Chapter II

CARBONATE MICROFACIES

INTRODUCTION

Microfacies analysis, i.e., petrographic study under microscope is the most important part of the investigations of carbonate rocks. Microfacies analysis helps in the interpretation of the depositional environments. This interpretation becomes meaningful when petrography is combined with detailed stratigraphic control and when comparison is made with depositional models constructed on the basis of study of Holocene sediments.

The concept of depositional interpretation of microfacies was evolved by Cuvillier and Schurmann (1951-1969). An excellent review of the importance of the concept was published by Fairbridge (1954). The early work on carbonate microfacies employed mainly palaeontological criteria. Flugel (1972) added sedimentological criteria to the basic palaeontological approach and described several basic types of microfacies. Excellent illustrations of some of the basic microfacies were given by Horowitz and Potter (1971).

Major textural constituents of the carbonate rocks of the Jaisalmer Formation were studied in 174 thin sections prepared from representative sample collected during
measurement of stratigraphic sections of the formation. Staining with Alizarin Red S helped in differentiating calcite and dolomite.

MAJOR TEXTURAL CONSTITUENTS

Following Folk's (1962) scheme, the major constituents are divisible into allochems (framework grains), spray calcite and micrite. The framework grains comprise bioclasts, peloids, ooids, faecal pellets and intraclasts in order of their abundance. Terrigenous admixture is present in most of the samples.

Bioclasts

Bioclasts are the most common constituents and occur throughout the Jaisalmer Formation with the exception of terrigenous clastic beds and some carbonate beds. The percentages of bioclasts in various thin sections range from 1.0 percent to 62.3 percent and average 17.5 percent. The various types of bioclasts were identified as fragments and whole fossils of molluscs, brachiopods, echinoderms, foraminifers, ostracods, broyozoans, corals, calcispheres, algae and tintinnines.

Molluscs

Molluscan fragments occur almost throughout the Jaisalmer Formation and constitute 0.3 - 40 percent of the total rock volume, averaging 7.5 percent. Among the molluscan fragments, representatives of pelecypods, gastropods
and belemnites have been recognised on the basis of shell shape and shell microstructure. In whole fossils and larger fragments, shell outlines easily identify the bioclasts. However, smaller fragments are difficult to identify especially the ones which have lost the original wall microstructure. In bioclasts which have lost all traces of original wall microstructure characteristic outlines of the shells are preserved by micrite envelopes and by internal and external sediment plus cement.

Gastropod shells are easily identifiable by their characteristic outlines. They have generally lost all traces of their wall microstructure during transformation from original aragonite to sparry calcite. Pelecypod fragments are comparatively less altered and show well preserved prismatic wall microstructure. The pelecypod debris consist of disarticulated valve fragments, ranging in size generally from 0.1 - 10.6 mm. The fragments are mostly subrounded to rounded. Serpulid worm tubes attached to pelecypod shells have been identified. Circular and oblique fragments of such tubes occur.

Belemnite fragments show concentric growth layers and concentric calcite prisms. They range in size from 3 mm - 27 mm and constitute 2.7 to 33.6 percent in certain microfacies of the Kuldhar Member. Molluscs are also represented by filamentous bivalves. Some bioclasts though identified as molluscs by their outlines and associations could not be further classified as they have lost all traces of their original wall
structure. Such 'unclassified' molluscs constitute 0.4 - 23.6 percent and average 4.3 percent. The size of these bioclasts ranges from 0.1 mm to 13.0 mm. They are generally subrounded to well rounded and occasionally subangular.

**Brachiopods**

Brachiopods occur throughout the Jaisalmer Formation but are almost absent from the Joyan Member of the formation. Brachiopods constitute 0.4 - 47.3 percent and average 5.0 percent. In majority of samples they rarely exceed 10 percent. The size of bioclasts generally ranges from silt size to fine sand size and occasionally much larger fragments and whole fossils upto 10.5 mm occur. The bioclasts are mostly subrounded to rounded and occasionally subangular to angular. They are characterised by fibrous wall microstructure with fibres aligned parallel and oblique to the wall surface. Some of the fragments appear to be transverse sections of spines showing concentric wall microstructure. The fragments generally show well preserved wall microstructure but in some thin sections they show recrystallisation and micritisation and microborings.

**Echinoderms**

Echinoderms are universally present in the Jaisalmer Formation but constitute generally less than 15.4 percent of the total rock volume and average 3.2 percent. In one microfacies they are abundant forming 49.2 percent. The
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The bioclasts are readily identifiable by their unit extinction in cross-polarised light. They comprise randomly cut sections of stem plates and spines of crinoids and echinoids. The bioclasts are porous and the pores are infilled with micrite and rarely iron oxide. They show overgrowths, ooidal coatings and micrite envelopes. In the Joyan Member, the bioclasts are partly replaced by ferruginous dolomite.

Foraminifers

Foraminifers form a minor constituent of the rocks under study, rarely exceed 1 percent, and average 0.5 percent. They range in size from 0.04 mm to 0.6 mm. They comprise uniserial to biserial and multichambored forms showing mostly micritised walls. In the well preserved forms, porcellaneous or fine granular wall microstructure is recognisable. The shell chambers are filled with either micrite or sparry calcite cement and rarely with quartz silt. Some forms show replacement by ferruginous dolomite/iron oxide.

Ostracods

Ostracods rarely exceed 1 percent and occur mainly in the lower part of the Fort Member and in the Kuldhar Member. They occur as mostly disarticulated but sometimes articulated valves, ranging in size from 0.1 mm to 0.7 mm. Recurved margins and overlapping of the valves are characteristic features.
A well preserved fine prismatic wall microstructure is seen. Ostracods form 0.3 - 2.2 percent and average 0.2 percent.

**Other Bioclasts**

Bryozoans, corals, algae, calcispheres and tintinnines occur rarely in the studied rocks. Bryozoan fragments comprise circular to elongated holes (zoecia) filled with micrite or sparry calcite. The zoecia are less than 0.5 mm in maximum diameter. The wall microstructure is generally altered but occasionally original fibrous wall microstructure is identifiable. The size of bryozoan fragments ranges from 0.3 mm to 7.0 mm. Coral debris occur very rarely as rounded bioclasts with altered shell wall and tubes of more than 0.5 mm diameter. Algae occur as dark coloured encrustations on bioclasts and probably belong to blue-green algae (Scholle, 1978, p.14). Minute spherical forms exhibiting circular outlines with well preserved shell wall were recognised as calcispheres. Their diameter ranges from 0.04 mm to 0.28 mm. Some very minute U-shaped (0.06 mm to 0.12 mm), circular and elliptical forms probably represent Tintinnines. These forms occur in traces in a few samples.

**Non-skeletal Grains**

Non-skeletal grains in the studied rocks comprise peloids, ooids, faecal pellets and intraclasts.

**Peloids**

Scholle (1978) defined 'peloid' as an allochem formed of
cryptocrystalline or microcrystalline carbonate irrespective of size or origin. In the study area peloids consist of generally well rounded, ovoid and circular grain of cryptocrystalline carbonate. They range in size from 0.02 mm to 0.7 mm. They comprise 0.9 - 55 percent and average 10.4 percent. The peloids of the study area appear to be micritised bioclasts and ooids, plus faecal pellets and pelletal intraclasts.

Ooids

Ooids include superficial, true and composite ooids. Superficial ooids are abundant whereas composite ooids are scarce. The thickness of cortex in superficial ooids is less than the diameter of nucleus whereas the thickness of cortex in true ooids is more than the diameter of nucleus. Composite ooids are composed of more than one nuclei. Sometimes the concentric layers of ooids are replaced by iron oxide. Replacement by iron oxide is a common feature in ooids occurring in the Kuldhar Member. The size of ooids ranges from 0.05 mm to 1.64 mm. They constitute 0.5 - 48 percent and average 8.6 percent.

Faecal Pellets

Faecal pellets closely resemble peloids in size, shape and composition, and it is difficult to differentiate them. Those, darker in appearance than the surrounding micrite
matrix possibly because of their higher organic content, and showing remarkable uniformity of size and shape are interpreted as faecal pellets. They comprise 8 - 62.8 percent, and average 6.6 percent.

**Intraclasts**

Folk (1962, p.63) defined 'intraclast' as a fragment of penecontemporaneous, generally weakly consolidated carbonate sediment that has been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment. Intraclasts in the study area are rounded with firm boundaries. They are composed of lithologies similar to the microfacies of the study area suggesting their origin by penecontemporaneous erosion. They range in size from 0.18 mm to 16.5 mm and form 0.1 - 49 percent, and average 3 percent.

**Sparry Calcite**

According to Folk (1962, p.66) sparry calcite generally forms grains or crystals 10 micron or more in diameter, and is distinguished from microcrystalline calcite by its clarity as well as coarser crystal size. Bathurst (1971, p. 417, 419) distinguished sparry calcite by the intercrystalline boundaries in the sparry mosaic which are made up of plane interfaces and characterized by enfacial junctions. In the studied carbonate rocks, sparry calcite occurs predominantly as interparticle pore filling cement. Sometimes it also fills shell cavities of gastropods and foraminifers.
and molds produced by leaching of mulluscan fragments. Some amount of sparry calcite is also present as syntaxial cement rims on echinodermal fragments. Interparticle pore filling sparry calcite cement is of granular type (Orme and Brown, 1963). The granular sparry calcite cement comprises small elongate acicular or fibrous crystals that rim the pore space and are designated as isopachous cement rim. Away from the boundary of pore space, crystal size increases and crystals become equant and anhedral and such type of granular cement is called as blocky cement (Dunham, 1969, p. 141). Sometimes it is difficult to distinguish sparry calcite cement where it is admixed with recrystallized pseudospar. The sparry calcite constitutes 2.5 - 46.6 percent and averages 14.1 percent.

**Micrite**

Micrite is microcrystalline carbonate material which is finer than 0.004 mm/4 microns (Folk, 1962). The upper size limit of micrite particles was fixed at 31 microns by Leighton and Pendexter (1962) and at 50 microns by Bissel and Chillingar (1967). In the carbonate rocks under study, carbonate material finer than 0.031 mm has been termed micrite following Leighton and Pendexter (1962). The micrite has occasionally recrystallized to 'pseudospar' which consists of grains more than 30 microns in diameter (Folk, 1965). The micrite matrix forms 2.2 - 80.7 percent, and averages 18 percent.
DESCRIPTION OF MICROFACIES

A total of 23 microfacies were recognised in the study area. Dunham's (1962) and Folk's (1962) classificatory schemes were followed for the classification and nomenclature of microfacies which are described below under five groups: A, Wackestones; B, Packstones; C, Packstones-Grainstones; D, Grainstones; and E, Boundstones.

A. Wackestones

A1. Pelletal Wackestone (pelmicrite)

This microfacies occurs in nodular-bedded limestone, in the middle part of the Fort Member. Its average composition is 71.9 percent pelleted micrite, 16.6 percent non-skeletal grains (mostly pellets), 6.7 percent bioclasts and 4.8 percent terrigenous admixture.

Micrite is predominant and vaguely pelleted. However, clearly demarcated pellets (average 16.6 percent) are also present. They range in size from 0.02 mm to 0.28 mm.

Bioclasts are larger than pellets and range in size generally from 0.12 mm to 0.6 mm and occasionally up to 3.2 mm. They consist of mostly debris of unidentifiable bioclasts (1.0 to 4.8 percent), molluscs (0.5 to 4.0 percent), and some echinoderms and brachiopods (up to 1.6 percent each), ostracods (up to 1.0 percent), and foraminifers and calcispheres occurring in traces. The molluscan bioclasts are generally recrystallized to sparry calcite. Echinodermal debris have
ragged boundaries. Foraminers show micritisation. The microfacies contains 1.6 percent superficial ooids of 0.2 mm average size and having nuclie of faecal pellets. Terrigenous admixture includes subangular quartz silt and minor amount of iron oxides.

The microfacies resembles biopelmicrite described elsewhere but differs in having larger percentage of pelleted mud and lesser percentage of bioclasts, and absence of whole fossils and higher percentage of terrigenous admixture. This microfacies resembles pellet mud lithofacies described from the Great Bahama Bank (Bathurst, 1971) and belongs to open marine platform facies (Wilson, 1975).

Abundance of micrite in the microfacies indicates lack of persistent and strong currents or waves and low-energy conditions of the environment of deposition. Micrite is mainly formed in shallow, sheltered lagoonal areas, or on broad, submerged shelves of little relief and moderate depth where wave action is cut off by the very width of the shelf. Some micrite may also form in deeper offshore areas.

Pellets of the microfacies are interpreted as faecal pellets on the basis of their dark colour and uniformity of shape and size. Organic pelleting of mud suggests only very slight water movement. Organic pelleting of micrite is a common feature of shelf lagoon sediments (Daetwyler and Kidwell, 1959; Hoskins, 1964; Kinsman, 1964; Bathurst, 1971; Wilson, 1975; Hine, 1977; Arakel, 1980), nearshore or
restricted marine sediments (Shinn et al., 1969), and open sea shelf (Wilson, 1975).

Fine to coarse size angular fossil fragments are the result of predatory (boring, opening, and breaking) activity and scavenging activity and imply lack of transport. Fossils consisting mostly of mulluscs, brachiopods and echinoderms indicate generally open circulation and normal marine salinity.

Thus, the diverse fauna and various characteristics of the microfacies suggest deposition in waters of normal marine salinity in an open sea or platform lagoon of shallow shelf environment which resembles the Standard Facies Belts 2 and 7 of Wilson (1975), subtidal shallow shelf of Heckel (1972), and subtidal, clear, interior shelf of Sodero and Hobson (1979).

A2. **Terrigenous peloidal wackestone (terrigenous pelmicrite)**

This microfacies is present in nodular-bedded limestone in the middle part of the Fort Member. Terrigenous admixture is abundant (41.8 percent). Other petrographic constituents include recrystallized micrite 39.4 percent, peloids 10 percent, bioclasts 8 percent and intraclasts 0.8 percent.

Micrite has mostly recrystallized to pseudospar. Peloids are ovoid to rod-shaped, well sorted, well rounded and range in size from 0.08 mm to 0.28 mm. Nannan wall microstructure in some peloids indicates their derivation from micritization of bioclasts. Bioclasts are of mulluscs (5.6 percent), corals (1.2 percent), echinoderms (0.8 percent) and brachiopods.
(0.4 percent). Bioclasts range in size from 0.14 mm to 3.3 mm. Most of the bioclasts show vague boundaries but some are rounded with thin micrite envelope. Terrigenous admixture includes fine sand and silt size, subangular to subrounded grains of quartz, chert, feldspar and green coloured glauconite grains. Burrows filled with quartz silt appear as elliptical to elongated patches.

Abundance of micrite and presence of varied fauna suggest that the microfacies was deposited in a shallow, neritic water of open circulation at or just below wave base. The microfacies resembles the Standard Facies Belts 2 and 7 of Wilson and unrestricted, subtidal quiet 'turbid shelf' facies in Lower Palaeozoic carbonate rocks, Northwest Canada (Sodero and Hobson, 1979). Abundance of terrigenous material reflects a sudden influx of clastic material.

A3. Terrigenous bioclastic wackestone (terrigenous biomicrite)

This microfacies occurs in nodular-bedded limestone, in the upper part of the Fort Member. The most dominant constituent of the microfacies is micrite (45.8 percent) (Plate IV, Fig. A). Other constituents are terrigenous admixture (30.2 percent), bioclasts (18 percent), peloids (5.6 percent) and intraclasts (0.6 percent).

Micrite matrix has occasionally recrystallized to pseudospar occurring in small patches. Micrite also fills shell cavities in ostracods.
Photomicrographs of carbonate microfacies and their characteristics features, Jaisalmer Formation.

(Plane - polarized)

**Figure A.** Terrigenous bioclastic wackestone. Micrite and terrigenous admixture are abundant. Bioclasts are mostly unabraded, poorly sorted and recrystallized molluscan fragments. (x 10)

**Figure B.** Bioclastic wackestone. Note the poorly sorted and unabraded bioclasts of brachiopods and whole fossils of gastropods. Parallel fibrous shell microstructure in brachiopod fragments. (x 13)

**Figure C.** Whole fossil wackestone showing abundant recrystallized pelecypod fragments. Note the whole fossil of gastropod at the upper left edge of photograph. (x 9)

**Figure D.** Whole fossil bioclastic pelletal packstone. Note the prominent whole fossil with geopetal sediment infilling. (x 12.5)

**Figure E.** Belemnite whole fossil packstone showing concentric growth lines in an oblique section of belemnite. (x 3.6)

**Figure F.** Terrigenous dolomite pelletal packstone. Note laminations and sparry calcite filled fenestral fabric and pelleted texture, 'Palisade' structure, formed by vertical algal filaments can be noted. (x 62.5)
Bioclasts include dominant fragments of mulluscs (16.8 percent), and disarticulated and articulated whole fossils of ostracods (1.1 percent). The molluscan fragments are unabraded, poorly sorted, and range in size from 0.24 mm to 16 mm. The bioclasts show occasionally stylolitic contacts along which black insoluble ferruginous material is concentrated.

The sparsely distributed peloids are ovoid, well rounded and well sorted. Some peloids have typical bioclastic shape and show remnant wall microstructure. As discussed elsewhere the peloids are probably a mixture of faecal pellets and rounded micritized bioclasts. Their size ranges from 0.04 mm to 0.2 mm. Intraclasts of lime mudstone are sparsely distributed. They are angular, irregular and range in size from 0.68 mm to 1.06 mm.

Terrigenous admixture mainly includes subangular to subrounded fine quartz sand and quartz silt with minor amount of feldspar, chert and opaque minerals.

Abundance of micrite, unabraded bioclasts and their poor sorting suggest lack of current and wave activity. The fauna indicates restricted circulation of water and higher salinity. Thus, the microfacies suggests deposition in shallow and quiet waters of a restricted shelf lagoon. The microfacies resembles the Standard Facies Belt 7 of Wilson (1975).

A4. Bioclastic wackestone (biomicrudite)

This microfacies occurs in thin, wavy-bedded fossiliferous limestones interbedded with cross-beded poorly
fossiliferous arenaceous limestones in the lower part of the Kuldhar Member. The microfacies comprises dominant micrite (49.0 percent) and bioclasts (39.6 percent) (Plate IV, Fig. B). Other textural constituents include ooids (4.4 percent), dolomite (3.1 percent), terrigenous admixture (2.2 percent), intraclasts (1.3 percent) and peloids (0.9 percent).

Micrite matrix is ferruginous and argillaceous. In parts it is entirely replaced by iron oxide. It also fills shell cavities of gastropods.

Bioclasts include molluscs (22.2 percent, mostly gastropods), brachiopods (14.4 percent), echinoderms (1.7 percent), bryozoans, ostracods and foraminifers (0.4 percent each), and traces of algal encrustations. Majority of bioclasts are disarticulated fragments but some whole fossils of gastropods and foraminifers also occur. The bioclasts are poorly sorted ranging in size generally from 0.26 mm to 7 mm (medium sand size to pebble size) and show sharp to ragged boundaries. Dark coloured algal encrustations occur on the fragments of brachiopods, molluscs, and echinoderms. Micrite filled bored fragments of brachiopods and molluscs are present. Dark brown, very small, irregular, ferruginous micrite filled algal microborings are common in micrite matrix. Shell cavities in gastropods are filled with darker coloured silty micrite, ferruginous micrite and silty ooidal packstone. Bioclasts show stylolitic contacts with concentration of black iron oxide.
Ooids include superficial and true ooids and occasionally composite ooids. They range in size from 0.22 mm to 0.99 mm. Ooids show coatings of calcium carbonate and iron oxide. Dolomite occurs in small patches. It is finely to mostly medium crystalline ranging in size from 0.025 mm to 0.21 mm. Dolomite rhombs are light brown coloured, ferruginous, euhedral and show cleavage. They have replaced molluscan fragments and algal encrustations. Intraclasts of silty lime mudstone and silty bioclastic packstone are sparsely distributed and well rounded. They range in size from 0.62 mm to 3.3 mm. Peloids are scattered, ovoid in outline and range in size upto 0.2 mm. Terrigenous admixture includes quartz, feldspar and iron minerals.

The dominant constituent of the microfacies is homogeneous, ferruginous, argillaceous micrite. Argillaceous material and micrite cannot be differentiated with each other. This nature of argillaceous micrite is suggestive of shallower water conditions where currents, wave action, and burrowing tend to intermix micrite and argillaceous material. Argillaceous nature of micrite also suggest turbid water which inhibits carbonate precipitation.

Presence of varied fauna suggests marine conditions with open circulation and normal salinity.

A5. **Whole fossil wackestone (whole fossil biomicrite)**

This microfacies occurs in nodular bedded limestones of the middle part of the Fort Member. It contains abundant
micrite (48.6 percent) and bioclasts (38 percent). Other components include faecal pellets (8 percent), intraclasts (1.4 percent) and terrigenous admixture (4.2 percent).

Micrite is occasionally recrystallized to pseudospar occurring as very small patches.

Bioclasts comprise molluscs (pelecypods and gastropods, 34.6 percent), brachiopods (1.4 percent), echinoderms (1 percent) ostracods and algae (0.5 percent each), and bryozoans, foraminifers and calcispheres in traces. They are represented by whole fossils and large unabraded fragments which are poorly sorted and have sharp boundaries (Plate IV, Fig. C). The bioclasts range in size from 0.1 mm to 8 mm. Sometimes bioclasts show dark brown micrite envelopes. Shell cavities in gastropods are filled with silty bioclastic pellet packstone. Drusy sparry calcite fills shell cavities in some brachiopods, ostracods, foraminifers and calcispheres. Umbrella effects are rare and shown by pelecypod fragment and the void filled with sparry calcite. One brachiopod shell shows geopetal structure in which pelleted lime mud is present towards bottom side followed by sparry calcite towards the top. Size of calcite crystals in geopetal structure increases towards the top.

Faecal pellets range in size from 0.025 mm to 0.2 mm and appear to float in micrite matrix. Intraclasts of silty lime mudstone and silty bioclastic wackestone are sparsely
distributed and well rounded.

Terrigenous admixture includes angular to sub-angular quartz sand and silt, and few opaque iron minerals.

Abundance of micrite, whole fossils, large size and angular nature of fossil fragments, their poor sorting, pelleting of lime mud, all point to low-energy conditions of deposition. Varied fauna indicates generally water of open circulation and normal marine salinity. The microfacies resembles the Standard Facies Belt 2 and 7 of Wilson (1975).

A6. Terrigenous dolostone (terrigenous dolomitized micrite)

The microfacies occurs in cross-beded arenaceous limestones of the upper 2 metres of the Hamira Member. The dominant constituents of the microfacies are dolomite (average 42 percent), terrigenous admixture (24.7 percent) and sparry calcite (21.5 percent). The other constituents include bioclasts (7 percent), peloids (5.1 percent) and intraclasts (0.1 percent).

The microfacies shows extensive dolomitization and recrystallization. Dolomite occurs in patches as well as single floating crystals. The dolomitized patches consist of very minute crystals in the centre whereas outwards the size of the crystals increases to medium crystalline and they become clearly zoned. Some dolomitized patches consist of aphanocrystalline dolomite in which rhombic shape is not discernible. The dolomite rhombohedra in patches are tightly
interlocked and mutually interfering. The floating crystals of dolomite are very finely crystalline to finely crystalline. The buff colour and zoning of dolomite crystals is due to increased iron content. Remnant micrite occurs in the centre of some dolomite crystals. In one thin section from top of the Hamira Member darker coloured finely crystalline dolomite laminae alternate with light coloured medium crystalline dolomite laminae which are richer in quartz grains. Sometimes, dolomite occurs as streaks.

Dolomitization has affected mainly peloids. Some completely dolomitized peloids still retain a typical peloidal shape. The dolomite has also replaced intraclasts and bioclasts.

Terrigenous admixture includes fine sand and silt size grains of quartz, feldspar, chert, muscovite, biotite, tourmaline, zircon, garnet and opaques. The grains are sub-angular to sub-rounded with corroded boundaries.

Bioclasts comprise molluscs (pelecypods and gastropods 4.0 percent), echinoderms (2.0 percent), brachiopods (0.5 percent), foraminifers (0.4 percent) and traces of ostracods and calcispheres. Bioclasts show two populations: (1) silt to fine sand size bioclastic debris and (2) larger bioclasts of sand to pebble size (upto 5 mm). The bioclasts are generally elongated, rounded and poorly sorted to moderately well sorted. They show ragged borders due to dolomitization. They also possess micrite envelopes. The
Wall microstructure in most bioclasts is recrystallized to spar.

Peloids are well rounded, well sorted, and 0.02 mm to 0.52 mm in size (silt size). Majority of them have been partially to totally dolomitized. Sparse intraclasts of coarse sand size to granule size are generally completely dolomitized and are difficult to identify. However, a few well rounded intraclasts of bioclastic wackestone are recognisable.

The microfacies was originally deposited as pelleted mudstone which, as a result of extensive dolomitization and recrystallization, has lost much of its original texture. However, micritic inclusions in dolomite rhombs and preferential dolomitization of pellets suggest that pellets and micrite were the main original constituents of the microfacies. The presence of pelleted mud, and extensive dolomitization suggest an intertidal environment and the microfacies is placed in the Facies Belt 8 (Facies of Restricted circulation or marine platform) of Wilson (1975).

B. Packstones

B1. Bioclastic ooidal packstone (bioclastic oomicrite)

The microfacies occurs in irregular- and nodular-bedded limestones in the middle parts of both the Fort Member and the Kuldhar Member. It consists of mainly micrite (average 37.4 percent), ooids (average 35.6 percent), and
bioclasts (average 17 percent). Other components include peloids (average 6.8 percent), intraclasts (average 1.4 percent), grapestone lumps (average 1.1 percent), and terrigenous admixture (average 0.8 percent).

The micrite matrix appears ferruginous and has recrystallized to pseudospar at some places. Superficial ooids are abundant but true ooids and composite ooids are also present. Ooids range in size generally from 0.16 mm to 0.9 mm and sometimes up to 1.4 mm. They are made up of concentric layers of calcite and iron oxide around the nuclei of bioclasts, peloids and occasionally quartz grains. The size of nuclei is almost equal. Ooidal coatings are mostly regular but few of them are incomplete and eccentric.

The bioclasts are predominantly fragmented, but occasionally whole fossils. They include molluscs (pelecypods, gastropods and belemnites), echinoderms, brachiopods, foraminifers, serpulid worms, calcispheres and traces of bryozoans, ostracods and unidentifiable bioclasts. The microfacies also contains belemnites, serpulid worms and calcispheres in the Kuldhar Member. Pelecypods occur in the form of both thick and thin filamentous fragments. Belemnites are represented by their transverse sections. Serpulid worms are present as circular to elliptical tubes showing well preserved laminated wall microstructure, and are attached to the surface of altered pelecypod fragments.
Gastropods are represented by whole fossils and their chambers have been filled with micrite which is similar to the micrite matrix of outside. The bioclasts are generally elongated, sub-angular to rounded with ragged boundaries and moderately - to poorly - sorted ranging in size from 0.1 mm to 6.5 mm. They have been partly micritized and sometimes, consist of ooidal coatings.

Peloids are well rounded and well sorted, ranging in size generally from 0.06 mm to 0.26 mm and occasionally upto 0.46 mm. Some peloids show the typical bioclastic shape and 'ghost' of original wall microstructure suggesting their derivation by micritization of bioclasts. The peloids, in parts, are also admixed with faecal pellets.

The intraclasts are made up of pelletal grainstone, ooidal bioclastic packstone, ooidal packstone and bioclastic wackestone. The intraclasts are generally equidimensional to ovoid, well rounded and range in size from 0.38 mm to 2.6 mm.

Terrigenous admixture includes sub-angular fine quartz sand grains and quartz silt grains. The dominant particles of the microfacies are of a high-energy environment which were deposited with the micrite matrix in low-energy environment. Such type of microfacies represent a transitional phase between low-energy environment and high-energy environment. The area of deposition of the microfacies was
possibly swales in proximity to shoals, of open marine neritic shelf environment. The microfacies resembles the Wilson's Standard Facies Belt 2 and unrestricted, quiet and subtidal shallow shelf of Heckel (1972).

B2. **Recrystallized microbioclastic pelletal packstone**

*(Microbioclastic pelmicrosparite)*

This microfacies is confined to nodular-bedded limestone of the middle part of the Fort Member. Pellets are abundant (62.8 percent) and range in size from 0.04 mm to 0.08 mm. The other constituents comprise recrystallized micrite (24.7 percent), bioclasts (10.1 percent), intraclasts (about one percent) and terrigenous admixture (1.3 percent). Micrite matrix fills up interparticle pore spaces, shell cavities and vugs. Due to extensive recrystallization micrite is now largely represented by pseudospar. Bioclasts are of echinoderms (4.0 percent), Ostracods (2.2 percent), molluscs (0.9 percent), brachiopods (0.4 percent), foraminifers (0.4 percent) and unidentifiable bioclasts (2.2 percent). Thin and filamentous shells of bivalves are common among the bioclasts. The bioclasts are generally very fine but occasionally coarse (upto 0.76 mm). All the bioclasts have well preserved wall microstructure. Intraclasts of pelletal wackestone and limy mudstone are sparsely distributed. They are well rounded, ovoid and elongated and range in size from 0.4 mm to 0.44 mm (medium sand size). Terrigenous admixture includes sub-angular quartz silt grains.
The microfacies resembles open shelf or platform lagoon Facies (Standard Facies Belts 2 and 7) of Wilson (1975) and subtidal quiet shallow shelf of Heckel (1972). A similar facies in the Cornwallis Group (Lower Palaeozoic) of Canada was assigned to a 'shelf-lagoon' environment of deposition behind an area of shoals (Morrow, 1973, 1978). The microfacies appears a close analogue to the 'subtidal clear shelf facies' of Sodero and Hobson (1979). Absence of restricted fauna from the microfacies suggests that instead of sheltered areas, deposition took place on broad, submerged shelves of little relief and moderate depth where wave action was cut off by the very width of the shelf. The presence of very thin-shelled pelagic bivalves also indicate an offshore environment.

B3. Whole fossil pelletal packstone (whole fossil biopelmicrite)

This microfacies occurs in nodular-bedded limestones, in the middle parts of both the Fort and Kuldhar members. The microfacies contains mainly bioclasts (average 39.3 percent), faecal pellets (36.2 percent), and micrite (23 percent). Other constituents are superficial ooids (0.5 percent), intraclasts (0.4 percent), and terrigenous material (1.1 percent).

Bioclasts include molluscs (29.1 percent), bryozoans (1.7 percent), echinoderms (2.0 percent), brachiopods (1.4 percent), foraminifers (1.7 percent), ostracodes
(0.6 percent), minor amounts of calcispheres and
tintinnines and some unidentifiable bioclasts. Fauna
comprise articulated and disarticulated whole fossils,
and un_abraded bioclasts (Plate IV, Fig. D). Whole fossils
mostly belong to gastropods. Thin filamentous valves
of pelecypods are also present. Bioclasts are poorly sorted.
The size of molluscs, brachiopods and bryozoans generally
ranges from 0.06 mm to 13 mm (very fine sand to coarse gravel
size). The remaining bioclasts are generally upto 0.6 mm
(silt size to coarse sand size). The bioclasts show vague
appearance and ragged boundaries. Gastropods are occasionally
coated by iron oxide. Shell cavities in gastropods are
filled with dark micrite.

Faecal pellets range in size generally from 0.02 mm
to 0.14 mm and rarely upto 0.35 mm. Ooids are mostly
superficial possessing nuclei of faecal pellets, intraclasts
and altered unidentifiable bioclasts. Their size ranges
generally from 0.1 mm to 0.7 mm. In some thin sections
their concentric layers have almost been replaced by sparry
calcite and iron oxide. Intraclasts are made up of lime
mudstone and bioclastic wackestone. They are well rounded
and sub-circular to elliptical with occasional superficial
ooloidal coatings. Their size ranges from 0.3 mm to 0.66 mm.
Stylolites of black colour are common. Terrigenous
material is present in some thin sections forming 1.2 to
2 percent. It includes angular quartz silt grains.
The microfacies resembles the Standard Facies Belt 2 of Wilson (1975), subtidal quiet water of shallow shelf of Heckel (1972) and clear interior shelf of Sodero and Hobson (1979). This microfacies also resembles pellet-mud lithofacies of the Great Bahama Bank which occurs in the region most sheltered from the trade winds and farthest from the strong tidal activity of the Bank edge (Bathurst, 1971). Pellets and gastropods are the dominant constituents of sediment deposited in lagoon of the Trucial Coast Embayment of Persian Gulf. Davies (1970a) has also suggested that gastropods are mainly responsible for the formation of faecal pellets in Carbonate Bank of Shark Bay, Western Australia.

B4. Recrystallized crinoid bioclastic packstone (recrystallized crinoid biomicrite)

This microfacies is present in irregularly bedded fossiliferous limestones of the middle part of the Kuldhar Member. Its petrographic constituents are crinoids (49.2 percent), other bioclasts (13.1 percent), peloids (12.7 percent), recrystallized micrite (22.6 percent), terrigenous admixture (2.5 percent), and traces of ooids and intraclasts.

Bioclasts other than crinoids include brachiopods (7.8 percent), molluscs (1.6 percent), bryozoans (1.2 percent), ostracodes and foraminifers (0.8 percent each), calcispheres and tintinnines (0.4 percent each). Crinoids are represented mostly by fragments of columns and some of them show rounded, transverse oblique sections. Few echinoid spines are also
present. Fragments are angular to subangular with ragged borders. They range in size from 0.18 mm to 1.3 mm.
The other bioclasts comprise fragments with original well-preserved wall microstructure. They are angular to subangular with ragged boundaries, poorly sorted, and range in size from 0.24 mm to 1.6 mm. Few elongated bioclasts have been totally micritized and cannot be identified.

Peloids are ovoid and superficial, and range in size from 0.05 mm to 0.3 mm. Sometimes they have very thin, superficial carbonate coatings. Superficial ooids have nuclei of faecal pellets and range in size from 0.1 mm to 0.9 mm. Intraclasts are of ferruginous silty lime mudstone and ferruginous bioclastic wackestone. They range in size up to 0.36 mm.

Micrite matrix is generally recrystallized. Syntaxial overgrowths on crinoidal fragments are common.

Terrigenous admixture includes silt size quartz and feldspar grains.

The presence of dominant crinoid fauna suggest water of open circulation and normal marine salinity and moderate currents and wave action. The stalked crinoids show adaptation for food gathering in moderately moving currents below active wave base. The low-energy conditions of deposition are also indicated by the presence of micrite matrix. The microfacies resembles the Standard Facies Belt 2 of Wilson (1975).
B5. **Belemnite whole fossil packstone (belemnite whole fossil biomicrite)**

This microfacies is confined to bioturbated, irregular-beded limestones of the upper part of the Kuldhar Member. It consists of dominant bioclasts (44.5 percent) and micrite (38 percent) (Plate IV, Fig. E). Other minor constituents include ooids and intraclasts (5.7 percent each), peloids (4.8 percent) and terrigenous admixture (1.3 percent).

Bioclasts include whole fossils of belemnite (33.6 percent), fragments of brachiopods (4.8 percent) echinoderms (4 percent), corals (0.4 percent), algae (1.8 percent) and foraminifers in traces. Size of belemnites ranges upto 27 mm. The size of other bioclasts ranges from silt size to 5.7 mm. Most bioclasts have well preserved wall microstructure. They are very poorly sorted and sub-angular with ragged borders. Bioclasts of brachiopods have ferruginous micrite envelops. The shell cavities in belemnites have been filled with ferruginous bioclastic wackestone. Abundant elongated borings and some elliptical borings are also present in the belemnite shells. The borings have been filled with the same micrite as present outside. These may be sponge borings because they are of relatively large size. Algae occur as dark coloured encrustations on bioclasts.

Micrite matrix is dark brown, ferruginous and appears homogeneous. Both superficial and true ooids are present. Ooids consist of brown coloured ferruginous coatings on
nuclei of bioclasts, intraclasts and peloids. The ooids range in size from 0.16 mm to 1.64 mm. Intraclasts of ooidal wackestone, bioclastic wackestone-packstone, and pelletal wackestone are well rounded, ovoid and irregular. Their size ranges from 0.5 mm to 2.1 mm. Peloids are brown coloured and range in size from 0.035 mm to 0.4 mm. Terrigenous admixture includes quartz silt grains.

The microfacies is interpreted as to representing deposition in quiet water of open circulation and normal marine salinity below wave base. The area of deposition was probably open shelf environment. The microfacies resembles the Standard Facies Belt 2 of Wilson and subtidal shallow shelf of Heckel (1972).

B6. Recrystallized coarse coated bioclastic packstone

(Recrystallized coarse coated biomicrite)

The microfacies is present in nodular bedded limestones of the middle part of the Fort Member. It includes micrite (average 38.2 percent), bioclasts (28.3 percent), peloids (18.3 percent), ooids (12.6 percent), and minor amounts of intraclasts (0.5 percent) and terrigenous admixture (2.1 percent).

Micrite matrix is homogeneous and mostly recrystallized to pseudospar. Bioclasts comprise fragments of molluscs (pelecypods and gastropods, 26.2 percent), brachiopods (one percent) and echinoderms (0.5 percent), and foraminifers (0.5 percent). Bioclasts are elongated, well rounded with
sharp boundaries. They are poorly sorted ranging in size from 0.16 mm to 12 mm. The bioclasts consist of micrite envelops with occasional algal encrustations.

Peloids are ovoid, well rounded and moderately well sorted ranging in size from 0.1 mm to 0.7 mm. Ooids include both superficial and true types but the former dominate. They are well rounded, elliptical to circular and mostly well sorted, ranging in size from 0.17 mm to 0.72 mm. Their nuclei are mostly of peloids and bioclasts. The sparsely distributed intraclasts are of lime mudstone, bioclastic wackestone and ooidal pelletal wackestone. They are generally elongated and rounded. Terrigenous admixture includes fine sand size, sub-rounded to rounded quartz grains.

This microfacies resembles the Standard microfacies SMF 10 of Wilson (1975, p.65). The sediment shows textural inversion. The dominant constituent of the microfacies (coated bioclasts and ooids) are of high-energy environment and have moved down local slopes to be deposited in quiet water. The microfacies represents open circulation shelf facies and was deposited in swales in proximity to shoals.

B7. Terrigenous dolomite pellet packstone (terrigenous dolomitized pelmicrite)

This microfacies occurs in the upper part of the Joyan Member. It contains abundant terrigenous admixture (average 41.8 percent). Other major constituents include pelleted micrite (23.8 percent), dolomite (20.6 percent) and sparry
calcite (9.3 percent). Intraclasts, superficial ooids and bioclasts occur in minor amounts.

Pellets range in size from 0.08 mm to 0.3 mm and are embedded in micrite matrix which has been generally recrystallized to pseudospar. The pellets have also been recrystallized together with the surrounding micrite matrix. A characteristic occurrence of pseudospar is seen as fringes around quartz and other allochem grains.

The microfacies shows irregular and discontinuous dark coloured organic rich algal laminations and associated fenestral fabric (Plate IV, Fig. F). The fenestrae are parallel to algal laminations and filled with sparry calcite cement. There are also irregular vugs filled with sparry calcite cement. Pseudospar and sparry calcite together form 2.5 to 20.3 percent, averaging 9.3 percent. Palisade structure (Davies, 1967) is distinctly seen in this microfacies.

Minor constituents of the microfacies include intraclasts (3.4 percent), bioclasts (1.0 percent) and superficial ooids (0.2 percent). The intraclasts are well rounded and range in size from 0.5 mm to 16.5 mm. They are composed of ferruginous lime mudstone with terrigenous grains.

Superficial ooids, ranging in size from 0.2 mm to 0.8 mm, show nuclei of quartz silt and unidentifiable bioclasts.

Bioclasts consist of whole fossils of gastropods, and echinodermal fragments, and traces of bryozoans and foraminifers.
Because of extensive dolomitization, recrystallization and replacement by iron oxide, wall microstructure of bioclasts has been largely destroyed. However, the whole fossils and larger bioclasts are recognisable by their outline. Whole fossils of gastropods are quite common. Presence of pelecypods is indicated by grains of a consistent 'tear drop' shape which appear to be internal filling of pelecypods (Scholle, 1978). The echinoderm fragments are mostly dolomitized and ferruginized. In some shell fragments remnant oblique fibrous wall microstructure suggest that they are brachiopods.

Dolomitization is common in the microfacies and the dolomite averages 20.6 percent. In various thin sections of this microfacies various stages of transition from calcite micrite (stained red by Alizarine Red S) to dolomite are seen. Aphanocrystalline to very finely crystalline dolomite crystals occur isolated or in clusters in calcite micrite. With increasing dolomite content the dolomite crystals form a continuous framework with small remnant patches of calcite micrite. With increasing dolomitization, dolomite crystals increase in size and become medium crystalline. The dolomitized patches show increase in crystal size outward from the central portion. The central portion of patches consists of aphanocrystalline to very finely crystalline dolomite crystals in which rhombic shape is not discernible. Towards the margin of patches dolomite crystals are medium crystalline and display rhombic outline. The larger dolomite crystals show zoning and the central part of such crystals is generally calcitic. Dolomite is intimately associated with iron oxide and therefore dolomi-
tized patches appear buff or brown coloured. Dolomitization appears to be selective as certain depositional carbonate constituents were more readily dolomitized than others. The order of preferential replacement by dolomite is micrite, bioclasts and intraclasts.

The abundant terrigenous admixture comprises mainly quartz sand and silt grains. Chert, orthoclase, microcline, plagioclase, muscovite and biotite, magnetite and tourmaline occur in minor amounts. The grains are generally sub-rounded to rounded. The fauna is sparse comprising mainly gastropods occurring as whole fossils. The microfacies resembles the modern pelleted tidal-flat sediment described from the Andros Island, Bahamas (Shinn et al., 1969). The microfacies shows fenestral fabric which results from desiccation and is found best developed in areas of tidal flats where persistent inundation is combined with maximum exposure (Fischer, 1964; Tebbutt et al., 1965). Irregular vugs are commonly present which have been filled with sparry calcite. Folk (1962) believes these vugs to form in several ways, such as by burrowing organisms, soft sediment deformation and bottom currents which rapidly redeposit the partially torn up lime mud. The presence of sparry calcite filled irregular vugs suggests shallow but protected lagoonal environment where burrowers and sudden bottom disturbances are common. Palisade structure is formed by vertical algal filaments growing upward through sediment laminae and may be preserved as molds or other relict textures in the sediment (Davies, 1970b).
Relict palisade structure also suggests that the sediment was deposited on tidal flats (Logan et al., 1964). Intraclasts of highly ferruginous micrite with admixture of terrigenous silt were probably derived from the dried-out silty lime mud and algal mats, and were buried more or less in situ by rapidly deposited sediment or they were redeposited in nearby channels and rills (Shinn et al., 1969).

Terrigenous material comprising mostly quartz sand and silt grains is quite abundant in this microfacies and ranges up to 53 percent. The abundance of terrigenous material indicates nearness to land. Davies (1970a) described an increase in the content of terrigenous grains in the intertidal zone of a carbonate bank of Western Australia where it fringes a subdelta.

Dolomite is very finely crystalline to medium crystalline occurring in layers which conform to the primary sedimentary layering. The sediment contains algal rich layers which, having excess of magnesium (Gebelein and Hoffman, 1973), might have contributed to dolomitization. Dolomite is formed by replacement of the surrounding calcium carbonate matrix and therefore, the dolomitization process is secondary but controlled by primary organic-rich layers, explaining its selective distribution (Gebelein and Hoffman, 1973).

The microfacies under description resembles the typical Loferite sediment of Fischer (1964) and many ancient intertidal deposits, such as the microfacies 'C' of Goldhammer and Elmore (1984).
C. Packstones-Grainstones

C1. **Peloidal brachiopod bioclastic packstone-grainstone**

(Poorly washed brachiopod pelbiosparite)

This microfacies occurs in parallel and ripple-cross-laminated limestones of the upper part of the Fort Member. The dominant constituent of the microfacies is bioclasts (47.6 percent). Other constituents are peloids (18.6 percent), superficial ooids (12.5 percent), intraclasts (8 percent), micrite (6.6 percent), sparry calcite (6.2 percent) and terrigenous admixture (0.5 percent).

Among the bioclasts brachiopods are dominant (41 percent) with minor amounts of echinoderms (6 percent), bryozoans (0.5 percent) and ostrocods (0.3 percent). The bioclasts show well preserved wall microstructure. They are rounded and poorly to moderately sorted, ranging in size from 0.18 mm to 3.4 mm. The bioclasts show thin envelopes of ferruginous micrite.

Peloids are probably a mixture of rounded micritized bioclasts and ooids, as well as faecal pellets. The peloids are generally ovoid, well rounded, well sorted, ranging in size from 0.04 mm to 0.74 mm. Ooids are mostly superficial type with rounded nuclei of bioclasts, peloids, and occasionally quartz.

Intraclasts are composed of lime mudstone, bioclastic, wackestone, ooidal bioclastic packstone, ooidal wackestone, and recrystallized silty lime mudstone. They are rounded to
irregular and range in size from 0.5 mm to 3 mm. Their colour is darker and composition is different from the surrounding material. A few micrite filled microborings are present in intraclasts.

Ferruginous micrite occurs as small irregular patches in the pore spaces. The rest of the pore spaces are filled with sparry calcite. Sometimes micrite matrix has recrystallized to pseudospar. Micrite and sparry calcite are almost in equal amount. Terrigenous material is scarce.

The fauna of the microfacies indicate water conditions of sufficiently open circulation and normal marine salinity. The occurrence of sparry calcite cement and micrite in almost equal amounts suggests that waves or currents were not strong and persistent enough to completely winnow the lime mud. The microfacies represents a transition from the underlying wackestones-packstones of low-energy quiet water conditions to the overlying cross-bedded grainstones of high-energy agitated water conditions. The microfacies resembles the Standard Facies Belt 6 of Wilson (1975).

C2. Terrigenous bioclastic packstone-grainstone (poorly washed terrigenous biosparite)

This microfacies occurs in cross-bedded arenaceous limestones of the lower part of the Kuldhara Member. The dominant constituent is terrigenous admixture (33.2 percent). Other constituents include sparry calcite (16.2 percent), micrite (15.8 percent), bioclasts (12.8 percent), peloids (11.2 percent),
oolids (5.6 percent), dolomite (4.8 percent) and intraclasts (0.4 percent).

Bioclasts include fragments of brachiopods (8.8 percent), molluscs (gastropods and pelecypods, 2 percent), echinoderms (1.2 percent), foraminifers (0.8 percent), and traces of ostracods and bryozoans. The bioclasts are moderately sorted, and well rounded with sharp boundaries. They range in size from 0.18 mm to 10 mm. Micrite filled algal borings are present in some larger brachiopod fragments.

Peloids are well rounded, well sorted, ovoid and rod-shaped and range in size from 0.28 mm to 0.6 mm. Ooids are generally superficial and range in size from 0.14 mm to 0.84 mm. Sometimes eccentric ooidal coatings also occur on the grains, which are quite thick, but only cover a portion of the grain. Dolomite occurs in small patches of finely crystalline to mostly medium crystalline rhombs. The size of dolomite rhombs ranges from 0.025 mm to 0.125 mm. Sparsely distributed intraclasts of pelletal bioclastic packstone and ferruginous silty wackestone are well rounded and range in size from 0.34 mm to 1.1 mm.

Micrite matrix occurs in small and irregular patches. Micrite matrix and sparry calcite cement are present in almost equal amounts. In parts both have been replaced by iron oxide.
Terrigenous admixture is of fine sand and silt size, and comprises dominant quartz with minor amount of feldspar, chert, tourmaline, biotite and muscovite. The grains are sub-angular to sub-rounded.

The microfacies, like the preceding microfacies (C1), was formed in an environment transitional between the quiet water wackestones-packstones and agitated water grainstones, and may belong to the Standard Facies Belt 6 of Wilson (1975). The higher percentage of terrigenous material in this microfacies may be due to a sudden influx of clastic material to the site of deposition.

D. Grainstones

D1. Peloidal grainstone (pelsparite)

This microfacies occurs in nodular bedded limestones of the Fort Member. Peloids are abundant (56.8 percent). Other constituents comprise sparry calcite (29 percent), bioclasts (8.4 percent), terrigenous admixture (2.7 percent), micrite (2.2 percent) and ooids (1.1 percent).

Peloids are circular well rounded, well-sorted and range in size from 0.05 mm to 0.3 mm (coarse silt to medium sand size). Fine sparry calcite cement fills interparticle pore spaces. Bioclasts occur as debris of very small size which include stem plates and spines (5.1 percent), brachiopods (1.5 percent), molluscs (0.4 percent) and foraminifers and ostracods (about one percent each). They range in size generally from 0.11 mm to
0.56 mm (very fine to medium sand size) and occasionally upto 0.71 mm (coarse sand size). The bioclasts show well preserved wall microstructure. They are sub-angular to sub-rounded with ragged boundaries. Superficial ooids have nuclei or peloids. A small amount of micrite matrix is present in between the grains. Terrigenous admixture includes angular to sub-angular quartz silt.

This microfacies is similar to microbioclastic calcisiltite (MF-2) described by Wilson (1975, p.64) from Basin and Lower Slope environments. The common features between the two microfacies are: (1) peloids mixed with fine bioclasts; (2) a fine grainstone texture; and (3) millimetre thick laminae grading from tiny bioclasts to dark peloids. The microfacies perhaps represents offbank deposits in the open shelf environment.

D2. Brachiopod bioclastic peloidal grainstone (brachiopod biopelipsparite)

This microfacies occurs in cross-bedded limestones in the upper part of the Fort Member. The various constituents of this microfacies and their average percentages are: peloids (31 percent), sparry calcite (26.6 percent), bioclasts (26.6 percent), ooids (10 percent), intraclasts (4.8 percent), and terrigenous admixture (1.1 percent).

Peloids are well sorted, well rounded, mostly ovoid, and range in size from 0.08 mm to 0.5 mm (very fine to medium sand size). Sparry calcite cement is generally fine to medium
crystalline and occurs as interparticle pore filling and comprises acicular or fibrous crystals that rim the pore space (isopachous cement rims). Away from the pore space boundary, crystal size increases and crystals become equant and anhedral forming blocky cement (Dunham, 1969, p.141). Sparry calcite also occurs as syntaxial cement rims on the fragments of echinoderms and as cavity fillings of fossil shells. Iron oxide replaces sparry calcite cement and is present as small irregular patches.

Bioclasts include mostly fragments of brachiopods (14.6 percent) followed by echinoderms (7.3 percent), and minor amounts of foraminifers (1.1 percent), molluscs (0.8 percent), ostracods (0.2 percent), bryozoans (0.1 percent) and traces of algae. Unidentifiable bioclasts average 2.7 percent. Bioclasts are well rounded with sharp borders and moderately well sorted to well sorted. Their size generally ranges from 0.14 mm to 2.5 mm (fine sand to granule size) and occasionally up to 4.8 mm (pebble size). Micrite envelops on bioclasts are rare.

Ooids include both true and superficial ooids and range in size from 0.1 mm to 0.82 mm (very fine sand to coarse sand size). Their nuclei are generally of peloids, bioclasts, and occasionally quartz and intraclasts. Intraclasts are generally composed of lime mudstone, ooidal packstone, peloidal packstone and bioclastic wackestone and occasionally ooidal grainstone and rarely calcareous fine sandstone. They are ovoid, well rounded and poorly sorted ranging in size from 0.14 mm to 3.1 mm
(fine sand to gravel size). They are mostly sparsely distributed but overpacked in some thin sections where present in significant amount.

The microfacies was deposited in shallow agitated water, above wave base. Mud was winnowed out and mostly sand sized peloids, bioclasts and ooids were deposited. Presence of ooids in appreciable amount indicates nearness to an oolite shoal in shallower water of the more shoreward zone. The fossil assemblage of the microfacies belongs to normal marine environment. The cementation of first generation was probably shallow marine evidenced by the presence of isopachous rims, and was followed by meteoric water cementation of second generation evidenced by granular blocky sparry calcite filling of interparticle pore spaces (Bathurst, 1971). The microfacies resembles Standard Facies Belt 6 (shoal environment in agitated water) of Wilson (1975). An analogy is made with lime sand bodies occurring in open leeward margin of Little Bahama Bank and Great Bahama Bank (Hine and Neumann, 1977; Palmer, 1979; Hine et al., 1981a,b; Hine and Steinmetz, 1984) where offbank transport takes place.

D3. Coarse coated bioclastic grainstone (coarse coated biosparite)

This microfacies occurs in cross-bedded limestones of the Bada Bagh Member and the Auldharr Member (lower part). The microfacies comprises bioclasts (average 36.5 percent), sparry calcite (28.0 percent), ooids (12.0 percent), peloids (8.0 percent), intraclasts (8.0 percent) and terrigenous admixture (7.0 percent).
PLATE V

Photomicrographs of carbonate microfacies and their characteristic features, Jaisalmer Formation.

(Plane - polarized)

Figure A. Coarse coated bioclastic grainstone. Bioclasts are mostly coated, well rounded but moderately sorted. ( x 14 )

Figure B. Coarse terrigenous coated bioclastic grainstone. Note the large size of molluscan fragment and abundant terrigenous admixture. ( x 8 )

Figure C. Ooidal grainstone showing mostly superficial ooids. ( x 62.5 )

Figure D. Coated Bioclastic intraclastic grainstone. The dark coloured well rounded grains are mostly intraclasts of lime mudstone. A well rounded echinoderm fragment and a coated bioclast can be seen in the upper left part of the photograph. ( x 14.2 )

Figure E. Recrystallized terrigenous boundstone. Laminated and contorted algal mat. Note irregular laminations and slightly pelletal texture. ( x 15.2 )

Figure F. An enlarge view of contorted and irregular laminations. ( x 62.5 )
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Bioclasts consist of mostly fragments of mulluscs (pelecypods and gastropods, 18.0 percent). Other bioclasts include fragments of brachiopods (9.7 percent), echinoderms (4.4 percent), and very small amounts of bryozoa and foraminifers. Unidentifiable bioclasts average 4.0 percent. Bioclasts are well rounded with sharp boundaries, poorly to moderately sorted ranging in size from 0.15 mm to 12 mm (fine sand to pebble size) (Plate V, Fig. A). Dark, thin micrite envelopes are common around bioclasts. Some bioclasts have been partially to entirely micritized producing rounded peloids. The shell cavities have been filled with dark colored micrite, silty micrite, bioclastic wackestone and silty ooidal packstone. Sparry calcite cement occurs as thin isopachous rims, syntaxial rims around echinodermal fragments, and abundant granular interparticle pore fillings.

Ooids include both superficial and true types but the former are common. Composite ooids are occasionally present. Their nuclei are mostly of quartz and occasionally of bioclasts. Their size ranges from 0.14 mm to 1.6 mm (fine to very coarse sand size). Peloids are well rounded, poorly sorted, and range in size generally from 0.1 mm to 0.8 mm (very fine to coarse sand size). Intraclasts are rounded, mostly elliptical, and range in size from 0.4 mm to 4.3 mm (medium sand to pebble size). They are composed of ooidal bioclastic packstone, bioclastic wackestone, lime mudstone and pelletal grainstone. Terrigenous admixture includes sand and silt size quartz and felspar.
Dolomite occurs up to 1.1 percent in one sample and is medium crystalline. Dolomite replaces some ooids and bioclasts, and occasionally fills gastropod chambers.

Bioclasts are the dominant constituent of the microfacies and represent organisms living in open marine conditions. The generally abraded and rounded nature of bioclasts and other allochems and the absence of micrite suggest deposition above wave base in agitated water environment. Appreciable presence of ooids indicates nearness to an oolite shoal. Whole fossil shells infilled with micrite and intraclasts of micritic composition indicate reworking of sediment deposited in a low-energy environment.

The microfacies was deposited at or above wave base in agitated water of open circulation, normal marine salinity and very shallow depth. The area of deposition was possibly subtidal shoal on the shelf environment. The microfacies is similar to the Standard Facies Belt 6 (shoal environment in agitated water) of Wilson (1975). Holocene analogues are 'rounded calcarenite' from open sea floor off Qatar, Persian Gulf (Houbolt, 1957, Bathurst, 1971); 'coarse-grained, poorly sorted sand' from open seaward margin of Berry Islands, Bahamas; 'skeletal-rich sand bodies' from Southern Margin of Little Bahama Bank, and 'medium to coarse, moderately to poorly sorted sand' from open Leeward Bank Margins, Northern Bahamas (Hine et al., 1981a, b). The 'skeletal grainstone' facies of Enos (1974) also resembles the microfacies under description.
D4. **Coarse terrigenous coated bioclastic grainstone**

*(coarse terrigenous coated biosparite)*

This microfacies is confined to cross-bedded limestones of the upper parts of both the Fort Member and the Bada Bagh Member. The various constituents of the microfacies are: terrigenous admixture (average 33.6 percent), sparry calcite (28 percent), bioclasts (25.2 percent), peloids (4.4 percent), ooids and intraclasts (3.8 percent each).

Bioclasts include molluscs (average 14.8 percent), brachiopods (6.7 percent), echinoderms (2.4 percent), corals (1.2 percent), and foraminifers (0.1 percent). Bioclasts consist of mostly rounded fragments with dark coloured micrite envelopes. Some whole fossils of gastropods also occur. They are generally poorly sorted ranging in size from 0.2 mm to 12 mm (fine sand to pebble size). Molluscs are generally of large size (Plate V, Fig. B).

Peloids range in size from 0.05 mm to 0.9 mm (coarse silt size to coarse sand size). Ooids, mostly superficial type, range in size generally from 0.14 mm to 1.6 mm (fine sand to very coarse sand size). Intraclasts are composed of lime mudstone, silty ooidal wackestone and bioclastic wackestone. They are mostly well rounded and generally range in size from 0.28 mm to 10.5 mm (medium sand to pebble size). A large intraclast in one thin section shows borings and burrows which have been filled with sparry calcite and calcareous silt.

Sparry calcite cement is present as granular inter-
particle pore filling. Ferruginous dolomite is present only in one thin section and constitutes upto 4.8 percent. It is aphanocrystalline to medium crystalline ranging in size upto 0.14 mm.

Terrigenous admixture includes sub-angular to sub-rounded, fine sand size grains of quartz, feldspar, chert and tourmaline.

This microfacies is similar to the earlier described microfacies D3 (Bioclastic grainstone) but the former has abundant terrigenous material which could be ascribed to a sudden influx of clastic material in the carbonate producing environment. The environment of deposition of the microfacies is broadly the same as that of E3, i.e., subtidal shoal on an open shelf.

D5. Ooidal grainstone (oosparite)

This microfacies occurs in cross-bedded limestones of the upper part of the Fort Member and of the lower part of the Bada Bagh Member. It comprises ooids (average 42.5 percent), sparry calcite (26.0 percent), peloids (14.0 percent), bioclasts (9.5 percent), terrigenous admixture (4.5 percent), intraclasts (3.5 percent).

Ooids are mostly superficial (Plate V, Fig. C) but some true ooids and composite ooids also occur. The size of ooids ranges from 0.07 mm to 0.7 mm (very fine sand to coarse sand size). Nuclei of ooids are rounded and consist of bioclasts, peloids, intraclasts and terrigenous grains. The ooidal coatings
show replacement by iron oxide and recrystallization to neomorphic spar. Sparry calcite occurs generally as granular interparticle pore filling.

Bioclasts include fragments of mulluscs (average 4.0 percent), brachiopods (3.5 percent), echinoderms (1.5 percent), foraminifers (0.5 percent) and traces of algae, bryozoans and ostracodes. Bioclasts are well rounded, and range in size generally from 0.2 mm to 1.0 mm (fine sand to coarse sand size) and occasionally up to 5.7 mm (pebble size). Micrite envelopes are present on most bioclasts but some are partially to wholly micritized. Peloids are mostly ovoid and their size ranges from 0.06 mm to 0.6 mm (very fine and coarse sand size). Intraclasts are composed of lime mudstone, ooidal packstone, bioclastic wackestone and pelletal wackestone. They are rounded, mostly elliptical, elongated and rod-shaped. They range in size from 0.18 mm to 3.8 mm (fine sand to granule size). Terrigenous admixture includes fine sand and silt size, sub-rounded to rounded quartz, feldspar, chert, mica and tourmaline.

The dominant constituent of the microfacies is ooids which are comparable in size to those described from various modern environments, such as the Bahamas, Persian Gulf, and Gulf of Batabano. The ooids occur in regions where a shoal bottom in proximity to the bank edge leads to the stronger tidal currents. Ooids are formed in strongly agitated water over the oolite shoals of the mobile habitat. Well rounded and well
sorted allochem and sparry calcite cement also bear witness to strongly agitated water conditions. The microfacies is comparable to the Standard Facies Belt 6 of Wilson (1975).

D6. Bioclastic intraclastic grainstone (bioclastic intrasparrite)

This microfacies occurs in intraformational conglomerate beds of the lower part of the Bada Bagh Member. It consists of abundant intraclasts (49 percent). Other components include sparry calcite (22.8 percent), bioclasts (18.5 percent), peloids (4.3 percent), ooids (3.4 percent), and terrigenous admixture (2.2 percent).

Intraclasts of lime mudstone are abundant but those of bioclastic wackstone, bioclastic ooidal packstone and calcareous siltstone are also common. They are mostly elliptical and elongated but sometimes circular. They are well rounded and range in size generally from 0.50 mm to 5 mm (coarse sand to pebble size) (plate V, Fig. D). Intraclasts are overpacked showing sutured and stylolitic contacts. Sometimes they possess micrite envelops with algal microborings. Sparry calcite cement occurs as finely to coarsely crystalline granular interparticle pore filling.

Bioclasts represent fragments of mulluscs (10.3 percent), brachiopods (4.7 percent), echinoderms (3 percent), and foraminifers (0.4 percent). They are well rounded and range in size from very small upto 2.84 mm. Shell cavities in gastropods and foraminifers have been filled with silty micrite.
Bioclasts have micrite envelops. Peloids range in size from 0.08 mm to 0.42 mm (very fine sand to medium sand size). Superficial ooids are more than true ooids. Ooids possess nuclei of quartz and bioclasts. They range in size generally from 0.07 mm to 1.00 mm (very fine sand to coarse sand size).

The dominant constituent of the microfacies is intraclasts of mostly micritic composition which are derived from sediments deposited in low-energy conditions. Reworking of such sediments and associated fauna is also indicated by micrite infillings of shell cavities of gastropods and foraminifera. The microfacies was probably formed as a lag deposit in tidal channels on the shoals. It resembles Standard Facies Belt 6 of Wilson (1975).

D7. Terrigenous pelletal grainstone (terrigenous pelsparite)

This microfacies occurs interbedded with intraclastic limestones of the upper part of the Fort Member and in ripple cross-laminated/cross-bedded limestones of the Bada Bagh Member. The petrographic constituents of the microfacies include peloids (average 40 percent), terrigenous admixture (29.5 percent), sparry calcite (23.5 percent), bioclasts (4.0 percent), ooids (2.5 percent) and intraclasts (0.5 percent). Peloids are well rounded well sorted and 0.02 mm to 0.5 mm (coarse silt to medium sand size). Sparry calcite occurs as fine granular cement, filling interparticle pore spaces. Bioclasts comprise brachiopods and echinoderms (average 1.5 percent each), foraminifers (0.5 percent) and molluscs (0.5 percent) and traces of ostracods. Bioclasts occur in the form
of rounded grains of 0.16 mm to 0.8 mm (fine sand to coarse sand size) and occasionally up to 2.8 mm (granule size).

The sparsely distributed, very fine sand size (and superficial ooids) have nuclei of quartz, peloids and bioclasts. Terrigenous admixture includes mostly silt size and some fine sand size grains of quartz, feldspar and chert. The grains are sub-rounded to rounded.


E. Boundstones

E1. Recrystallized terrigenous boundstone

This microfacies occurs in parallel- and ripple cross-laminated beds interbedded with cross-bedded limestones of the upper part of the Fort Member. It consists of abundant algal laminated micrite (average 60.5 percent) (Plate V, Fig. E and F). Other constituents are terrigenous admixture (19.4 percent), sparry calcite (13.8 percent), peloids (3.4 percent), ooids (2.6 percent), and bioclasts (average 0.3 percent).
Highly irregular, contorted and laminated algal mat structure is characteristic of the microfacies. Dark micrite rich laminae alternate with spar rich laminae trapping fine quartz and silt size terrigenous material with occasional pellets and ooids. Individual micrite rich laminae are semicontinuous, varying between 0.02 mm to 4 mm in thickness. The sparry laminae are thinner and less continuous than the micrite laminae and resemble the fenestral fabric. Bioclasts are almost entirely absent excepting minor amounts and traces of calcisphere and foraminifers. Terrigenous admixture comprises fine sand and silt size quartz, feldspar, mica, heavies and opaques.

The microfacies closely resembles the modern algal mat sediments of intertidal-supra tidal environment (Black, 1933; Kendall and Skipwith, 1968; Davies, 1970b). Algal mats also form in the subtidal environment (Gebelein, 1969), but contortion and crinkling of laminae accompanied by fenestral fabric in the microfacies indicate subaerial exposure and dessiccation.