between Cr and Zn; G, between Cr and V; and H, between V and Pb.

Zn are high, in calcareous shale the concentration of Sr is high and in arenaceous limestone and shale Ba, Cr, and Zr are high.

Strontium (Sr):-

Strontium as one of the most important trace elements in the sedimentary carbonate rocks, has been a subject of studies for a considerable period of time. The general subject of strontium distribution in carbonate rocks was reviewed by Graf (1960), Wolf et al. (1967), Flugel and Wedepohl (1967), Kinsman (1969), Bathurst (1971), Veizer and Demovic (1974), and others. The strontium behaviour during precipitation of carbonate phases and its diagenetic partition is discussed by Flugel and Wedepohl (1967), Wedepohl (1969), Kinsman (1969), Kinsman and Holland (1969) and Katz et al. (1972).

Strontium is an important constituent of the precursor carbonate sediments and is usually used as an indicator of precursor carbonate mineralogy (Fig. 7.5A), being enriched in marine aragonite (such as corals and ooids) with an average Sr content of about 9800 ppm (Kinsman, 1969) relative to high-Mg calcite with Sr content ranging from 400 to 1000 ppm (Lands and Goreau, 1970) to typically less than 4000 ppm (Lands and Hoops, 1973). Because of the greater ionic radius of strontium, it is more likely to enter the structure of aragonite than that of calcite. The concentration of Sr is high in hypersaline, dark coloured and deep sea rock types and low in littoral, neritic and shallow bathyal limestones of organogenic and organodetrital types (Veizer and Demovic, 1974).

The difference in the Sr content between different facies (from peritidal to basin) can be explained by difference in the clay mineral content of the sediments of these facies

areas. Very pure limestone contain 100 to 300 ppm; with a 5 to 15% clay content contain 400 to 700 ppm; and limestone with more than 20% clay content contain 1000 ppm strontium or more (Bauch, 1968).

In general the concentration of strontium in the carbonate rock is depend on the original mineralogy of the sediments (Fig. 7.5A), (the greater the amount of aragonite, the greater the concentration of strontium) and the concentration of clay minerals (the greater the clay content in the limestone the greater the concentration of strontium in the limestone).

The concentration of strontium in Dungan Formation is listed in Table 7.1. The average concentration of strontium in different facies, recognised in Dungan Formation in this study, is given in Table 7.5. In these studied samples the concentration of strontium is not high. In all the facies on average it ranges from 91 to 793 ppm. It increases from facies 1 to 4, which are the inner ramp facies, after that in facies 5, it decreases and again increases from facies 5 to 8, which are the middle and outer ramp facies. In details in facies 1 the concentration of Sr is 91 ppm, which is very low due to the presence of high detrital material (mainly quartz). From facies 1 to 4, the amount of detrital material (mainly quartz) decreases and the amount of carbonate increases, which virtually increases the concentration of strontium. The inner lagoon facies has the concentration of strontium 222 ppm, which indicates that the carbonate is mainly high magnesium calcite (Kinsman, 1969) and the clay contents are low. In the oolitic facies the concentration of Sr is 357 ppm, which is in the range of normal limestone (Bausch, 1968). It indicates the allochems are high magnesium calcitic and the clay contents are not high. The outer lagoonal facies has a concentration of Sr 496 ppm, which is in the range of 5 to 15% of clay contents

(Bausch, 1968). It indicates the allochems are the high magnesium calcitic and the detrital material (quartz) is very low. In the rhodolith platform facies the Sr is 314 ppm, which is in the range of pure calcite. The allochems are of the high magnesium calcitic and the detrital and clay minerals are negligible. The nummulitic facies has a strontium concentration of 528 ppm. It is in the range of 5 to 15% clay contents, the allochems are high magnesium calcitic. In the larger foraminiferal facies the Sr is 731 ppm which is in the range of 5 to 15% clay content, the allochems are of the high magnesium calcitic. In planktonic foraminiferal facies the concentration of Sr is 793 ppm. It is slightly more than the range of 5 to 15% clay content, and the allochems are the mixture of low magnesium calcite and high magnesium calcite.

In general the concentration of Sr increases from facies 1 to 8, except in facies 5. It indicates clay contents are high in facies 7 and 8. The detrital material (quartz) is high in facies in 1 and 2. The facies 3 and 4 have the moderate amount of clay and detrital material. The facies 5 and 6 are mainly the pure limestone. In all facies of the Dungan Formation the allochems were dominantly of high magnesium calcite, except in facies 8, which had a mixture of low magnesium calcite and high magnesium calcite.

7.6.3. Isotope Geochemistry:-

The geochemistry of stable carbon and oxygen isotopes is a powerful tool for the study of carbonate diagenesis (Veizer and Hoefs, 1976; Hudson, 1977; Veizer, 1983; Land, 1986; and many others). Carbon oxygen isotope values of the facies, cement type, and veins present in Dungan Formation are listed in Table 7.6. They are represented by a scattered plot between $\delta^{18}\text{O}$ PDB and $\delta^{13}\text{C}$ PDB (Fig. 7.12).

Table. 7.6. Carbon and oxygen stable isotope data with its mean, standard deviation, maximum, and minimum values in different facies.

Facies	2	2	2	3	3	3	3	3	4	4
Sample No.	RK21	RK41	RK42	RK13	RK17	RK33	RK36	RK44	RK15	RK25
Grains	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
δC^{13} PDB	-0.88	-0.42	-0.13	-1.74	-0.23	-0.16	0.33	-1.14	0.59	0.5
δO^{18} PDB	-8.8	-6.02	-4.56	-7.51	-7.63	-7.33	-6.49	-8.23	-5.73	-6.89
Facies	4	4	4	4	5	5	5	5	5	5
Sample No.	RK27	RK28	RK30	RG32	RG8	RG11	RG13	RG19	RG30	RG33
Grains	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
δC^{13} PDB	0.36	0.79	0.63	0.63	0.83	1.06	1.1	0.33	0.99	0.92
δO^{18} PDB	-6.12	-6.88	-6.92	-6.93	-5.81	-7.34	-7.15	-7.98	-6.22	-6.12
Facies	5	5	5	5	6	6	6	6	6	6
Sample No.	RG37	RG46	RG22	RG26	RG39	ZP10	ZP13	ZP15	ZP25	ZP32
Grains	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
δC^{13} PDB	1.04	1.29	0.43	0.07	1.58	1.75	1.45	1.68	1.76	1.85
δO^{18} PDB	-6.46	-4.57	-7.57	-7.71	-5.95	-4.8	-5.45	-4.41	-5.54	-4.26
Facies	6	6	7	7	7	7	7	7	7	8
Sample No.	ZP52	ZP56	ZP9	ZP22	ZP29	ZP36	ZP38	ZP40	ZP54	ZP48
Grains	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
δC^{13} PDB	1.8	1.54	1.98	2.47	2.25	2.12	2.21	1.87	2.43	0.61
δO^{18} PDB	-3.32	-5.28	-3.88	-3.64	-4.28	-3.93	-4.93	-4.53	-3.65	-5.36
Facies	All	All	All	All	All	All	All	All	All	All
Sample No.	RG3	RG5	RG28	RG19	RG34	RG31	ZP13	ZP27A	ZP28	ZP40
Grains	C	C	V	V	V	VF	VF	VF	VF	VF
δC^{13} PDB	-0.4	-0.38	-0.03	-2.17	-0.46	0.91	1.13	1.26	1.3	1.38
δO^{18} PDB	-9.78	-9.61	-10.77	-13.42	-11.69	-8.99	-10.59	-9.44	-9.48	-7.08
Facies	2	2	2	2	3	3	3	3	4	4
Grains	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
No.of samples	3	3	3	3	5	5	5	5	6	6
	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.
δC^{13} PDB	-0.48	0.38	-0.13	-0.88	-0.59	0.83	0.33	-1.74	0.58	0.14
δO^{18} PDB	-6.46	2.15	-4.56	-8.8	-7.44	0.63	-6.49	-8.23	-6.58	0.52
Facies	4	4	5	5	5	5	6	6	6	6
Grains	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
No.of samples	6	6	10	10	10	10	8	8	8	8
	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Mini.
δC^{13} PDB	0.79	0.36	0.81	0.39	1.29	0.07	1.68	0.14	1.85	1.45
δO^{18} PDB	-5.73	-6.93	-6.69	1.05	-4.57	-7.98	-4.88	0.85	-3.32	-5.95
Facies	7	7	7	7	8	All	All	All	All	All
Grains	WR	WR	WR	WR	WR	C	C	C	C	V
No.of samples	7	7	7	7	1	2	2	2	2	3
	Mean	St.Dev.	Maxi.	Mini.	Mean	Mean	St.Dev.	Maxi.	Mini.	Mean
δC^{13} PDB	2.19	0.22	2.47	1.87	0.16	-0.39	0.01	-0.38	-0.4	-0.89
δO^{18} PDB	-4.12	0.48	-3.64	-4.93	-5.36	-9.7	0.12	-9.61	-9.78	-11.96
Facies	All	All	All	All	All	All	All	All	All	All
Grains	V	V	V	VF	VF	VF	VF	VF	VF	VF
No.of samples	3	3	3	5	5	5	5	5	5	5
	St.Dev.	Maxi.	Mini.	Mean	St.Dev.	Maxi.	Min.			
δC^{13} PDB	1.13	-0.03	-2.17	1.2	0.18	1.38	0.91			
δO^{18} PDB	1.35	-10.77	-13.42	-9.12	1.28	-7.08	-10.59			

C=Drusy cement

V=Vein

VF=Ferroan Vein

WR=Whole Rock

7.6.3.1. Carbon Isotopes:-

Carbon Isotope values $\delta^{13}\text{C}$ PDB varies between -1 to +2, through the Phanerozoic, with lighter values characterising the early-mid Palaeozoic (400 to 500 Ma), more positive values occurring in Late Precambrian, Cambrian and Permian, and intermediate values since the Triassic (Veizer et al. 1980). The mean $\delta^{13}\text{C}$ values of Tertiary marine sediments as reported by Keith and Weber (1964), is -0.05 PDB, with 1.05 standard deviation, and freshwater limestone have -5.27 with 3.15 standard deviation, but Veizer et al. (1976) gave $\delta^{13}\text{C}$ values ranging from 0.3 to 1.0 PDB. The sediments of Dungan Formation have mean value of $\delta^{13}\text{C}$.78 PDB with 1.05 standard deviation. The plot of $\delta^{18}\text{O}$ against $\delta^{13}\text{C}$ (Fig. 7.12) indicate the data lie in the range of common shallow marine and fresh water limestones (Hudson, 1977). Marine sediments are composed primarily of aragonite and high magnesium calcite, which persist in sea water. These carbonate sediments are unstable in fresh water and when exposed to fresh water are dissolved and reprecipitated as low magnesium calcite (Chave and others 1962; Matthews, 1968, 1974). There is a reaction between marine carbonate sediments of varied mineralogy and meteoric water of the shallow phreatic zone which changes the carbon isotope composition. These changes correlate with degree of diagenetic alteration, particularly to low magnesium calcite (Bathurst 1971, Hudson 1975). According to Hoefs (1973) during diagenesis, marine carbonates generally become lighter in carbon isotope composition. Keith and Weber (1964) suggest that marine carbonate do not show any changes, but Bathurst (1975), Hudson (1975) and others do not agree with this. The present studies show that the carbon isotope values of marine sediments changes during diagenetic processes.

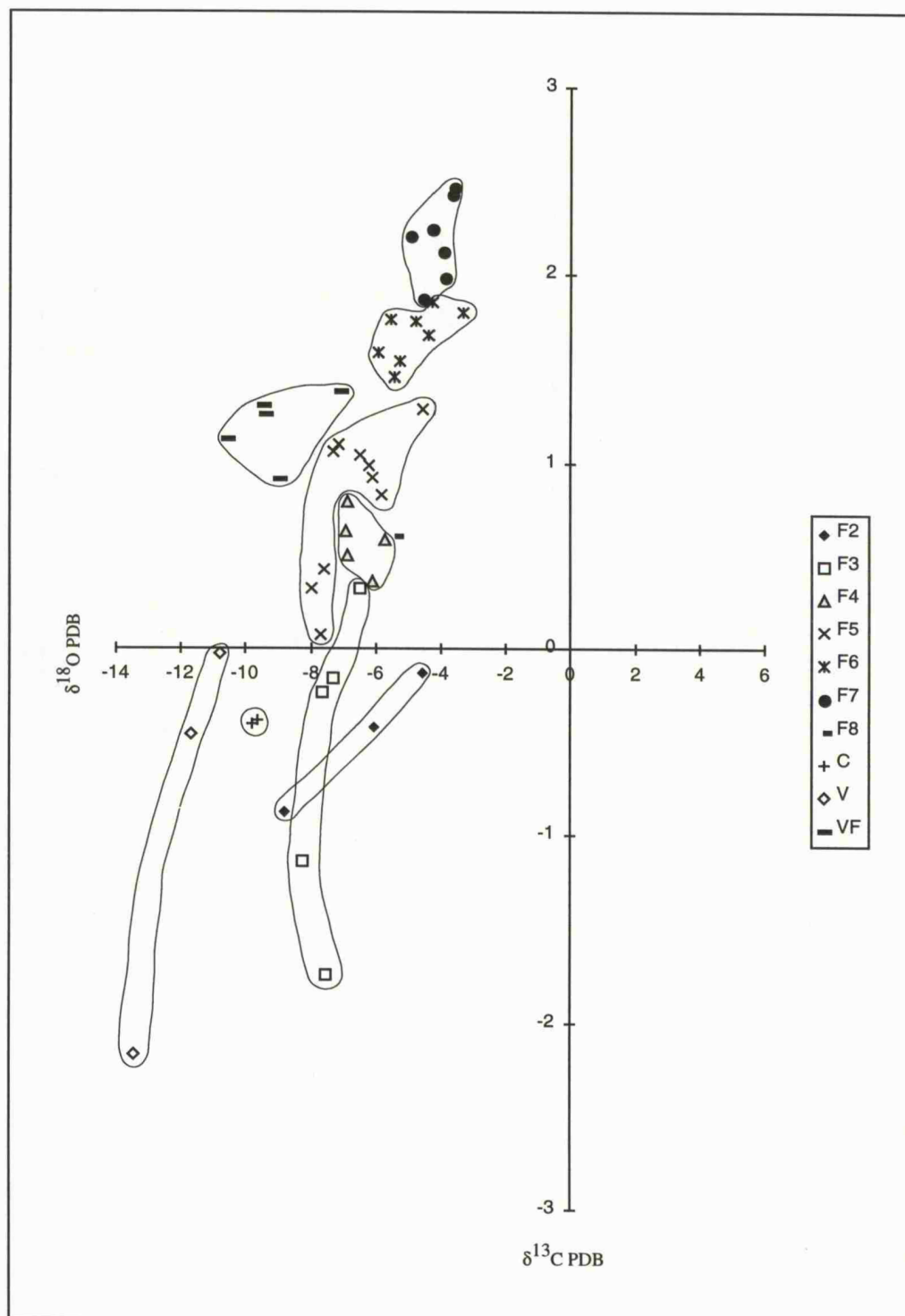


Fig. 7.12. Scatter plot of carbon and oxygen isotope values of different facies, drusy cement, ferroan and non-ferroan veins, present in Dungan Formation.

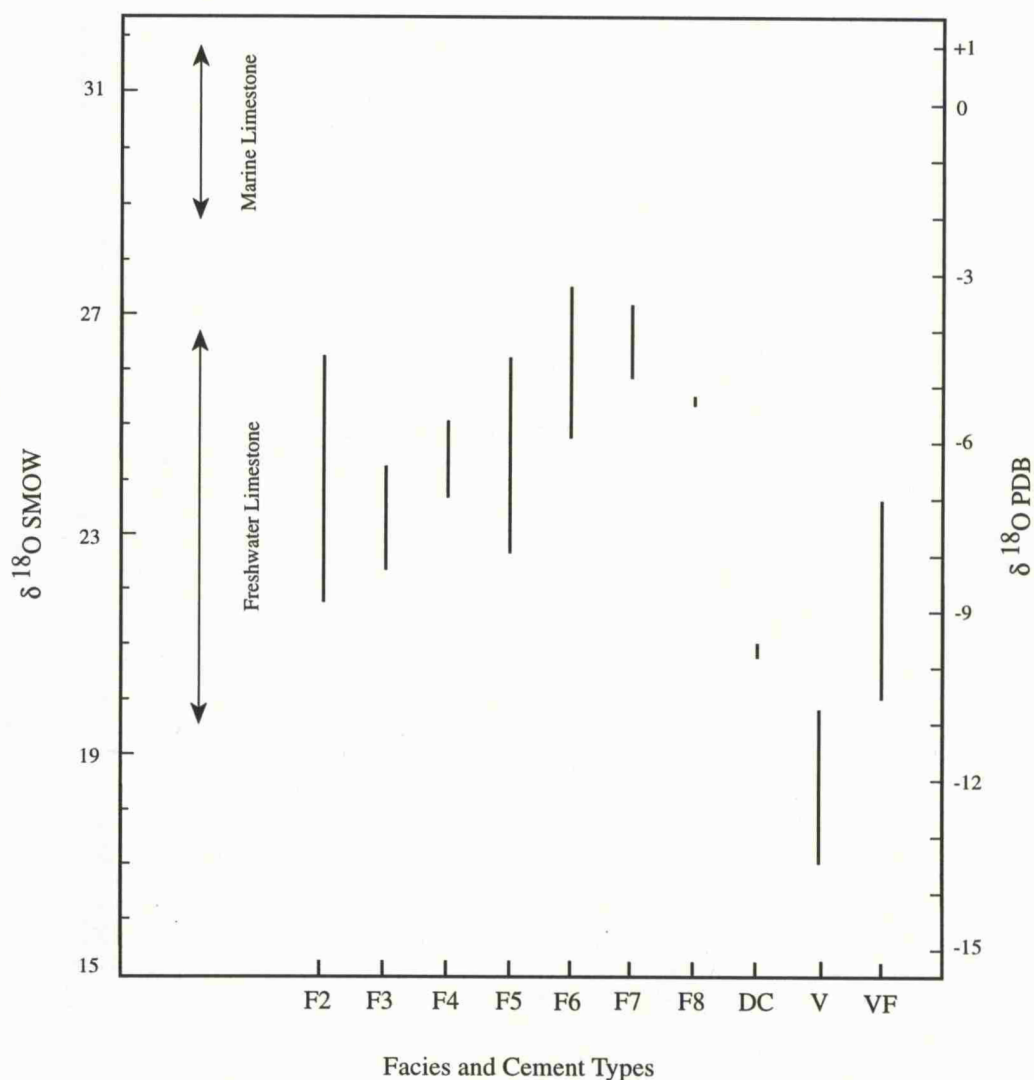
F2=Inner Lagoonal Facies; F3=Oolitic Facies; F4=Outer Lagoonal Facies; F5=Rhodolith Platform Facies; F6=Nummulitic Facies; F7=Larger Foraminiferal Facies; F8=Planktonic Foraminifera Facies; C=Drusy Cement; V=Vein (Non-ferroan); VF=Vein (Ferroan).

Isotopic data on several hundred limestone samples have been reported so far in the literature, the majority of which have a $\delta^{13}\text{C}$ -content close to zero. Keith and Weber (1964) have stated that the average carbon isotopic composition of marine limestones appears to be moderately constant from Cambrian through Tertiary time. Later on most researchers agreed with the conclusion of Veizer and Hoefs (1976) that the carbon isotopic composition of limestone changes through the time. According to their conclusion $\delta^{13}\text{C}$ of limestone decreasing with increasing age. During diagenesis marine carbonates generally become lighter in carbon isotope composition (Baertschi, 1957; Gross, 1964; Bathurst, 1975; Hudson, 1975). Submarine alteration, however, may generate heavier cement than primary bioclastic carbonate (Friedman, 1964).

The carbon isotope values of Dungan Formation increases from landward to seaward. It correlates with an increase in depth. The Dungan Formation as described in chapter five is mainly composed of skeletal limestone. In peritidal facies the skeletal allochems are low (see Table.5.1) as compared to drusy cement, so the carbon isotopic values in these facies are more negative. In the middle and outer ramp facies the skeletal grains are higher as compared to drusy cement, so the carbon isotopic values of these facies are higher than the peritidal facies.

7.6.3.2. Oxygen Isotopes:-

Secular variations also occur in the oxygen isotope values (Tucker, 1988). However in this case there is much more scatter in the data since the $\delta^{18}\text{O}$ of a limestone (whole rock) in an average of sedimentary components and cement, and the latter are commonly very depleted relative to the former. Nevertheless, on a broad scale a trend



(Modified after Veizer & Hoefs, 1976;
and Hudson, 1977)

Fig.7.13. Variation of $\delta^{18}\text{O}$ values of marine and freshwater limestone of different facies and cement types present in Dungan Formation of Palaeocene age.

F2=Inner Lagoonal Facies; F3=Oolitic Facies; F4=Outer Lagoonal Facies; F5=Rhodolith Platform Facies; F6=Nummulitic Facies; F7=Larger Foraminiferal Facies; F8=Planktonic Foraminiferal Facies; DC=Drusy Cement; V=Veins (non-ferroan); and VF=Veins (ferroan).

is apparant, of increasingly negative $\delta^{18}\text{O}$ limestone back through the Phanerozoic, but particularly from the Permian back to the Precambrian. There is less variation over the last 250 Ma; limestone values are generally +1 to -2 PDB. Hudson (1977) gave the oxygen isotope values of generally fresh-water limestones as ranging from -4 to -11 PDB. The oxygen isotopes of Tertiary period for generally marine limestones ranges from 0 to -4.8, and for fresh water have a wide range from -5.2 to -13.8 PDB (Keith and Weber, 1964). During early diagenesis most limestones also re-equilibrate their $\delta^{18}\text{O}$ content with the surrounding pore-fluids, which are generally different from ocean water; and the most carbonate becomes lighter in $\delta^{18}\text{O}$. The variation in the isotope composition of $\delta^{18}\text{O}$ of marine and fresh water limestones are shown in Figure 7.13.

The mean value of oxygen isotope for Dungan Formation is -6.7 PDB with standard deviation of 2.24. It ranges from -3.32 to -13.42 (Table 7.6). In general the oxygen isotopic values increase with facies from peritidal to planktonic, it is the agreement with the observations of Allan and Matthews, (1977). In the inner ramp facies the values are more negative where as in the middle and outer ramp facies they are less negative. The mean oxygen isotope values for drusy cement of all the facies is -9.61. The $\delta^{18}\text{O}$ values of carbonate sediments changes during diagenesis (Hudson, 1977). It increases with deeper facies, a plot against $\delta^{18}\text{O}$ versus Sr concentration in different facies (Fig. 7.15) indicates the same obsevation. The carbon and oxygen isotope values of all the facies, cements, and veins present in Dungan Formation are represented by a plot (Fig. 7.12). On the basis of above discussion it is suggested that the sediments are deposited in the shallow marine environments and the diagenesis is taken place in fresh water environments. The drusy cement which is formed under fresh water diagenesis

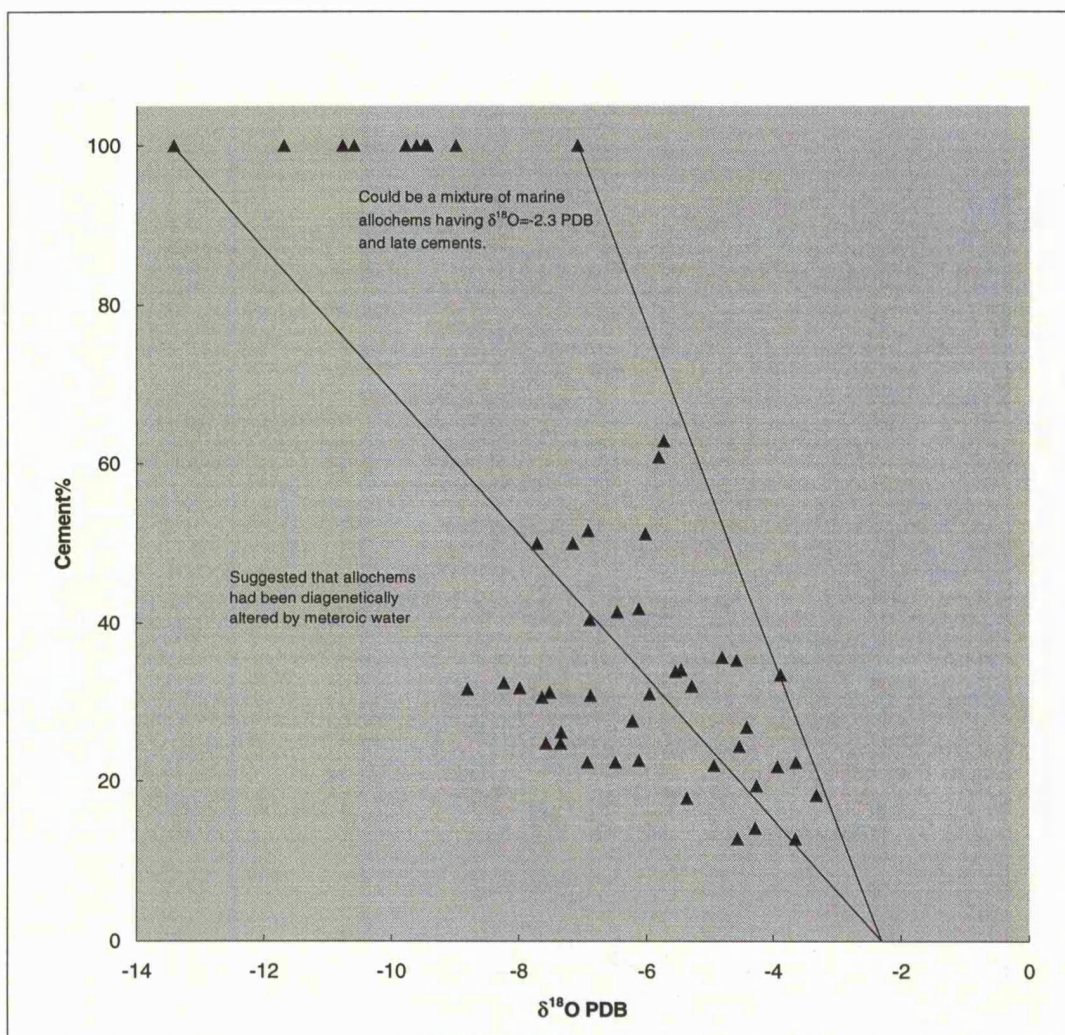


Fig.7.14. Scatter plot of percentage of Drusy cement versus $\delta^{18}\text{O}$ values in PDB. The plot showing the range of oxygen isotope values of marine allochems, late cement, and allochems which are diagenetically altered by meteoric water in Dungan Formation.

has more negative oxygen values as compared to the whole rock (Table 7.6). Similarly the non-ferroan veins have more negative values than the ferroan veins, as they are formed in shallow buried environment by formation water.

In summary the diagenetic environments and facies of Dungan Formation may be differentiated on the basis of stable carbon oxygen isotopic values. The peritidal facies have low values of carbon and oxygen isotopes. These facies have less skeletal allochems and more drusy cement, so they have more negative values of carbon and oxygen isotopes. The drusy cement is formed in the fresh water diagenetic environment. The outer lagoon facies has slightly higher values than the peritidal facies. In this facies the allochems are 30.7% and the drusy cement is 43.5%. The allochems are deposited in the marine environment, the diagenesis takes place in the fresh water regime and after the diagenesis the carbon oxygen isotope values are changed. In the rhodolith platform facies the carbon oxygen values become more high. The skeletal allochems in this facies is 39.5% and the drusy cement is 35.9%. The sediments are deposited in the shallow marine environment, and then subjected to fresh water environment for diagenesis. The drusy cement is formed in this environment along with slight changes in carbon oxygen isotopic values of the marine sediments, and the overall change in the isotope values is also low. In the nummulitic facies the carbon oxygen isotope values are become slightly more higher. In this facies the skeletal allochems are 50.4% and the drusy cement is 26.4%. The same environments are suggested for this facies, but as the skeletal allochems are more and the drusy cement is less so the carbon oxygen isotope values become more higher than the rhodolith platform facies. The larger foraminiferal facies becomes more rich in higher carbon oxygen isotopes. The skeletal allochems in this facies are 64.9% and the drusy

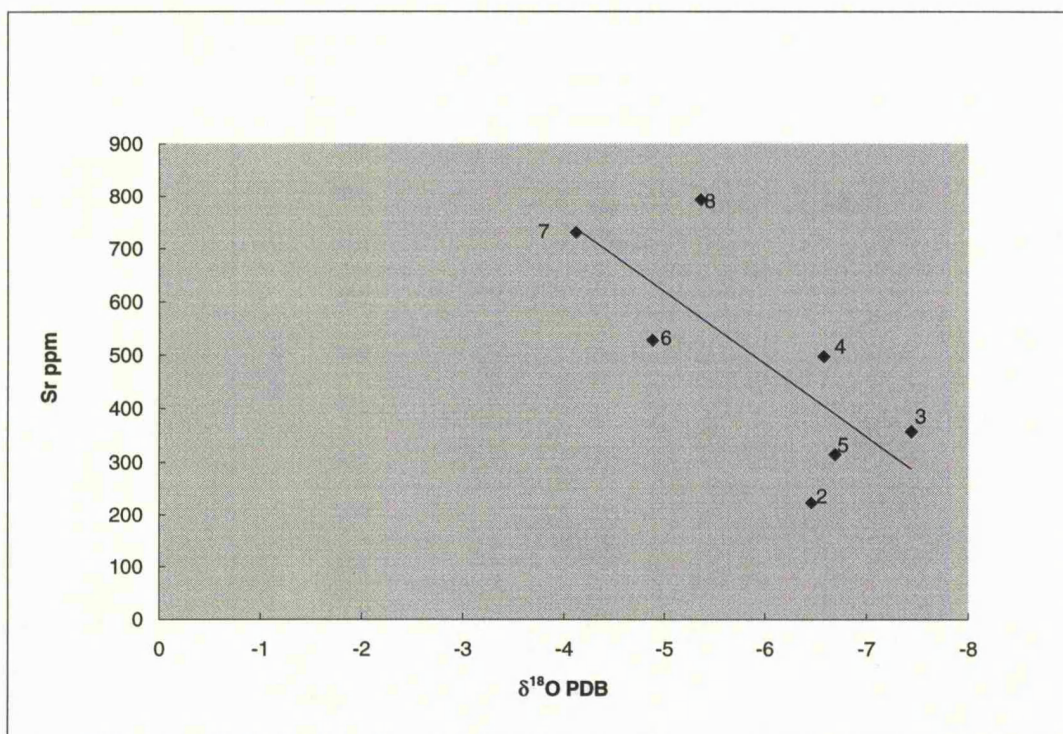


Fig. 7.15. Strontium and oxygen isotopic values changes during diagenesis of different facies in Dungan Formation. The shallow facies showing more freshwater diagenesis than the deeper facies.

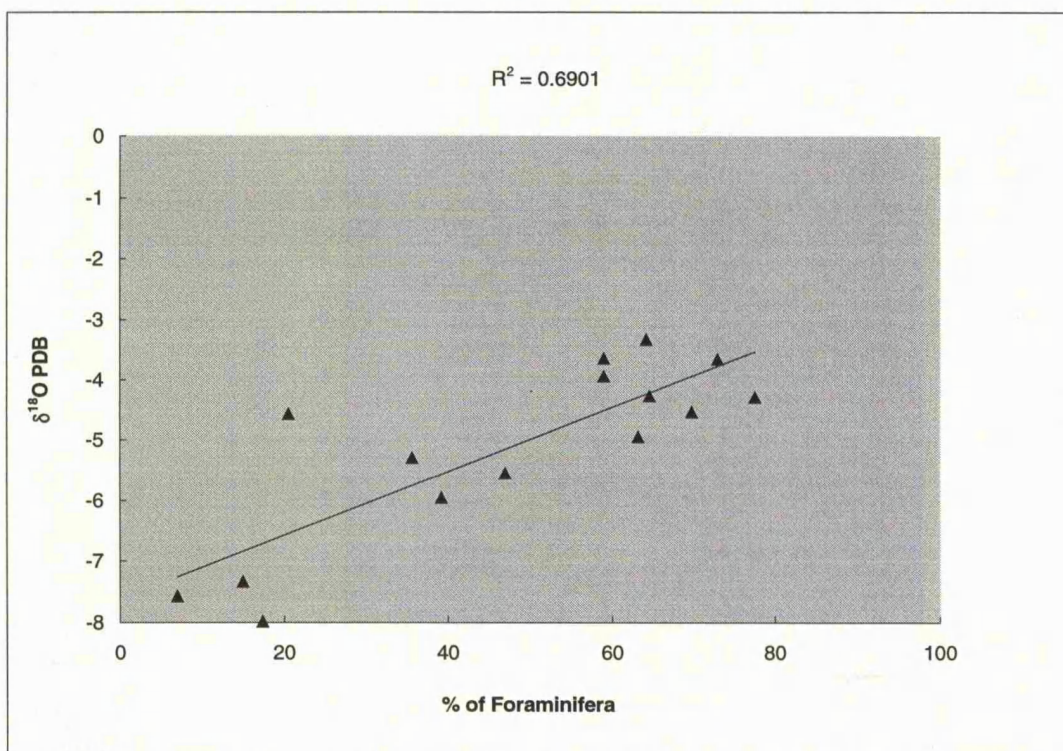


Fig. 7.16. Showing the relationship between percentage of foraminifera and oxygen isotope values.

cement is 20.3%. The skeletal allochems are more abundant and the drusy cement is more less in this facies than the nummulitic facies. The sediments of this facies are deposited in marine environment, and then subjected to fresh water environment for diagenesis. The drusy cement is formed in the fresh water environment and the carbon oxygen isotope values also change after the diagenesis. As the drusy cement is to less than the skeletal allochems, so the whole rock shows little bit higher values than the fresh water limestone. A plot versus the percentage of drusy cement present in the rock and the $\delta^{18}\text{O}$ PDB values (Fig. 7.14) show the same observations.

The carbon oxygen isotope values of drusy cement are more negative than those of the whole rock (Table.7.6). It agreed with the interpretation as done above, that the diagenesis has taken place in the fresh water environment. Similarly the non-ferroan veins have less negative values than that of drusy cement, but more negative than that of ferroan veins. It suggests that the non-ferroan veins are formed slightly later than the drusy cement and the ferroan vein are formed later on in the shallow buried environments.

7.7. Palaeotemperature:-

The variation in precipitation temperatures of calcium carbonate from water should lead to measurable variations in the $^{18}\text{O}/^{16}\text{O}$ ratio of the calcium carbonate. The determination of temperatures of the ancient oceans should be possible by measuring the ^{18}O content of unaltered fossil calcite shells. It is assumed that only the $^{18}\text{O}/^{16}\text{O}$ ratio of the carbonate will be temperature dependent, because the amount of water in the oceans is so much greater than the amount of dissolved carbonate. The basis of the

oxygen isotope method of palaeotemperature determination is the fact that the difference between the $^{18}\text{O}/^{16}\text{O}$ of calcium carbonate or calcium phosphate, and the water from which it precipitates, is temperature dependent. Thus, for known $^{18}\text{O}/^{16}\text{O}$ of water, the $^{18}\text{O}/^{16}\text{O}$ of the mineral depends only on temperature. The palaeotemperature is calculated by the equation given by Hudson and Anderson, (1989).

$$T\text{ }^{\circ}\text{C} = 16.0 - 4.14(\delta\text{C} - \delta\text{W}) + 0.13(\delta\text{C} - \delta\text{W})^2,$$

where $\delta\text{C} = \delta^{18}\text{O}$ for calcite of 100% foraminiferal shell on PDB scale; $\delta\text{W} = \delta^{18}\text{O}$ of water on the SMOW scale, which is assumed as -1.0.

The petrographic studies of the Dungan Formation shows that the mean values of nummulitic and larger foraminiferal facies have the fossil foraminifera 30.8 and 56.3 percent respectively, these two facies are rich in foraminifera. Such samples from these facies are selected which have more than 20 percent foraminifera. The fossil foraminifera is considered to be the calcite shell. A graph is plotted against the $\delta^{18}\text{O}$ values of the whole rock and the percentage of foraminifera present in the rock (Fig. 7.16). A trendline is drawn which gives the $\delta^{18}\text{O}$ value for 100% foraminifera, which is -2.3 PDB. Consequently the palaeotemperature for deposition of the sediments of Dungan Formation is calculated as,

$$T\text{ }^{\circ}\text{C} = 16.0 - 4.14(\delta\text{C} - \delta\text{W}) + 0.13(\delta\text{C} - \delta\text{W})^2,$$

$$T\text{ }^{\circ}\text{C} = 16.0 - 4.14\{-2.3 - (-1.0)\} + 0.13\{-2.3 - (-1.0)\}^2$$

$$T\text{ }^{\circ}\text{C} = 16.0 + 5.382 + 2.197$$

$$T\text{ }^{\circ}\text{C} = 21.60$$

In summary the Dungan Formation is deposited under shallow marine environments and the palaeotemperature was 21.6 $^{\circ}\text{C}$.

Chapter Eight

DIAGENESIS AND DIAGENETIC HISTORY OF DUNGAN FORMATION

8.1. Introduction:-

This chapter deals with the main diagenetic environments, and their products which are recognised in the course of the petrographic studies of the stained thin section by reflected light microscopy, cathodoluminescence microscopy, electron microprobe and scanning electron microscopy in back scattered mode. It also includes the geochemical investigations as described in the preceeding chapter.

8.2. Diagenesis:-

Carbonate sediments are deposited as metastable assemblage mainly of aragonite and Mg-calcite. The transformation of such assemblages of metastable minerals towards rocks composed of stable assemblage of calcite takes place by stages until the rocks are destroyed by weathering or metamorphism. The sediments of the Dungan Formation are mainly shallow marine, dominated by tests of Mg-calcite (red algae, foraminifers, echinoderms and bryozoa) and aragonite (bivalves, gastropods and corals).

The term diagenesis refers to all natural processes acting on sediments since their initial deposition to the time of erosion. These include dissolution, replacement,

neomorphism, cementation, micritization and compaction. Other processes such as metamorphism and weathering are excluded in this study. During diagenesis sediments are encountered by pore-water such as sea-water, meteoric-water (Fig. 8.1) and formation water with diverse histories that move through the compacting sediments of a subsiding basin. The movements of these waters are controlled by the pattern of permeabilities. Precipitation and dissolution are commonly closely related.

The Dungan Formation underwent severe diagenetic alteration which have altered its original components and texture since the time of their initial deposition until the present time. The diagenetic environments have been distinguished one from another by their own characteristic processes and the resultant features such as dissolution and cementation. The diagenetic history of Dungan Formation commenced in the early marine phreatic environment as most of the carbonate rocks started their diagenetic history there, then passed via an active fresh water phreatic environment to the last stage of shallow burial phase.

8.3. Marine Diagenesis:-

Marine diagenesis takes place on sea-floor and just below, and on tidal flats and beaches (Fig. 8.1). A wide variety of cement morphologies are present in modern carbonates. They are essentially of only two mineralogies: aragonite and high-Mg calcite. The high-Mg calcite cement occurs as acicular-bladed isopachous fringes, equant crystals, micrite and peloids (Tucker and Wright, 1990).

The Dungan Formation was deposited in warm shallow (<100 m) seas, with all the pore spaces in the sediments filled with normal marine water. At this stage two

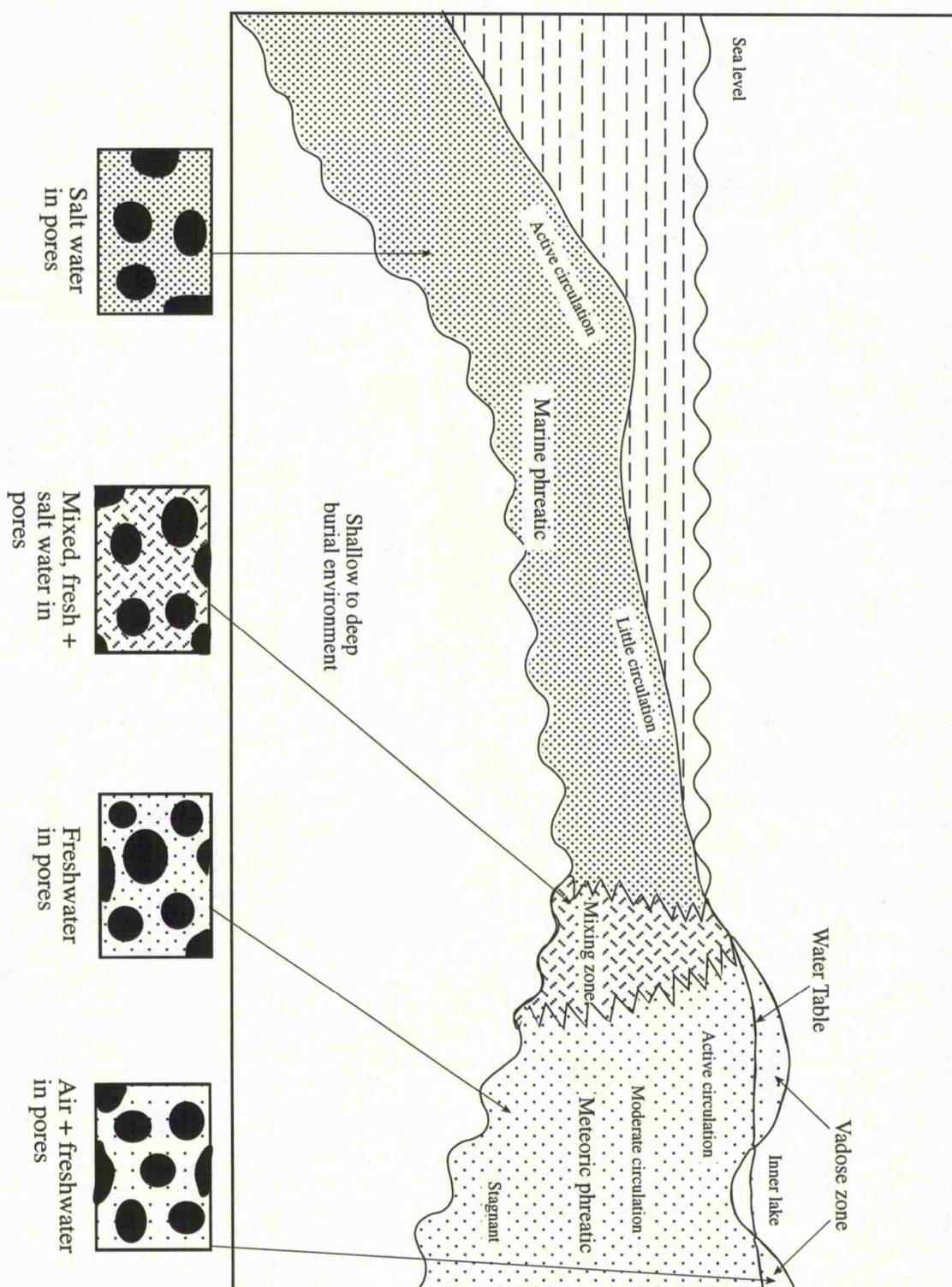


Fig. 8.1. Cross-section shows the distribution and relationships of major carbonate diagenetic environments, schematically drawn for a homoclinal ramp (modified after Tucker and Wright, 1990).

principal diagenetic changes affected the sediments, which are micritization and the peloidal cement.

8.3.1. Micritization:-

This is one of the first stage of diagenesis seen in the sediments of Dungan Formation and it occurred during deposition as most carbonates are deposited in marine environment and thus begin their diagenetic history there. Micrite envelopes are present commonly in almost all the facies except planktonic foraminifera facies of the study area. Micritic envelopes enclose the petrographically unaltered cores of the skeletal carbonate generally high Mg-calcite (foraminifera, coralline algae) (Figs. 5.2C), and the totally/partially altered cores of aragonite skeletal (molluscs) (Fig. 8.2C). In most of the cases the micrite envelopes are regular (Fig. 8.2A). The encrusting algae and boring organisms are common in rhodolith platform facies. Under cathodoluminescence they do not show luminescence or very dull luminescence (Fig. 8.2B). Eight analysis of micrite by electron microprobe indicate the wt.% of CaCO_3 is 97.25 and mol% of MgCO_3 is 1.83 whereas in drusy cement the wt.% of CaCO_3 is 98.84 and mol% of MgCO_3 is 1.21.

Interpretation:-

Micritization of grains by boring algae resulted in the formation of a micritic envelope similar to those described by Bathurst (1966, 1975) and Kendall and Skipwith (1969). Many skeletal grains, such as molluscs and algae, on the present sea floor, and in ancient limestone, have been replaced partly or wholly by a fine-grained greyish

mosaic of carbonate crystals, the micrite of Folk (1959). The replacement began at the exposed surface of the grain and spread irregularly inwards. An envelope of micrite was formed that simply enclosed the unaltered core of skeletal carbonate generally foraminifera, algae or molluscs. The process goes on centripetally within the grains and partially converted them to micrite. Absence of broken envelopes indicated that the dissolution and void-filling were completed before compaction. The encrusting algae and boring organisms that micritized the outer portions and occasionally the inner portions of the bioclastics have been observed in recent sediments of Abu Dhabi by Kendall and Skipwith (1969) and they concluded it was a marine phreatic processes. Bathurst (1966, 1975) and Kobluk and Risk (1977) believed that these processes took place in marine phreatic zone. The mol% of MgCO_3 is higher as compared to that of drusy cement which suggests the same agreement. In summary it is concluded that the micritization takes place in the marine phreatic environment.

8.3.2. Peloidal Cement:-

As described in chapter five the peloidal cement consists of subspherical bodies of 20 to 50 μm . and are composed of micrite of less than 3 μm . The microspar cement crystal of 5 to 8 μm . are embedded in between the subspherical bodies of peloidal cement. This type of cement occurs in rhodolith platform and nummulitic facies. These facies are the main carbonate accumulating facies. In the studied sections it is mainly present in the mid-ramp. Under cathodoluminescence microscopy it does not show luminescence.

Fig. 8.2. A.

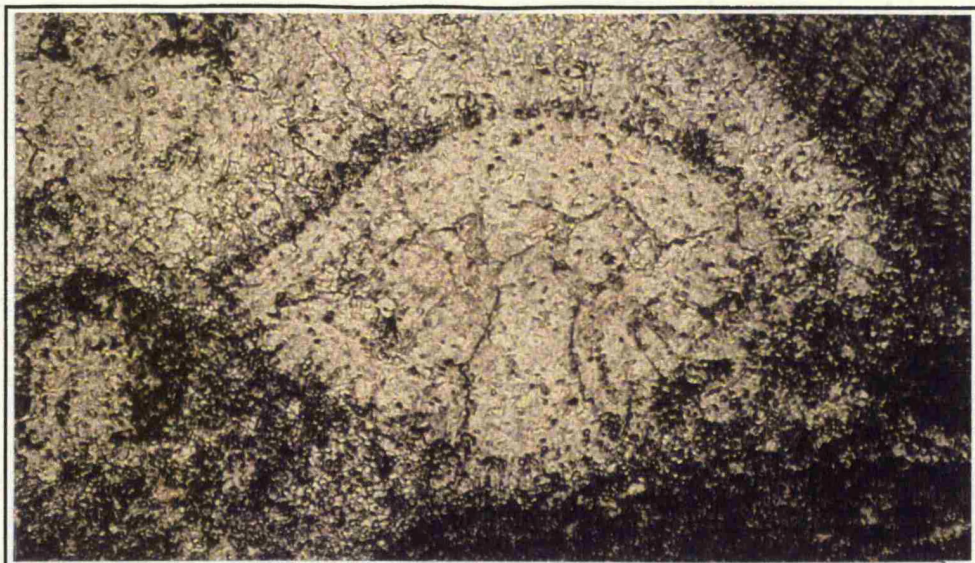
Thin section photomicrograph from sample RG 11, illustrating the micritic envelope around the foraminifera.

Fig. 8.2. B.

Thin section cl photomicrograph of the above photograph (RG 11), the micritic envelope shows dull luminescence, the chambers and the original shell are non-luminescent.

Fig. 8.2. C.

Thin section photomicrograph from sample RG 5, illustrating the process of dissolution and cementation. The molluscs fragments are totally dissolved leaving micritic envelopes around them, and then filled by non-ferroan sparry calcite cement.



A

400μm



B

400μm



C

1000μm

Fig. 8.2.

Interpretation:-

According to Scoffin (1987) peloidal cements are formed under active marine environment in reef frame. In recent sediments the peloidal cement is composed of high-Mg calcite and form in marine environment (Tucker and Wright, 1990). The peloidal cements occur in interskeletal and intraskeletal cavities, but they also form surficial crust on corals (Lightly, 1985). The origin of the peloids has been much discussed by Lightly, 1985; Macintyre, 1985; Chafetz, 1986; with five likely explanations: 1) an algal origin, 2) a replacement texture, 3) detrital sediment, 4) the product of pelletizing organisms or 5) in situ precipitation. In this study it is only present in the rhodolith platform and nummulitic facies which are considered to be the main carbonate accumulating facies. The peloidal cement is mainly present in algae rich facies and it is suggested that the peloids are made from algal origin. The cathodoluminescence studies show the lower concentration of Mn and Fe which takes place mainly in the marine water. On the basis of this it is suggested that the peloidal cements are developed in the marine environment.

8.4. Fresh-water Diagenesis:-

The freshwater phreatic zone (Fig. 8.1). lies between the vadose and the mixed marine phreatic-freshwater zones. All pore spaces in this zone were filled with meteoric water containing variable amounts of dissolved carbonate. The top of the phreatic zone is marked by the water table; the lower boundary is gradational with marine water in areas proximal to the sea. In inland areas, the freshwater phreatic zone graded downward into a zone with subsurface fluids which might contain brines deriving from

sediment compaction, clay dehydration, heating and differences in density. The geometry of the freshwater meteoric zone is controlled by topography, rainfall, and the distribution of porosity and permeability in the rocks. The saturation of water with respect to CaCO_3 may increase as water moves downward (Longman 1980).

Aragonite and high Mg-calcite are more soluble than low Mg-calcite in meteoric waters. Their dissolution leads to supersaturation with respect to calcium carbonate and, in the meteoric waters with a low Mg/Ca ratio, low Mg-calcite precipitates (Tucker and Wright, 1990).

During freshwater diagenesis both aragonite and high-Mg calcite are replaced by low Mg-calcite. As a result of these mineralogical changes, geochemical changes also occur (Gavish and Friedman, 1969) involving loss of cations present in the original marine carbonate and gains of other trace or minor elements from the meteoric fluid: strontium (from aragonite) and Mg (from high Mg-calcite) are depleted (Benson, 1974), while Mn and Fe (typically present in greater amount in groundwater than sea water) may be incorporated into the diagenetic low Mg-calcite. Changes in isotopic composition of carbonate also occur (Hudson, 1977).

The first investigations of meteorically altered Pleistocene carbonate shows them to be cemented by calcite and stabilized to low-Mg calcite (Land et al., 1967; Gavish and Friedman 1969). Many workers believe that meteoric diagenesis is the main cause of transformation of carbonate sediments to limestones. However, many limestones in the geological record did not undergo meteoric diagenesis, while others had only the weakest of meteoric overprints (Tucker and Wright, 1990).

8.4.1. Neomorphic Spar:-

Fig. 8.3. A.

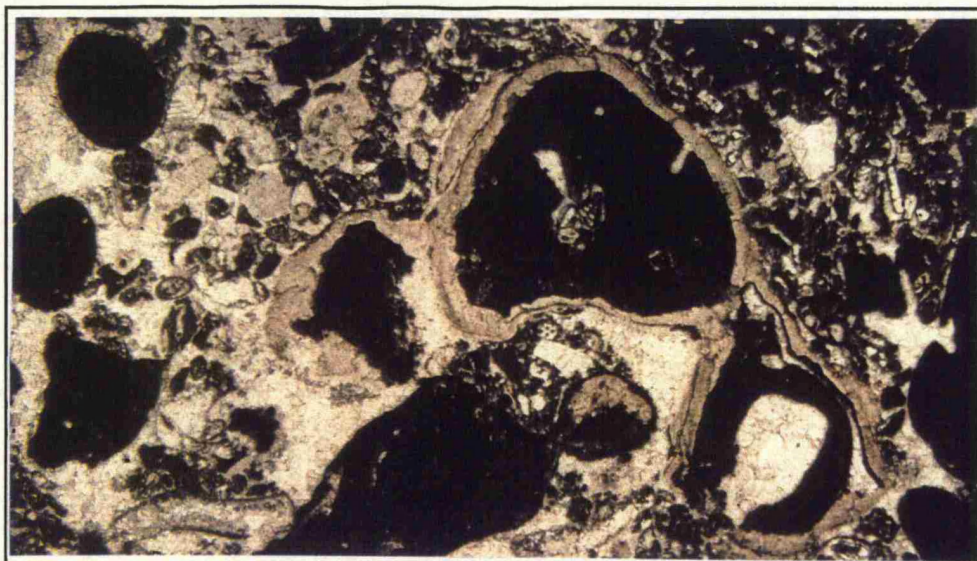
Thin section photomicrograph from sample RG 7 illustrating the coralline algal rhodolith structure encrusted by *peysssonnelia*.

Fig. 8.3. B.

Thin section photomicrograph from sample RG 29 illustrating the neomorphic spar having irregular boundaries and patches within the crystals.

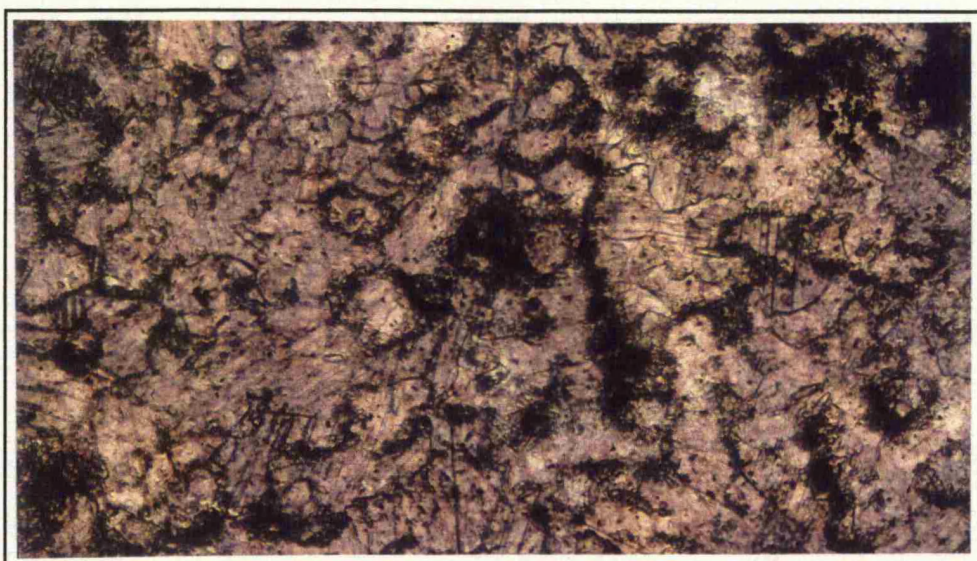
Fig. 8.3. C.

Thin section photomicrograph from sample RG 8 illustrating the process of dissolution, the ghost structure, the skeletal allochem is totally dissolved, the original structure of the allochem is totally destroyed, creating a mold porosity, which later on filled by sparry calcite cement.



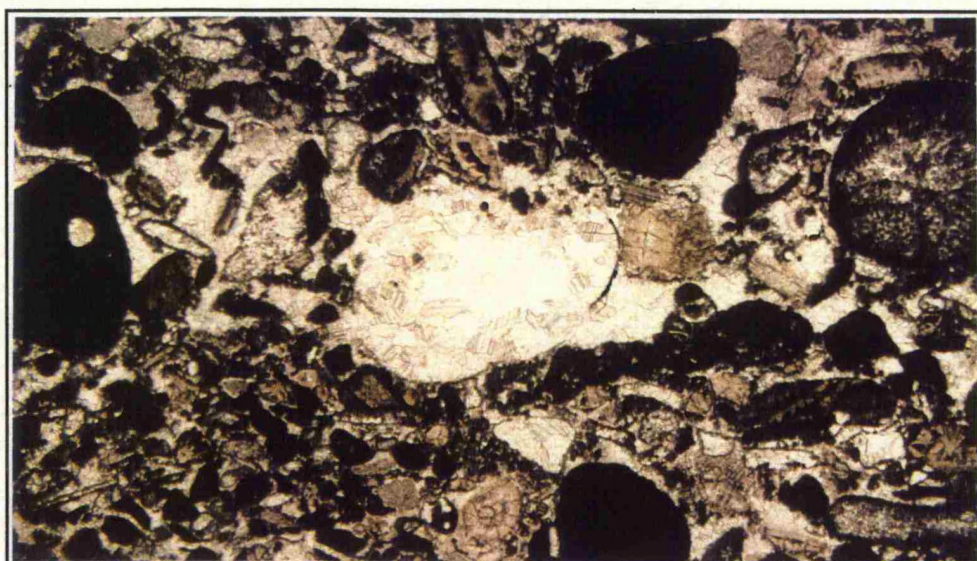
A

1000μm



B

200μm



C

1000μm

Fig. 8.3.

These are the microsparry calcite between the grains, and within the skeletal grains. The crystals are sub-equant to irregular in shape and have irregular intercrystalline boundaries (Fig. 8.3B). Extinction within the crystal, rarely uniform, is mainly patchy. The crystals stain pink and blue, and consequently they are non-ferroan and ferroan low magnesium calcite. There is little tendency for crystal size to increase into the pore space.

The dissolution and reprecipitation of the aragonite of shells, mainly molluscs, as a mosaic of sparry calcite is common in inner lagoonal, oolitic, outer lagoonal and rhodolith platform facies. The outer lagoonal and rhodolith platform facies are observed associated with recrystallization of some portions such as micritic matrix into microcrystalline calcite (Fig. 8.3B). Relics of the original grains can be faintly seen. Under cathodoluminescence microscopy the neomorphic spar crystals are mainly non luminescent but in some cases they show bright orange lines of luminescence.

Interpretation:-

Neomorphism is defined by Folk (1965) as transformation between one mineral and itself or a polymorph which results in the growth of new crystals that are larger or different in shape from the previous crystals. Carbonate minerals are very susceptible to such recrystallization. Neomorphism in the limestones described in this thesis was produced by micrite enlargement, a process by which crystals that measure only a few microns in diameter enlarge to a size measuring tens of microns in diameter. This micrite enlargement creates neomorphic products similar to cement in crystal size. The new crystals are known as pseudospar (Folk, 1965) or neospar (Nichols, 1967 and Flugal, 1982). Depending on water chemistry and rates of water flow, micrite may

recrystallize and be neomorphosed to coarser grains in freshwater phreatic environment or in a fresh water vadose environment (Longman, 1980; Flugel, 1982). The neomorphic microspar occurs in the updip part where pore water are fresh, and it is absent downdip where formation water is saline (Longman and Mench, 1978). Aggrading neomorphism has commonly taken place in fine grained limestones to give mosaics of microspar crystals (generally in the range of 5-10 μm) and coarser pseudospar crystals ($>30 \mu\text{m}$). This neomorphism may take place during early meteoric diagenesis (Tucker and Wright, 1990).

The neomorphic microspars are observed in outer lagoonal and rhodolith platform facies of the studied area. The size distribution of the individual crystals is usually random and devoid of any regular pattern. This neosparite exists as isolated patches and thus appears to be floating in the rock. The parts of limestone which have undergone extensive micrite enlargement display relic patches of non replaced micrite. These patches reveal that the limestone originally was a micrite rather than a sparite. In summary, it is concluded that the microcrystalline calcite cement was formed due to neomorphism.

8.4.2. Dissolution:-

The effect of dissolution is seen in almost all the facies particularly in oolite, outer lagoonal, rhodolith platform, nummulitic, and larger benthonic foraminifera facies. The petrographic investigation indicated that the sediments had been affected by probably only one stage of dissolution. This stage probably occurred after the precipitation of first calcite cement. This is indicated by the presence of moulds of large bivalve

fragments (which were probably aragonite originally) and vugs which are filled by large blocky calcite crystals (Fig. 8.3C), interpreted as representing a second generation of calcite cementation (drusy cement).

Interpretation:-

Undersaturated meteoric water dissolved carbonate sediments and limestones. The meteoric waters were acidified by atmospheric and soil CO₂, as well as by soil acids. Aragonite, being more soluble than calcite, underwent more rapid dissolution. The solution chemistries are complex and are discussed by Thraillkill (1968), Plummer et. al. (1979), Bogli (1980), Drever (1982), Trudgill (1985), and Lohmann (1988).

The effect of dissolution had a broad range of intensity and generally increased the porosity. Dissolution also formed solution vugs and mouldic voids which are locally interconnected by the enlargement of the basic intergranular porosity. As a matter of fact, the dissolution process had created a vast amount of vuggy and mouldic secondary porosity.

In the freshwater environment, the content of Mg²⁺ is normally low and the precipitation of low-magnesian calcite is no longer inhibited. So, the more soluble phases, aragonite and various Mg-calcite, dissolve and the Ca²⁺ ions are reprecipitated as calcite (Bathurst, 1975, 1980). Aragonite grains dissolved totally to give a mould which filled later with calcite cement (Fig. 8.3C). On the basis of above discussion it is concluded that the dissolution was caused by meteoric water.

8.4.3. Cementation:-

Fig. 8.4. A.

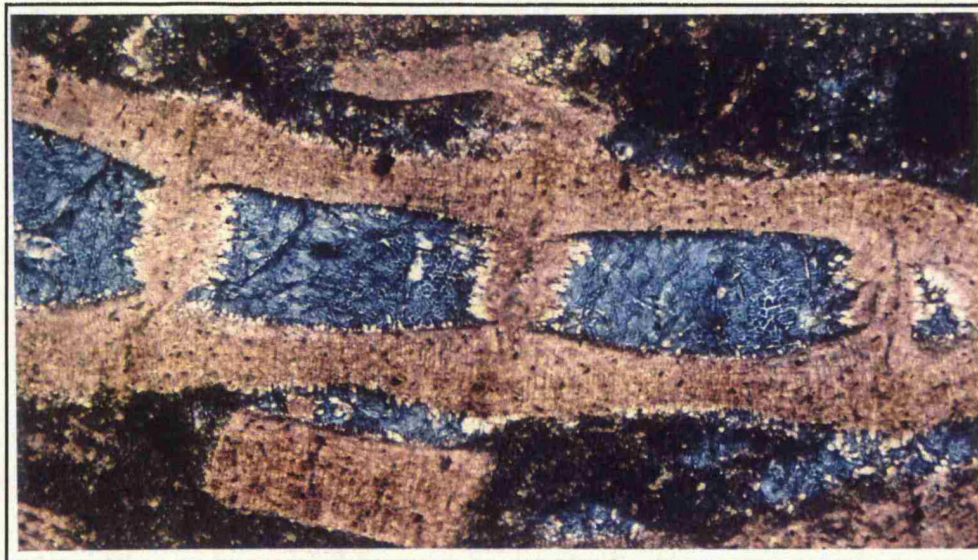
Thin section photomicrograph from sample ZP 24 showing the chambers of the foraminifera are filled by ferroan sparry calcite cement and the original structure of the foraminifera is unaltered.

Fig. 8.4. B.

Thin section photomicrograph from sample ZP 23 illustrating the isopachous bladed cement around the foraminifera. The isopachous bladed cement is non-ferroan whereas the drusy cement is ferroan. The chambers are filled partially by ferroan and partially by non-ferroan calcite cement.

Fig. 8.4. C.

Thin section cl photomicrograph from sample RK 13 showing the orange luminescence of isopachous bladed cement around the oolites.



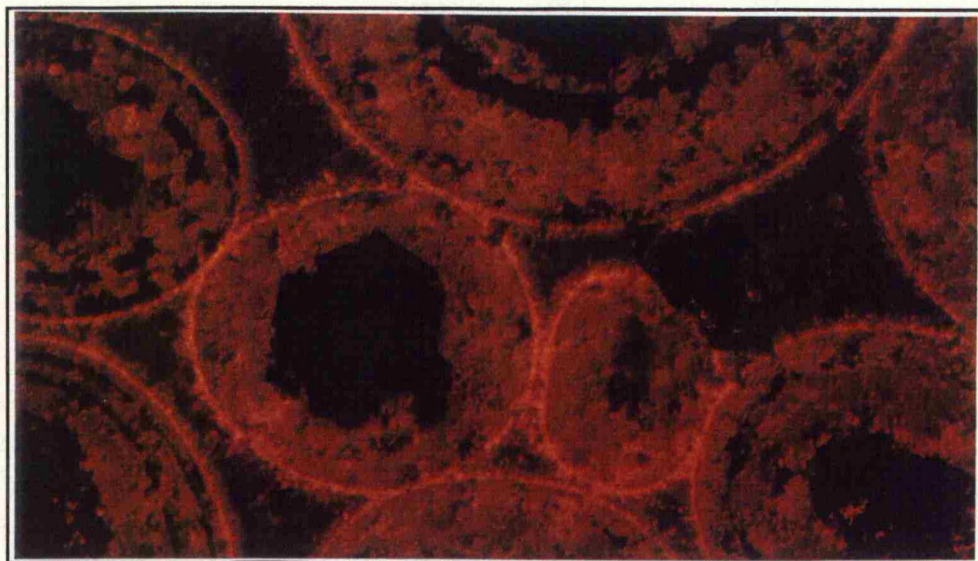
A

200μm



B

200μm



C

200μm

Fig. 8.4.

8.4.3.1. Isopachous Bladed Cement:-

Isopachous bladed cement is found in oolitic, outer lagoonal, rodolith platform, nummulitic and larger foraminiferal facies (Fig. 8.4A &B). As described in chapter five section 5.5.3, the isopachous bladed cement is in the form of thin uniform fringe surrounding ooids in the case of oolite, and on the walls of foraminifera and grow outwards into the pore space. In general isopachous bladed calcite crystals are fine grained and they are non-ferroan. Under cathodoluminescence microscopy they show bright orange luminescence (Fig. 8.4C).

Interpretation:-

According to Scoffin, (1987) isopachous bladed cements are found in the phreatic zone of permanent water where major changes in the mineralogy and texture of the original marine sediment takes place. There is an undersaturated zone near the level of water-table where solution is prevalent, and below this is the zone of active circulation of saturated water, calcite precipitated as a isopachous bladed cement. Pores in the freshwater phreatic zone are always filled with water, and so crystals can grow unimpeded except by intercrystalline competition, Thus cement rind formed here, at least in the shallow lenticular phreatic, are either well developed isopachous layers of calcite crystals around pore walls (Jones and Choquette, 1984). The cathodoluminescence microscopic studies indicate the higher concentration of Mn and Fe which is normally in the freshwater phreatic zone as compared to sea water, consequently, it is suggested the isopachous bladed cement is formed in the freshwater phreatic environment.

Fig. 8.5. A.

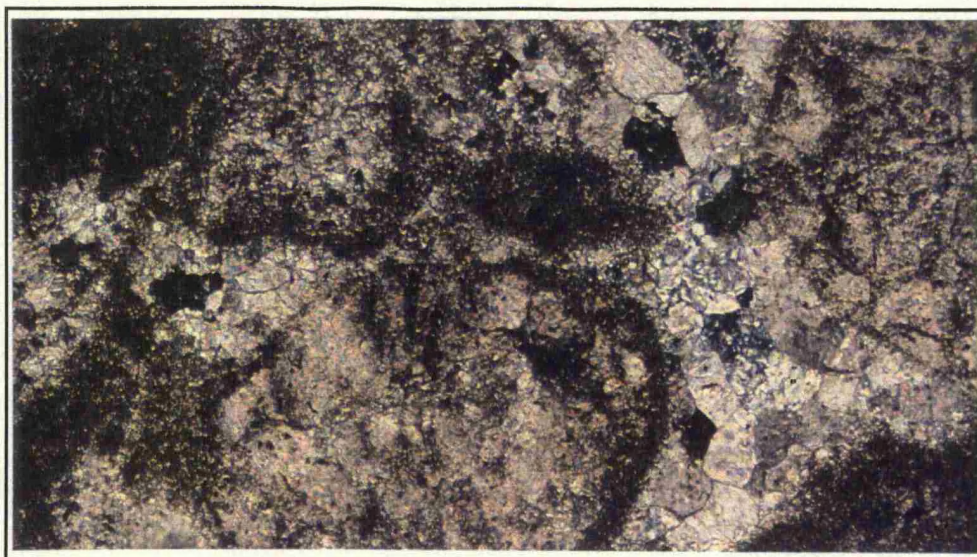
Thin section photomicrograph from sample RG 15 showing a) the micritic envelope around the foraminifera and b) the drusy cement in between the grains.

Fig. 8.5. B.

Thin section photomicrograph from sample RG 22 illustrating the drusy cement.

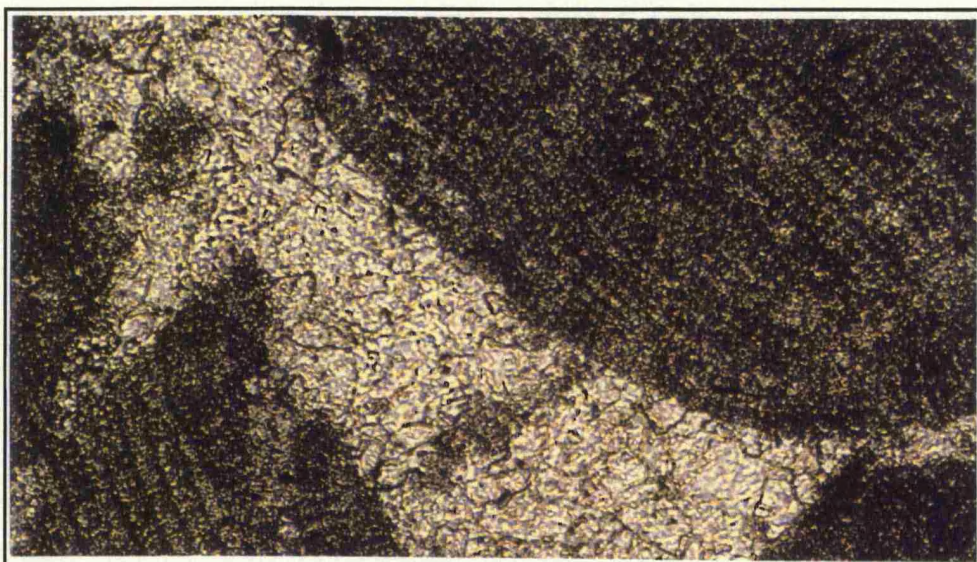
Fig. 8.5. C.

Thin section cl photomicrograph of the above photograph (RG 22) of drusy cement, showing the orange luminescence.



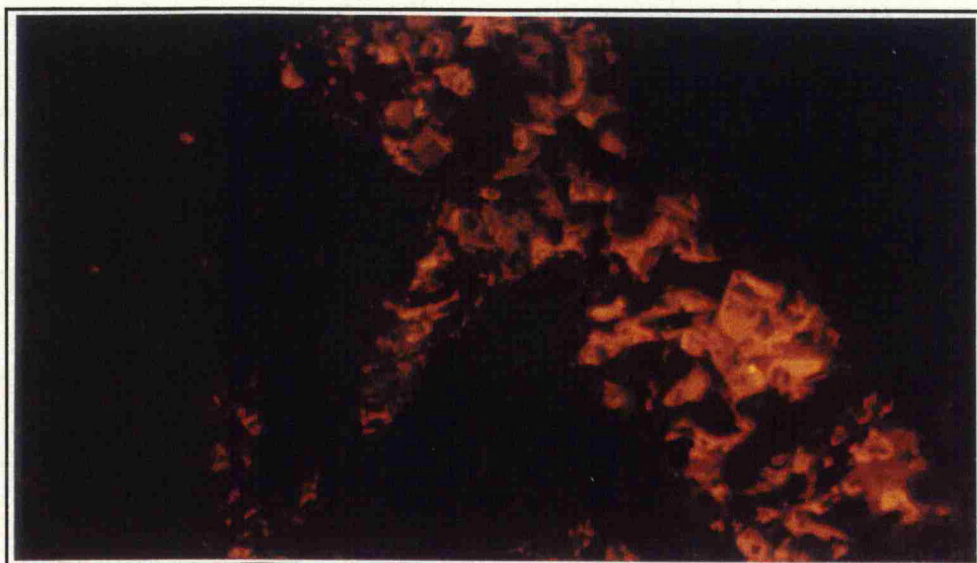
A

200μm



B

200μm



C

200μm

Fig. 8.5.

8.4.3.2. Drusy Cement:-

As described in chapter five section 5.5.4, the drusy cement is the major cement type which found in all the facies. This type of cement occurred, as all the aragonite dissolved and low magnesian calcite precipitated, both in the primary pores and the secondary pores by the dissolution of the aragonite grains. The crystal size of the drusy cement is $>10\text{ }\mu\text{m}$ and it increases from pore walls to the centre of cavity. The crystals are clear, anhedral to subhedral. The pore filling calcite is commonly an equant mosaic of ferroan and non-ferroan calcite (Fig. 8.5A & B). The morphology of these crystals is similar to those described by Longman (1982); i.e., crystals of void filling cement which are optically continuous over large areas and showing almost irregular boundaries.

Under cathodoluminescence microscopy this type of cement shows dull to orange luminescence (Fig. 8.5C). 198 analysis by electron microprobe of ferroan drusy cement show 1.9 mol% of MgCO_3 and the concentration of Fe, Mn, and Sr, is 8394, 1925, and 719 ppm respectively. 207 analysis of non-ferroan drusy cement were made. On the basis of these analysis the mol% of MgCO_3 is 1.21, and the concentration of Fe, Mn, and Sr is 874, 281, and 646 ppm respectively.

Drusy cement was picked from two samples for the carbon and oxygen isotope analysis. On the basis of these analysis $\delta^{13}\text{C}$ values ranges from -0.38 to 0.40, mean -0.39 PDB; and $\delta^{18}\text{O}$ ranges from -9.61 to 9.78, mean -9.70 PDB.

Fig. 8.6. A.

Thin section photomicrograph (from sample RG 39) of echinoderm fragment showing the syntaxial overgrowth cement.

Fig. 8.6. B.

Thin section cl photomicrograph of the above echinoderm fragment (RG 39). The syntaxial overgrowth cement showing the bright zoned luminescence, indicating different zones of Fe and Mn concentrations.

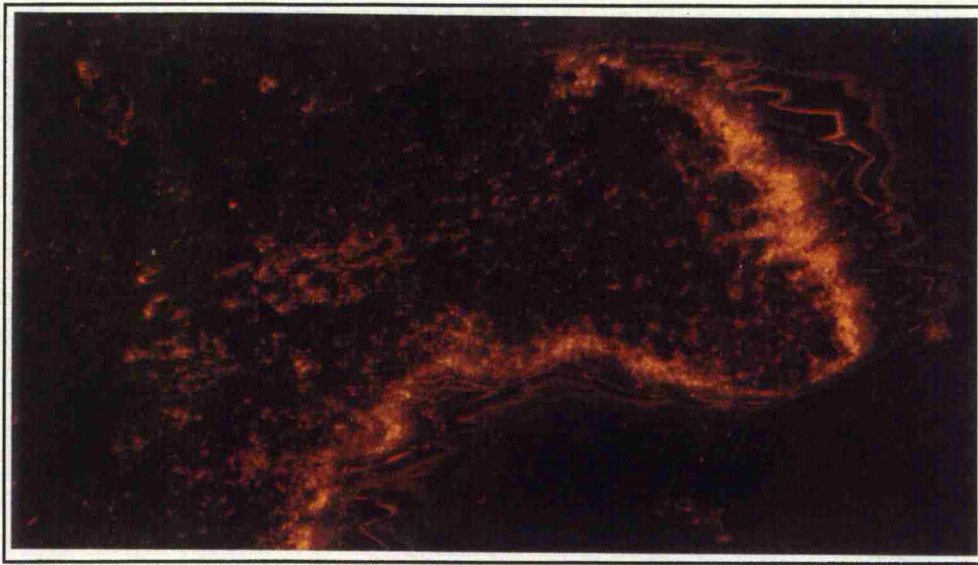
Fig. 8.6. C.

Thin section photomicrograph from sample ZP 40, illustrating most of the foraminifera chambers are filled by ferroan sparry calcite cement, whereas the walls of most of the foraminifera are unaltered.



A

200μm



B

200μm



C

1000μm

Fig. 8.6.

Interpretation:-

In the freshwater phreatic aragonite and high Mg-calcite are more soluble than low Mg-calcite. Their dissolution makes supersaturated solutions with respect to calcium carbonate resulting in precipitation of low Mg-calcite. In the studied thin sections the bioclasts have originally high Mg-calcite (foraminifera, coralline algae, echinoderms, and bryozoa) and aragonite (corals and molluscs). The aragonite grains dissolved in slightly acidic freshwater; thus, voids originated between the grains (as long as smaller particles or cements formed earlier can be dissolved) or in the grains (as long as micrite envelopes prevent the dissolution of the whole grains). During the dissolution of a great deal of material collapse structure resulted, after which calcite precipitated as cement in the voids or between the particles. The carbonate supersaturated water precipitated calcite cement which rapidly closed the original pores. Bioclasts consisting of high Mg-calcite are an exception (e.g. coralline algae); they inverted to calcite without destroying their original structure (Richter, 1979). The cathodoluminescence studies suggest the higher concentration of Mn and Fe in the drusy cement, which is further confirmed by the electron microprobe analysis. The drusy cements are typically clear, blocky calcite, with rich in iron and Mn (Tucker and Wright, 1990). Such cements show normally dull luminescence with minor bright zones (Neimann and Read, 1988) reflecting the apparently original nature of the shallow meteoric waters. Down dip, reducing conditions develop resulting in calcite capable of luminescence. Stable carbon oxygen isotopes values are also more negative as compared to that of whole rock (Table 7.6). $\delta^{18}\text{O}$ values for marine limestones ranges from +1 to -1, and for freshwater limestones it ranges from -4 to -12 PDB, (Veizer and Hoefs, 1976, Hudson, 1977 and many others). The present study indicates that the drusy cement has

an average value of $\delta^{18}\text{O}$ -9.70 PDB, which is agreement with their conclusions. In summary, on the basis of this discussion it is suggested that the drusy cement was formed in freshwater phreatic environment.

8.4.3.3. Syntaxial Overgrowth Cement:-

This type of cement is present in all the facies except planktonic foraminifera facies, but it is common in outer lagoonal, rhodolith platform and nummulitic facies. As described in chapter five section 5.5.5, the syntaxial overgrowth cement commonly forms on echinoderm fragments and it has been described by Evamy and Shearman (1965) and many others. The calcite of echinoderm fragments and of the inner parts of the overgrowths remained iron free calcite. The outer part of each overgrowth, however, showed a succession of zones of varying iron contents (Fig. 8.6A). The outlines of these zones represented the shape of the overgrowth at the various stages in their development. Under cathodoluminescence microscopy the syntaxial overgrowth cement shows bright zoned luminescence around the echinoderm fragments which represents the various zones of varying concentration of Mn and Fe contents (Fig. 8.6B).

Interpretation:-

According to Evamy and Shearman (1965), the syntaxial overgrowth cement served as an important clue for distinguishing the various diagenetic environments. Syntaxial overgrowths form most rapidly in the freshwater phreatic environment and generally surround the grains although they may be elongate along the c-axis. Because of the

large crystal nucleus and absence of competitive crystal growth, they grow much faster than cements from adjacent non-echinoderm grains, as shown by the larger proportion of the pore they fill. According to Longman (1980), syntaxial overgrowths form most commonly in freshwater phreatic environment, they may also form in vadose (rarely) and deeper subsurface diagenetic environments.

The syntaxial overgrowth cement is very common in the studied sections. According to cathodoluminescence studies the concentration of Mn and Fe are high in the syntaxial overgrowths. On this discussion it is suggested that the syntaxial overgrowth cements are developed in the freshwater phreatic environment.

8.5. Shallow Burial Diagenesis:-

8.5.1. Compaction:-

As described in chapter five section 5.8, the effect of compaction is seen in larger foraminiferal and planktonic foraminiferal facies. Compaction is a common diagenetic process in carbonate rocks, and compactional processes are generally divided into two categories; mechanical and chemical processes. Mechanical compaction begins soon after deposition. Sediments of the Dungan Formation generally show only shallow burial compaction, as bioclasts are preserved without deformation or breakage in the studied thin sections. The bioclasts were probably preserved from compaction by early cementation of these sediments. The textures produced by mechanical compaction are recognised and occurred in few facies. In oolite, rhodolith platform and nummulitic facies the grains have point contacts with each others, whereas in larger foraminifera facies the grains have a concavo-convex contacts with each other (Fig. 8.6C).

Fig. 8.7. A.

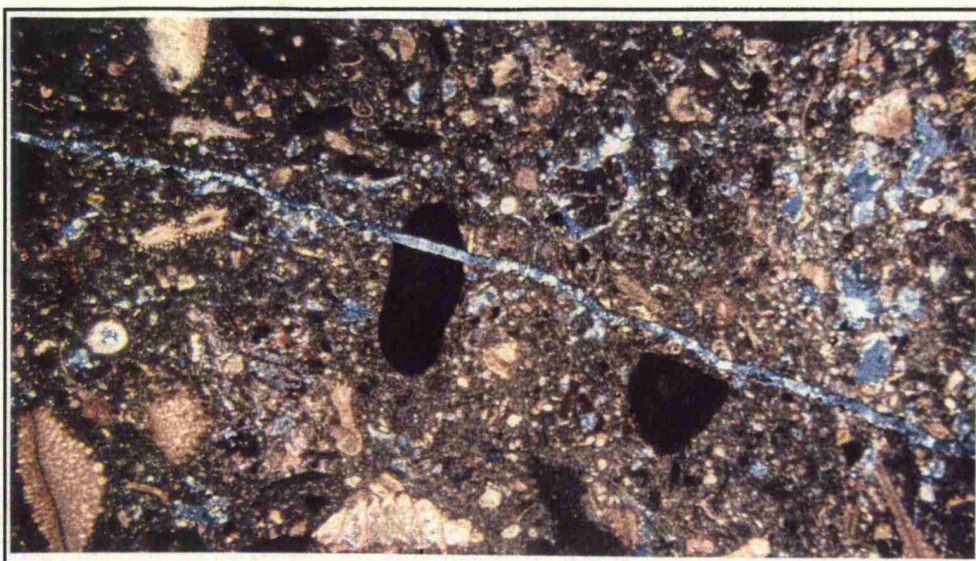
Thin section photomicrograph from sample ZP 25, illustrating the ferroan calcitic vein intersecting the skeletal allochems, indicating the late generation of the vein.

Fig. 8.7. B.

Thin section photomicrograph (from sample RG 24) of the non-ferroan calcitic vein, showing the irregular boundaries and anhedral to subhedral crystals.

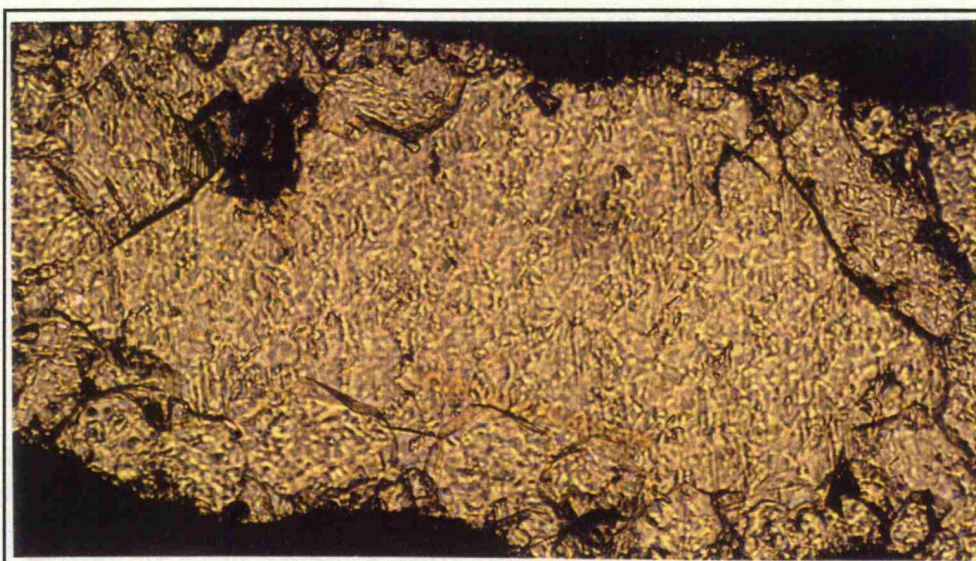
Fig. 8.7. C.

Thin section cl photomicrograph of the above vein (RG 24), illustrating the bright zoned luminescence. The zones can be differentiated, showing different concentrations of Fe and Mn.



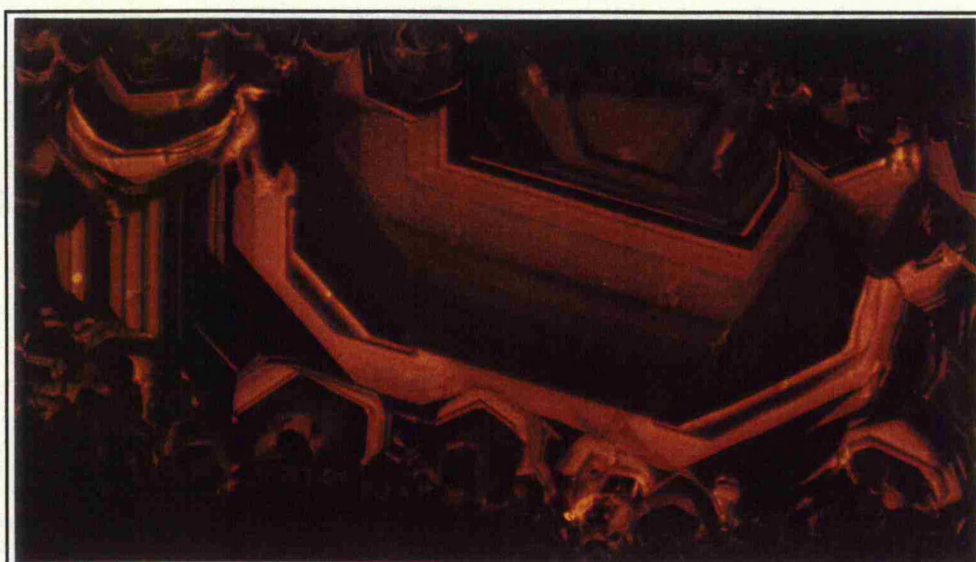
A

1000 μ m



B

200 μ m



C

200 μ m

Fig. 8.7.

8.5.2. Pressure Dissolution:-

8.5.2.1. Dissolution Seams:-

Dissolution seams as described in chapter five section 5.8, are recognised in the planktonic foraminifera facies only, as this facies is more argillaceous. These are smooth, undulose seams of insoluble residue which lack the distinctive sutures of stylolites. Wanless (1979) described them as the non-sutured seams which pass around and between grains, rather than cutting through them. They are common in more argillaceous limestones, and develop preferentially along thin clay layers or at the junction of clay-rich and clay-poor limestones.

8.5.2.2. Stylolite:-

The stylolites are seen only in the larger benthonic foraminifera and planktonic foraminifera facies as described in chapter five section 5.8. The seams of the stylolite usually consist of residues of dark material. The maximum amplitude observed is 1cm. although the length of the stylolite peaks is variable and ranges down to 1mm (Fig. 5.7B).

Dunnington (1967) suggested that undersaturated pore fluids play a role in the formation of stylolites and are necessary for solution-compaction processes. This requires increased overburden pressure or undersaturated water from an outside source (Becher and Moore, 1979). Solution results in the formation of stylolitic boundaries between clasts in response to the overburden pressure. Compaction and

Fig. 8.8. A.

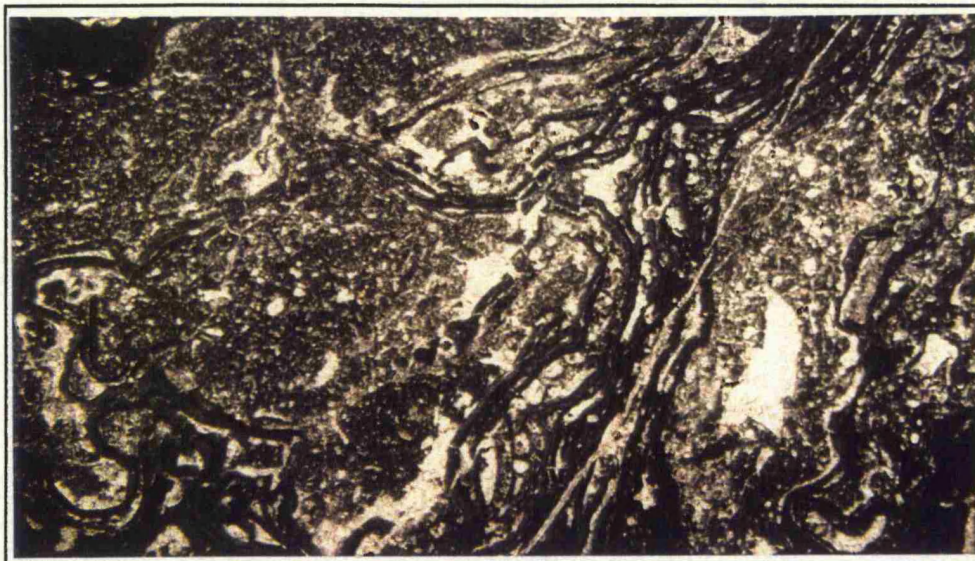
Thin section photomicrograph from sample RG 31, illustrating the micritization (may be rhodolith coralline algae) by boring algae.

Fig. 8.8. B.

Thin section photomicrograph (from sample RG 21) of drusy cement showing irregular boundaries and the crystal size increases towards the centre of the pore space.

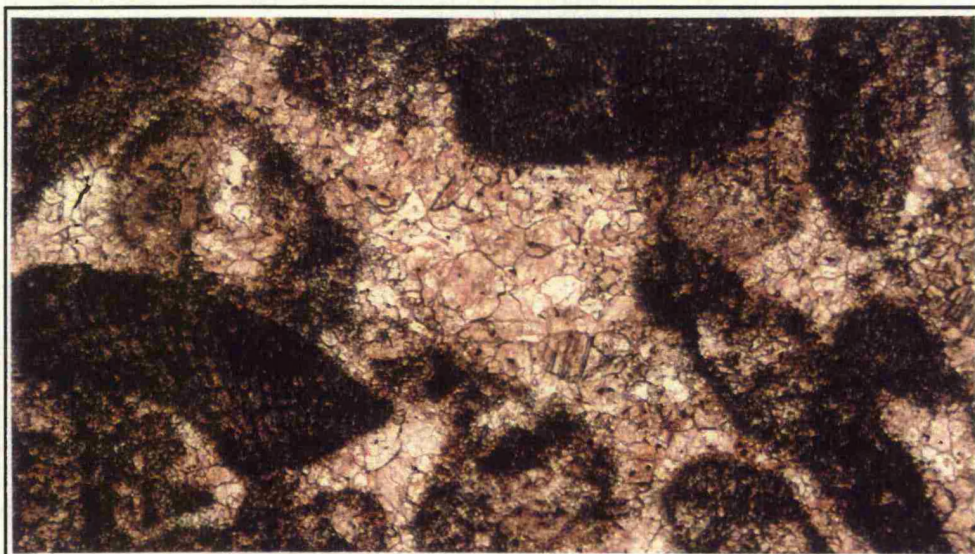
Fig. 8.8. C.

Thin section photomicrograph from sample ZP 39, illustrating the shallow burial environment in which the drusy cement and the walls of the foraminifera became ferroan.



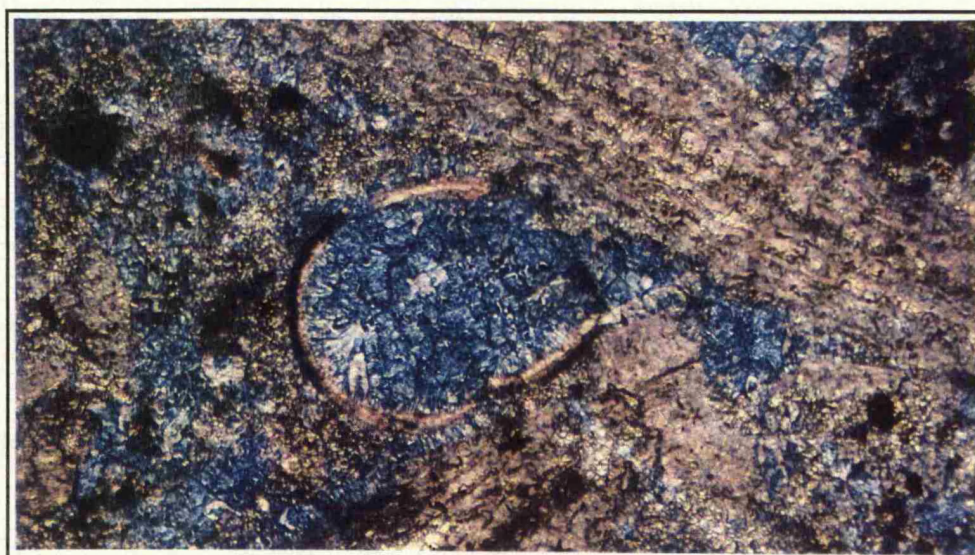
A

1000 μ m



B

200 μ m



C

200 μ m

Fig. 8.8.

tight packing of clasts could be the result of this pressure solution (Longman, 1980).

8.5.3. Fractures and Veins:-

There are two generations of calcite filled fractures/veins, early fractures which are distinguished from the later generation by being cross-cut by them. The early fractures are filled by non-ferroan calcite cement, whereas the later veins are filled by ferroan calcite cement.

8.5.3.1. Early Fractures:-

The fractures are seen in almost all the facies of the studied area. The characteristic feature of the cement fill, is pink stained non-ferroan calcite. The fracture filling calcite crystals are larger than the drusy cement, anhedral to subhedral, and have irregular boundaries. The veins are generally small ranging up to several centimeters in length and ranging from 0.3mm to 0.8mm in width (Fig. 8.7B). Most of the fractures run parallel to each other. Under cathodoluminescence microscopy they show bright zoned luminescence (Fig. 8.7C), which indicate the different zones of concentration of Mn and Fe contents. Three samples of cement filling the fractures were picked for carbon and oxygen isotope analysis. On the basis of these analysis $\delta^{13}\text{C}$ values ranges from -0.03 to -2.17, mean -0.89 PDB; and $\delta^{18}\text{O}$ ranges from -10.77 to -13.42, mean -11.96 PDB.

Interpretation:-

These early fractures are interpreted as mechanical fractures that developed after lithification, probably during burial. These fractures are filled by sparry calcite cement under shallow burial freshwater environment, as the concentration of Fe and Mn are high in the cement (on the basis of cathodoluminescence microscopy). The concentration of Fe and Mn are high in fresh water as compared to sea water. The average $\delta^{18}\text{O}$ values of cement filling fractures is -11.96 PDB, which also indicates that the cement is formed in freshwater environment (Hudson, 1977; Allan and Matthews, 1977 and 1982).

8.5.3.2. Later Veins:-

These later veins are observed in the rhodolith platform, nummulitic and larger benthonic foraminifera facies. The characteristic features of the cement filling veins is blue stained ferroan calcite. The veins are generally larger ranging up to several centimeters in length and ranging from 0.3 mm to 0.7 mm in width. They run parallel to each other but intersect the early fractures/veins (Fig. 8.7A). They are filled by equant anhedral to subhedral calcite crystals. Under cathodoluminescence microscopy they show bright lines of luminescence.

Five samples of cement filling the veins are picked for carbon and oxygen isotope analysis. On the basis of these analysis $\delta^{13}\text{C}$ values ranges from +1.38 to +0.91, mean +1.20 PDB; and $\delta^{18}\text{O}$ ranges from -7.08 to -10.59, mean -9.12 PDB.

Interpretation:-

These veins are also filled by sparry calcite cement which are mainly ferroan. They

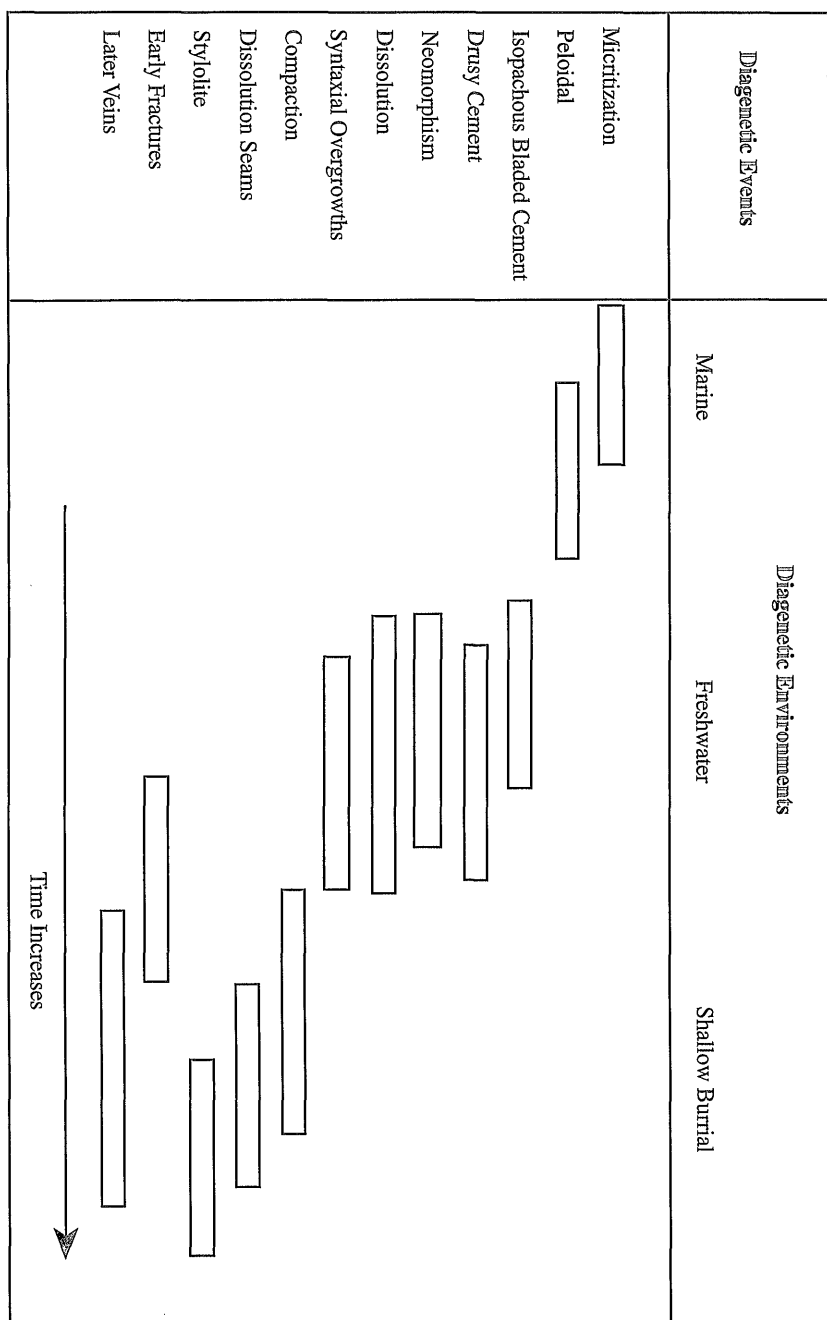


Fig. 8.9.: Different diagenetic events observed in Dungan Formation in relation to both time and diagenetic environments.

indicate the freshwater phreatic environment as the fresh water has more concentration of dissolved Mn and Fe ions as compared to sea water. The $\delta^{18}\text{O}$ values (-9.12 PDB), further strengthen the view of a fresh water diagenetic environment (Hudson, 1977; Allen and Matthew, 1977, and 1982). $\delta^{18}\text{O}$ values of later veins are greater as compared to early fractures which indicates that the later veins are formed probably later under shallow burial environments by formation water. On the basis of this discussion it is suggested that the later veins were formed at later stage in shallow burial freshwater phreatic environment.

8.6. Diagenetic History of Dungan Formation:-

With the marine, freshwater, and shallow burial environments and the variable array of cement texture that may be produced in each zone, interpreting diagenetic history is complex. However, sufficient evidence exists for the interpretation of these events and these are shown in Figure 8.9.

The sediments of the Dungan Formation were deposited in the shallow marine environment and they are composed of red algae, foraminifera, molluscs, bryozoa, coral and echinoderm fragments. They contain both aragonite (coral and molluscs) and high Mg-calcite (red algae, foraminifera, bryozoa and echinoderm) grains. Marine water saturated the pores. The first stage of diagenesis occurred after the deposition in the relatively stagnant marine phreatic environment in the form of micritization of grains by boring algae (Fig. 8.8A). The micritic envelopes were formed around the grains. Minor cementation occurred inside small pores of the red algae and foraminifera, perhaps because of bacterial activity (Longman, 1980). No alteration of

grains nor leaching occurred.

Then it entered into the freshwater phreatic zone. In this zone cementation occurred and all pore spaces were filled with equant calcite cement (drusy cement). The cement coarsened towards the pore centres (Fig. 8.8B). Bladed isopachous cement formed on some grains if the cements nucleate on the grains and grow fastest along a preferred crystallographic axis (Longman, 1980). Syntaxial overgrowth cements formed on echinoderm fragments and grew more rapidly than the cement on adjacent grains. Because the water was saturated with respect to calcite, no leaching of the grains occurred prior to cementation. Recrystallization of unstable grains to calcite took place. Meanwhile diagenesis continued in the zone of undersaturation with aragonite. Aragonite leached from the original grains to produce mouldic porosity. The solution also attacked some Mg-calcite grains and these Mg-calcite grains neomorphosed to calcite without undergoing a solution stage. Cement so formed, in the pores of red algae, was more stable than the red algae itself. Reprecipitation of the dissolved material as equant calcite (drusy cement) occurred almost simultaneously with solutions. Then it changed into the shallow burial environment. In this environment, compaction of the skeletal grains, dissolution seams and stylolite and features/veins were developed. Finally the veins were formed in the freshwater phreatic zone. The early fractures were filled by the equant calcite (non-ferroan) and the veins were filled later on under shallow burial environments by the formation water, and these veins cut the original grains and early features and some of the drusy cement also became ferroan (Fig. 8.8C).

Chapter Nine

CONCLUSIONS

The present work done on the sediments of Dungan formation in the Sulaiman Range, Pakistan, is summarized with the following conclusions.

- Eight microfacies have been identified on petrographic studies.
- These microfacies from landward to seaward, and are peritidal carbonates; inner lagoonal; oolitic; outer lagoonal; rhodolith platform; nummulitic; larger foraminiferal; and planktonic foraminiferal facies.
- The homoclinal, windward, carbonate ramp model is suggested for the palaeoenvironments of Dungan Formation, on which all these facies can be interpreted to have been deposited.
- The inner ramp has the microfacies of peritidal carbonate, inner lagoon, and oolitic facies.
- The middle ramp has the microfacies of outer lagoon, rhodolith platform and the nummulitic facies.
- The outer ramp has the microfacies of larger foraminiferal (other than nummulites, such as, *Discocyclina* and *Athecocyclina*) and planktonic foraminiferal facies.
- The inner ramp facies are mainly grainstone and packstone, with clastic material. The skeletal allochems are molluscs and foraminifera, which are in very small amount. The non-skeletal allochems are oolites and are confined in oolitic facies. The middle ramp facies are mainly wackestone and packstone with negligible

amount of impurities. The skeletal allochems are mainly the red coralline algae in rhodolith structure, and benthonic foraminifera. The outer ramp facies are mainly mudstone with clay minerals. The skeletal allochems are mainly the larger benthonic foraminifera and the planktonic foraminifera.

- The sediments were deposited in the shallow marine environments and they are subjected to fresh water environment for diagenesis.
- The diagenetic cements are of two types, marine cement and fresh water cement. The facies which have a greater percentage of allochems as compared to drusy cement are inclined to marine environment where as the facies having less percent of allochems as compared to drusy cement are inclined to fresh water environments.
- The whole rock $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values increases with depth. In inner ramp facies the values are less as compared to mid ramp. The outer ramp facies have the highest values of stable carbon and oxygen isotopes.
- $\delta^{18}\text{O}$ values increases with increasing the percent of foraminifera present in Dungan Formation.
- It has been found if the concentration of Mn is equal to or more than 100 ppm, calcite shows luminescence. The intensity of luminescence increases with increasing concentration of Mn provided the Fe/Mn ratio is constant.
- If the Fe/Mn ratio is less than one it shows bright luminescence, and if it is more than one it shows dull luminescence.
- It is suggested few more sections may be studied to establish the lateral extent of the microfacies identified in the present work.

APPENDIX 1

Details of the method used for staining the thin sections.

The thin sections were stained according to the technique of Dickson (1966), which is modified from Friedman (1959), and summarised by Adam et al., (1984) as follows,

1- Prepare two staining solution

A. Alizarine Red S of 0.6 gm per 300 ml of 1.5% HCl (15 ml pure HCl made up to one litre with deionised water).

B. Potassium ferricyanide of 4.0 gm per 200 ml of 1.5% HCl.

2. Mix the solution A and solution B in the proportion 3 parts volume of A to 2 parts of B.

3. Immerse the thin section in a mixture of solution for 30 to 45 seconds.

4. Washed the stained thin section in running water for few seconds. Allow to dry and then cover the thin section with glass cover.

APPENDIX 2

Details of the method used for Cathodoluminescence Microscopy.

One hundred and thirty polished thin-sections from the Dungan formation were examined by Technosyn Cold Cathodoluminescence Model 8200 Mark II. Operation conditions were 16-20 kV gun potential, 420 μ A beam current, 0.05 Torr vacuum and 5 mm beam width.

The luminescence is produced when atoms absorb one form of energy and emit energy as visible light. Cathodoluminescence is produced from the absorbed energy produced by an electron beam. Many materials luminesce when excited in this manner (Smith and Streastorm, 1965). The colour of emitted radiation tends to remain constant for the range of voltages used in cathodoluminescence (10 to 20 kV).

APPENDIX 3

Details of the method used for XRD.

Fifty samples from the Dungan Formation were crushed into 5mm or less size using a flypress. These samples were ground into 50 μm or less size using the Tungsten Carbide Tema Mill (T100) for 30 seconds. The samples were finally micronised to reduced in size from 5 to 10 μm by McCrone Micronizing Mill Model Ompron H3BA for about 10 minutes and dried in a furnace at 100 °C for overnight.

A Philip PW 1729 x-ray diffractometer generator attached to PW diffractometer controlled by Sieronics Sie 1710 Software running on a Viglen 386 computer were used. The operating conditions were as follows:

X-ray radiation	Cu, k alpha	
Generator voltage and current	Kv m, A 40, 30	
Scanning speed	1°/min.	Time constant 2 sec.
Start position	2 θ	End position 65 θ
Count full scale	2000 counts/sec.	
Tube	Coppe	
Filament	Nickel	

APPENDIX 4

Details of method and precision used for Microprobe Analysis.

Polished thin sections were carbon coated in order to determine the major elements using the Microprobe instrument JEOL JXA-8600S, with an on-line computer for ZAF corrections.

The running conditions were as follows;

Beam conditions:

Accelerating Voltage	15kV
Probe Current	30nA
Beam Diameter	15 μ m

Analysed Elements:

Element	X-ray line	Analysing crystal	Count time peak	Count time (-) Bg	Count time (+) Bg	Standard
Ca	K α	PET	20	10	10	Wollastonite (natural)
Mg	K α	TAP	20	10	10	MgO (synthetic)
Fe	K α	LiF	20	10	10	Fe ₃ O ₄ (synthetic)
Mn	K α	LiF	20	10	10	Rhodonite (natural)
Sr	K α	PET	20	10	10	SrF ₂ (synthetic)
Ba	K α	LiF	20	10	10	Barite (natural)

The carbonate was analysed for all common major oxides (i.e. CaO, MgO, FeO, MnO, SrO, and BaO) and the amount of CO₂ was calculated by difference. The accuracy of the ZAF correction is as follow;

The minimum detection limit (MDL) (3 σ), average calcite analysis (TC), and degree of precision (2 σ) for probe analysis is given as;

Oxide	MDL(3 σ)	TC	Precision(2 σ)
CaO	0.03	55.60	0.35
MgO	0.02	0.62	0.03
FeO	0.04	0.13	0.06
MnO	0.05	0.05	0.06
SrO	0.06	0.18	0.07
BaO	0.14	0.14	0.18

Precision and Accuracy:-

Precision (2σ) and minimum detection limits (MDL) (3 above background) are calculated from the standard deviations of the raw intensity data, propagated through the calculation. Precision, and to a lesser extent MDL, is dependent on chemistry and varies from analysis to analysis even within the same set of analytical conditions.

Accuracy is difficult to determine for microprobe data, since independent analysis of the same microvolume of potentially zoned or otherwise inhomogeneous material is not possible.

APPENDIX 5

Details of method and precision used for X-ray Fluorescence Spectrometry.

The major element analysed were carried out on glass discs (fusion beads). Procedure adopted for the preparation of each of the beads is as follow:

Approximately 5 gm of each of the powdered sample was dried overnight at 110 °C to remove adsorbed H₂O. The dried samples were used for determining the weight loss of ignition values (LOI) (H₂O⁺). To do this, each of the dried samples was weighted, heated in a muffle furnace at 950 °C for 90 minutes, and reweighted after cooling in a dissicator. 1.0 gm of the dried sample was thoroughly mixed with 5.0 gm of flux (lithium tetraborate). The weight loss of ignition of the flux was determined each day by fusing it at 1100 °C for about 15 minutes. An amount equal to this value was added to that (5.0 gm) used for making a bead. This is important to mention that ignited, instead of dried, samples were used in case of carbonate-poor rocks (i.e. samples with LOI<18%).

The homogenised mixture of sample and flux was fused in a Pt(95%)-Au(5%) crucible over a Spartan Bunsen burner at 1200 °C for 20-25 minutes. During this period, the crucible was swirled periodically over the burner to eliminate gas bubbles and ensure a through mixing and homogeneity of the melt. After fusion, the melt was cast between the Pt(95%)-Au(5%) disc and left there for sometime to ensure annealing. The bead was brought to room temperature gradually by leaving overnight between hot sindanyo bricks. The beads, now ready for chemical analysis, was labelled and stored in a polythene bag.

The analyses were carried out on a Philips 1400 x-ray spectrometer and ARL 8420+ spectrometer, each equipped with rhodium anode x-ray tube. Each of the bead was analysed for SiO₂, TiO₂, Al₂O₃, MnO, CaO, Na₂O, K₂O, and P₂O₅. Fusion beads giving the total falling outside the acceptable range (98.5 to 101.5%) were remade from the fresh aliquot of the original dried (or ignited, in case of carbonate-poor rocks) sample. The standards such as ARCaCO₃, NIM-G, MRG-1, W-1, JB-1A, JA-3, JR-1, JG-3, WS-1car, BH-1car, JA-2, ARSIO2, BCS376 and ARAL2O3, were alternately run with each batch of samples to monitor and quantify the precision and accuracy of the machine.

For the acquisition of trace element data powdered discs were prepared. Following are the details of method used for the preparation of each powder pellet:

Approximately 15 gm of overnight dried sample at 110 °C was placed into a small glass beaker. A small amount (20-26 drops) of Mowiol 88 (a solution of polyvinyl alcohol in a 1:5 mix of methanol and distilled, deionised water) was added and thoroughly mixed, with the help of a glass rod, to bind the powder into small lumps. This mixture was then placed in a small die and pressed into the shape of a pellet by applying a pressure of 15 tons per square inch by means of a hydraulic press. The pellet was allowed to dry overnight. Next morning the pellet was labelled and stored in a small polythene bag.

The powder pellets were run on a Philips PW 1400/10 XRF equipped with either a 3KW rhodium or tungsten anode tube. Each of the sample was analysed for the following elements: Ba, Cr, Cu, Mo, Ni, Pb, Rb, S, Sr, V, Zn, and Zr. A set of international and internal standards was run with each batch of samples to monitor the accuracy and precision of the machine.

APPENDIX 6

Details of the method used for Stable Isotope Analyses.

Powdered samples from whole rock limestone and picked cement from the rock sample by hand drill were analysed at NERC Isotope Geosciences Laboratory, Keyworth, by Mass Spectrometry for carbon and oxygen isotopes.

The samples were prepared for isotope determination using the phosphoric acid reaction method of McCrea 1950. Stable isotope determinations of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ were carried out on a triple collector VG SIRA 10 Mass Spectrometer.

Results are reported relative to the PDB standard and the estimated overall analytical reproducibility is $\pm 0.1\%$.

APPENDIX 7

Table. A6.1. Point counting data. All components are in percent.

Sample No.	RK53	RK54	RK55	RK56	RK57	RK59	RK60	RK61	RK62
Facies	1	1	1	1	1	1	1	1	1
Algae	0	0	0	0	0	0	0	0	0
Forams	0	0	0	0.4	0	0	0	0	0
Echinoids	0	0	0	0.4	0	0	0	0	0.8
Molluscs	0	0	0	0	0	0	0	0	0
Bryozoa	0	0	0	0	0	0	0	0	0
Coral	0	0	0	0	0	0	0	0	0
Unidentified	4.4	2.4	0	6	0.8	0	2	2	3.8
Total Allochems.	4.4	2.4	0	6.8	0.8	0	2	2	4.8
Oolites	0	0	0	0	0	0	0	0	0
Cement	24.4	18.8	34.8	18.8	12.8	12.8	13.6	12.8	11.6
Matrix	0	0	0	0	0	0	0	0	0
Non-Carbonate	71.2	78.8	65.2	74.4	86.4	87.2	84.4	85.2	83.6
Total	100	100	100	100	100	100	100	100	100

Sample No.	RK12	RK21	RK22	RK23	RK24	RK35	RK39	RK40	RK41
Facies	2	2	2	2	2	2	2	2	2
Algae	0	0.2	0.2	0	0.2	0	0	0	0
Forams	0.2	0.6	1.2	0.8	0.8	0.8	0.4	1.2	0.8
Echinoids	0	2.6	0.8	0.6	0.2	0.4	0.4	0	0.4
Molluscs	0	3.2	0.6	0.4	1.2	0.8	2	0.4	4
Bryozoa	0	0.8	0.8	0.2	0.2	0	1.2	0	0.8
Coral	0	0	0	0	0	0	0.4	0	0.4
Unidentified	0.8	8	3	4.2	5.4	0	0	0	3.6
Total Allochems.	1	15.4	6.6	6.2	8	2	4.4	1.6	10
Oolites	0.2	5	0.2	0	0	0	5.2	5.2	5.6
Cement	40	31.6	49.2	45.2	57	23.6	30	18.4	51.2
Matrix	0	18.8	0	0.2	0.2	12	6.8	6	0
Non-Carbonate	58.8	29.2	44	48.4	34.8	62.4	53.6	68.8	33.2
Total	100	100	100	100	100	100	100	100	100

Sample No.	RK42	RK43	RK48	RK49	RK50	RK51	RK13	RK14	RK17
Facies	2	2	2	2	2	2	3	3	3
Algae	0	0	0	0	0	0	0	0	0.4
Forams	2.4	0.4	1.2	0.8	0	0	0.6	1	1
Echinoids	2	0	1.2	1.6	0.4	0	0.6	1.6	3.4
Molluscs	0.8	1.2	0.4	0.4	0	0	0.6	1.4	11.2
Bryozoa	0	0.4	0	0	0.8	0	0	0.8	0
Coral	0	0	0	0	0	0	0	0.4	0.2
Unidentified	1.2	0.8	2	0	2.8	2	8.4	10.8	31.4
Total Allochems.	6.4	2.8	4.8	2.8	4	2	6.6	5.6	15.2
Oolites	0	4	1.6	0	0	0	34	19.4	10.8
Cement	12.8	53.6	14.8	14	20.4	27.2	31.2	35	30.6
Matrix	0	0	0	0	0	0	0	0	0
Non-Carbonate	80.8	39.6	78.8	83.2	75.6	70.8	26.4	34.8	27.2
Total	100	100	100	100	100	100	100	100	100

Table. A6.1. (contd.)

Sample No.	RK18	RK19	RK32	RK33	RK36	RK44	RK45	RK46	RK15
Facies	3	3	3	3	3	3	3	3	4
Algae	0.2	0.2	0	0	0	0	0	0	0
Forams	1	1.6	1.4	0.4	0.4	0.8	0.4	1.2	0.4
Echinoids	3.8	2.4	0.6	1.8	0.8	0.4	8	0.4	9.6
Molluscs	5	5.2	0.6	0.6	2	0	1.2	0.4	10.2
Bryozoa	3	1	0.4	0.8	0	0.4	5.6	0	0
Coral	0.6	1	0	0	0	0	1.2	0	0
Unidentified	8.4	15.6	4.2	9	0	2.4	6.8	2.4	11.8
Total Allochems.	22	27	7.2	12.6	3.2	4	23.2	4.4	32
Oolites	8.2	12	31.8	33.6	6	18	7.2	10.4	2.6
Cement	36.8	38.4	25.8	26.2	22.4	32.4	43.6	37.2	62.8
Matrix	2.2	0.8	0	0	20	0	0	0	0
Non-Carbonate	30.8	21.8	35.2	27.6	48.4	45.6	26	48	2.6
Total	100	100	100	100	100	100	100	100	100

Sample No.	RK25	RK26	RK27	RK28	RK30	RG4	RG5	RG6	RG32
Facies	4	4	4	4	4	4	4	4	4
Algae	0.2	0.2	0.2	0.2	1	0.8	0	0	15
Forams	2.4	1.2	3	1	0.4	7	6.8	8	0.8
Echinoids	3	3	2	5.6	3.4	6.6	16.8	9.6	4
Molluscs	5	6.4	2.6	10	10.8	1.4	3.8	5.8	0.6
Bryozoa	0.4	2.8	0.8	1.4	1.4	0	0.4	0	17
Coral	1	0.2	0	1	0.2	0	0.8	0	0
Unidentified	22.8	15.4	17.2	21.8	20.8	0	0	0.4	0
Total Allochems.	34.8	29.2	25.8	41	38	16.8	28.6	23.8	37.4
Oolites	4.8	0.6	5	0.2	0	0	0	0	0
Cement	40.4	45	41.8	30.8	51.6	49	47	44.2	22.4
Matrix	0	0	0	0.2	0	27	18.4	30.2	40.2
Non-Carbonate	20	25.2	27.4	27.8	10.4	7.2	6	1.8	0
Total	100	100	100	100	100	100	100	100	100

Sample No.	RG7	RG8	RG9	RG10	RG11	RG12	RG13	RG14	RG15
Facies	5	5	5	5	5	5	5	5	5
Algae	39.2	16.8	36	23	27	9	21.2	20.6	5.2
Forams	4.4	7	2.6	4.8	15	15.6	5	12.2	24.2
Echinoids	5.4	4	0.8	2.4	1.2	3	6.4	6.6	1.6
Molluscs	0.2	0.8	0.2	0	1	0	0.2	0	0
Bryozoa	0.6	0.6	0.2	8.8	8.8	6	2.2	5.4	2.2
Coral	0	0	0	0	0	0	0	0	0
Unidentified	0	0	0.2	0	0	0	0	0	0
Total Allochems.	49.8	29.2	40	39	53	33.6	35	44.8	33
Oolites	0	0	0	0	0	0	0	0	0
Cement	41.6	60.8	50	56.2	24.8	42	50	39.2	46.4
Matrix	8.6	10	10	4.8	22.2	24.4	15	16	20.6
Non-Carbonate	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100

Table. A6.1. (contd.)

Sample No.	RG18	RG19	RG20	RG23	RG24	RG25	RG29	RG30	RG31
Facies	5	5	5	5	5	5	5	5	5
Algae	33.8	18.6	27.6	26	30.8	20.6	9.4	28.6	28.2
Forams	19.2	17.4	15.4	3.2	1	0.4	0.4	0.6	1.4
Echinoids	10	6.6	6.2	6.8	2.6	1	2.8	2.6	3.8
Molluscs	0.2	0	0	0	0.8	0.2	0.2	0.2	0.2
Bryozoa	4.4	2.4	3.2	1.6	1.4	0	8.6	0.8	1.2
Coral	0	0	0	0	0	2.6	3.2	3.2	0
Unidentified	0	0	0	0	0	0	0	0	0
Total Allochems.	67.6	45	52.4	37.6	36.6	24.8	24.6	36	35.2
Oolites	0	0	0	0	0	0	0	0	0
Cement	9.8	31.8	19	33.6	40.8	55.2	56.8	27.6	41.6
Matrix	22.6	23.2	28.6	28.8	22.6	20	18.6	36.4	23.2
Non-Carbonate	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100

Sample No.	RG33	RG34	RG37	RG38	RG41	RG42	RG43	RG44	RG45
Facies	5	5	5	5	5	5	5	5	5
Algae	23.2	20	19.6	16.6	2.8	15.6	20.4	19	9.4
Forams	2	3.4	0.8	6.8	15.2	24.2	33	14.6	25.6
Echinoids	5.6	10.6	7.2	3.8	3.8	4	5.4	4.8	5.4
Molluscs	0.6	0.4	0.2	0.6	0	0	0	1	0.2
Bryozoa	0.4	3.2	3.4	1.8	1	3.8	4.8	3.6	1.2
Coral	0	0	0	2	5	0	0	0	0
Unidentified	0	0	0	0	0	0	0	0	0
Total Allochems.	31.8	37.6	31.2	31.6	25.8	47.6	63.6	44.4	41.8
Oolites	0	0	0	0	0	0	0	0	0
Cement	22.6	25.4	41.4	44.4	30	17.8	6.8	19	20.4
Matrix	45.6	37	27.4	24	44.2	34.6	29.6	35.8	37.4
Non-Carbonate	0	0	0	0	0	0	0	0.8	0.4
Total	100	100	100	100	100	100	100	100	100

Sample No.	RG45A	RG46	RG22	RG26	RG16	RG17	RG21	RG27	RG35
Facies	5	5	5	5	6	6	6	6	6
Algae	10.2	6.8	11.8	26.4	25.4	36.4	23.2	35	25.6
Forams	20	20.6	7	0.2	10.2	15	16.8	0.4	11.8
Echinoids	12.4	6	8	6	4.4	5.2	4.4	1.6	11
Molluscs	0.4	0.8	0	0.2	0	0	0.2	0.2	0.4
Bryozoa	2.2	2	9	0.8	3	3.6	7.6	0.6	2.2
Coral	0.6	0	0	0	0	0	0	0	0
Unidentified	0	0	0	0.2	0	0	0	0	0
Total Allochems.	45.8	37	35.8	33.8	43	60.2	52.2	37.8	51
Oolites	0	0	0	0	0	0	0	0	0
Cement	27.8	35.2	24.8	50	33.4	21.2	30.4	42	18
Matrix	26.2	27.6	39.4	16.2	23.6	18.6	17.4	20.2	31
Non-Carbonate	0.2	0.2	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100

Table. A6.1. (contd.)

Sample No.	RG36	RG36 A	RG39	RG40	ZP8	ZP10	ZP13	ZP14	ZP15
Facies	6	6	6	6	6	6	6	6	6
Algae	19.2	13.8	6	11.4	10.8	7.6	18.2	15	16.8
Forams	11	10.2	39.2	18.8	8.2	3.2	6	3.4	5.6
Echinoids	12	14.4	6.4	7.8	0.8	2.4	1	1.8	1.6
Molluscs	0.6	0.2	0	0.2	0.2	0.8	0.2	0.2	0
Bryozoa	2.8	1.4	1	1.6	1.8	6.4	1	21.6	3
Coral	0	0	0	0	0.2	0	6.8	0.8	2.6
Unidentified	0.4	1	0	0	4.6	4.8	2.8	0.8	6
Total Allochems.	46	41	52.6	39.8	26.6	25.2	36	43.6	35.6
Oolites	0	0	0	0	0	0	0	0	0
Cement	14.6	23.4	31	19.8	24.8	35.6	34	30.2	26.8
Matrix	39.4	35.6	16.4	40.4	48.6	39.2	29.2	26.2	37.4
Non-Carbonate	0	0	0	0	0	0	0.8	0	0.2
Total	100	100	100	100	100	100	100	100	100

Sample No.	ZP18	ZP23	ZP24	ZP25	ZP26	ZP27	ZP31	ZP32	ZP33
Facies	6	6	6	6	6	6	6	6	6
Algae	2.8	2.4	11.6	4.6	7	8.2	6.6	3.8	2
Forams	40.4	55.2	44.6	47	59.2	45	61.4	64.6	70
Echinoids	3.2	4.4	1	3	4.2	2	2.6	1.8	0.6
Molluscs	0	0.4	0	0	0.4	0	0.2	0.4	0.4
Bryozoa	2.6	1	2.8	0.2	0	0	0	0	0.6
Coral	2.2	0	0	0	0.2	0	0	0	0
Unidentified	2.2	0	1.2	0.2	0.4	0.2	0.2	0	0
Total Allochems.	53.4	63.4	61.2	55	71.4	55.4	71	70.6	73.6
Oolites	0	0	0	0	0	0	0	0	0
Cement	29.2	26.2	23.8	33.8	19.2	33.8	19.2	19.4	17.6
Matrix	17	10	14.6	10.6	6.2	10.8	9.2	9.4	8
Non-Carbonate	0.4	0.4	0.4	0.6	3.2	0	0.6	0.6	0.8
Total	100	100	100	100	100	100	100	100	100

Sample No.	ZP35	ZP52	ZP53	ZP55i	ZP55ii	ZP56	ZP9	ZP20	ZP21
Facies	6	6	6	6	6	6	7	7	7
Algae	7.8	2	4.4	1.2	5.4	4	10.8	2.2	4.8
Forams	64.4	64.2	13.2	43.2	26.2	35.6	6.6	61.8	60.6
Echinoids	3	2.2	3.4	4.4	2.4	2	0.6	4.8	4.2
Molluscs	1.2	0	0.2	0	0	0.6	0.6	0	0.6
Bryozoa	0	2.4	0.2	1	0.2	0	0.8	0	0.2
Coral	0	0	0.8	0	0	0	0.2	0	0.4
Unidentified	0.2	0	0	0	0	0	4	0	0
Total Allochems.	76.6	71	22.2	49.8	34.2	42.2	23.6	68.8	70.8
Oolites	0	0	0	0	0	0	0	0	0
Cement	18	18.2	32.4	26.6	30.2	32	33.4	19.4	19
Matrix	4.8	10.8	45.4	22.2	35.6	24.8	43	10.6	9.2
Non-Carbonate	0.6	0	0	1.4	0	1	0	1.2	1
Total	100	100	100	100	100	100	100	100	100

Table. A6.1. (contd.)

Sample No.	ZP22	ZP29	ZP30	ZP36	ZP37	ZP38	ZP39	ZP40	ZP51
Facies	7	7	7	7	7	7	7	7	7
Algae	4	1.4	2	9.8	17.2	3.6	1.2	2.4	1.4
Forams	59	77.6	70.8	59	44	63.2	65.8	69.8	20.2
Echinoids	2.2	1	3.2	1.2	4.8	0.8	1.2	0.4	3.4
Molluscs	0.2	0.4	0	0.2	0.4	0.2	1	0.2	0.2
Bryozoa	0.6	0	0.4	0	1.8	0	0.6	0.6	0.6
Coral	0	0	0	0	0	0	0	0	0
Unidentified	0	0	0	0	0	0	0	0	2.4
Total Allochems.	66	80.4	76.4	70.2	68.2	67.8	69.8	73.4	28.2
Oolites	0	0	0	0	0	0	0	0	0
Cement	22.4	14.2	18.8	21.8	21.6	22	20.4	24.4	14
Matrix	9.6	4.2	4	8	10	10	9.4	1.8	57.6
Non-Carbonate	2	1.2	0.8	0	0.2	0.2	0.4	0.4	0.2
Total	100	100	100	100	100	100	100	100	100

Sample No.	ZP54	ZP7A	ZP11	ZP12	ZP41	ZP42	ZP43	ZP44	ZP45
Facies	7	8	8	8	8	8	8	8	8
Algae	1.2	0	0	0	0	0	0	0.4	0
Forams	73	5.2	4.4	4.8	15.4	13.8	15.8	17	12.4
Echinoids	5.4	0	0.4	1	0.4	0.2	0.6	1.4	0.4
Molluscs	0.4	0.2	0.2	0.2	0.6	0.8	0.4	0.8	0.2
Bryozoa	0.4	0	0	0.8	0	0	0	0	0
Coral	0	0	0	0	0	0	0	0	0
Unidentified	0	0	2	0.4	0	0	0	0	0
Total Allochems.	80.4	5.4	7	7.2	16.4	14.8	16.8	19.6	13
Oolites	0	0	0	0	0	0	0	0	0
Cement	12.8	5.4	11.6	9.4	9	8.2	13.2	7	6.6
Matrix	6.8	89.2	80.2	82.2	73.8	76.2	69.6	73	80.2
Non-Carbonate	0	0	1.2	1.2	0.8	0.8	0.4	0.4	0.2
Total	100	100	100	100	100	100	100	100	100

Sample No.	ZP46	ZP48	ZP49	ZP50
Facies	8	8	8	8
Algae	0	0	0	0
Forams	5.8	8.6	3.4	6.4
Echinoids	0	2.6	0.4	0.6
Molluscs	0	0	0	0
Bryozoa	0	0	0	0
Coral	0	0	0	0
Unidentified	0	0	3.4	1.8
Total Allochems.	5.8	9.8	7.2	8.8
Oolites	0	0	0	0
Cement	12.6	17.8	12.2	16.2
Matrix	81.2	72.4	80.2	75
Non-Carbonate	0.4	0	0.4	0
Total	100	100	100	100

APPENDIX 8

Table. A7.1. Electron microprobe analyses of some selected samples of the Dungan Formation.

Sample No.	RG10	RG10	RG11	RG11	RG11	RG11	RG11	RG11	RG11	RG11
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	C	Bryo	Bryo	Bryo	C	C	C	C	C
CaO	56.40	56.19	55.67	55.07	55.39	55.03	55.49	56.22	55.66	55.62
MgO	0.20	0.31	0.62	0.64	0.73	0.54	0.23	0.14	0.44	0.46
FeO	0.01	0.01	0.07	0.05	0.12	0.02	0.04	0.04	0.03	0.01
MnO	0.03	0.01	0.04	0.02	0.07	0.00	0.03	0.03	0.00	0.03
SrO	0.03	0.03	0.02	0.06	0.02	0.03	0.01	0.21	0.09	0.12
BaO	0.19	0.05	0.05	0.08	0.13	0.24	0.10	0.08	0.24	0.06
Total	56.85	56.59	56.47	55.92	56.46	55.87	55.90	56.72	56.47	56.29
Sample No.	RG11	RG11	RG11	RG11	RG13	RG13	RG13	RG13	RG13	RG13
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	Ech	F	Mic	C	C	C	C	C	C FCh
CaO	55.91	54.40	56.04	55.51	56.18	55.55	55.54	55.28	55.57	55.35
MgO	0.62	1.54	0.61	0.56	0.19	0.17	0.26	0.30	0.21	0.57
FeO	0.06	0.07	0.02	0.07	0.01	0.02	0.03	0.02	0.02	0.05
MnO	0.04	0.04	0.01	0.03	0.02	0.03	0.01	0.02	0.03	0.03
SrO	0.04	0.06	0.03	0.04	0.05	0.06	0.16	0.08	0.06	0.04
BaO	0.08	0.24	0.02	0.24	0.12	0.24	0.04	0.24	0.02	0.24
Total	56.76	56.34	56.73	56.45	56.58	56.06	56.03	55.94	55.91	56.27
Sample No.	RG13	RG14	RG14	RG14	RG14	RG14	RG14	RG14	RG14	RG14
Facies	5	5	5	5	5	5	5	5	5	5
Grain	F	C	C	C	C	C	C	C Bryo	C Bryo	Ech.
CaO	55.04	54.91	55.67	55.79	55.00	56.26	56.22	55.12	54.75	55.00
MgO	0.38	0.44	0.39	0.38	0.47	0.39	0.40	0.51	0.42	1.43
FeO	0.06	0.03	0.01	0.01	0.00	0.00	0.01	0.05	0.02	0.04
MnO	0.00	0.01	0.01	0.05	0.02	0.03	0.01	0.03	0.02	0.02
SrO	0.03	0.06	0.02	0.07	0.03	0.09	0.02	0.06	0.04	0.01
BaO	0.11	0.04	0.02	0.05	0.02	0.02	0.02	0.03	0.01	0.04
Total	55.61	55.48	56.13	56.34	55.54	56.79	56.68	55.80	55.26	56.52
Sample No.	RG19	RG19	RG19	RG19	RG19	RG19	RG19	RG19	RG19	RG19
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	C	C	C	C	C	C	C	C	C
CaO	55.41	55.18	55.46	55.48	55.60	55.17	56.04	56.04	55.55	55.42
MgO	0.43	0.38	0.34	0.42	0.27	0.31	0.09	0.29	0.49	0.41
FeO	0.05	0.07	0.07	0.03	0.04	0.01	0.02	0.06	0.05	0.05
MnO	0.01	0.04	0.01	0.01	0.04	0.03	0.00	0.02	0.00	0.02
SrO	0.38	0.32	0.40	0.15	0.01	0.01	0.16	0.20	0.27	0.33
BaO	0.23	0.23	0.02	0.23	0.23	0.08	0.23	0.23	0.15	0.23
Total	56.51	56.22	56.31	56.33	56.19	55.60	56.55	56.84	56.52	56.46
Sample No.	RG19	RG19	RG19	RG19	RG19	RG19	RG19	RG19	RG22	RG22
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	C	C	V	V	V	V	V F	C	C
CaO	54.89	55.85	55.31	56.11	56.16	55.82	56.16	56.04	55.99	55.99
MgO	0.44	0.42	0.38	0.39	0.49	0.13	0.20	0.44	0.21	0.30
FeO	0.12	0.02	0.11	0.02	0.01	0.02	0.04	0.17	0.00	0.02
MnO	0.01	0.01	0.03	0.10	0.02	0.03	0.01	0.01	0.00	0.02
SrO	0.27	0.37	0.34	0.05	0.01	0.02	0.03	0.10	0.01	0.01
BaO	0.09	0.11	0.23	0.06	0.04	0.09	0.04	0.05	0.01	0.04
Total	55.82	56.78	56.39	56.73	56.73	56.11	56.47	56.81	56.23	56.37
Sample No.	RG22	RG22	RG22	RG22	RG22	RG24	RG24	RG24	RG24	RG24
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	C	C Alg	C Alg	Ech	C	Ech	V	V	V
CaO	56.07	55.94	56.13	56.26	56.09	56.11	50.93	56.45	55.39	56.47
MgO	0.21	0.25	0.26	0.20	0.46	0.46	4.82	0.19	0.12	0.25
FeO	0.00	0.00	0.02	0.03	0.02	0.02	0.02	0.02	0.04	0.03
MnO	0.00	0.02	0.01	0.02	0.02	0.00	0.00	0.02	0.05	0.04
SrO	0.03	0.06	0.08	0.03	0.08	0.04	0.02	0.03	0.02	0.00
BaO	0.24	0.04	0.01	0.05	0.01	0.09	0.02	0.01	0.02	0.03
Total	56.55	56.31	56.52	56.59	56.69	56.72	55.81	56.72	55.64	56.82

Table. A7.1. (contd.)

Sample No.	RG24	RG24	RG24	RG24	RG24	RG24	RG24	RG24	RG24	RG24
Facies	5	5	5	5	5	5	5	5	5	5
Grain	V	V	V	V	V	V	V	V	V	Alg
CaO	56.43	56.31	56.44	55.89	56.37	56.05	55.75	56.35	56.25	55.66
MgO	0.14	0.23	0.18	0.30	0.16	0.18	0.12	0.14	0.22	0.56
FeO	0.01	0.01	0.00	0.03	0.03	0.03	0.02	0.02	0.03	0.01
MnO	0.03	0.04	0.02	0.05	0.04	0.03	0.03	0.03	0.05	0.01
SrO	0.02	0.01	0.04	0.00	0.01	0.03	0.02	0.01	0.01	0.01
BaO	0.02	0.02	0.01	0.04	0.02	0.03	0.01	0.08	0.08	0.11
Total	56.65	56.61	56.69	56.31	56.63	56.35	55.95	56.62	56.64	56.37

Sample No.	RG26	RG26	RG26	RG26	RG26	RG26	RG26	RG26	RG26	RG26
Facies	5	5	5	5	5	5	5	5	5	5
Grain	Alg	Bryo	C	C	C	C	C	C Alg	C Alg	C Alg
CaO	55.65	54.71	55.38	54.99	55.85	55.90	55.73	55.80	55.44	55.58
MgO	0.55	0.60	0.28	0.44	0.08	0.47	0.14	0.33	0.45	0.45
FeO	0.03	0.03	0.03	0.01	0.02	0.02	0.01	0.02	0.03	0.01
MnO	0.02	0.02	0.01	0.05	0.03	0.03	0.02	0.01	0.02	0.01
SrO	0.05	0.07	0.14	0.05	0.09	0.08	0.17	0.01	0.08	0.05
BaO	0.02	0.27	0.08	0.01	0.24	0.28	0.15	0.01	0.24	0.01
Total	56.32	55.70	55.92	55.55	56.31	56.79	56.22	56.18	56.25	56.11

Sample No.	RG26	RG27	RG27	RG27	RG27	RG3	RG3	RG3	RG3	RG3
Facies	5	6	6	6	6	4	4	4	4	4
Grain	C Alg	C	C	C	C	C	C	C	C	C
CaO	55.73	56.31	56.27	56.05	56.19	55.94	54.55	55.58	54.57	55.53
MgO	0.46	0.33	0.32	0.54	0.46	0.23	0.35	0.42	0.41	0.35
FeO	0.01	0.03	0.02	0.02	0.03	0.11	0.23	0.35	0.15	0.34
MnO	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.01
SrO	0.14	0.12	0.05	0.05	0.04	0.05	0.07	0.04	0.11	0.07
BaO	0.05	0.01	0.18	0.10	0.04	0.06	0.02	0.12	0.24	0.02
Total	56.40	56.80	56.84	56.78	56.76	56.39	55.24	56.52	55.49	56.32

Sample No.	RG3	RG3	RG3	RG3	RG3	RG3	RG3	RG30	RG30	RG30
Facies	4	4	4	4	4	4	4	5	5	5
Grain	C	C	C	C	C	C	C	C	C	C
CaO	54.56	55.09	54.66	55.48	55.57	55.52	54.85	55.44	55.82	55.81
MgO	0.31	0.35	0.31	0.32	0.26	0.27	0.23	0.40	0.43	0.26
FeO	0.37	0.13	1.22	0.13	0.18	0.11	0.15	0.02	0.01	0.02
MnO	0.04	0.02	0.01	0.04	0.03	0.03	0.03	0.03	0.01	0.02
SrO	0.09	0.02	0.04	0.02	0.32	0.11	0.26	0.07	0.13	0.13
BaO	0.11	0.05	0.01	0.24	0.08	0.02	0.04	0.13	0.09	0.08
Total	55.47	55.67	56.25	56.22	56.44	56.06	55.56	56.09	56.49	56.32

Sample No.	RG30	RG30	RG30	RG30	RG32	RG32	RG32	RG32	RG32	RG32
Facies	5	5	5	5	4	4	4	4	4	4
Grain	C	C	C	C Alg	C	C	C	C	C Alg	C Alg
CaO	56.28	55.74	55.64	55.76	56.10	56.07	55.69	56.00	56.09	56.04
MgO	0.33	0.36	0.31	0.31	0.25	0.39	0.36	0.36	0.45	0.42
FeO	0.01	0.02	0.02	0.02	0.02	0.01	0.05	0.02	0.00	0.02
MnO	0.02	0.01	0.01	0.03	0.03	0.05	0.04	0.03	0.01	0.00
SrO	0.06	0.11	0.03	0.01	0.02	0.05	0.10	0.09	0.03	0.11
BaO	0.01	0.24	0.24	0.24	0.11	0.05	0.24	0.09	0.24	0.04
Total	56.71	56.47	56.25	56.36	56.53	56.61	56.47	56.60	56.82	56.63

Sample No.	RG32	RG32	RG32	RG32	RG32	RG32	RG33	RG33	RG33	RG33
Facies	4	4	4	4	4	4	5	5	5	5
Grain	C Alg	C Alg	C Alg	C Alg	C Alg	C Alg	C	C	C	C
CaO	56.32	56.08	56.30	56.26	56.27	55.87	55.71	56.03	55.17	55.27
MgO	0.22	0.31	0.27	0.24	0.25	0.24	0.26	0.43	0.47	0.36
FeO	0.02	0.01	0.04	0.01	0.03	0.02	0.02	0.04	0.04	0.02
MnO	0.03	0.01	0.01	0.02	0.01	0.03	0.03	0.01	0.02	0.02
SrO	0.06	0.03	0.02	0.03	0.02	0.04	0.01	0.12	0.11	0.08
BaO	0.24	0.02	0.07	0.24	0.24	0.01	0.02	0.24	0.02	0.04
Total	56.89	56.47	56.70	56.79	56.82	56.22	56.06	56.87	55.84	55.79

Table. A7.1. (contd.)

Sample No.	RG33	RG33	RG33	RG34	RG34	RG34	RG34	RG34	RG34	RG34
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C Alg	C Alg	C Alg	V	V	VF	VF	VF	VF	VF
CaO	56.12	56.05	56.28	56.10	56.18	55.19	55.13	55.21	55.67	55.48
MgO	0.32	0.35	0.31	0.21	0.27	0.40	0.45	0.52	0.49	0.49
FeO	0.02	0.03	0.01	0.02	0.03	0.07	0.07	0.08	0.05	0.12
MnO	0.01	0.02	0.03	0.03	0.04	0.03	0.02	0.00	0.01	0.03
SrO	0.06	0.06	0.01	0.03	0.28	0.60	0.60	0.50	0.59	0.49
BaO	0.02	0.19	0.24	0.18	0.09	0.18	0.05	0.06	0.03	0.18
Total	56.56	56.71	56.87	56.58	56.89	56.46	56.33	56.38	56.84	56.79

Sample No.	RG34	RG34	RG34	RG34	RG34	RG34	RG34	RG34	RG34	RG34
Facies	5	5	5	5	5	5	5	5	5	5
Grain	VF	VF	VF	VF	VF	VF	VF	VF	VF	VF
CaO	55.53	54.11	54.55	54.81	55.42	55.58	55.45	55.68	55.38	55.87
MgO	0.55	0.51	0.60	0.57	0.51	0.55	0.52	0.54	0.55	0.45
FeO	0.03	0.08	0.15	0.04	0.07	0.05	0.05	0.05	0.08	0.03
MnO	0.05	0.02	0.03	0.00	0.02	0.02	0.00	0.03	0.03	0.02
SrO	0.43	0.44	0.39	0.46	0.52	0.43	0.57	0.45	0.40	0.38
BaO	0.18	0.24	0.03	0.07	0.06	0.18	0.18	0.11	0.12	0.06
Total	56.77	55.41	55.74	55.96	56.58	56.81	56.77	56.85	56.56	56.81

Sample No.	RG34	RG34	RG34	RG34	RG34	RG34	RG37	RG37	RG37	RG37
Facies	5	5	5	5	5	5	5	5	5	5
Grain	VF	VF	VF	VF	VF	VF	Alg	Alg	Alg	C Alg
CaO	55.48	55.77	55.54	55.68	55.68	55.64	54.88	55.49	55.50	55.62
MgO	0.49	0.47	0.59	0.58	0.49	0.50	0.54	0.56	0.68	0.49
FeO	0.08	0.06	0.09	0.11	0.09	0.10	0.02	0.04	0.03	0.02
MnO	0.03	0.03	0.02	0.03	0.02	0.01	0.03	0.04	0.04	0.03
SrO	0.49	0.41	0.43	0.43	0.50	0.22	0.02	0.03	0.05	0.04
BaO	0.18	0.10	0.03	0.04	0.04	0.19	0.06	0.10	0.24	0.18
Total	56.74	56.84	56.70	56.86	56.80	56.65	55.54	56.26	56.55	56.37

Sample No.	RG37	RG37	RG37	RG37	RG37	RG37	RG37	RG37	RG37	RG37
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C Alg	C Alg	C Alg	C FCh	Ech	F	F	F	Mic	Mic
CaO	55.01	55.21	55.54	54.98	55.48	55.52	55.22	55.09	54.70	55.76
MgO	0.46	0.38	0.43	0.61	0.42	0.37	0.66	0.47	0.45	0.46
FeO	0.02	0.02	0.02	0.02	0.05	0.01	0.03	0.01	0.02	0.02
MnO	0.01	0.00	0.02	0.04	0.01	0.01	0.04	0.01	0.02	0.01
SrO	0.10	0.09	0.10	0.08	0.03	0.10	0.05	0.04	0.02	0.02
BaO	0.02	0.06	0.10	0.02	0.02	0.24	0.08	0.05	0.02	0.24
Total	55.62	55.77	56.19	55.76	56.01	56.25	56.09	55.67	55.23	56.50

Sample No.	RG39	RG39	RG39	RG39	RG39	RG39	RG39	RG39	RG39	RG39
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C	C	C	C	C	C	C	C	C	C
CaO	55.94	55.96	56.25	55.61	55.89	56.40	56.39	56.53	55.90	55.88
MgO	0.30	0.17	0.10	0.44	0.30	0.08	0.22	0.10	0.44	0.41
FeO	0.02	0.01	0.01	0.04	0.02	0.02	0.01	0.03	0.02	0.03
MnO	0.00	0.01	0.03	0.00	0.03	0.02	0.06	0.02	0.02	0.02
SrO	0.04	0.13	0.12	0.06	0.11	0.24	0.16	0.16	0.05	0.06
BaO	0.14	0.12	0.13	0.04	0.24	0.05	0.04	0.02	0.02	0.04
Total	56.44	56.40	56.63	56.19	56.59	56.81	56.86	56.85	56.45	56.43

Sample No.	RG39	RG39	RG39	RG39	RG39	RG39	RG45	RG45	RG45	RG45
Facies	6	6	6	6	6	6	5	5	5	5
Grain	C	C	C	C FCh	C FCh	Ech	C	C	C	C
CaO	55.56	55.96	55.88	56.30	56.06	55.17	55.24	55.37	55.65	55.48
MgO	0.40	0.31	0.37	0.27	0.41	0.54	0.41	0.44	0.42	0.42
FeO	0.02	0.01	0.02	0.02	0.02	0.03	0.15	0.12	0.13	0.13
MnO	0.04	0.03	0.02	0.04	0.06	0.01	0.01	0.03	0.03	0.05
SrO	0.04	0.01	0.17	0.04	0.05	0.03	0.08	0.03	0.07	0.08
BaO	0.02	0.24	0.14	0.11	0.11	0.24	0.15	0.02	0.04	0.05
Total	56.09	56.55	56.61	56.78	56.70	56.01	56.04	56.01	56.33	56.21

Table. A7.1. (contd.)

Sample No.	RG45	RG45	RG45	RG45	RG45	RG45	RG45A	RG45A	RG45A	RG45A
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	C	C	C	C	C	Alg	C	C	C
CaO	55.79	56.04	55.71	54.80	55.60	55.07	55.51	55.34	55.14	55.51
MgO	0.37	0.40	0.47	0.42	0.38	0.47	0.84	0.48	0.31	0.33
FeO	0.18	0.15	0.18	0.15	0.01	0.01	0.11	0.08	0.16	0.05
MnO	0.03	0.00	0.01	0.04	0.03	0.02	0.01	0.04	0.02	0.06
SrO	0.13	0.04	0.01	0.05	0.10	0.02	0.06	0.03	0.07	0.06
BaO	0.04	0.02	0.04	0.04	0.06	0.24	0.06	0.23	0.23	0.13
Total	56.53	56.67	56.41	55.50	56.17	55.84	56.59	56.20	55.93	56.13

Sample No.	RG45A	RG45A	RG45A	RG45A	RG45A	RG45A	RG45A	RG45A	RG45A	RG45A
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	C	C	C	C	C	C	C	C	C
CaO	55.16	55.18	55.31	54.84	55.62	55.82	55.41	55.78	56.14	55.85
MgO	0.33	0.28	0.38	0.32	0.38	0.36	0.44	0.27	0.35	0.38
FeO	0.02	0.11	0.13	0.11	0.24	0.17	0.17	0.16	0.20	0.17
MnO	0.02	0.02	0.04	0.01	0.01	0.03	0.03	0.03	0.03	0.05
SrO	0.11	0.07	0.10	0.03	0.08	0.00	0.09	0.04	0.04	0.09
BaO	0.05	0.12	0.15	0.01	0.11	0.14	0.08	0.11	0.02	0.13
Total	55.69	55.77	56.12	55.33	56.45	56.53	56.21	56.37	56.79	56.66

Sample No.	RG45A	RG45A	RG45A	RG46	RG46	RG46	RG46	RG46	RG46	RG46
Facies	5	5	5	5	5	5	5	5	5	5
Grain	C	Ech	Mic	Alg	Alg	Alg	Alg	C	C	C Alg
CaO	56.28	54.85	53.77	55.04	53.89	54.44	54.61	55.60	56.33	55.38
MgO	0.22	0.78	0.84	1.05	0.76	0.67	0.78	0.51	0.09	0.43
FeO	0.08	0.24	0.49	0.02	1.30	0.10	0.10	0.03	0.01	0.03
MnO	0.02	0.05	0.00	0.01	0.01	0.02	0.00	0.03	0.02	0.01
SrO	0.02	0.00	0.02	0.05	0.03	0.05	0.01	0.01	0.08	0.02
BaO	0.07	0.06	0.23	0.07	0.18	0.18	0.10	0.01	0.08	0.18
Total	56.68	55.97	55.36	56.24	56.15	55.46	55.59	56.19	56.61	56.05

Sample No.	RG46	RG5	RG5	RG5	RG8	RG8	RG8	RG8	RG8	RG8
Facies	5	4	4	4	5	5	5	5	5	5
Grain	C Alg	C	C	C	C	C	C	C	C	C
CaO	54.67	55.90	55.49	55.59	55.04	55.51	55.84	55.34	54.93	55.09
MgO	0.39	0.25	0.74	0.41	0.48	0.14	0.24	0.37	0.39	0.53
FeO	0.77	0.16	0.33	0.35	0.19	0.11	0.12	0.05	0.04	0.02
MnO	0.03	0.03	0.03	0.01	0.00	0.03	0.03	0.02	0.02	0.03
SrO	0.04	0.06	0.08	0.03	0.13	0.20	0.07	0.15	0.05	0.03
BaO	0.08	0.13	0.01	0.24	0.02	0.02	0.08	0.24	0.06	0.07
Total	55.98	56.52	56.67	56.63	55.87	56.02	56.38	56.15	55.48	55.77

Sample No.	RG8	RG8	RG8	RG8	RG8	RG8	RG8	RG8	RG9	RK 33
Facies	5	5	5	5	5	5	5	5	5	3
Grain	C	C	C	C	C	C	Mic	V F	C	Bryo
CaO	54.44	55.10	54.71	55.66	55.70	55.22	54.71	55.51	55.97	50.55
MgO	0.63	0.70	0.32	0.35	0.37	0.34	0.56	0.27	0.56	1.59
FeO	0.03	0.02	0.13	0.11	0.13	0.10	0.04	0.10	0.09	2.10
MnO	0.01	0.03	0.04	0.01	0.03	0.01	0.00	0.00	0.01	1.30
SrO	0.05	0.08	0.06	0.06	0.00	0.03	0.08	0.18	0.03	0.09
BaO	0.14	0.04	0.02	0.02	0.01	0.24	0.06	0.08	0.10	0.04
Total	55.30	55.96	55.28	56.20	56.24	55.93	55.44	56.15	56.76	55.67

Sample No.	RK 33	RK 33	RK 33	RK 33	RK 33	RK 33	RK 33	RK 33	RK13	RK13
Facies	3	3	3	3	3	3	3	3	3	3
Grain	C	C	C	C	C Coral	Ech.	Ech.	F	C	C
CaO	53.38	52.04	51.96	53.06	52.52	51.55	51.49	53.07	53.15	52.86
MgO	0.31	0.57	0.53	0.92	0.72	1.49	1.69	0.85	1.00	1.16
FeO	1.20	1.51	1.34	1.17	1.27	1.62	0.87	1.17	1.20	1.19
MnO	0.78	2.17	2.32	0.36	0.69	0.75	1.19	0.52	0.19	0.26
SrO	0.04	0.07	0.04	0.12	0.06	0.05	0.04	0.09	0.14	0.08
BaO	0.01	0.14	0.01	0.02	0.06	0.18	0.12	0.13	0.08	0.04
Total	55.72	56.50	56.19	55.64	55.32	55.64	55.40	55.82	55.78	55.58

Table. A7.1. (contd.)

Sample No.	RK13	RK13	RK13	RK13	RK15	RK15	RK15	RK15	RK15	RK17
Facies	3	3	3	3	4	4	4	4	4	3
Grain	C Moll	C Moll	O	O	C	C	C	C	C Moll	C
CaO	53.38	53.24	52.44	52.69	53.96	55.57	54.96	55.40	54.26	52.68
MgO	0.92	0.95	0.64	1.33	0.91	0.37	0.83	0.45	0.82	0.97
FeO	0.36	0.99	1.83	1.69	0.98	0.34	0.34	0.62	0.38	1.19
MnO	0.61	0.19	0.44	0.29	0.23	0.17	0.11	0.27	0.19	0.48
SrO	0.09	0.15	0.09	0.11	0.06	0.13	0.08	0.11	0.03	0.11
BaO	0.14	0.14	0.23	0.13	0.24	0.09	0.01	0.05	0.04	0.24
Total	55.50	55.66	55.67	56.25	56.37	56.67	56.35	56.90	55.72	55.66

Sample No.	RK21	RK21	RK21	RK21	RK21	RK21	RK25	RK25	RK25	RK27
Facies	2	2	2	2	2	2	4	4	4	4
Grain	C	C	C	C	C	C	C FCh	C	C	C
CaO	52.75	53.01	52.28	51.83	53.18	53.58	53.39	52.70	53.34	53.34
MgO	1.06	0.81	0.69	0.78	0.89	0.34	0.83	1.10	0.80	1.30
FeO	1.36	1.02	1.89	1.64	1.08	1.14	0.96	1.07	0.78	1.23
MnO	0.30	0.24	0.87	1.07	0.30	0.61	0.23	0.15	0.36	0.13
SrO	0.09	0.08	0.04	0.05	0.14	0.07	0.08	0.11	0.08	0.16
BaO	0.18	0.04	0.04	0.02	0.11	0.07	0.06	0.04	0.18	0.11
Total	55.74	55.20	55.81	55.38	55.69	55.80	55.54	55.18	55.54	56.26

Sample No.	RK27	RK27	RK27	RK27	RK27	RK27	RK27	RK27	RK27	RK27
Facies	4	4	4	4	4	4	4	4	4	4
Grain	C	C	C	C	C	C	C	C	C	C
CaO	52.82	52.42	51.73	53.06	53.43	52.97	52.51	52.61	53.08	53.22
MgO	1.44	1.29	0.69	1.19	1.29	1.26	1.55	1.40	1.24	1.19
FeO	1.63	1.73	3.13	1.23	1.30	1.47	1.76	1.43	1.24	1.30
MnO	0.15	0.17	0.56	0.11	0.12	0.20	0.21	0.16	0.15	0.09
SrO	0.16	0.04	0.07	0.19	0.17	0.11	0.69	0.09	0.21	0.23
BaO	0.05	0.02	0.07	0.05	0.18	0.11	0.10	0.04	0.18	0.18
Total	56.24	55.67	56.25	55.83	56.50	56.11	56.83	55.73	56.10	56.22

Sample No.	RK27	RK27	RK27	RK27	RK27	RK27	RK27	RK27	RK27	RK28
Facies	4	4	4	4	4	4	4	4	4	4
Grain	C Moll	C Moll	Ech	F	Iso	Iso	Iso	Iso	Iso	C
CaO	54.94	55.48	46.81	52.35	53.03	51.13	51.31	52.65	51.70	54.36
MgO	0.70	0.72	5.78	1.37	1.11	1.99	0.94	1.22	1.55	0.73
FeO	0.18	0.09	1.29	1.99	1.33	1.64	3.52	1.29	1.90	0.83
MnO	0.07	0.04	0.58	0.43	0.16	0.54	0.42	0.52	0.52	0.30
SrO	0.07	0.12	0.05	0.07	0.15	0.11	0.08	0.15	0.11	0.16
BaO	0.18	0.05	0.06	0.04	0.10	0.08	0.09	0.04	0.18	0.04
Total	56.12	56.51	54.57	56.23	55.87	55.49	56.36	55.86	55.95	56.41

Sample No.	RK28	RK28	RK28	RK28	RK28	RK28	RK28	RK28	RK30	RK30
Facies	4	4	4	4	4	4	4	4	4	4
Grain	C	C Coral	C Coral	C Moll	C Moll	Coral	Ech	Ech	Alg	Alg
CaO	54.13	51.14	53.11	53.68	54.39	53.58	53.06	53.13	53.71	53.40
MgO	0.99	1.78	0.98	1.45	0.67	0.27	0.76	2.50	1.14	1.34
FeO	0.93	2.41	1.06	0.32	0.18	1.10	0.89	0.40	0.64	0.92
MnO	0.37	0.64	0.25	0.10	0.09	0.50	0.40	0.20	0.46	0.35
SrO	0.04	0.04	0.07	0.12	0.03	0.01	0.11	0.06	0.07	0.06
BaO	0.02	0.24	0.24	0.04	0.24	0.17	0.19	0.23	0.02	0.18
Total	56.48	56.24	55.71	55.70	55.59	55.63	55.42	56.52	56.04	56.25

Sample No.	RK30	RK30	RK30	RK30	RK30	RK30	RK30	RK30	RK30	RK36
Facies	4	4	4	4	4	4	4	4	4	3
Grain	Alg	C	C	C	C	C Coral	C Coral	C Coral	C Moll	C
CaO	53.08	53.50	53.34	53.68	52.59	53.01	52.88	53.80	55.08	52.89
MgO	1.26	0.97	0.98	1.07	0.84	1.02	1.07	0.93	0.61	1.99
FeO	1.15	0.83	1.02	1.16	1.36	1.19	1.22	0.94	0.18	0.52
MnO	0.20	0.25	0.27	0.23	0.34	0.29	0.23	0.30	0.13	0.47
SrO	0.03	0.08	0.07	0.04	0.11	0.06	0.07	0.07	0.13	0.11
BaO	0.05	0.02	0.09	0.03	0.05	0.09	0.18	0.09	0.18	0.11
Total	55.76	55.66	55.78	56.20	55.29	55.65	55.65	56.13	56.30	56.09

Table. A7.1. (contd.)

Sample No.	RK36	RK36	RK36	RK36	RK44	RK44	RK44	RK44	RK44	RK44
Facies	3	3	3	3	3	3	3	3	3	3
Grain	C Moll	C Moll	Iso	Iso	C	C	C	C	C	C
CaO	53.87	55.26	54.57	53.93	52.32	52.30	51.62	53.13	51.17	51.36
MgO	1.02	0.60	0.59	0.59	1.18	1.53	1.21	0.75	1.47	1.25
FeO	0.50	0.08	0.31	0.98	0.74	0.72	0.99	0.87	0.79	0.83
MnO	0.47	0.05	0.37	0.37	0.79	0.89	1.75	1.64	2.48	1.97
SrO	0.07	0.08	0.07	0.11	0.06	0.06	0.04	0.04	0.06	0.05
BaO	0.18	0.11	0.18	0.11	0.08	0.02	0.04	0.02	0.05	0.20
Total	56.12	56.18	56.08	56.09	55.18	55.51	55.65	56.44	56.03	55.65

Sample No.	RK44	RK44	RK44	RK44	ZP10	ZP10	ZP10	ZP10	ZP10	ZP10
Facies	3	3	3	3	6	6	6	6	6	6
Grain	C	C	C	C	C	C	C	C	C	C
CaO	52.22	51.58	52.77	52.57	54.85	54.69	54.17	54.26	55.14	55.12
MgO	1.36	0.93	1.41	1.45	0.55	0.63	0.80	0.48	0.59	0.70
FeO	0.83	1.03	0.74	0.79	0.37	0.37	0.48	1.37	0.39	0.42
MnO	1.72	1.78	0.93	0.74	0.01	0.03	0.04	0.03	0.02	0.02
SrO	0.03	0.11	0.06	0.06	0.10	0.10	0.08	0.07	0.10	0.08
BaO	0.04	0.01	0.03	0.08	0.22	0.08	0.08	0.22	0.22	0.03
Total	56.20	55.43	55.94	55.69	56.10	55.90	55.64	56.43	56.46	56.38

Sample No.	ZP10	ZP10	ZP10	ZP10	ZP10	ZP10	ZP10	ZP10	ZP10	ZP11
Facies	6	6	6	6	6	6	6	6	6	8
Grain	C	C	C	C	C	C	C	C Alg	C Alg	C F(PL)
CaO	54.26	54.87	54.50	54.22	54.90	53.90	53.53	54.17	54.10	54.42
MgO	0.82	0.43	0.29	0.53	0.41	0.41	0.52	0.58	0.52	0.66
FeO	0.52	1.41	1.12	1.52	1.34	1.33	1.63	1.48	1.71	0.42
MnO	0.00	0.04	0.03	0.02	0.06	0.05	0.02	0.03	0.03	0.03
SrO	0.10	0.04	0.12	0.07	0.03	0.10	0.10	0.09	0.07	0.20
BaO	0.22	0.03	0.17	0.06	0.09	0.22	0.13	0.01	0.11	0.08
Total	55.91	56.82	56.23	56.41	56.82	56.02	55.93	56.37	56.54	55.81

Sample No.	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C	C	C	C	C	C	C	C	C	C
CaO	55.39	55.64	54.02	53.56	54.39	54.94	55.91	54.83	55.23	53.87
MgO	0.48	0.25	0.82	0.48	0.28	0.46	0.34	0.77	0.59	0.49
FeO	0.27	0.38	0.53	1.73	1.22	1.02	0.47	0.57	0.77	1.62
MnO	0.02	0.06	0.02	0.04	0.04	0.08	0.05	0.04	0.04	0.05
SrO	0.04	0.05	0.10	0.11	0.17	0.02	0.04	0.06	0.07	0.07
BaO	0.03	0.18	0.18	0.07	0.18	0.15	0.03	0.18	0.18	0.01
Total	56.22	56.55	55.66	55.98	56.29	56.66	56.84	56.45	56.88	56.11

Sample No.	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C	C	C	C	C	C	C	C	C	C
CaO	55.52	53.86	53.77	53.74	53.92	53.97	53.81	53.62	55.13	55.80
MgO	0.62	0.51	0.48	0.52	0.44	0.49	0.48	0.57	0.43	0.27
FeO	0.42	1.83	1.74	1.91	1.65	1.76	1.63	2.00	0.23	0.23
MnO	0.04	0.09	0.04	0.06	0.03	0.08	0.10	0.03	0.04	0.01
SrO	0.10	0.06	0.08	0.04	0.08	0.11	0.08	0.03	0.06	0.15
BaO	0.18	0.02	0.04	0.17	0.16	0.10	0.18	0.04	0.18	0.04
Total	56.89	56.37	56.15	56.45	56.28	56.51	56.28	56.27	56.07	56.50

Sample No.	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C	C	C	C Bryo.	C Bryo.	C Bryo.	C Bryo.	C Bryo.	C Bryo.	C Bryo.
CaO	54.93	55.06	54.87	55.49	54.50	55.23	55.46	54.93	53.52	54.68
MgO	0.64	0.61	0.47	0.70	0.73	0.70	0.62	0.59	0.60	0.69
FeO	0.45	0.34	0.24	0.50	1.08	0.69	0.53	0.68	1.97	0.77
MnO	0.03	0.01	0.04	0.04	0.02	0.08	0.00	0.02	0.08	0.01
SrO	0.04	0.09	0.04	0.09	0.06	0.02	0.06	0.07	0.08	0.02
BaO	0.04	0.04	0.01	0.04	0.01	0.05	0.18	0.11	0.03	0.02
Total	56.13	56.14	55.67	56.86	56.39	56.76	56.85	56.39	56.28	56.18

Table. A7.1. (contd.)

Sample No.	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP13	ZP14	ZP14	ZP14
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C Bryo.	Ech.	Ech.	Ech.	Ech.	Ech.	Ech.	C Coral	C Coral	C Coral
CaO	55.36	55.33	55.33	55.62	54.21	54.51	55.70	55.68	54.34	55.98
MgO	0.69	0.91	1.10	0.81	1.66	1.62	0.87	0.58	0.48	0.52
FeO	0.53	0.15	0.22	0.23	0.06	0.01	0.07	0.36	1.73	0.24
MnO	0.04	0.02	0.01	0.04	0.02	0.02	0.00	0.02	0.03	0.05
SrO	0.10	0.08	0.07	0.04	0.11	0.06	0.05	0.10	0.15	0.05
BaO	0.15	0.02	0.18	0.09	0.18	0.18	0.18	0.03	0.02	0.01
Total	56.87	56.52	56.91	56.83	56.24	56.39	56.87	56.77	56.74	56.84

Sample No.	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral
CaO	55.72	53.19	53.72	53.79	54.09	54.09	54.58	53.52	55.37	55.53
MgO	0.68	0.54	0.51	0.57	0.48	0.55	0.64	0.41	0.69	0.67
FeO	0.29	1.79	1.81	1.76	1.52	1.78	0.76	2.17	0.35	0.25
MnO	0.05	0.06	0.09	0.05	0.02	0.07	0.06	0.04	0.02	0.09
SrO	0.07	0.09	0.04	0.01	0.09	0.05	0.05	0.13	0.09	0.09
BaO	0.05	0.15	0.17	0.07	0.01	0.04	0.04	0.11	0.08	0.03
Total	56.85	55.82	56.34	56.25	56.21	56.58	56.12	56.38	56.59	56.65

Sample No.	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14	ZP14
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C Coral	C Coral	C Coral	Coral	VF	VF	VF	VF	VF	VF
CaO	55.54	53.15	55.14	55.54	54.55	54.59	54.88	55.26	54.96	54.81
MgO	0.62	0.52	0.73	0.39	0.91	0.66	0.71	0.63	0.56	0.51
FeO	0.25	1.89	0.76	0.50	0.91	0.77	0.84	0.79	1.02	0.95
MnO	0.03	0.05	0.02	0.02	0.02	0.02	0.04	0.01	0.04	0.05
SrO	0.01	0.08	0.15	0.18	0.07	0.16	0.12	0.08	0.10	0.07
BaO	0.15	0.01	0.03	0.07	0.06	0.07	0.04	0.18	0.18	0.03
Total	56.59	55.70	56.84	56.71	56.53	56.26	56.62	56.94	56.85	56.42

Sample No.	ZP14	ZP14	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15
Facies	6	6	6	6	6	6	6	6	6	6
Grain	VF	VF	C	C	C	C	C	C	C	C Coral
CaO	54.60	54.63	54.86	54.02	53.16	53.05	53.03	53.99	54.66	54.70
MgO	0.53	0.68	0.80	0.36	0.56	0.54	0.47	0.43	0.73	0.74
FeO	1.23	0.80	0.11	1.42	1.91	1.78	1.70	1.66	0.00	0.22
MnO	0.01	0.02	0.04	0.05	0.07	0.07	0.07	0.06	0.08	0.01
SrO	0.19	0.08	0.05	0.09	0.08	0.03	0.04	0.13	0.06	0.10
BaO	0.18	0.18	0.22	0.10	0.06	0.15	0.22	0.22	0.22	0.03
Total	56.75	56.39	56.07	56.04	55.84	55.62	55.53	56.47	55.75	55.80

Sample No.	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C Coral	C Coral	C Coral	C Coral	C Coral	Mic	V	V	V	V
CaO	55.20	55.57	54.47	55.53	53.87	54.28	54.69	55.60	55.62	55.13
MgO	0.79	0.68	0.64	0.56	0.82	1.03	0.74	0.37	0.29	0.75
FeO	0.02	0.10	0.45	0.38	0.29	0.11	0.02	0.03	0.03	0.07
MnO	0.08	0.07	0.03	0.03	0.05	0.01	0.06	0.02	0.04	0.07
SrO	0.05	0.10	0.10	0.06	0.11	0.14	0.11	0.01	0.09	0.05
BaO	0.07	0.22	0.22	0.22	0.08	0.22	0.22	0.02	0.06	0.22
Total	56.20	56.73	55.91	56.77	55.21	55.80	55.84	56.04	56.13	56.28

Sample No.	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP15	ZP20	ZP20	ZP20
Facies	6	6	6	6	6	6	6	7	7	7
Grain	VF	VF	VF	VF	VF	VF	VF	C	C	C
CaO	54.96	54.94	55.01	55.03	55.47	55.23	55.01	54.33	54.63	54.42
MgO	0.74	0.35	0.52	0.71	0.75	0.67	0.58	0.57	0.58	0.55
FeO	0.05	0.05	0.06	0.21	0.18	0.14	0.15	1.20	1.19	1.23
MnO	0.01	0.04	0.03	0.03	0.03	0.04	0.02	0.02	0.02	0.04
SrO	0.09	0.08	0.02	0.01	0.08	0.10	0.05	0.11	0.07	0.13
BaO	0.22	0.08	0.22	0.22	0.02	0.14	0.08	0.05	0.04	0.01
Total	56.07	55.52	55.86	56.21	56.53	56.32	55.90	56.29	56.53	56.37

Table. A7.1. (contd.)

Sample No.	ZP20	ZP20	ZP20	ZP20	ZP20	ZP20	ZP20	ZP20	ZP20	ZP20
Facies	7	7	7	7	7	7	7	7	7	7
Grain	C	C FCh	C FCh	C FCh	C FCh	F	F	F	F	F
CaO	53.86	54.63	53.92	53.48	53.28	54.87	55.06	54.27	53.71	54.91
MgO	0.56	0.51	0.61	0.62	0.59	1.33	1.14	1.41	1.48	1.39
FeO	1.20	1.22	1.22	1.29	1.47	0.26	0.44	0.25	0.38	0.31
MnO	0.04	0.01	0.02	0.03	0.05	0.03	0.03	0.00	0.05	0.00
SrO	0.09	0.13	0.07	0.15	0.12	0.02	0.06	0.08	0.04	0.08
BaO	0.09	0.02	0.02	0.18	0.18	0.04	0.04	0.01	0.01	0.02
Total	55.83	56.51	55.85	55.74	55.69	56.55	56.78	56.01	55.66	56.71

Sample No.	ZP20	ZP22	ZP22	ZP22	ZP25	ZP25	ZP25	ZP25	ZP25	ZP25
Facies	7	7	7	7	6	6	6	6	6	6
Grain	F	C FCh F	C FCh F	F	C FCh	V	V	V F	V F	V F
CaO	54.47	54.28	54.30	54.36	54.25	55.90	55.41	55.60	55.39	55.48
MgO	1.56	0.56	0.50	1.23	1.23	0.40	0.37	0.25	0.19	0.12
FeO	0.30	0.88	0.91	0.24	0.13	0.02	0.00	0.11	0.13	0.22
MnO	0.05	0.05	0.03	0.03	0.02	0.02	0.02	0.03	0.01	0.01
SrO	0.06	0.12	0.11	0.08	0.08	0.10	0.10	0.12	0.08	0.09
BaO	0.05	0.23	0.23	0.23	0.02	0.07	0.24	0.23	0.09	0.02
Total	56.50	56.12	56.08	56.18	55.73	56.52	56.12	56.34	55.90	55.94

Sample No.	ZP25	ZP25	ZP25	ZP25	ZP25	ZP26	ZP26	ZP26	ZP26	ZP26
Facies	6	6	6	6	6	6	6	6	6	6
Grain	V F	V F	V F	V F	V F	C FCh F	C FCh F	C FCh F	F	F
CaO	55.62	54.89	56.26	55.64	55.65	55.52	53.69	54.71	54.32	54.67
MgO	0.29	0.25	0.09	0.24	0.43	0.28	0.54	0.62	1.03	1.01
FeO	0.14	0.19	0.08	0.13	0.04	0.71	1.28	0.96	0.38	0.35
MnO	0.01	0.01	0.00	0.03	0.02	0.01	0.01	0.05	0.02	0.01
SrO	0.09	0.10	0.10	0.10	0.07	0.12	0.02	0.09	0.05	0.09
BaO	0.24	0.05	0.24	0.09	0.24	0.12	0.11	0.04	0.23	0.19
Total	56.40	55.47	56.78	56.24	56.44	56.76	55.64	56.47	56.03	56.32

Sample No.	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26
Facies	6	6	6	6	6	6	6	6	6	6
Grain	F	F	F (F)	V F	V F	V F	V F	V F	V F	V F
CaO	54.55	55.09	53.67	53.72	53.54	53.95	54.16	53.14	54.16	53.93
MgO	0.85	1.06	0.63	0.67	0.46	0.73	0.74	0.71	0.76	0.67
FeO	0.40	0.23	1.58	1.50	1.28	1.45	1.53	1.48	1.60	1.41
MnO	0.04	0.05	0.07	0.02	0.03	0.01	0.06	0.04	0.03	0.03
SrO	0.09	0.06	0.14	0.09	0.12	0.07	0.08	0.11	0.06	0.06
BaO	0.05	0.02	0.01	0.08	0.09	0.16	0.15	0.08	0.06	0.24
Total	55.97	56.51	56.11	56.08	55.54	56.38	56.73	55.56	56.66	56.34

Sample No.	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26	ZP26
Facies	6	6	6	6	6	6	6	6	6	6
Grain	V F	V F	V F	V F	V F	V F	V F	V F	V F	V F
CaO	53.50	53.14	53.23	52.95	53.56	54.55	53.81	53.98	54.06	53.60
MgO	0.50	0.70	0.73	0.68	0.62	0.73	0.60	0.54	0.52	0.61
FeO	1.38	1.57	1.64	1.58	1.52	1.34	1.44	1.46	1.46	1.49
MnO	0.04	0.06	0.06	0.02	0.06	0.05	0.04	0.07	0.04	0.06
SrO	0.10	0.10	0.11	0.12	0.11	0.07	0.10	0.10	0.11	0.10
BaO	0.24	0.15	0.05	0.25	0.01	0.06	0.05	0.23	0.07	0.23
Total	55.76	55.73	55.82	55.58	55.88	56.80	56.04	56.39	56.26	56.09

Sample No.	ZP26	ZP29	ZP29	ZP29	ZP29	ZP29	ZP32	ZP32	ZP32	ZP32
Facies	6	7	7	7	7	7	6	6	6	6
Grain	V F	C FCh F	F	F	F	F	C FCh	C FCh	C FCh	C FCh
CaO	54.18	53.74	54.60	54.23	54.49	54.42	54.35	53.66	53.67	54.06
MgO	0.55	0.41	0.77	0.93	0.82	0.87	0.61	0.60	0.66	0.60
FeO	1.44	1.08	0.63	0.68	0.73	0.73	0.78	0.94	0.87	0.81
MnO	0.01	0.09	0.03	0.03	0.03	0.04	0.06	0.11	0.06	0.03
SrO	0.10	0.10	0.13	0.12	0.11	0.02	0.11	0.11	0.08	0.04
BaO	0.23	0.01	0.23	0.14	0.09	0.23	0.01	0.11	0.06	0.04
Total	56.51	55.43	56.39	56.12	56.27	56.31	55.93	55.53	55.38	55.57

Table. A7.1. (contd.)

Sample No.	ZP32	ZP32	ZP32	ZP32	ZP32	ZP32	ZP32	ZP36	ZP36	ZP36
Facies	6	6	6	6	6	6	6	7	7	7
Grain	F	F	F	F	F	F	F	C	C	C
CaO	54.31	54.23	54.26	54.38	54.15	54.32	54.60	52.84	52.94	52.47
MgO	0.81	0.86	0.81	0.87	0.80	0.78	0.90	0.58	0.60	0.69
FeO	0.46	0.37	0.43	0.50	0.52	0.46	0.49	1.53	1.94	2.23
MnO	0.00	0.04	0.04	0.07	0.02	0.02	0.06	0.06	0.07	0.06
SrO	0.05	0.00	0.06	0.08	0.10	0.09	0.13	0.09	0.08	0.00
BaO	0.20	0.24	0.24	0.24	0.01	0.24	0.04	0.24	0.07	0.08
Total	55.83	55.73	55.84	56.14	55.59	55.90	56.21	55.34	55.71	55.53

Sample No.	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36
Facies	7	7	7	7	7	7	7	7	7	7
Grain	C	C	C	C	C	C	C	C	C	C Alg
CaO	52.66	53.63	53.30	53.11	53.07	52.59	52.64	52.98	53.46	53.88
MgO	0.67	0.58	0.59	0.61	0.53	0.62	0.61	0.61	0.66	0.65
FeO	1.99	1.50	1.95	2.05	2.01	2.01	2.05	1.96	1.78	0.75
MnO	0.09	0.08	0.12	0.05	0.08	0.05	0.05	0.05	0.06	0.04
SrO	0.09	0.12	0.06	0.11	0.12	0.07	0.11	0.12	0.14	0.02
BaO	0.02	0.24	0.02	0.10	0.02	0.24	0.05	0.10	0.05	0.24
Total	55.53	56.14	56.04	56.02	55.83	55.57	55.51	55.81	56.15	55.57

Sample No.	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36	ZP36
Facies	7	7	7	7	7	7	7	7	7	7
Grain	C Alg	C Alg	C Alg	C FCh	C FCh	C FCh	C FCh	C FCh	C FCh	C FCh
CaO	54.37	53.71	54.10	54.27	54.47	54.96	54.94	54.80	55.26	55.17
MgO	0.55	0.65	0.55	0.40	0.43	0.57	0.35	0.56	0.23	0.40
FeO	0.88	0.92	0.86	0.65	0.62	0.78	0.62	0.82	0.49	0.65
MnO	0.09	0.03	0.04	0.04	0.05	0.03	0.04	0.03	0.04	0.07
SrO	0.11	0.11	0.09	0.10	0.12	0.04	0.11	0.10	0.10	0.08
BaO	0.01	0.08	0.14	0.24	0.01	0.04	0.11	0.01	0.04	0.24
Total	56.01	55.50	55.78	55.69	55.70	56.41	56.17	56.32	56.16	56.61

Sample No.	ZP36	ZP36	ZP36	ZP36	ZP36	ZP38	ZP38	ZP38	ZP38	ZP38
Facies	7	7	7	7	7	7	7	7	7	7
Grain	C FCh	C FCh	C FCh	F	F	C FCh F	C FCh F	C FCh F	F	F
CaO	54.58	53.71	53.96	54.46	54.22	53.45	53.27	52.74	52.96	53.52
MgO	0.53	0.58	0.64	1.10	1.05	1.09	0.83	0.86	1.12	0.93
FeO	0.77	0.77	0.82	0.61	0.52	1.25	1.26	1.60	0.90	0.81
MnO	0.02	0.03	0.06	0.04	0.07	0.02	0.04	0.05	0.03	0.04
SrO	0.09	0.05	0.10	0.08	0.11	0.04	0.09	0.06	0.15	0.11
BaO	0.13	0.23	0.24	0.11	0.24	0.23	0.09	0.04	0.23	0.02
Total	56.12	55.36	55.81	56.39	56.21	56.08	55.58	55.34	55.39	55.43

Sample No.	ZP38	ZP38	ZP40	ZP40	ZP40	ZP40	ZP40	ZP40	ZP40	ZP48
Facies	7	7	7	7	7	7	7	7	7	8
Grain	F	F	C FCh	F	F	F	F	F	V F	C F(PL)
CaO	53.47	53.85	54.58	54.88	55.47	54.42	55.50	54.85	54.20	54.92
MgO	1.26	1.11	0.56	0.73	0.76	0.77	0.97	0.85	0.80	0.60
FeO	0.74	0.77	0.89	0.50	0.35	0.46	0.08	0.88	1.12	0.17
MnO	0.04	0.03	0.06	0.01	0.07	0.00	0.00	0.02	0.05	0.01
SrO	0.13	0.16	0.09	0.08	0.13	0.10	0.04	0.06	0.12	0.14
BaO	0.23	0.02	0.04	0.18	0.04	0.08	0.01	0.11	0.09	0.08
Total	55.87	55.95	56.22	56.37	56.81	55.83	56.60	56.77	56.38	55.93

Sample No.	ZP48	ZP48	ZP50	ZP50	ZP52	ZP52	ZP52	ZP52	ZP52	ZP52
Facies	8	8	8	8	6	6	6	6	6	6
Grain	F(PL)	V	C	C	C	C	C	C	C FCh	C FCh
CaO	55.15	55.81	55.54	54.53	55.14	55.34	55.57	55.50	54.91	55.33
MgO	0.36	0.49	0.58	0.53	0.35	0.47	0.15	0.40	0.35	0.54
FeO	0.03	0.33	0.08	0.10	0.18	0.19	0.05	0.04	0.13	0.02
MnO	0.02	0.01	0.03	0.02	0.03	0.02	0.01	0.03	0.02	0.02
SrO	0.14	0.08	0.13	0.21	0.06	0.03	0.08	0.12	0.08	0.10
BaO	0.05	0.01	0.08	0.05	0.08	0.14	0.13	0.08	0.06	0.24
Total	55.74	56.74	56.44	55.45	55.84	56.19	55.99	56.16	55.56	56.25

Table. A7.1. (contd.)

Sample No.	ZP52	ZP52	ZP53	ZP53	ZP53	ZP53	ZP53	ZP53	ZP53	ZP53
Facies	6	6	6	6	6	6	6	6	6	6
Grain	F	F	C	C	C	C	C	C	C	C
CaO	54.61	55.04	54.34	54.93	55.72	55.07	55.12	54.99	54.72	55.53
MgO	0.90	0.85	0.63	0.67	0.33	0.84	0.44	0.81	0.92	0.79
FeO	0.03	0.07	0.26	0.27	0.16	0.26	0.22	0.25	0.33	0.17
MnO	0.03	0.02	0.00	0.04	0.01	0.01	0.06	0.04	0.05	0.03
SrO	0.06	0.14	0.08	0.15	0.16	0.18	0.09	0.16	0.12	0.19
BaO	0.07	0.06	0.18	0.01	0.02	0.18	0.16	0.07	0.02	0.08
Total	55.69	56.18	55.49	56.08	56.39	56.53	56.09	56.31	56.15	56.78

Sample No.	ZP53	ZP53	ZP53	ZP53	ZP53	ZP53	ZP53	ZP53	ZP54	ZP54
Facies	6	6	6	6	6	6	6	6	7	7
Grain	C	C	C	C	C	C	C	C	CFCh	F
CaO	55.89	55.01	55.39	55.84	55.20	55.97	55.15	55.69	54.44	54.51
MgO	0.51	0.80	0.79	0.51	0.78	0.30	0.93	0.67	0.65	0.94
FeO	0.03	0.29	0.28	0.16	0.27	0.15	0.32	0.23	0.39	0.11
MnO	0.03	0.02	0.05	0.02	0.03	0.05	0.04	0.01	0.02	0.01
SrO	0.13	0.13	0.14	0.14	0.10	0.18	0.14	0.12	0.08	0.16
BaO	0.07	0.07	0.03	0.03	0.01	0.02	0.17	0.10	0.04	0.12
Total	56.66	56.32	56.68	56.70	56.39	56.66	56.74	56.81	55.61	55.84

Sample No.	ZP54	ZP54	ZP54	ZP54	ZP54	ZP56	ZP56	ZP56	ZP56	ZP56
Facies	7	7	7	7	7	6	6	6	6	6
Grain	F	F	F	F	Mic	Bryo	C	C	C	C
CaO	54.73	54.04	54.44	54.82	53.61	55.10	55.26	55.31	55.47	54.59
MgO	1.09	0.80	0.83	1.01	0.98	0.72	0.30	0.58	0.61	0.65
FeO	0.19	0.25	0.18	0.18	0.25	0.06	0.02	0.02	0.02	0.17
MnO	0.01	0.04	0.02	0.06	0.03	0.05	0.05	0.00	0.02	0.03
SrO	0.09	0.09	0.11	0.09	0.06	0.07	0.06	0.07	0.08	0.09
BaO	0.07	0.24	0.02	0.24	0.24	0.24	0.06	0.01	0.02	0.24
Total	56.18	55.45	55.61	56.40	55.16	56.24	55.75	56.00	56.22	55.77

Sample No.	ZP56	ZP56	ZP56	ZP56	ZP56	ZP7A	ZP7A	ZP8	ZP8	ZP8
Facies	6	6	6	6	6	8	8	6	6	6
Grain	CFCh	CFCh	Ech	F	Mic	CFCh	CFCh	C	C	C
CaO	54.64	55.47	54.19	54.43	54.33	55.08	54.87	53.72	55.01	53.23
MgO	0.39	0.82	0.82	0.64	0.67	0.50	0.48	0.64	0.48	0.57
FeO	0.01	0.03	0.06	0.18	0.35	0.23	0.25	0.99	0.28	1.46
MnO	0.09	0.01	0.01	0.04	0.04	0.04	0.04	0.04	0.04	0.09
SrO	0.10	0.06	0.12	0.14	0.10	0.13	0.10	0.07	0.09	0.04
BaO	0.19	0.08	0.24	0.07	0.24	0.22	0.12	0.18	0.18	0.02
Total	55.42	56.48	55.44	55.51	55.73	56.21	55.86	55.63	56.08	55.41

Sample No.	ZP8	ZP8	ZP8	ZP8	ZP8	ZP8	ZP8	ZP8	ZP8	ZP8
Facies	6	6	6	6	6	6	6	6	6	6
Grain	C	C	C	C	C	C	C	C	C	C
CaO	54.01	54.56	53.12	53.50	54.58	54.45	53.42	53.94	53.37	54.44
MgO	0.44	0.42	0.56	0.44	0.71	0.56	0.58	0.49	0.49	0.68
FeO	1.39	0.83	1.67	1.65	0.70	0.68	1.61	1.52	1.65	0.61
MnO	0.05	0.03	0.05	0.09	0.02	0.07	0.08	0.04	0.05	0.02
SrO	0.13	0.06	0.15	0.14	0.02	0.08	0.10	0.11	0.13	0.04
BaO	0.02	0.08	0.26	0.17	0.09	0.05	0.17	0.04	0.04	0.18
Total	56.04	55.97	55.81	55.99	56.11	55.89	55.97	56.13	55.73	55.96

Sample No.	ZP9	ZP9	ZP9	ZP9	ZP9	ZP9	ZP9	ZP9	ZP9	ZP9
Facies	7	7	7	7	7	7	7	7	7	7
Grain	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral	C Coral
CaO	54.37	54.35	55.00	54.66	54.93	53.56	53.32	54.58	53.35	54.59
MgO	1.12	0.90	0.82	1.18	1.06	0.55	0.50	0.64	0.50	0.62
FeO	0.14	0.21	0.32	0.18	0.22	1.39	1.44	1.30	1.66	0.47
MnO	0.03	0.02	0.01	0.02	0.01	0.05	0.05	0.08	0.10	0.01
SrO	0.06	0.03	0.07	0.00	0.06	0.02	0.09	0.02	0.05	0.05
BaO	0.02	0.03	0.04	0.22	0.08	0.03	0.07	0.02	0.02	0.11
Total	55.74	55.55	56.26	56.27	56.35	55.60	55.46	56.64	55.69	55.84

Table. A7.1. (contd.)

Sample No.	ZP9	ZP9	ZP9
Facies	7	7	7
Grain	C Coral	C Coral	Coral
CaO	54.79	54.25	54.36
MgO	0.68	0.52	0.40
FeO	0.40	1.51	0.77
MnO	0.04	0.03	0.03
SrO	0.14	0.07	0.12
BaO	0.04	0.03	0.07
Total	56.09	56.42	55.76

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