CHAPTER - V

PETROGRAPHY AND MICROFACIES

Often it is difficult to identify a limestone composition in the field, as diagenesis causes the original limestone type unrecognizable. In order to define microfacies in carbonates, it is usually necessary to go beyond field work data. Laboratory studies of carbonates are thus, of cardinal importance to confirm field identifications and to classify them accordingly to the standard schemes of classification like those of Folk (1959, 1962) and Dunham (1962). This also helps in elucidating the rock's diagenesis besides identification of the microfacies. The author, in the present chapter, has endeavoured to concentrate more on the microfacies aspects of the Middle Jurassic rocks of the study area as these have remained uninvestigated so far. A careful and critical scrutiny of the microfacies data generated from this study has thrown much light on depositional and diagenetic history, that has been discussed in the subsequent chapters.

For petrography and microfacies analyses, besides Folk's (1962), mostly Dunham's classification amplified by Embry and Klovan (1972) has been used. This is an ideal classification depicting the textural maturity and in turn, the energy conditions of the depositing medium. These provide a better understanding of possibilities of the development of reservoir characteristics in relation to the rock type deposited. During the present study, staining techniques suitable for use on thin sections have been attempted. To differentiate calcite from dolomite, an organic stain i.e. Alizarine red S (Friedman, 1959) has been used. Besides Alizarine red S, combined organic and inorganic stains specific for calcite, ferroan calcite, and ferroan Dolomite (Evamy, 1963) have also been used. In order to study the grain fabric in micron range like pore geometry, nature of pores and pore throats, coating of clay on individual grains and other diagenetic features, scanning electron microscopy has been carried out. The instrument used is Phillips 515 SEM using 30 KV with spot size ranging from 100 to 150 um.

As pointed out by Flugel (1982), the microfacies categorization requires for a quantification of the features recognizable in thin sections. The study of stained thin sections aided by SEM studies has helped the author considerably in identification of such features and the relative microfacies. The author has used semi-quantitative methods as a part of frequency analysis (Constituent analysis) and the data were compared with the 'Comparison Charts' of Baccelle and Bosellinni (1965) and Schafer (1969). The microfacies, thus recognized, in each lithofacies of individual formation in all three domes are described in the pages that follow.

JHURIO FORMATION

JHURA DOME

The following microfacies have been identified under various lithofacies recognized during field studies.

1. LIMESTONE AND SHALE FACIES (KJH-I)

One major microfacies i.e. pelloidal packstone within carbonates of this facies has been identified. However, few patches of wackestone are also present which are occasionally oolitic in nature.

a) **Pelloidal Packstone:** The rock predominantly contains micritized pelloids scattered within sparitized calcitic groundmass. Among bioclasts, broken shell fragments and laths of echinoids, brachiopods and foraminifers are common. The arenaceous fraction is mainly fine sandsized subangular grains of quartz. Locally the rock has been recrystallized and in consequence the pelloid boundaries are diffused in variable degree. **(Plate V.1)**

2. **SHALES FACIES (KJH-II)**

The calcareous bands within this lithofacies exhibit only one microfacies.

a) **Pelloidal wackestone:** Here micritized pelloids are dominating grains alongwith calcispheres and sponge spicules as important constituents. The calcispheres are unwalled indicating their non algal origin (Scholle, 1978). Longitudinal and cross sections of Monaxon sponge spicules show a thick wall and central canal, characteristic of many originally opaline spicules **(Plate V.2)**. Few broken shell fragments of brachiopods and echinoid grains are also seen alongwith foraminifers. The micritic groundmass is partly sparitised. Quartz grains are scattered within the groundmass.

3. **GOLDEN OOLITE FACIES (KJH-III)**

Three microfacies have been identified within two bands of golden oolite facies.

a) **Pelloidal Packstone:** The limestone bed lying below the massive lower golden oolite bed are pelloidal packstone. The average grain size is larger than that of the facies KJH-I. This is dominated by larger shell fragments of brachiopods showing good micritic rim and drusy growth. Micritized pelloids with diffused boundaries, echinoids and foraminifers

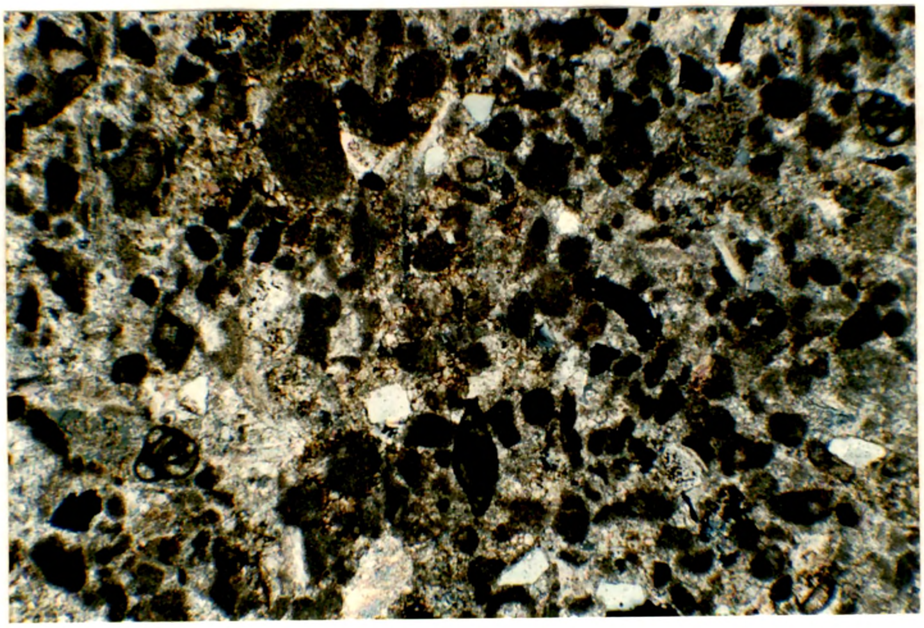

Plate V.1 Photomicrograph of a pelloidal packstone showing micritized pelloids within sparitized calcitic groundmass (Crossed nicols, X 60)

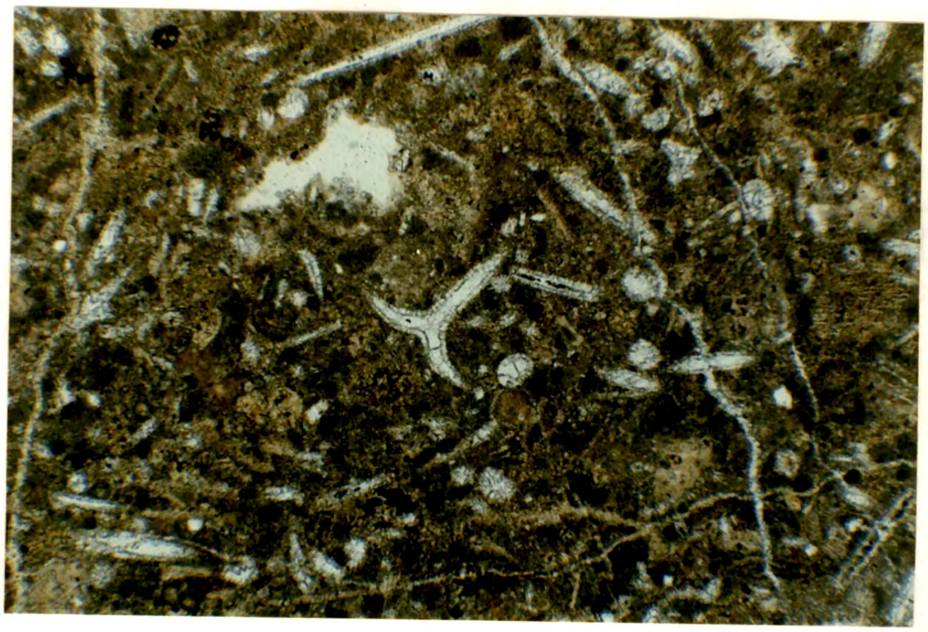

Plate V.2 Photomicrograph showing longitudinal and cross sections of Monaxon sponge spicules with thick wall and central canal. (Plane polarised light, X 60) are also significant contributors **(Plate V.3)**. The matrix is partly sparitized with neomorphic development of calcite and is dotted with very fine to fine sand size quartz grains. Patches of ferruginous matter are also present which are lacking in the same microfacies under KJH-I.

b) **Oolitic packstone:** The lower golden oolite bed above the pelloidal packstone is oolitic packstone. In general, it is coarse grained. The ooids are strongly deformed and often difficult to be identified as ooids. Among bioclasts, brachiopods, gastropods and echinoids are common. Lumps and intraclasts when present contain subrounded to subangular grains of quartz alongwith the ooids, bioclasts and micritised pelloids **(Plate V.4)**. The terrigenous material consists mainly sand and silt grade quartz and is less than 10%.

c) **Oolitic grainstone:** The upper band of golden oolite facies is in fact oolitic grainstone **(Plate V.5)**. Here, moderate to strongly deformed ooids form the major constituent and most them are reworked, containing micritised pelloids and quartz grains. Intraclasts and lithoclasts are also present. Among bioclasts, brachiopods, echinoids and gastropod fragments and foraminifers are common. The intergranular spaces are sparitized. The isopachous rim cement is also seen surrounding few of the

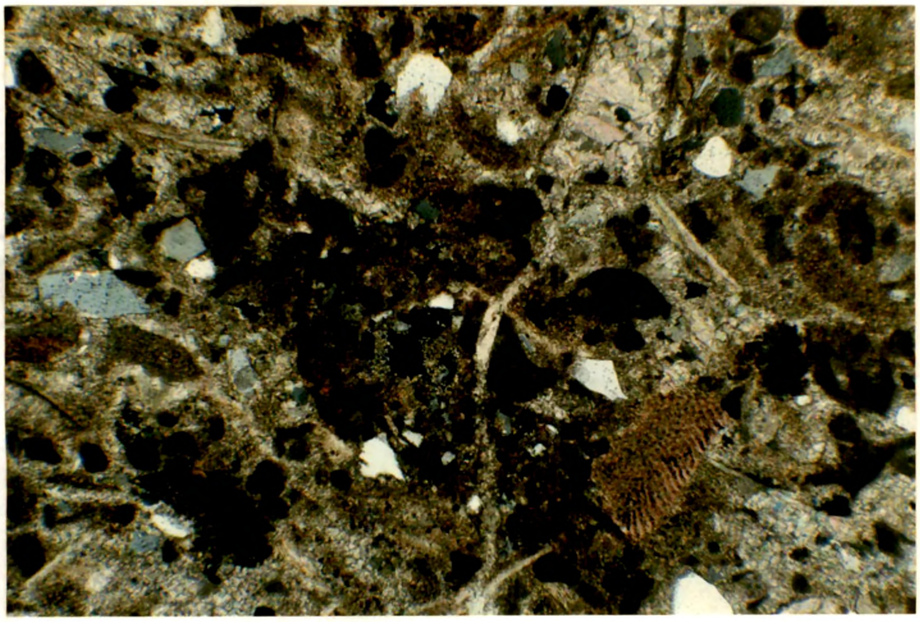

Plate V.3 Pelloidal packstone with shell fragment of bivalve showing good micritic rim and echinoids showing syngenetic overgrowth. (Crossed nicols, X 60)

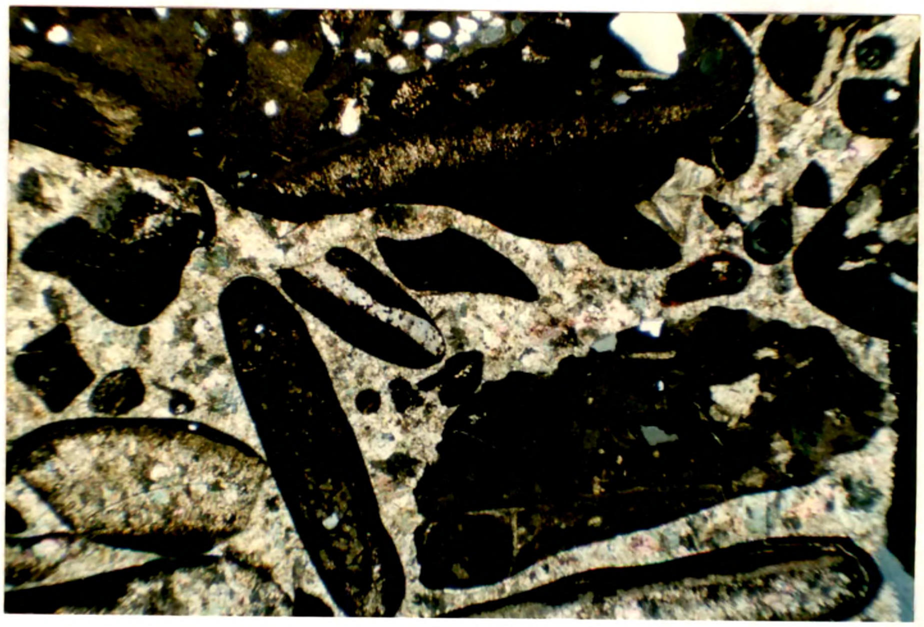

Plate V.4 Oolitic packstone showing lumps and intraclasts embedded within sparitized groundmass. (Crossed nicols, X 25) grains. The concentric laminae of ooids are ferruginous; details of which can be beautifully seen in SEM photograph **(Plate V.6)**.

4. LIMESTONE WITH GOLDEN OOLITE FACIES (KJH-IV)

Two microfacies have been identified under this lithofacies.

a) **Bioclastic Packstone:** The limestones interbedded with golden oolite beds are bioclastic packstones. This microfacies is dominated by elongated broken shell fragments of brachiopods which are showing a preferred orientation and micritic rim around the grains **(Plate V.7)**. A fair amount of echinoids, gastropods and foraminifers are also encountered embedded within micritic groundmass. The shell fragments are partly sparitized with few echinoids showing syngenetic overgrowth. Few ferruginous ooids are also present.

b) **Oolitic packstone:** Petrographically this is similar to the oolitic packstone microfacies of Golden Oolitic Facies (KJH-III). However, the present microfacies is subjected to relatively less deformation. The ooids are mostly non-spherical with less number of ferruginous cortices ranging in size from 0.25 to 0.6 mm **(Plate V.8)**, while the shell fragments of bioclasts and intraclasts are coarser. Among bioclasts, the bivalves are dominating followed by echinoids and gastropods which are partly sparitized.

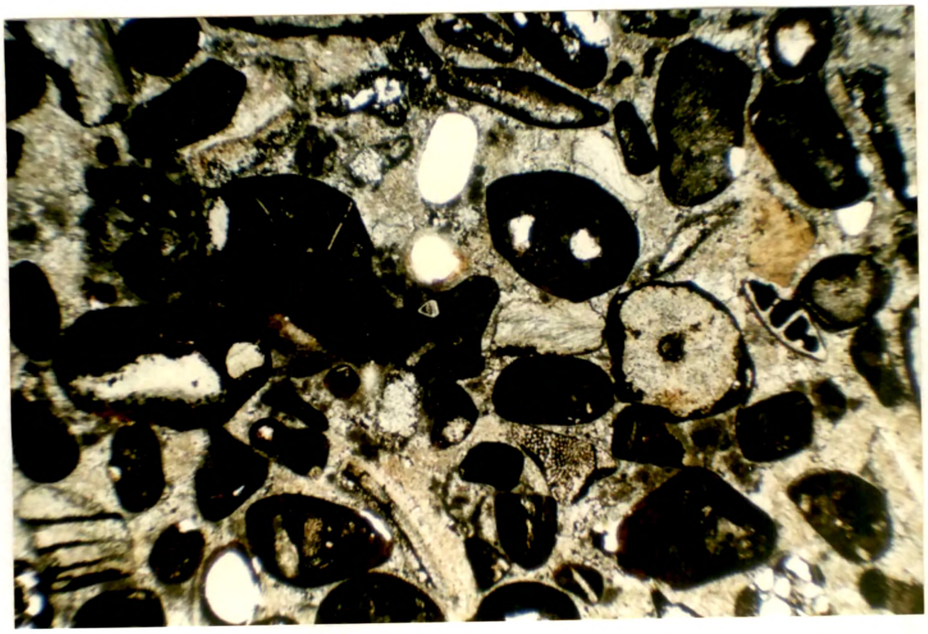

Plate V.5 Oolitic grainstone showing moderately deformed ooids, brachiopod laths with good micritic rim within sparitized groundmass. (Plane polarised light, X 25)

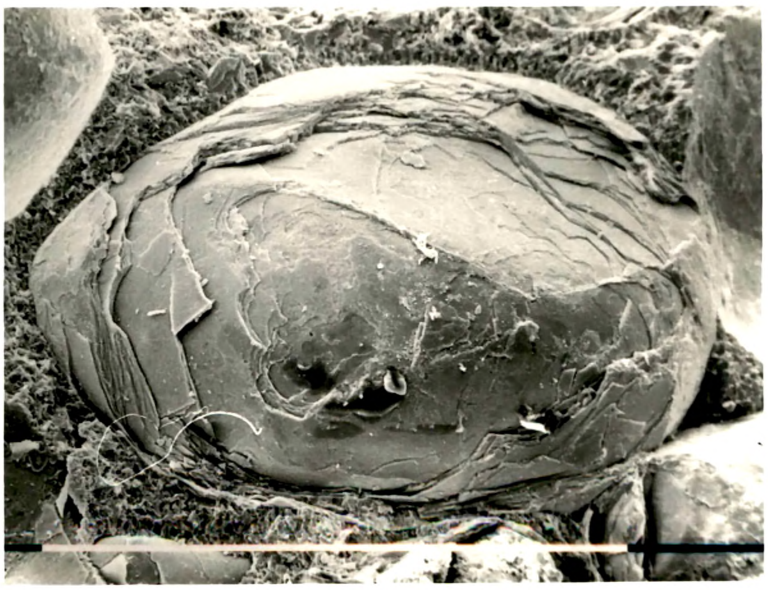

Plate V.6 SEM photograph of a single ooid showing details of thin concentric laminae. (X 82)

Plate V.7 Bioclastic packstone with elongated shell fragments of brachiopods showing preferred orientation with good micritic rim. (Plane polarised light, X 25)

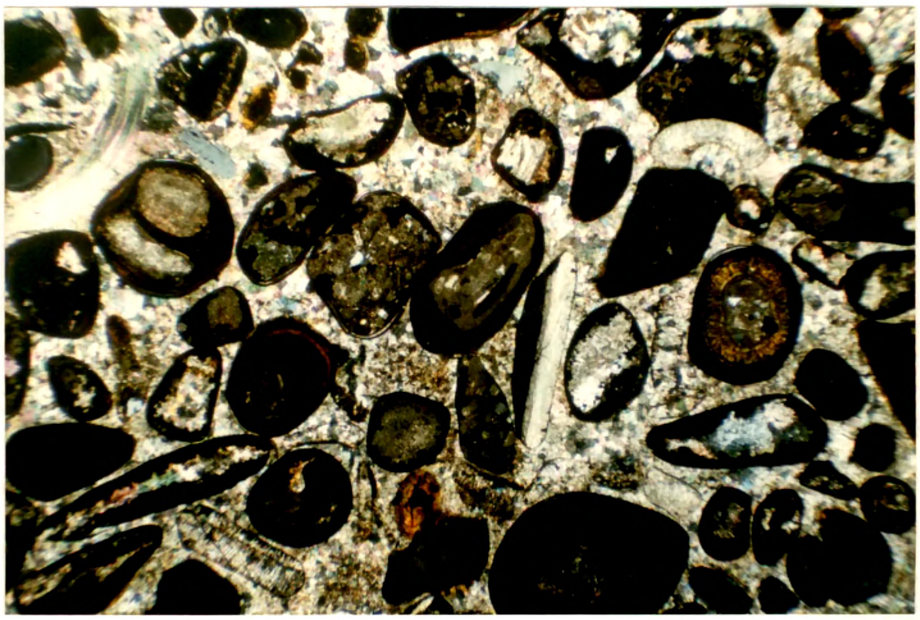

Plate V.8 Oolitic packstone showing moderately deformed ooids within sparitized groundmass. (Crossed nicol, X 25)

5. **BEDDED LIMESTONE FACIES (KJH-V)**

A. **Chalky limestone subfacies**

Here also two microfacies have been identified:

a) **Mudstone:** The soft calcareous marly beds characterize this microfacies. The mudstone microfacies is chiefly made up of uniform compact micrites traversed by sparite veins **(Plate V.9)**. Few micritized pelloids, very fine shell fragments and clots of ferruginous matter are also seen scattered within micritic groundmass.

b) **Pelloidal wackestone:** The rock is full of pelloidal micritic masses alongwith calcispheres. The calcispheres are unwalled and may be of non algal origin (Scholle, 1978). Well oriented laths of echinoids and few small foraminifers are also present. The bioclasts are mostly micritized. This microfacies shows bands of pelloidal wackestone alternating with packstone **(Plate V.10)**. SEM study of this rock shows neomorphic development of sparry calcite crystals within the micrite **(Plate V.11)**.

B. **Flaggy limestone subfacies**

Two microfacies have been identified under this lithofacies.

a) **Pelloidal packstone:** The rock is dominated by rounded to subrounded micritized pelloids. Among bioclasts, shell fragments of Pelecypods, brachiopods, echinoids and small forams are common **(Plate V. 12)**. The intergranular spaces are occupied by ferruginous matter and sparitized cement. In the

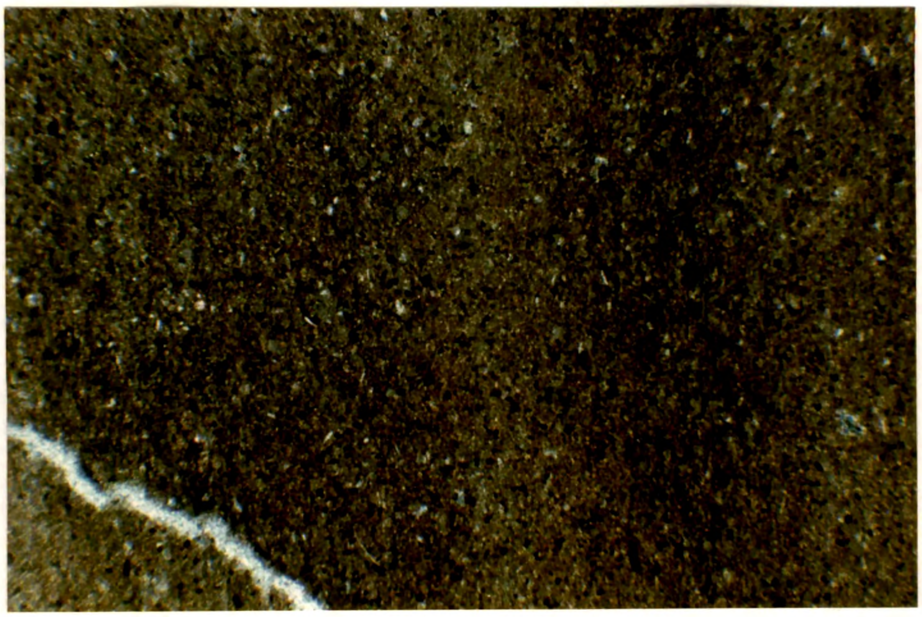

Plate V.9 Mudstone with clots of ferruginous matter. A sparitized fracture is also seen. (Plane polarised light, X 60)

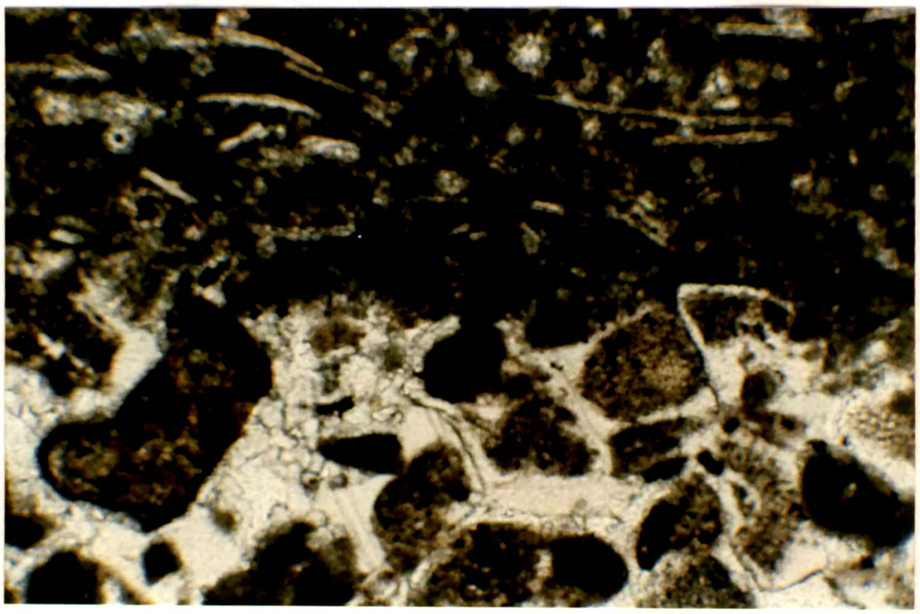

Plate V.10 Bands of pelloidal wackestone and packstone. Bioclasts are mostly micritized. Note the neomorphic development of calcite. (Plane polarised light, X 73)

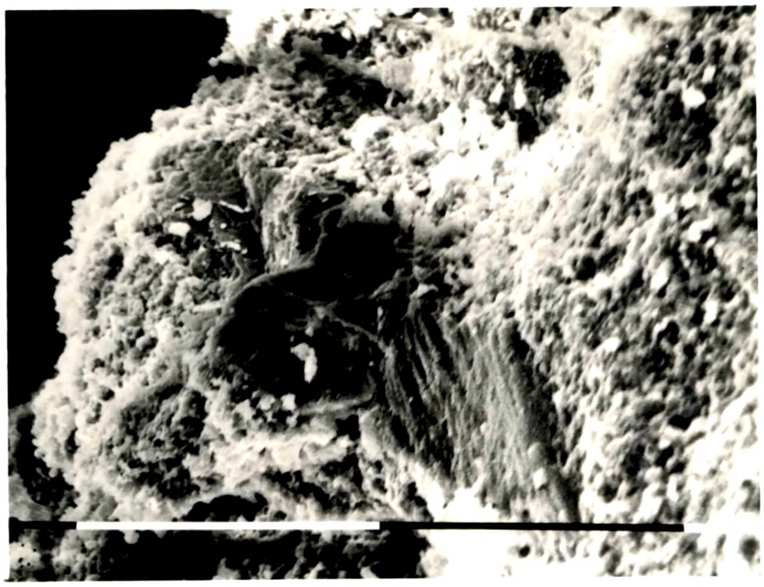

Plate V.11 SEM Photograph showing neomorphic development of calcite crystals within the micrite (X 425)

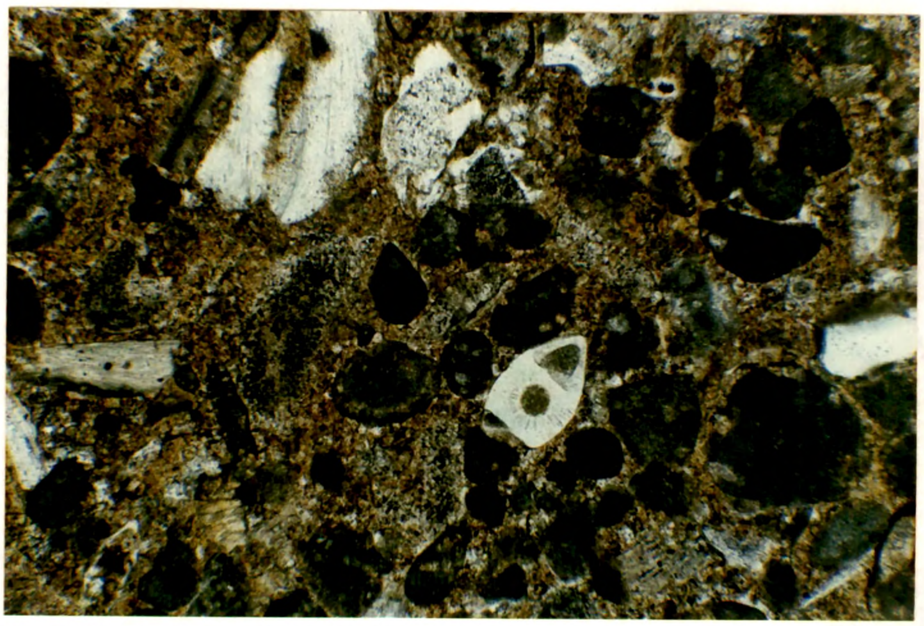

Plate V.12 Pelloidal packstone with micritized pelloids having diffused boundaries alongwith brachiopods, echinoids and chambered foraminifers. Fine ferruginous matrix is also present. (Plane polarised light, X 60) southern limb of the dome the same facies is coarse grained and at places dominated by authigenic quartz.

b) **Pelloidal grainstone:** This is a microfacies of relatively high energy environments. It is dominated by rounded to subrounded micritized pelloids which are surrounded by ferruginous matter. The overall concentration of ferruginous matter is more towards the periphery of individual pelloids. The grain to grain contact and pressure welding is commonly seen, however, the available intergranular spaces are infilled by sparry calcite cement. The pressure of authigenic quartz is distinctly seen in this microfacies **(Plate V.13)**. In the southern limb of the dome the facies is rich in bioclasts with a number of authigenic quartz crystals replacing the bioclastic grains/ooids.

JUMARA DOME

1. CORALLINE LIMESTONE FACIES (KJ-I)

Petrographically, the facies can be divided into two microfacies i.e. packstone and grainstone.

a) **Packstone:** The coral rich beds come under this category. Here, the micrite and dark ferruginous mud occur as infilling interstitial spaces between the bioclasts and micritic rounded to subrounded intraclasts **(Plate V.14)**. The microfacies represents a hardground which is encrusted and bored. They are heavily impregnated with iron minerals mainly goethite. The bioclasts include broken pieces of corals, bivalves,

Plate V.13 Pelloidal grainstone with micritized pelloids and authigenic development of quartz. The pelloidal boundaries are marked by high concentration of ferruginous matter.(Crossed nicols, X 73)

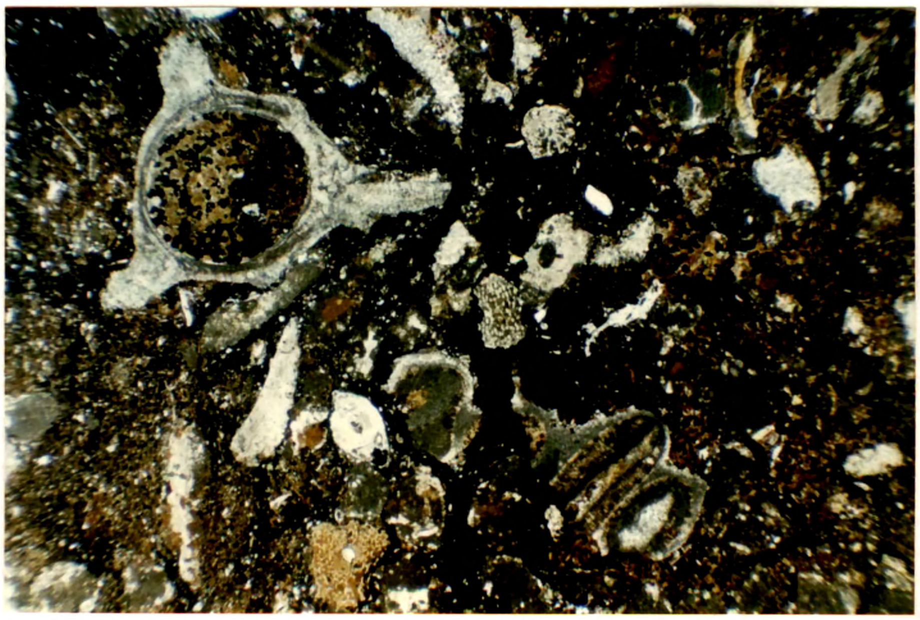

Plate V.14 Packstone with micritized intraclasts and a cross section of a gastropod shell alongwith broken shell fragments of brachiopod and corals. Note the abundance of ferruginous matter in the form of dark clots. (Plane polarised light, X 25) gastropods, echinoids, foraminifers, calcispheres and other indeterminate fragments. Few reworked ooids are also present showing concentric laminae.

The intergranular pores within the bioclasts are generally filled by mud, at places with dots of ferruginous materials such as limonite and/or goethite. Neomorphic development of calcite is seen within the micritic groundmass alongwith fine grained quartz.

b) Grainstone: The microfacies characterizing this bed is rich in terebratula. The rocks are devoid of mud and brachiopod shells are the dominant component of bioclasts. Besides, echinoids, corals & other indeterminate bioclasts form bulk of the grains. These show a preferred orientation. Grain to grain contact is visible. Crinoid grains generally show syntaxial overgrowths which often completely destroys the porosity **(Plate V.15)**. At places, dots of ferruginous material are strewn within the intergranular spaces. The cement within the interstitial spaces is blocky in nature. Terrigenous quartz is seen in traces.

Besides the above two microfacies, the coralline limestone facies is rich is varied sizes of loose coral fragments. This, under the microscope show alternate bands of light and dark colour. The dark coloured bands are septas consisting of micritic material and light bands are chambers that are completely infilled by sparite **(Plate V.16)**.

Plate V.15 Grainstone with evidence of pressure welding. Note the abundance of elongated shell fragments and syntaxial overgrowth in echinoids. (Crossed nicols, X 73)

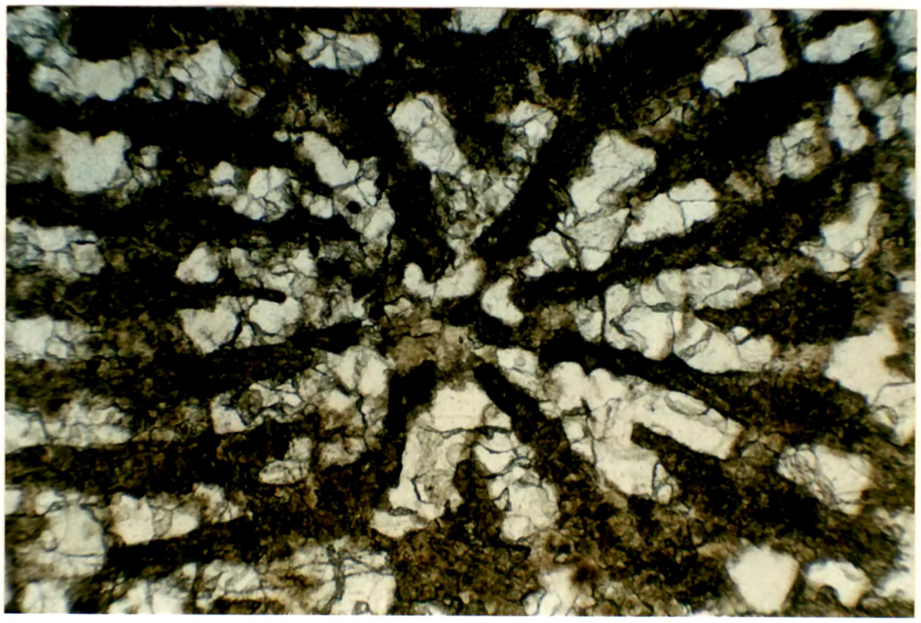

Plate V.16 Cross section of a coral showing bands of light and dark colour. The dark bands are septas consisting of micritic mass with dots of ferruginous material. Light bands are chambers completely sparitized. (Plane polarised light, X 25)

2. LIMESTONE AND MARL FACIES (KJ-II)

Two microfacies have been identified in this unit.

a) Wackestone: The limestone associated with the marls is wackestone composed of pelloidal mud with scattered fragments of bioclasts which show distinct bimodality with respect to grain size ; the majority being very small and thin, the rest are large and stout **(Plate V.17)**. Small grains of foraminifera and calcisphere are present. The bioclasts are mostly of brachiopods, bivalves and echinoids. They lack preferred orientation and grain to grain contact is also rare.

b) Mudstone: The bed alternating with the above microfacies is a mudstone consisting of about 90% of micritic mass. The scarce bioclasts are mostly microfilaments, broken shell fragments of echinoids and brachiopods; the echinoids showing syngenetic overgrowth **(Plate V.18)**. Quartz is present in traces. At places clots of ferruginous material are seen.

3. WHITE LIMESTONE FACIES (KJ-III)

Two microfacies have been identified under this lithofacies:

a) **Pelloidal Wackestone:** Under the microscope, the rock is a pelloidal wackestone. The pelloids are commonly elongated, their average length being 0.05 mm. Locally the rock has been recrystallized and in consequence, the pelloid boundaries are diffused in variable degree. The rock so contains sparsely distributed comminuted fragments of shells. Majority of the

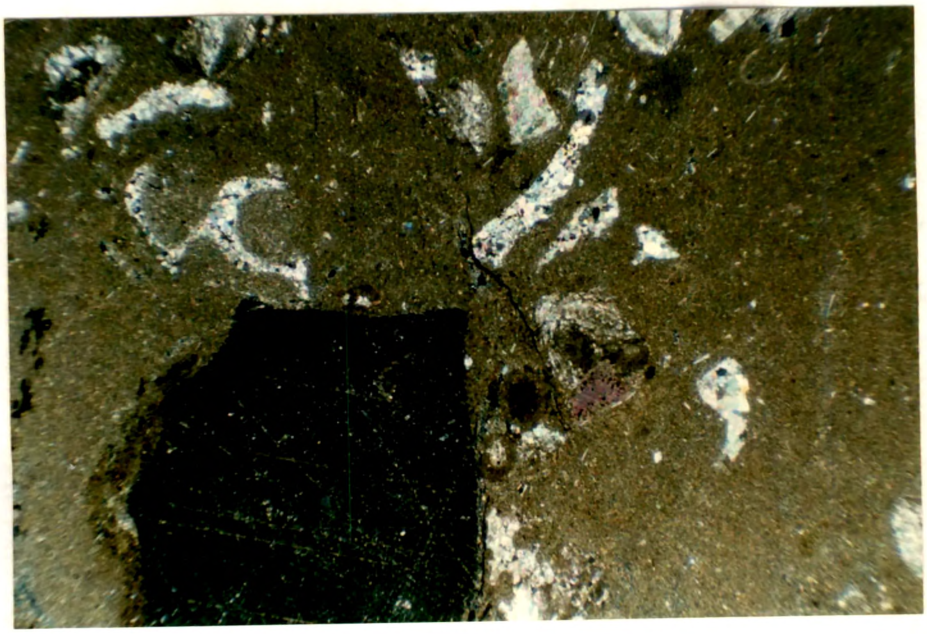

Plate V.17 Wackestone showing a crinoidal grain with syngenetic overgrowth. Note the distinct bimodality in fossil grain sizes. (Crossed nicols, X 25)

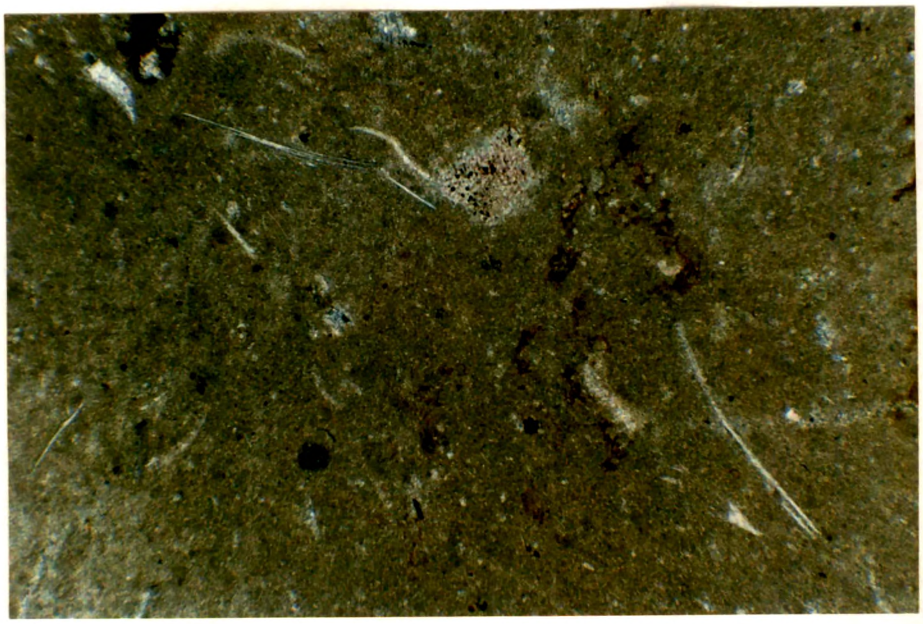

Plate V.18 Mudstone with microfilaments and few echinoid grains displaying syngenetic overgrowth. (Crossed nicols, X 60) shells have been dissolved, and the voids are now filled by blocky nonferroan calcite cement. A major fraction of this bioclastic community are calcispheres, now recognized as circular moldic pores. Many of these moldic pores also contain dark ferruginous matter presumed to be alteration product of pyrite **(Plate V.19)**. This microfacies differs from wackestone microfacies of KJ-II due to the smaller size of bioclasts and abundance of elongated microfilaments and calcispheres **(Plate V.20)**.

b) **Mudstone:** This microfacies is a part of several shoaling up sequences. Petrographically, it is similar to mudstone microfacies of KJ-II. Among bioclasts, small microfilaments and sparitized calcipheres are common. Dots of ferruginous material are scattered within the micritic groundmass.

HABO DOME

1. BEDDED LIMESTONE FACIES (KH-I)

Petrographically, the lower part of the facies can be divided into two microfacies:

a) **Wackestone:** The light grey bands of limestone alternating with dark coloured (Packstone) bands are Wackestone. They consist of fine grained argillaceous pelloidal mud with very fine laths of echinoids and microfilaments showing a preferred orientation **(Plate V.21)**. The matrix also displays few silt size grains of detrital quartz. Scattered patches of glauconite have also been observed.

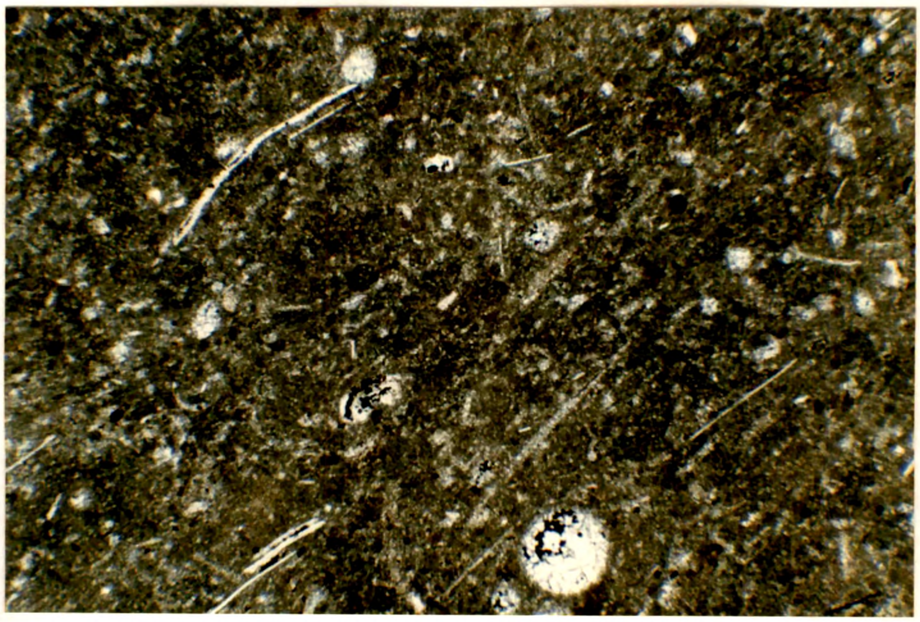

Plate V.19 Pelliodal wackestone with abundance of calcispheres and few microfilaments. The circular moldic pores of calcispheres are now filled by blocky non ferroan calcite cement. (Crossed nicols, X 60)

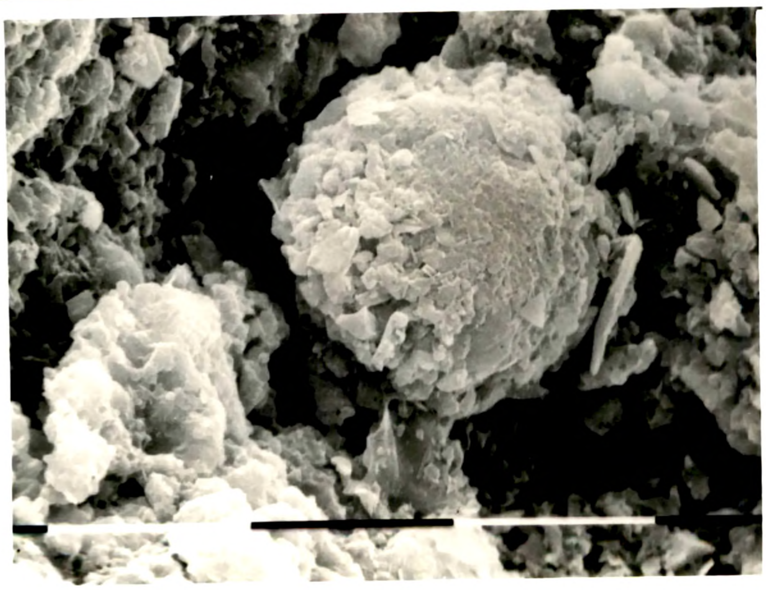

Plate V.20 SEM photograph showing a calcisphere within partly sparitized groundmass (X 2850)

Plate V.21 Wackestone consist of fine grained argillaceous pelloidal mud with laths of echinoids and microfilaments showing a preferred orientation. (Plane polarised light, X 60)

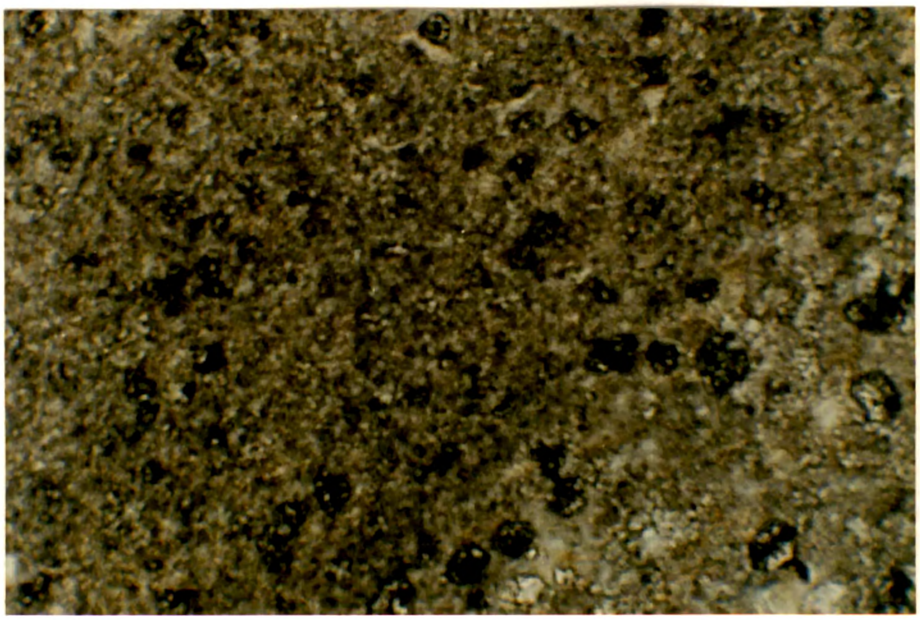

Plate V.22 Dolomitic wackestone with dolomite crystals showing prominent boundary. The matrix and the fossil grains are mostly sparitized. (Plane polarised light, X 73)

b) **Dolomitic Wackestone**: The dark grey coloured limestone bands characterize this microfacies wherein fine dolomite crystals are seen replacing the micritic groundmass **(Plate V.22)**. This also possesses few bioclastic grains mostly made up of tiny fragments of bivalves and echinoids. Intergranular spaces are partly sparitized.

The upper portion of the facies (KH-I) is represented by beautiful banding of limestones and thinly bedded calcareous marly beds and is exposed in the Kalajar nala about 2 Km. south east of Dhrang. Here also two microfacies have been identified:

a) **Calcitic grainstone**: The hard limestone alternating with soft marly beds is Calcitic grainstone, chiefly made up of clear sparry calcite grains showing sharp crystal boundaries **(Plate V.23)**. Few bioclasts have been identified by their external shape though they are totally sparitized. Echinoid grains showing syntaxial rim cement are also present. The intergranular spaces are occupied by very fine grains of neospar.

b) **Dolomitic wackestone**: The soft beds which appear like marls in the field are, in fact, dolomitic wackestone. Small rhombohedral crystal of dolomites with prominent boundaries are scattered within a partly sparitized micritic groundmass **(Plate V.24)**. These dolomite rhombs are more distinctly seen in their SEM photograph **(Plate V.25)**. The bioclasts present

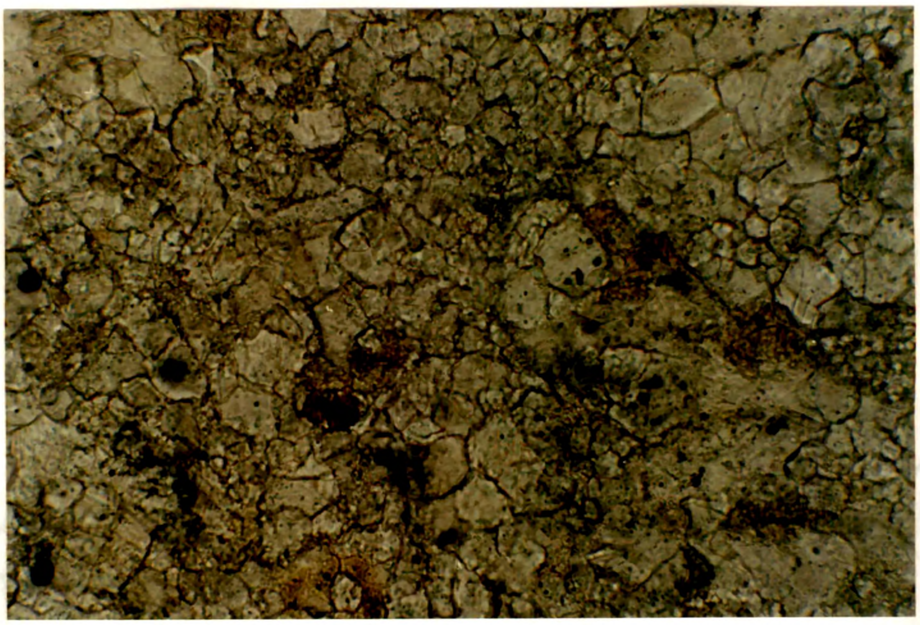

Plate V.23 Calcitic grainstone. Note the close packing of grains. The intergranular spaces are filled by fine grained neomorphosed calcite crystals. (Crossed nicols, X 73)

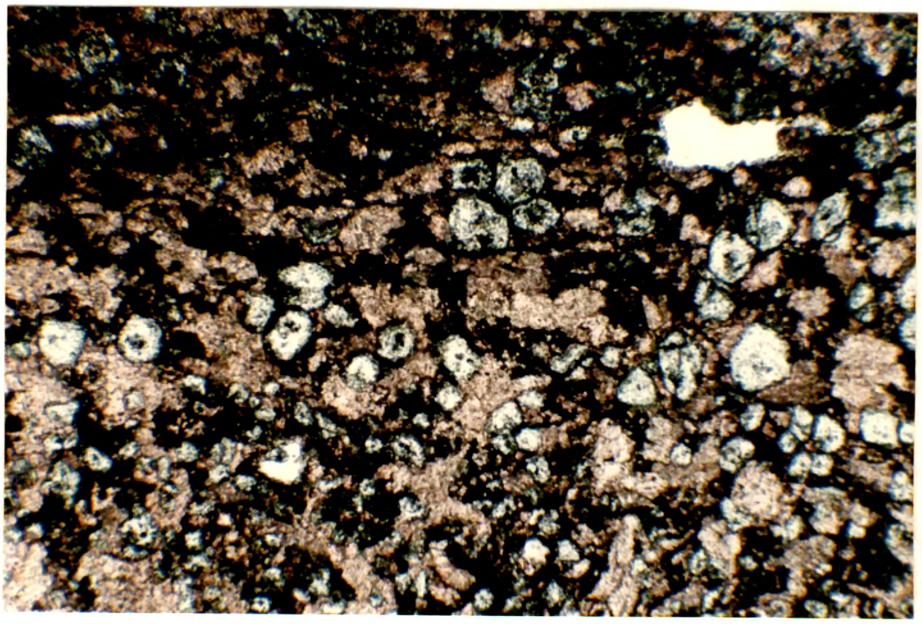

Plate V.24 Stained photomicrograph of dolomitic wackestone showing rhombohedral crystals of dolomites scattered within pink stained non-ferroan calcitic groundmass.(Plane polarised light, X 60)

Plate V.25 SEM photograph showing rhombohedral crystals of dolomites in a partly sparitized groundmass. (X 220) are mostly laths of echinoids, broken fragments of brachiopods and calcispheres. This microfacies differs from the same in lower portion of the facies due to the better developed coarser crystals of dolomite.

As stated earlier, a frequency analysis (constituent analysis) has been carried out for Jhurio Formation exposed in the three domal structures of the study area. This semiquantitative method of analysis includes proportionate number of thin sections from different microfacies. A visual percentage of individual grains has been estimated and average percentages of individual constituents have been calculated. These are plotted in bar charts for the Jhurio Formation under study area. i.e Jumara, Jhura and Habo domes. **Figure V.1, V.2 and V.3** represent average grain percentages of Jhurio Formation in respect of Jumara, Jhura and Habo dome respectively.

JUMARA FORMATION

JUMARA DOME

The five lithofacies of the Jumara Formation identified during field studies in Jumara dome can be subdivided into a number of microfacies which are described as under in the individual lithofacies.

1. OOLITIC LIMESTONE FACIES (KJ-IV)

Two microfacies have been identified within this lithofacies:

a) Intraclastic Packstone: This is the upper portion of the

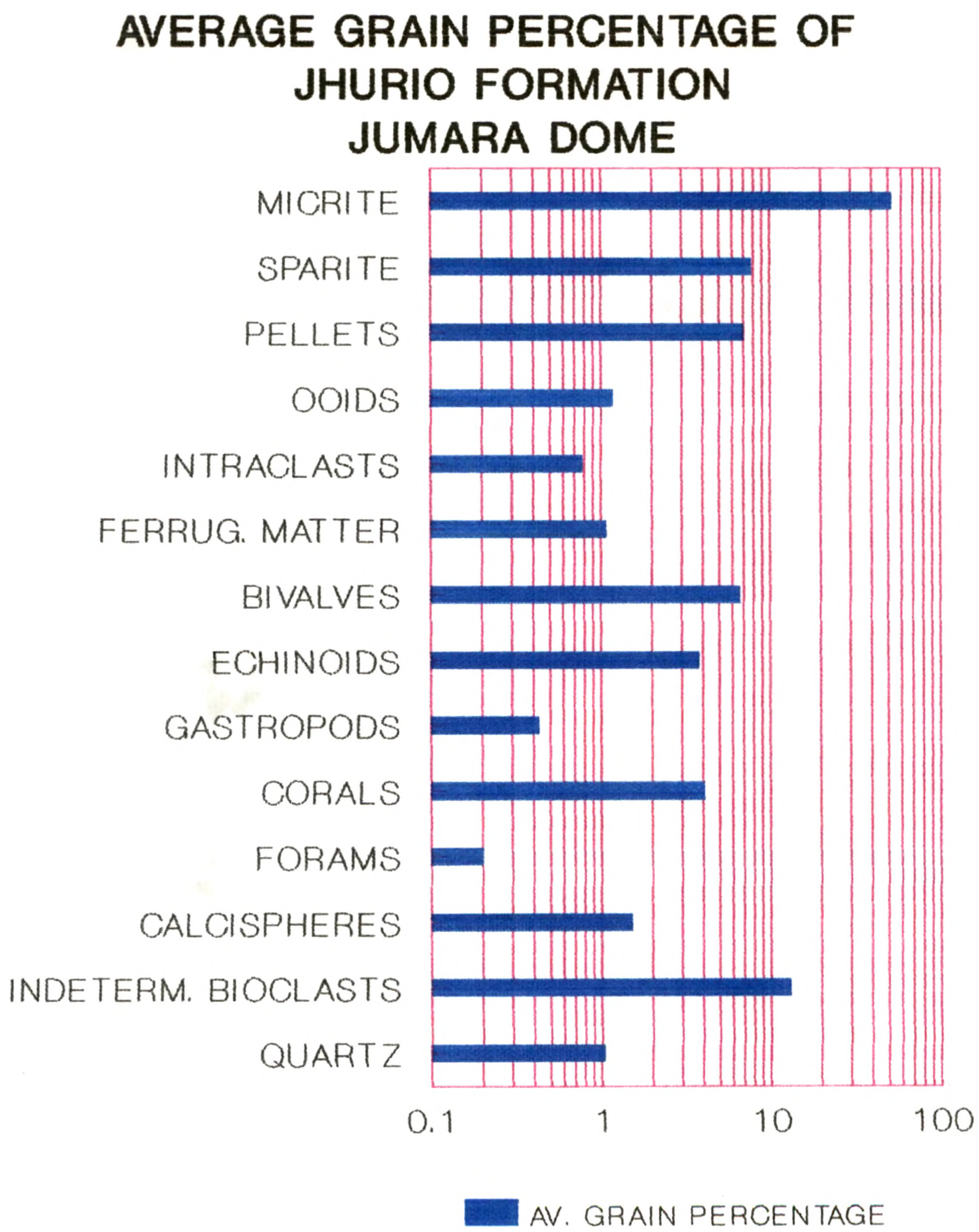
AVERAGE GRAIN PERCENTAGE OF
JHURIO FORMATION
JUMARA DOME
MICRITE
SPARITE
PELLETS
OOIDS
INTRACLASTS
FERRUG. MATTER
BIVALVES
ECHINOIDS
GASTROPODS
CORALS
FORAMS
CALCISPHERES
INDETERM. BIOCLASTS
QUARTZ
0.1
1
10
100
AV. GRAIN PERCENTAGE

FIG.V.1

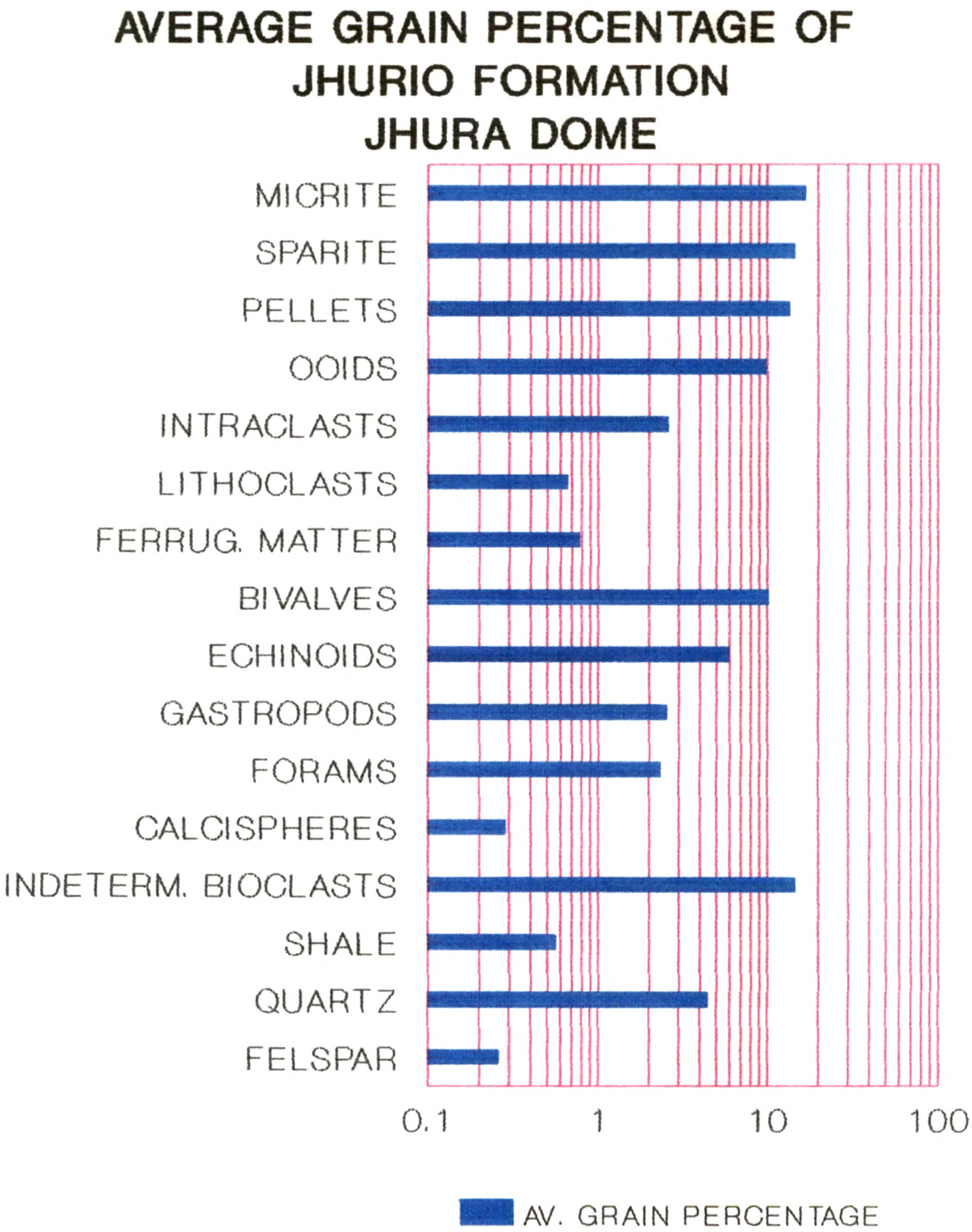
AVERAGE GRAIN PERCENTAGE OF
JHURIO FORMATION
JHURA DOME
MICRITE
SPARITE
PELLETS
OOIDS
INTRACLASTS
LITHOCLASTS
FERRUG. MATTER
BIVALVES
ECHINOIDS
GASTROPODS
FORAMS
CALCISPHERES
INDETERM. BIOCLASTS
SHALE
QUARTZ
FELSPAR
0.1
1
10
100
AV. GRAIN PERCENTAGE

FIG.V.2

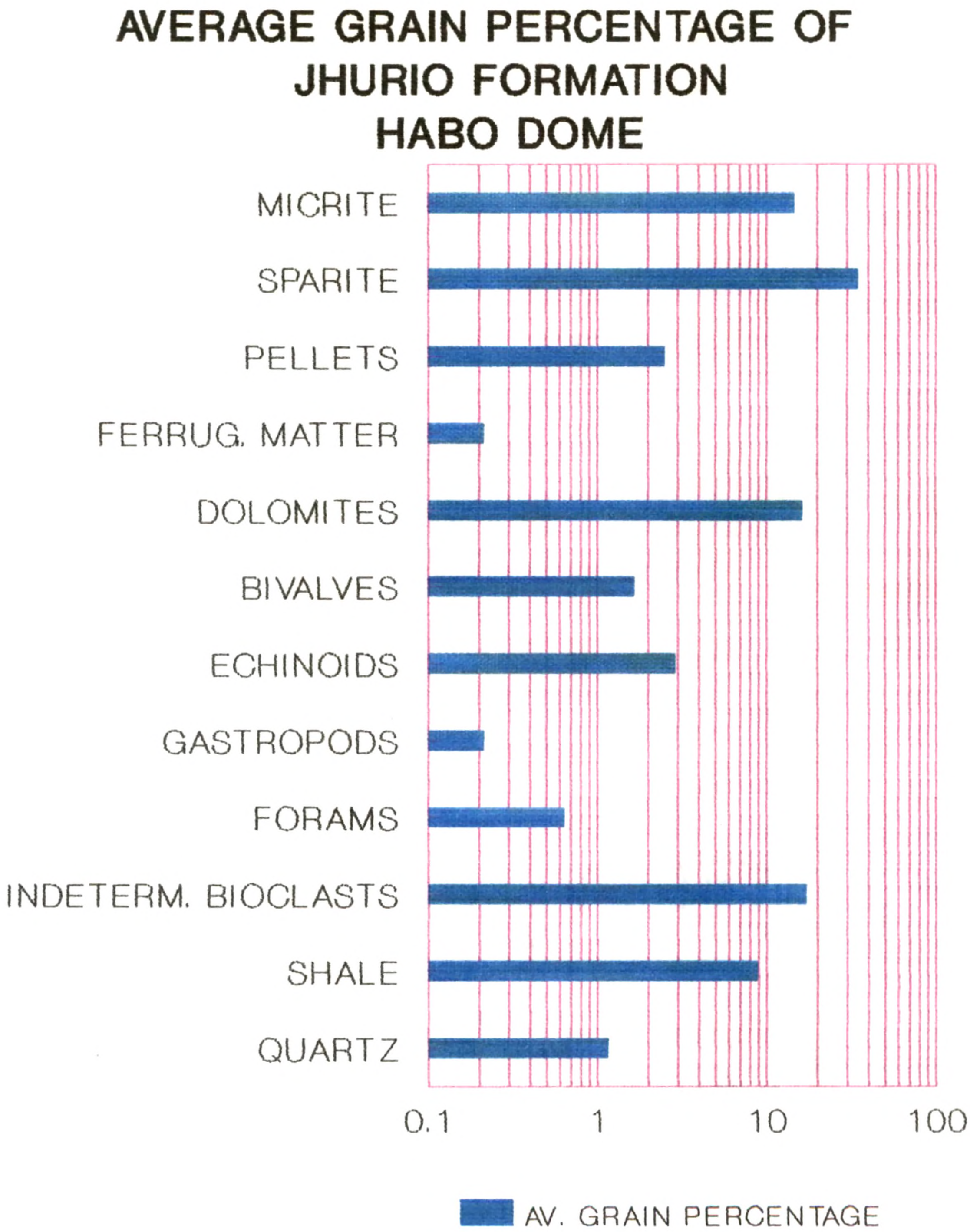
AVERAGE GRAIN PERCENTAGE OF
JHURIO FORMATION
HABO DOME
MICRITE
SPARITE
PELLETS
FERRUG. MATTER
DOLOMITES
BIVALVES
ECHINOIDS
GASTROPODS
FORAMS
INDETERM. BIOCLASTS
SHALE
QUARTZ
0.1
1
10
100
AV. GRAIN PERCENTAGE

FIG.V.3

facies locally grading into the grainstone. The sand size fraction is represented dominantly by intraclasts, fossils, ooids (mostly unbroken) and quartz grains **(Plate V.26)**. Many of the quartz grains bear abraded overgrowths implying their recycling. Quartz grains often form the nucleii of ooids; some of these quartz grains have sharply angular bipyramidal overgrowths terminating primary laminae of the ooids. In certain instances there are fibrous cement around the constituent grains of intraclasts. An uncommon type of intraclasts is composed of smaller darker micritic clasts embedded within lighter micritic groundmass. Occasionally, some intraclasts within the micritic groundmass are identifiable by their micritic outlines only. The dissolved parts of the intraclasts are now filled up by sparry carbonate cement. A few of intraclasts are evidently made up of pelloidal mud. The interstitial spaces are occupied mostly by micritic matrix which is dotted with sparry calcite patches. The ferruginous stringers present in this rock are often broken, pulled apart and to a certain extent crumpled.

b) Oolitic wackestone: The lower portion of the facies is greenish grey in colour and identical with the microfacies under Dhosa oolite facies. Petrographically, the microfacies is Oolitic Wackestone locally grading into Packstone **(Plate V.27)**. Here a very good bladed to isopachous rim cement is common around ooids. The individual ooid shows very good isogyre extinction. Angular to subangular quartz grains are

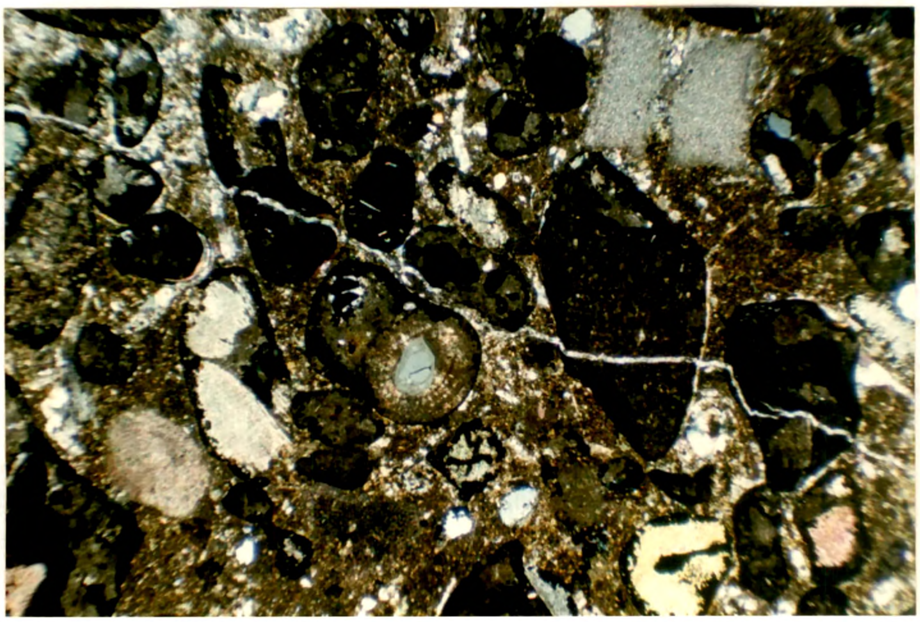

Plate V.26 Intraclastic packstone with ooids, intraclasts and partly sparitized shell fragments. Note the quartz grain forming the nucleii of ooid (Crossed nicols, X 25)

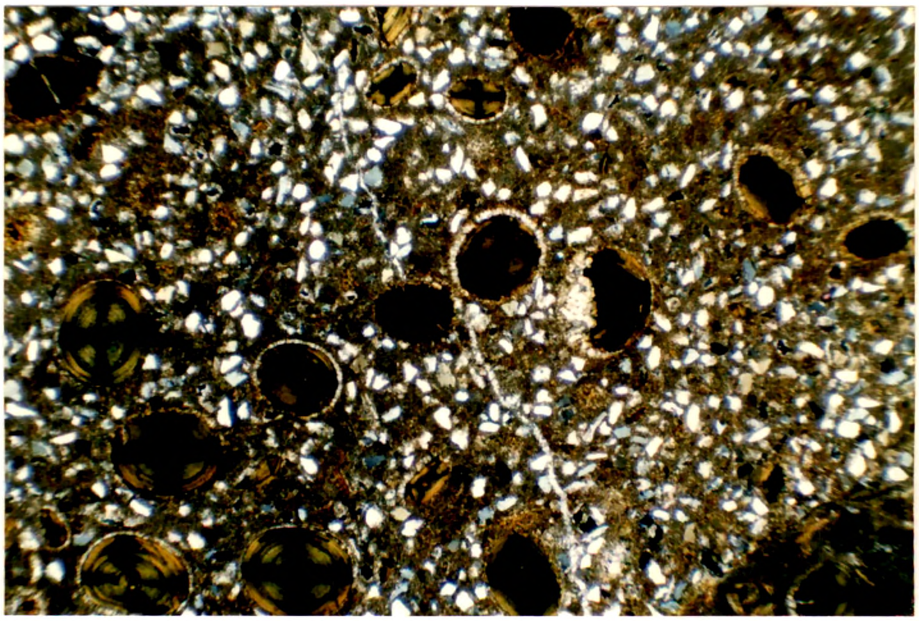

Plate V.27 Photomicrograph of oolitic wackestone with good isopachous rim cement and isogyre extinction (crossed nicols, X 25) scattered within the micritic groundmass. Neomorphic development of calcite within the groundmass is also seen. Presence of few intraclasts and lithoclasts are also evident.

2. **SHALE/IRONSTONE FACIES (KJ-V)**

This facies comprises only one carbonate microfacies.

a) **Bioclastic Packstone:** This is rich in bioclasts like shell fragments of gastropods, echinoids and foraminifers embedded in ferruginous matrix **(Plate V.28)**. The shell fragments and sheltered porosity are sparitized. Few echinoid grains also show syntaxial overgrowth.

3. **GREY LIMESTONE FACIES (KJ-VI)**

Two microfacies have been identified within this lithofacies:

a) Wackestone: The wackestone present within the thick shale unit is rich in terrigenous grains which are of fine sand size. The broken shell fragments are relatively more and are stouter and larger than those in white limestone facies of Jhurio Formation **(Plate V.29)**. The sediment presumably represents an admixture of bank derived carbonate and land derived terrigenous fractions. The random orientation of the elongated clasts may be indicative of rapid deposition, however, this chaotic arrangement might be due to intense bioturbation.

b) Mudstone: Mudstone within the parasequences are micritic limestones heavily stained with iron. The rock also contains

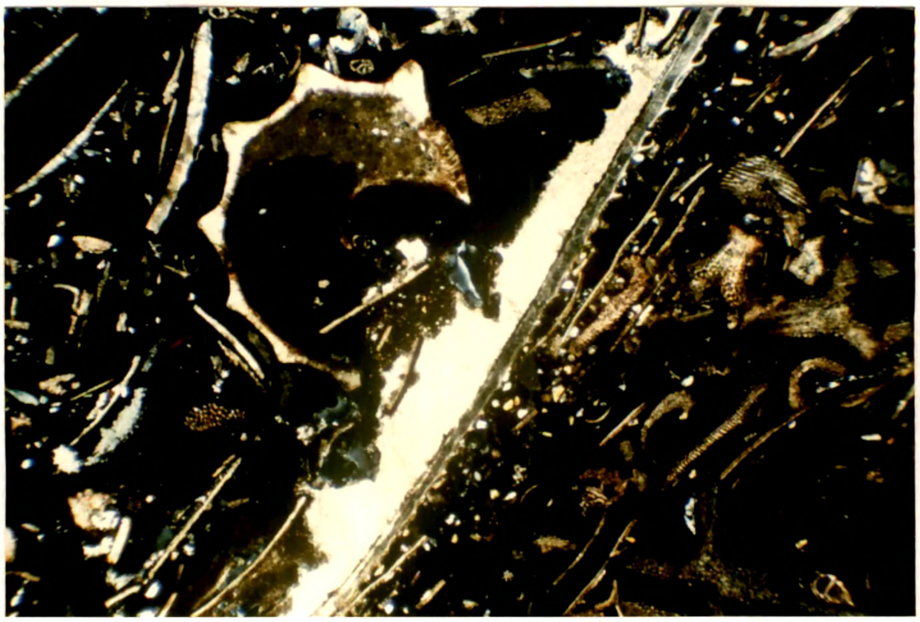

Plate V.28 Bioclastic packstone with ornamented shell fragments of gastropods, echinoids, forams and other indeterminate fossil fragments within a ferruginous mass. (Crossed nicols, X 25)

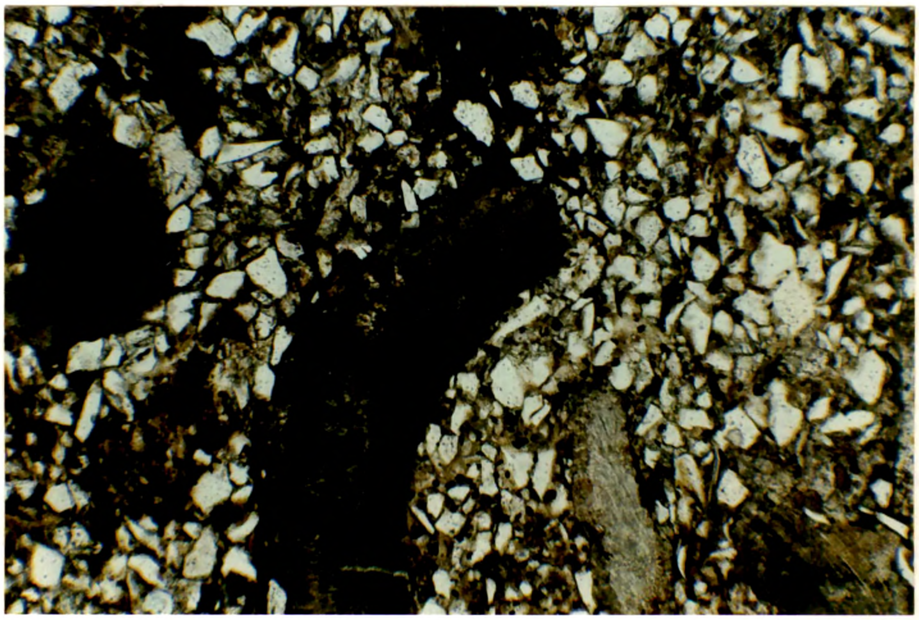

Plate V.29 Wackestone showing the high concentration of arenaceous fractions in the form of quartz. Elongated shell fragments of brachiopod are also seen (Plane polarised light, X 60).

scarcely distributed commuted fossil fragments and few ornamented grains of forams as also few quartz grains **(Plate V.30)**.

4. CALCAREOUS SANDSTONE FACIES (KJ-VII)

The rock is mixture of terrigenous grains as well as fossil fragments. The terrigenous fraction being mostly of corroded quartz **(Plate V.31)** is more dominant and is well sorted, subangular and very fine to fine grained nature. The matrix is calcareous and ferruginous. The nonferroan sparry calcite cements occur within the moldic pores created by dissolution of bioclasts; patchy ferruginous cement is also not uncommon.

The sandstone towards the top of the Jumara formation becomes coarser with varying framework composition from medium to coarse grained sand **(Plate V.32)**. Quartz is by far the major component of the terrigenous fraction, however, feldspar constitutes about 5-10% by volume. The feldspar grains mainly microcline with subordinate plagioclase are more or less fresh and concentrated in the finer subfraction which is rounded than the coarser ones. The rock is fairly compact with primary calcite cement within the interstitial spaces. Ferruginous cement occurs only in patches. The poor sorting of the framework grains indicates short transportation and quick dumping, which is also reflected in the freshness of the feldspar grains.

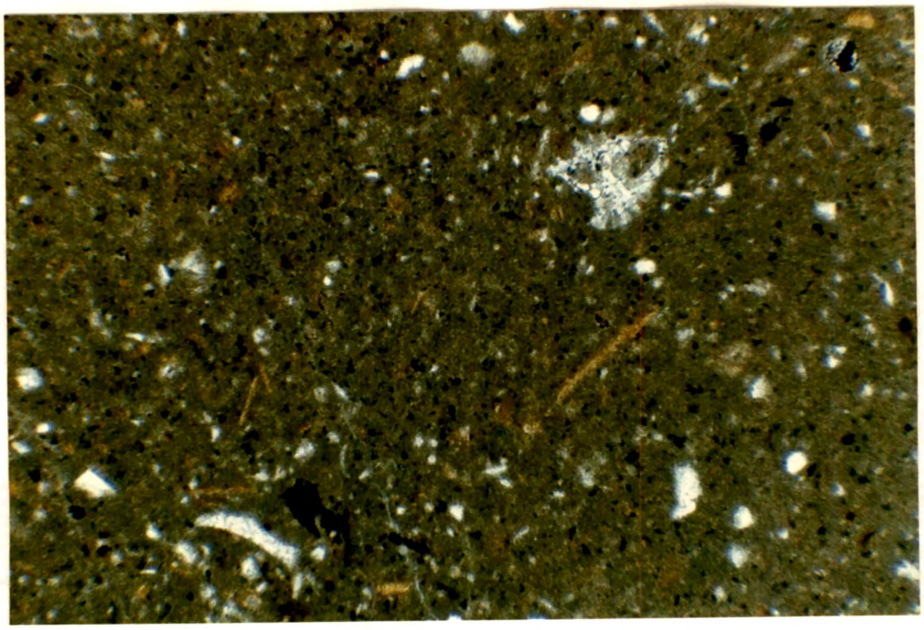

Plate V.30 Mudstone heavily stained with iron. Note the presence of ornamented forams alongwith few microfilaments. (Plane polarised light, X 60)

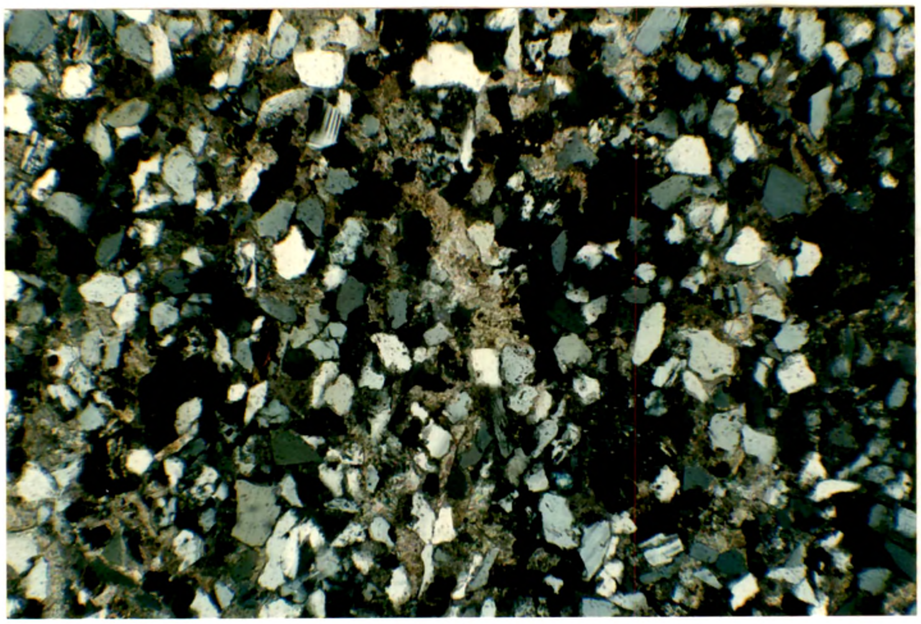

Plate V.31 Photomicrograph showing fine grained calcareous sandstone with angular to subangular grains of quartz with calcareous cement. (Crossed nicols, X 60)

5. DHOSA OOILITE FACIES (KJ-VIII)

Petrographically, the limestone within the facies can be divided into two microfacies.

a) Echinoidal Mudstone: Among three bands of grey coloured limestones alternating with shales; the uppermost limestone bed is an echinoidal mudstone. Here, within a fine grained micritic groundmass, elongated thin spines of echinoids are very common **(Plate V. 33)**. At places, curved shells of bivalves are also seen. The echinoid spines are fairly parallel to each other and to the bedding plane. Few globular tests of forams and calcispheres are also present. The rock is devoid of ooids.

b) Oolitic wackestone: The lower two beds alternating with shales are oolitic wackestones **(Plate V.34)**. The terrigenous angular to subangular quartz grains are present mostly in subordinate amounts. However, in certain beds, their proportion is considerably high. The mean size of quartz grains is about 0.06 mm and the average diameter of the ooids is 0.5 mm. The ooids cortices despite ferruginous stain on them, display very fine concentric laminations. Under crossed nicols, the cortices show isogyre-like lines of extinction moving across the laminae. In certain cases the cortex laminae are slightly crinkled suggesting their algal origin. The nucleii of the ooids are either bioclasts or quartz grains. The bioclastic nucleii have often been

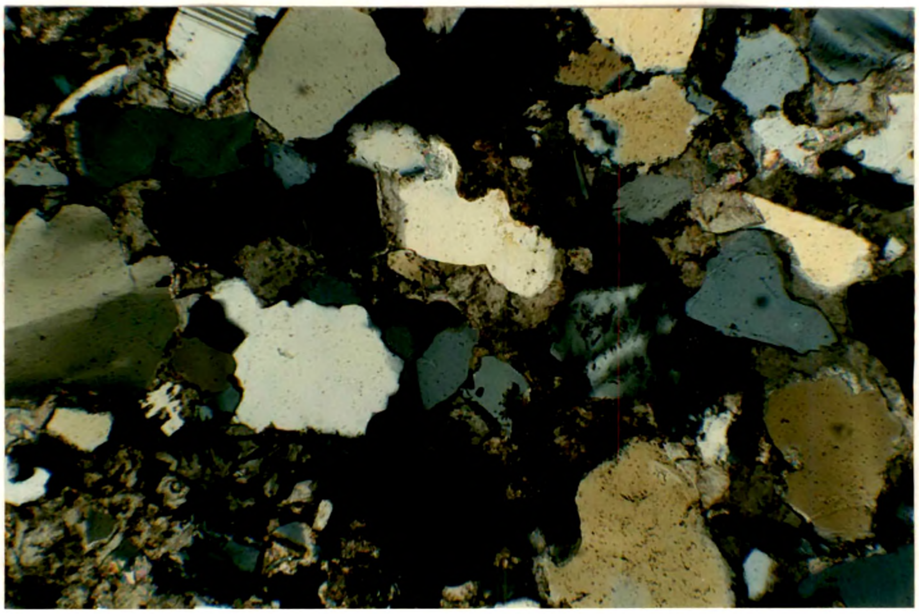

Plate V.32 Medium to coarse grained poorly sorted calcareous sandstone. Quartz boundaries are corroded by calcite. (Crossed nicols, X 60)

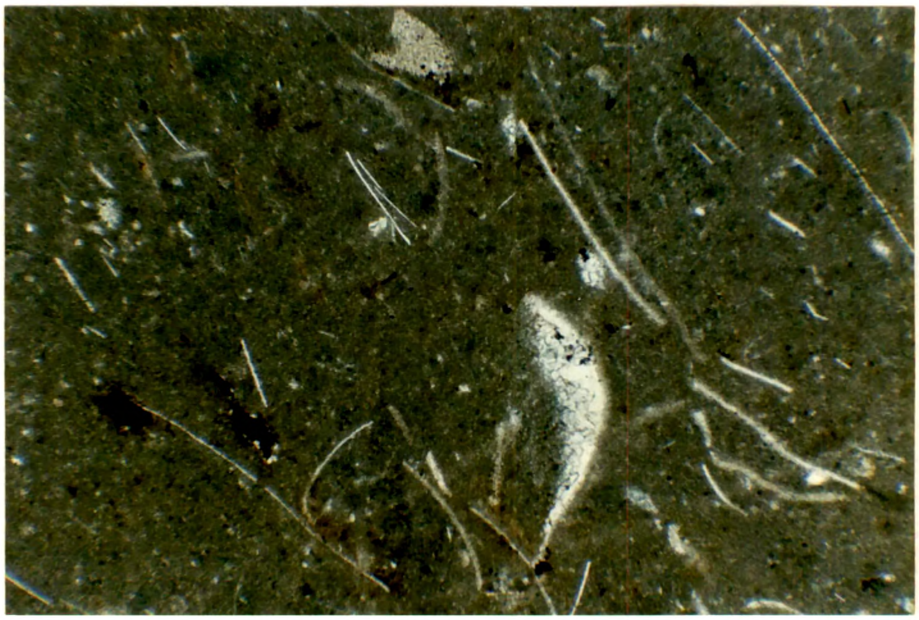

Plate V.33 Mudstone with elongated thin spines of echinoids, and sparitized curved shell fragment. (Plane polarised light, X 60) dissolved resulting into secondary voids. These voids are mostly still vacant but some of them are filled by nonferroan blocky calcite cement. Some ooids are multicomponent- the larger ooids forming around two or three smaller ooids coalesced together. At places, broken fragments of cortices form the nucleii, however, the ooids are mostly unbroken. The rock also contains a small percentage of larger fossil clasts which are devoid of such cortices.

JHURA DOME

The following microfacies have been identified under the major lithofacies identified during the field studies:

1.GYPSEOUS SHALE FACIES (KJH-VI)

The carbonates associated with this facies show three major microfacies.

a) **Argillaceous Packstone:** Petrographically, the calcareous shaly beds are argillaceous packstone **(Plate V.35)**. It is medium to fine grained with ghosts of ooids, rounded micritized pelloids and silt size quartz grains as dominating constituents. The ooids show good micritic rim. Among bioclasts, fragments of echinoids and brachiopods are common.

b) **Pelloidal packstone:** This microfacies is dominated by micritized pelloids and the intergranular spaces are completely infilled by syntaxially grown ferroan calcite cement **(Plate V.36)**. The microfacies is alternating with

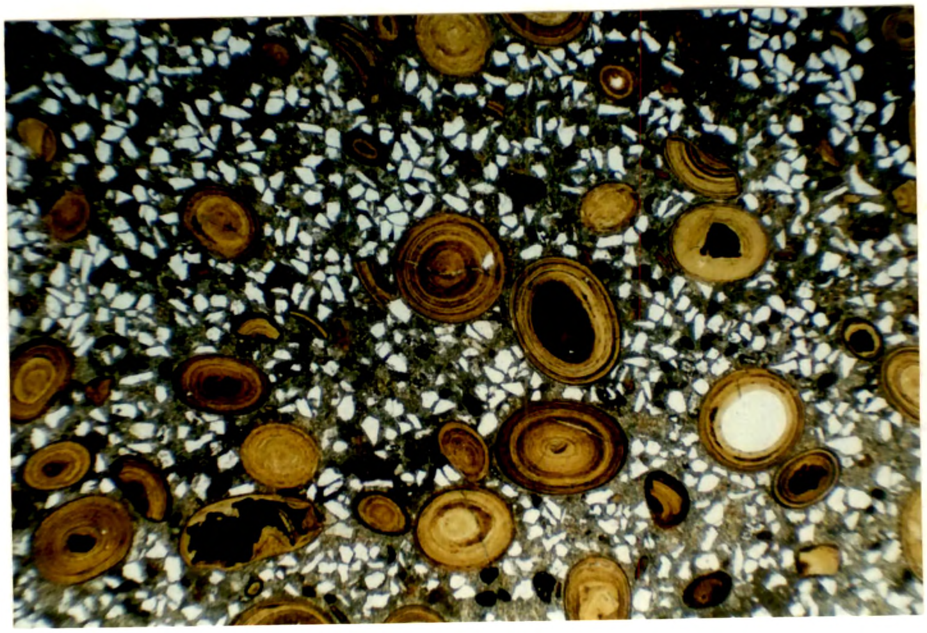

Plate V.34 Oolitic wackestone with angular to subangular grains of quartz; note the fine concentric laminations in the ooid cortices despite ferruginous stain on them. (Plane polarised light, X 25)

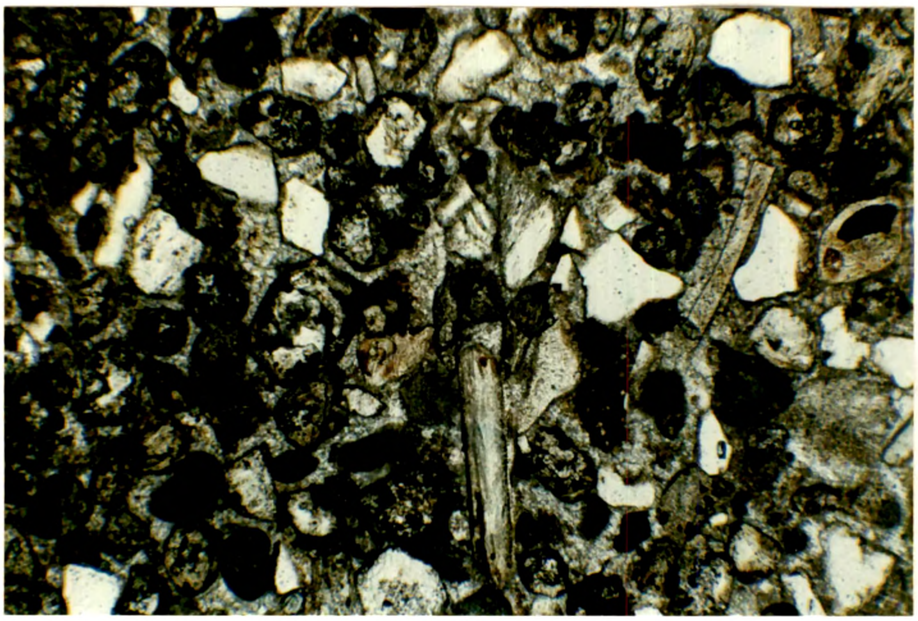

Plate V.35 Packstone with argillaceous impurities. Note the presence of ghosts of ooids, rounded micritized pelloids and siltsize quartz grains.(Plane polarised light, X 60) the shale and represented by four to five bands in the northern limb of the dome. The lower beds are rich in calcispheres and smaller forams. Besides pelloids, broken shell fragments of brachiopods and echinoids are common.

c) **Calcareous sandstone:** This bed underlies the packstone microfacies. The microfacies is dominated by sub-rounded to sub-agnular medium sand size quartz grains cemented by microsparitic calcite cement. The quartz grains show cracks which are filled by calcite. Among bioclasts, echinoid and bivalves are common.

2 RIDGE SANDSTONE FACIES (KJH-VII)

Petrographically the rock is medium to coarse grained calcareous bioclastic sandstone **(Plate V.37)**. Subangular to sub-rounded grains of quartz are common; at places showing polycrystalline extinction. Grains of felspar, echinoids and few ooids are also seen alongwith elongated laths of brachiopod shell fragments. The intergranular spaces are occupied by sparitic calcite. Pressure solution and dissolution features are also seen. The fractures within quartz grains are infilled by calcite cement.

3. CALCAREOUS PEBBLY GRIT FACIES (KJH-VIII)

The facies comprises a mixture of clastic and carbonate facies. Here, the carbonate facies is dominated by large shell fragments of brachiopods and echinoid grains, as

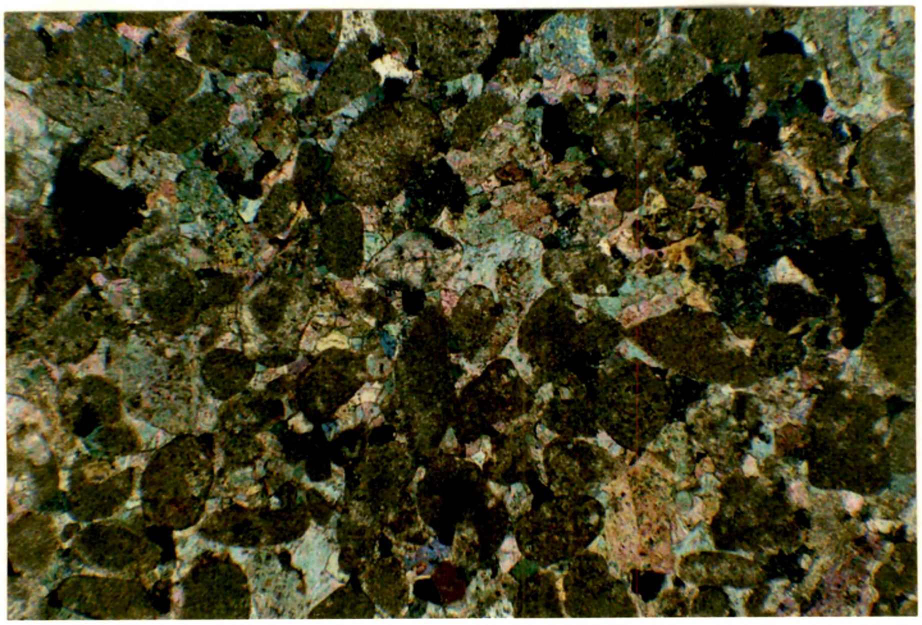

Plate V.36 Pelloidal packstone with micritized pelloids within sparitized calcite cement. (Crossed nicols, X 60)

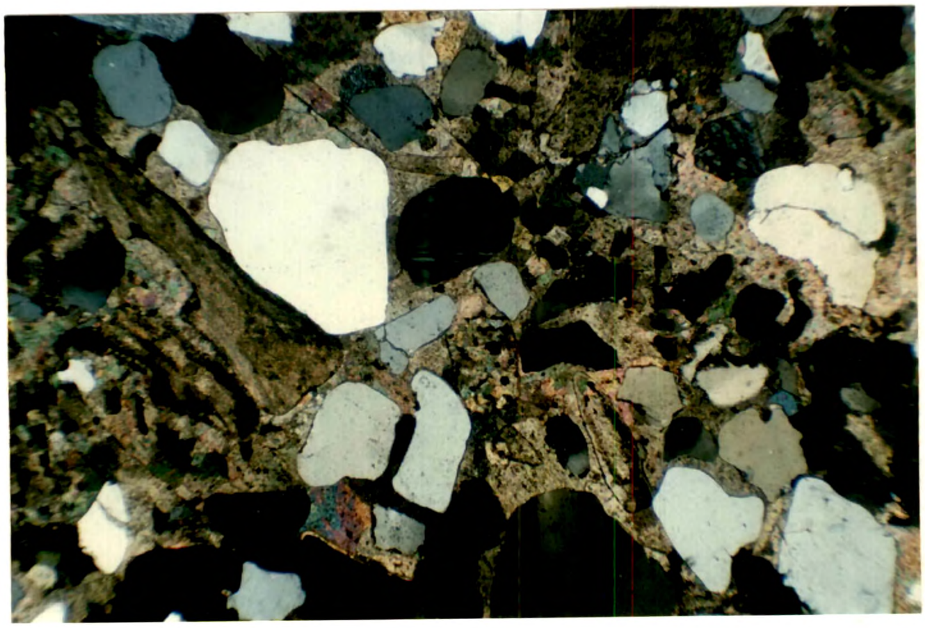

Plate V.37 Medium to coarse grained calcareous bioclastic sandstone ; note the poor sorting of grains and sparitized groundmass. (Crossed nicols, X 25) well as pebbles at older limestones. The rock can be termed as 'Rudstone'.

4. DHOSA OOLITE FACIES (KJH-IX)

Like Jumara dome, here also the Dhosa oolite beds are overlain by a conglomerate bed exposed to the east of Jhura dome (east of Kaila river).

Below the conglomeratic bed occur three bands of reddish brown coloured limestone alternating with shales. Here the limestone facies can be divided into two microfacies:

a) **Wackestone:** The microfacies is yellowish brown in colour and devoid of ooids. Here, the arenaceous fractions are indicated by angular quartz and bioclastic fragments are represented by laths of echinoids within micritized mass. **(Plate V.38)**.

b) **Oolitic packstone:** Here, the ooids showing oomoldic porosity are embedded in an arenaceous groundmass **(Plate V.39)**. The arenaceous fractions are mainly silt size quartz grains. The ooids are coated by dark coloured ferruginous material and their average size is 0.25 mm. Bioclastic broken fragments are present in a minor quantity.

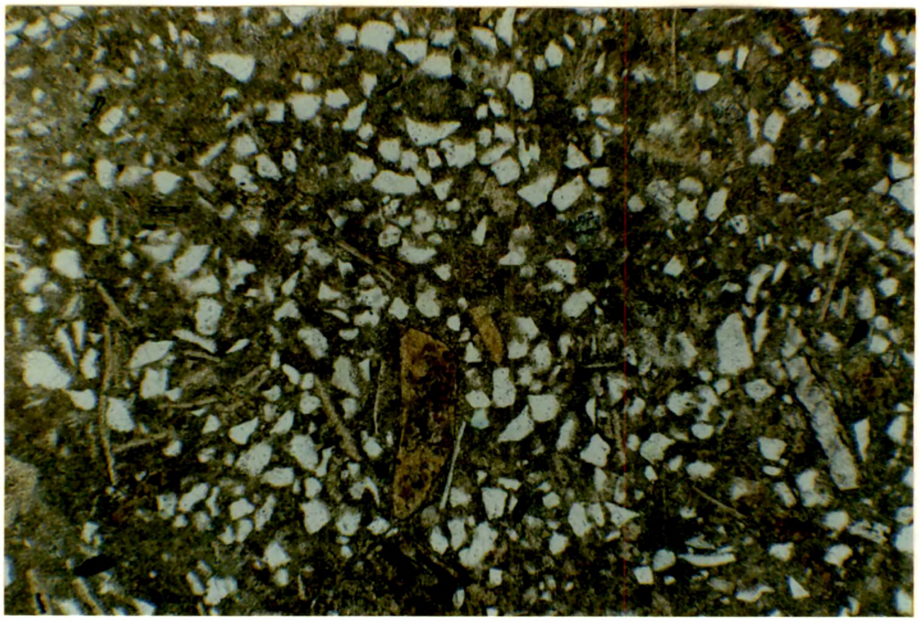

Plate V.38 Wackestone, arenaceous with laths of echnioids within a micritized mass; note the angularity of quartz grains. (Plane polarised light, X 60)

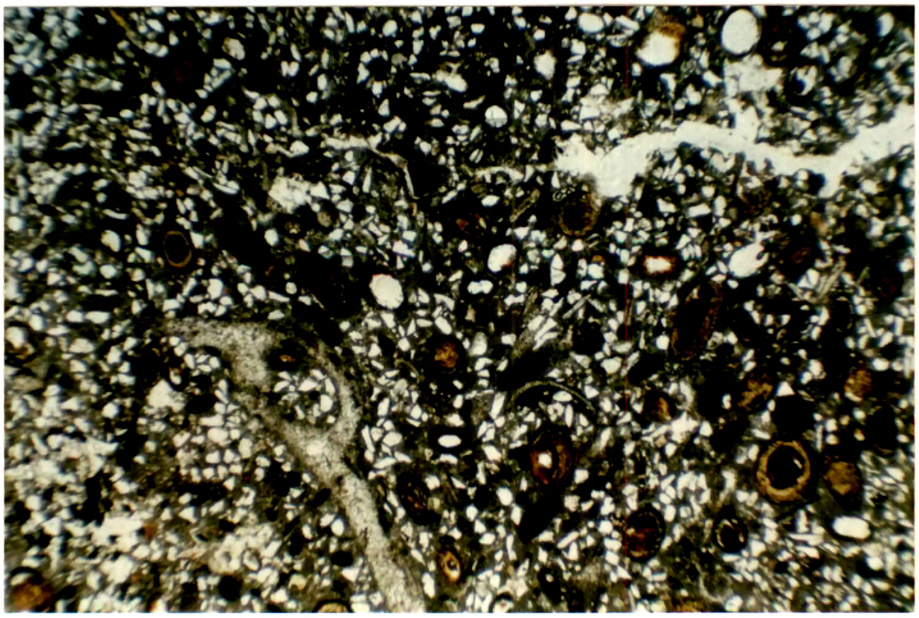

Plate V.39 Oolitic packstone showing ooides embedded in an arenaceous groundmass showing and oomoldic porosity within ooids. (Plane polarised light, X 25)

HABO DOME

The following microfacies have been identified under the four major lithofacies of Jumara Formation.

1. GYPSEOUS SHALE FACIES (KH-III)

The associated carbonate facies within gypseous shale facies can be divided into three microfacies.

a) **Crystalline Grainstone:** These dark grey coloured fossiliferous limestones, mostly belong to the crystalline grainstone microfacies. The dominant constituent comprise elongated shell fragments of bivalves which are totally sparitized. The cement here is mostly iron poor sparry calcite **(Plate V.40)**.

b) **Floatstones:** The microfacies is dominated by large rounded to ovoidal shell fragments of bivalves floating in the partly sparitized micritic groundmass. The center of few shell fragments show very good drusy growth of calcite cements and geopetal structures **(Plate V.41)**. The matrix is rich in iron content and silt size quartz grains. Beside bivalves, echinoids are also seen.

c) **Calcareous siltstone:** This microfacies is a mixture of silt size quartz grains and small shell fragments of brachiopods, echinoids and other micro-filaments. The grains also show a preferred orientation.

Besides, the above three microfacies, the KH-III facies also comprises the solitary coral beds. Here, the

Plate V.40 Stained photomicrograph of grainstone with completely sparitized calcite and shell fragments of bivalves; note the close packing and pink stained non-ferroan calcite cement. (Crossed nicols, X 25)

Plate V.41 The transerve cut shell fragment with geopetal structure in floatstone of KH-III lithofacies in Habo dome. (Crossed nicols, X 25) coral chambers are completely sparitized and the septas are represented by thin partly sparitized brownish lines **(Plate V.42)**. At places, the calcite crystal show distinct cleavage planes.

2. **SANDSTONE/SILTSTONE FACIES (KH-IV)**

Petrographically, the sandstones are dominated by coarse to medium grained quartz grains embedded in a calcareous groundmass. The shell fragments are present alongwith the detritals **(Plate V.43)**. The quartz grains, at places, show corrosion and replacement by calcite. In few places, the sandstones are gritty in nature. The associated siltstone contains well sorted quartz grains embedded within a calcitic groundmass.

3. **PEBBLY GRIT FACIES (KH-V)**

This is interbedded with shales and sandstone facies and occur in patches. The rock can be termed as bioclastic Rudstone **(Plate V.44)**. Here, large elongated shell fragments of bivalves are dominating and mostly sparitized. The pebbles are in fact, large micritized grains, at places enclosing quartz and other bioclastic grains. The interparticle spaces are filled with sparitic calcite and siltsize quartz grains. The quartz grains show a distinct bimodality in size with dominance of finer grains.

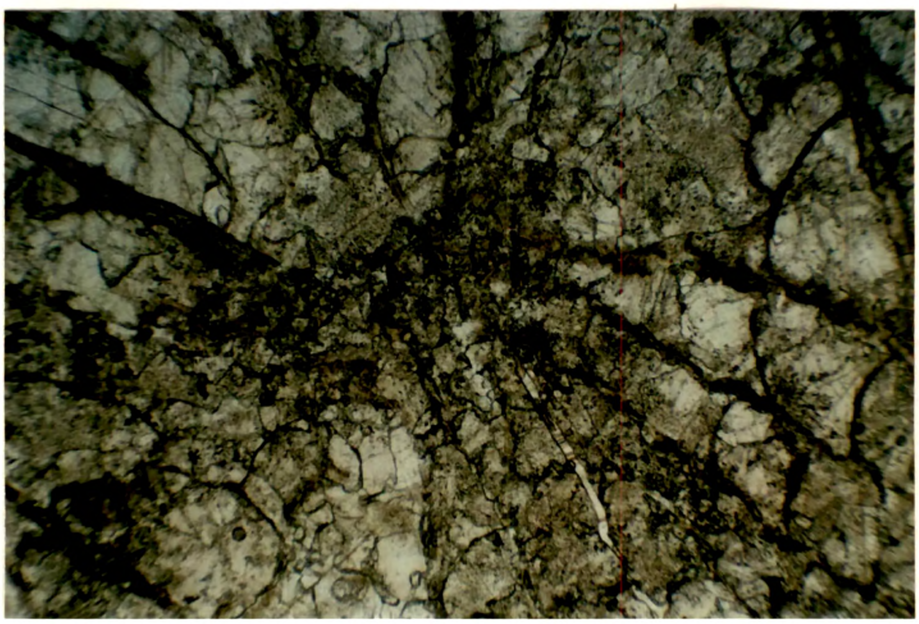

Plate V.42 Solitary coral with completely sparitized chambers and thin partly sparitized brownish lines as septas. (Plane polarised light, X 25)

Plate V.43 Calcareous sandstone with dominance of quartz grains; note the infilling of calcite cement within cracks of quartz grains and on sparitized brachiopod shell fragment. (Crossed nicols, X 25)

4. DHOSA OOLITE FACIES (KH-VI)

The facies can be divided into two microfacies on the basis of concentration of ooids and bioclastic shell fragments within partly sparitized micritic groundmass .

a) **Oolitic packstone**: Petrographically, the upper portion of the facies can be termed as oolitic packstone. The framework grains are mostly fine to very fine quartz and ooids with mostly sparitized micrite in their pore spaces. The ooids are ferruginous and show distinct isogyre extinction **(Plate V.45)**. Besides, the microfacies also contains bioclastic shell fragments mostly of echinoids, gastropods and brachiopods. The SEM photo of this rock exhibits more clearly the fabric of this microfacies and the closer view shows very thin distinct cortices of an ooid **(Plate V.46)**.

b) **Oolitic wackestone**: The lower portion of the facies is in fact oolitic wackestone with more of arenaceous fractions. The arenaceous fraction is mainly well sorted sub-angular fine sand size quartz grains. The average size of ooids are 0.35 mm and their number is smaller than the overlying microfacies. The ooids show good isogyre extinction. Few ooids are devoid of internal laminae and are identified by their outer ferruginous micritic rim. Few ooids are showing oomoldic porosity. Here, a characteristic feature is the occurrence of a lithoclastic rock fragment which is rich in fine sand size subangular quartz grains. The ooids are

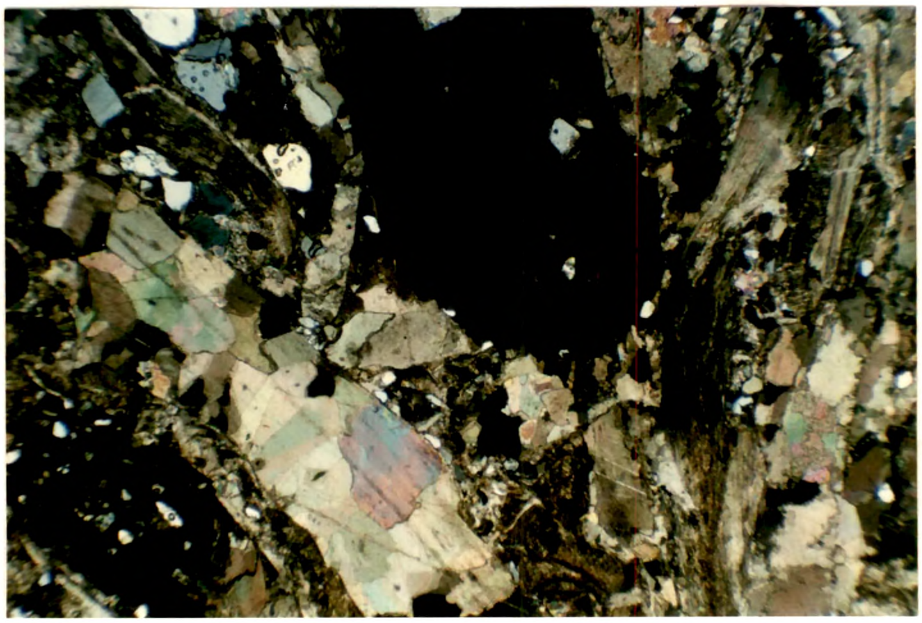

Plate V.44 Rudstone of pebbly grit facies; note the presence of micritized pebble within mostly sparitized shell fragmenmts of bivalve. Crossed nicols, X 25)

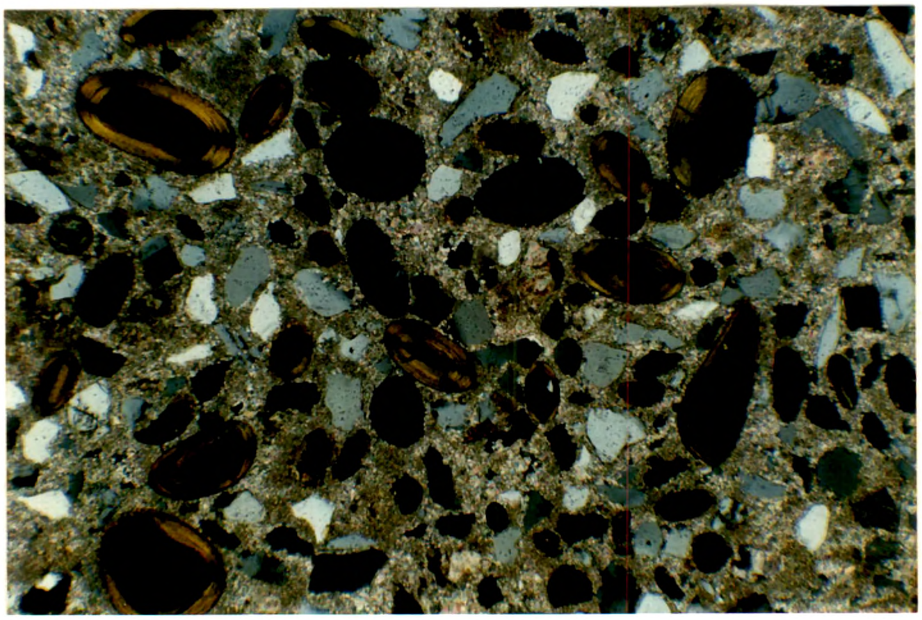

Plate V.45 Oolitic wackestone showing isogyre extinction in ooids and partly sparitized micritic groundmass with subangular grains of quartz. (Crossed nicols, X 60)

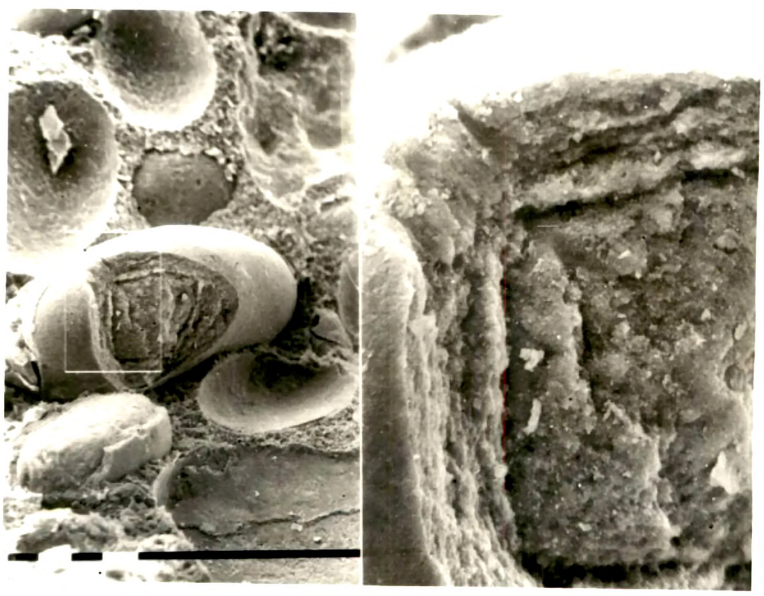

Plate V.46 SEM photograph showing closer view of an ooid with thin distinct cortices.(X 45 and X 206) embedded within partly sparitized micritic groundmass. The bioclastic grains are represented by few long shell fragments of bivalves.

As mentioned earlier, a semi-quantitative method of analysis has been used for Jumara formation also, exposed in all three domes. The frequency analysis (constituent analysis) has been done based on proportionate number of thin section analysis using Standard comparison charts of Baccelle and Bosellinni (1965) and Schafer (1969). These are plotted in bar charts similar to the chart of Jhurio formation (**Fig. V.4, V.5 and V.6**). Finally, a comparison has been made of Jhurio and Jumara formation from Jumara Dome in the west to Habo dome to the east (**Fig.V.7 and V.8**).

The different microfacies of carbonate sequences identified under both the formations can be accommodated within seven Standard Microfacies Types of Wilson (1975) and Flugel (1972, 1982). These are SMF Types 8, 9, 10, 11, 15, 16, and 24. The microfacies of Jhurio Formation is represented by SMF type 8, 9, 11, 15 and 16 whereas microfacies of Jumara formation is accommodated within SMF type 9, 10 and 24 in the study area. These standard microfacies types represent a particular set of depositional environments, the details of which are given in the relevant chapters.

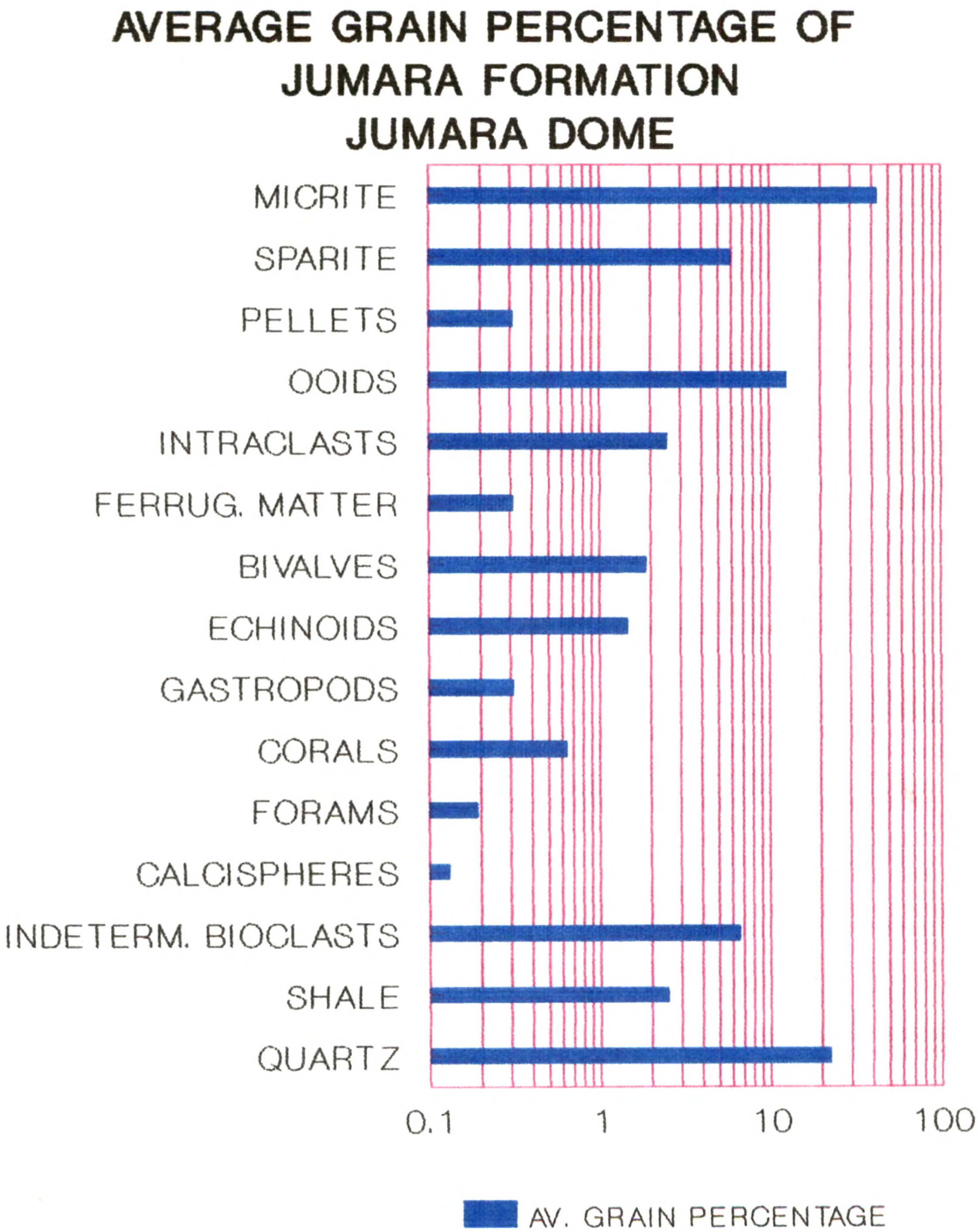
AVERAGE GRAIN PERCENTAGE OF
JUMARA FORMATION
JUMARA DOME
MICRITE
SPARITE
PELLETS
OOIDS
INTRACLASTS
FERRUG. MATTER
BIVALVES
ECHINOIDS
GASTROPODS
CORALS
FORAMS
CALCISPHERES
INDETERM. BIOCLASTS
SHALE
QUARTZ
0.1
1
10
100
AV. GRAIN PERCENTAGE

FIG.V.4

AVERAGE GRAIN PERCENTAGE OF JUMARA FORMATION JHURA DOME

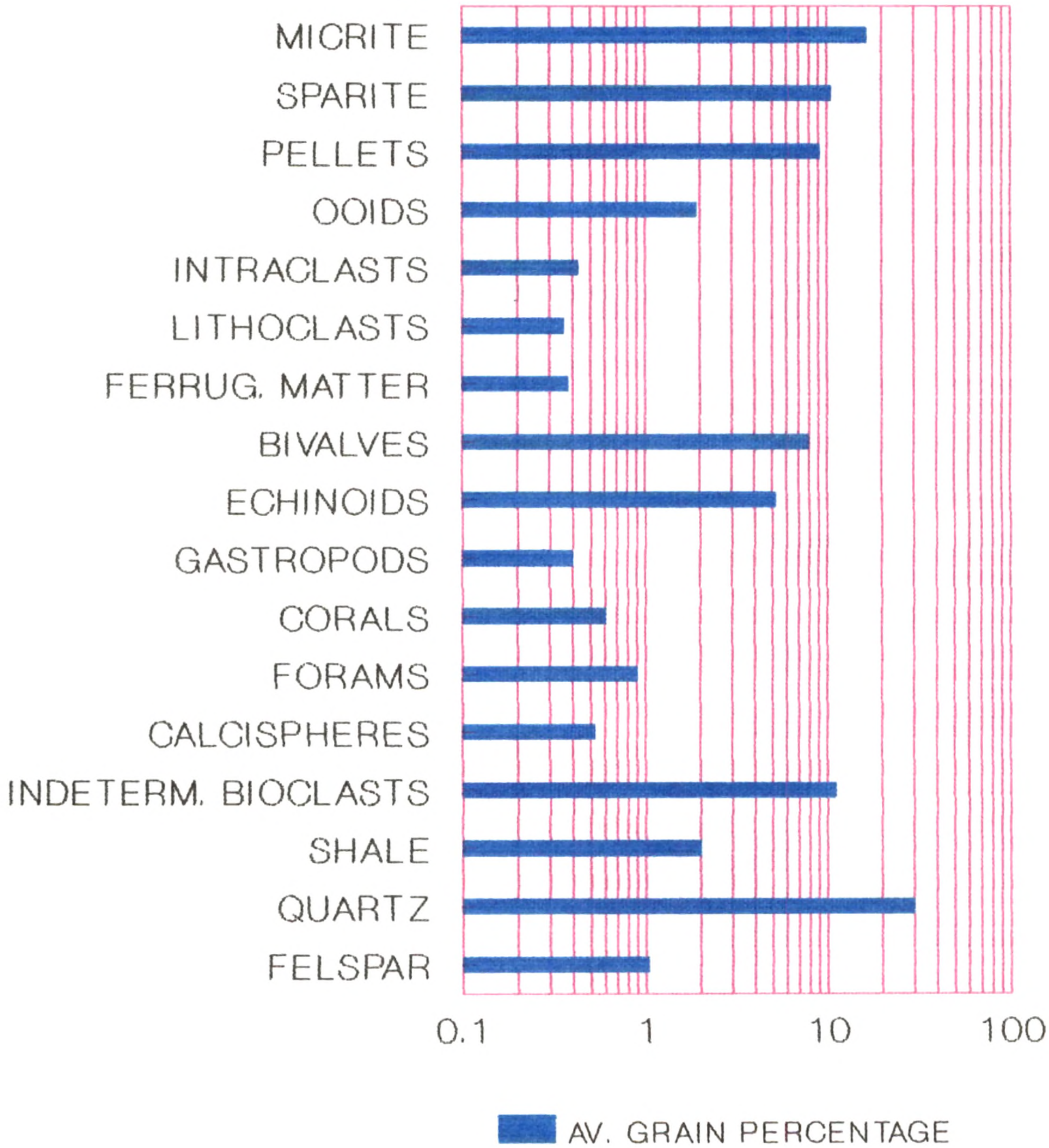

FIG.V.5

AVERAGE GRAIN PERCENTAGE OF JUMARA FORMATION HABO DOME

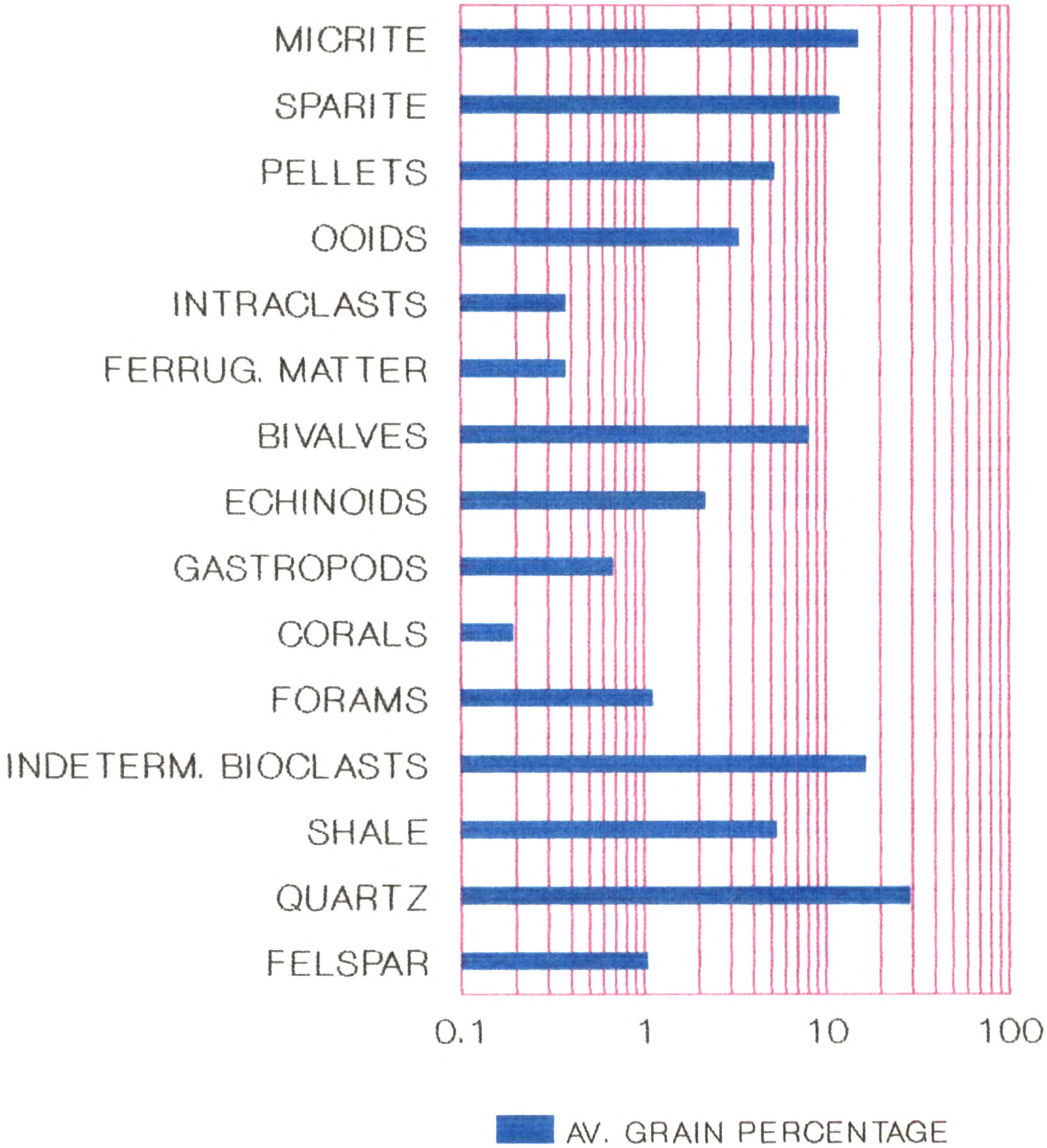

FIG.V.6

AVERAGE GRAIN PERCENTAGE OF JHURIO FORMATION

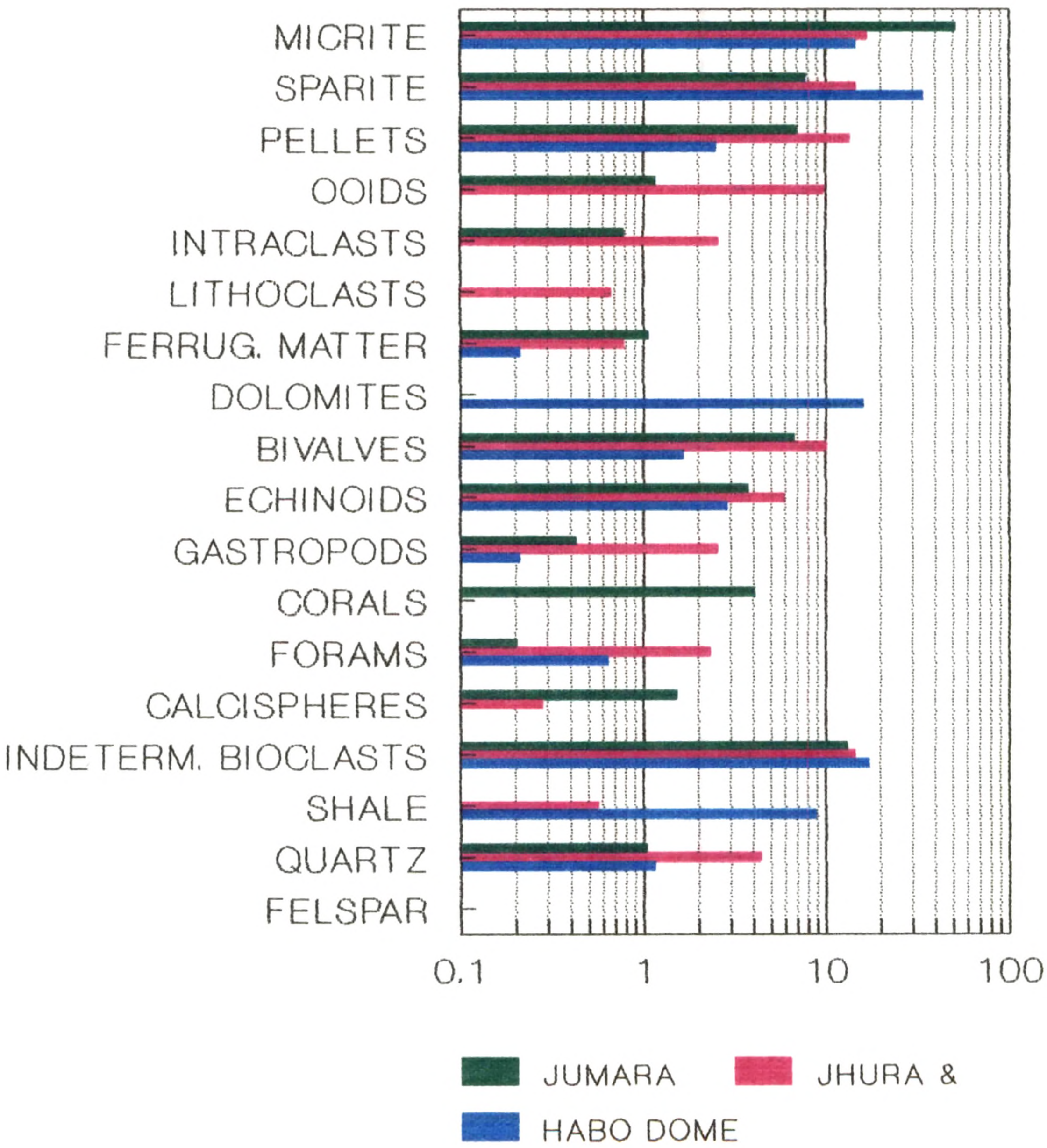

FIG.V.7.

AVERAGE GRAIN PERCENTAGE OF JUMARA FORMATION

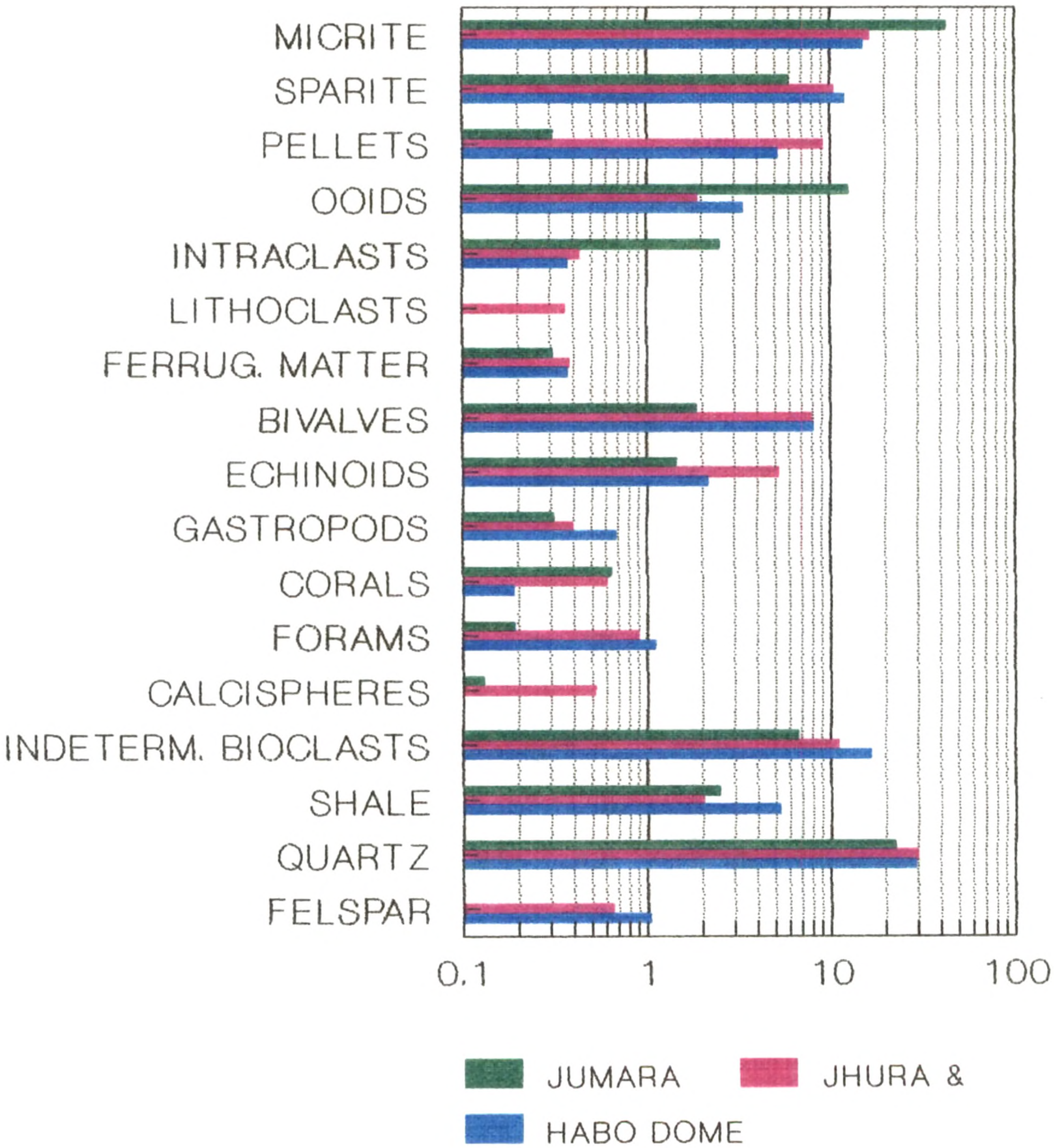

FIG.V.8