CHAPTER VII

DIAGENESIS

Biogenic carbonate sediments possess an extremely sensitive record of past life and conditions on the earth. This record is often blurred or rendered illegible by diagenesis. Paradoxically, the same diagenesis is beneficial to society because the holes and voids created during alteration are often filled later by base metals and hydrocarbons. So, to understand these carbonates for any purpose, it is important to decipher the complex series of processes that have modified their texture and composition through the geologic time.

The diagenesis of carbonate sediments includes all the processes involving solution, cementation, lithification and alteration of the sediments during the interval between deposition and metamorphism. The various factors that determine the nature of the end product of diagenesis are :

- The composition of the original sediments,
- The nature of the interstitial fluids,
- The physical and chemical processes involved, and
- The time subjected to them.

The primary driving force in carbonate diagenesis is rock-water interaction, hence, the key factor in the diagenetic equation is the composition of surface and subsurface fluids. The waters most commonly in contact with carbonate rocks and sediments are marine, meteoric or deep subsurface in origin. After the carbonates are deposited, precipitated, buried, eroded, exposed and reburried, with time they interact with different fluids. Such interaction of fluid and sediments take place in a special way and leave unique diagenetic signatures behind.

The regions characterised by waters of different composition, can be thought of as a separate diagenetic environment (Purdy 1968). In this synthesis three major diagenetic environments can be recognized;

1) the sea floor and underlying marine phreatic, characterised by marine waters, together with the shoreline bathed in mixed marine and fresh waters,

2) the meteoric, distinguished by the fresh water vadose and phreatic zones, and

3) the deep subsurface, where pores are filled with waters that were once marine but have been moderately to drastically

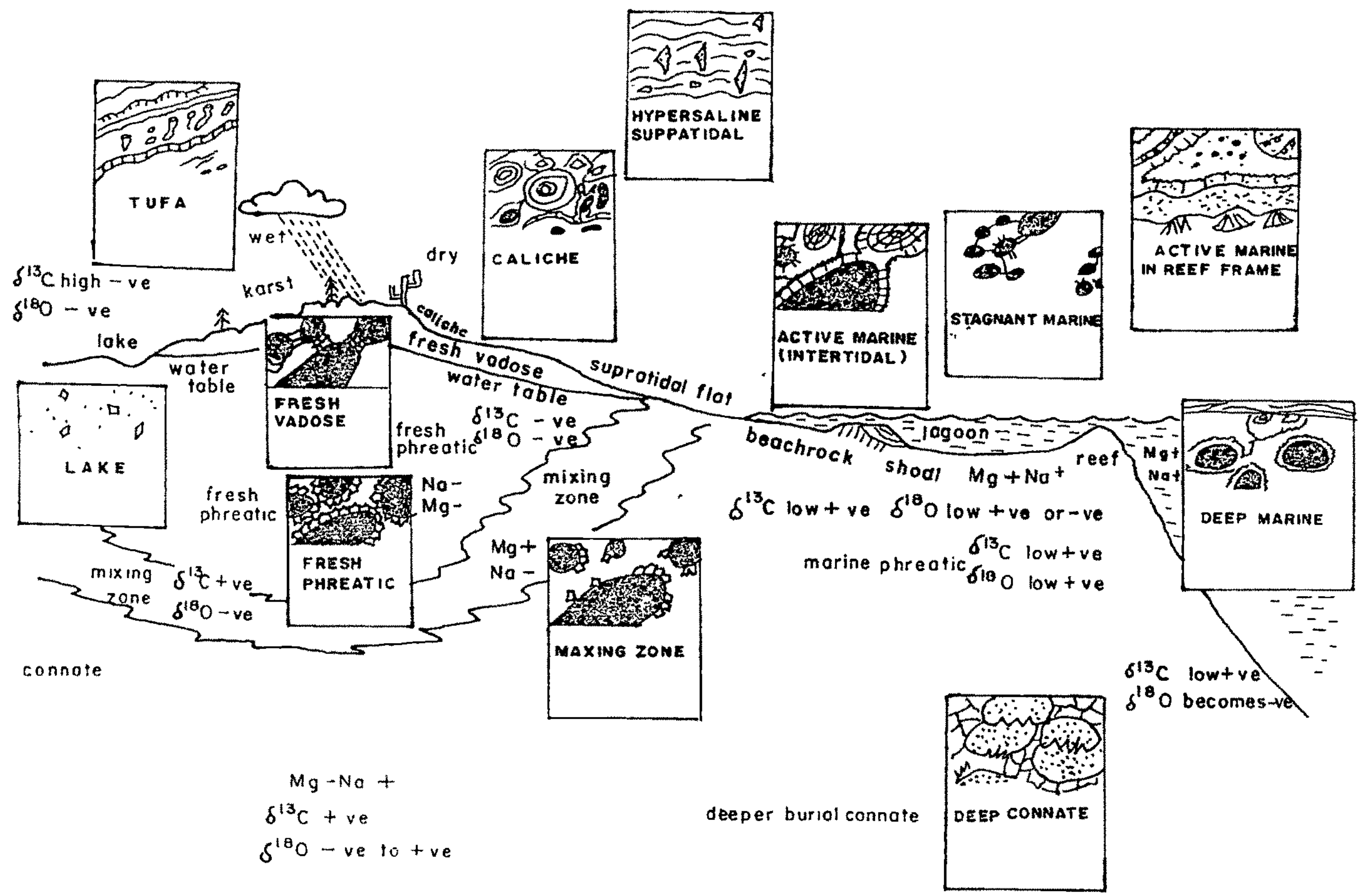
modified by burial diagenesis.

Each diagenetic environment stated above is characterized by a typical carbonate crystal fabric in the form of cement, trace element content and stable isotope values as discussed by various workers (Fig.VII.1). The diagenetic environments pass vertically and laterally one into the other (Tucker and Wright, 1990) and the carbonate sediments also generally pass from one environment to another with time due to their deposition and burial, sea level changes and/or tectonic movements.

PRESENT STUDY

Since the changes that take place during the diagenesis of carbonate rocks are largely textural and chemical, the study of carbonate diagenesis of the study area has been made both through petrography and geochemical analyses. The basic relationships are seen from thin sections or stained sections and have been augmented by Scanning electron microscopy. Especially useful are the trace element concentrations of Strontium (Sr), Magnesium (Mg), Iron (Fe), and Manganese (Mn) and ratios of carbon ($^{13}C/^{12}C$) and oxygen ($^{18}O/^{16}O$) isotopes.

The various diagenetic features developed during the different stages of diagenesis in the rocks of Jhurio and Jumara formations as observed in the thin sections are complex but indicative of depositional and post depositional



MAJOR ENVIRONMENTS OF INORGANIC CALCIUM CARBONATE PRECIPITATION INDICATING THE TYPICAL RESULTANT CRYSTAL FABRIC $\delta^{13}C$ AND $\delta^{18}O$ VALUES, AND RELATIVE AMOUNTS OF NA AND MG IN THE INTERSTITIAL FLUIDS (SIMPLEFIED AFTER SCOFFIN 1987).

FIG.VII.1

changes that took place mostly under the phreatic conditions in the marine as well as fresh water environments. The evidences also suggest diagenesis in a mixed marine and fresh water as well as burial environment. The different diagenetic features indicative of specific diagenetic environment in Jhurio and Jumara Formations of the study area are described in the following paragraphs:

1. Micritization

Micritization takes place by endolithic algae, fungi and bacteria. Here, bioclasts present on the sea floor or just below are altered by the process of microbial micritization. The skeletal grains are bored around the margins and the holes are filled with fine grained sediment or cement. Micritic envelopes and completely micritized grains are produced in this way. This diagenetic feature is common in both the formations of study area (**Plate VII.1**).

2. Hardground with iron impregnation

The presence of hardground is the main feature of sea floor cementation of shelf sands and mud. These generally form just below the sea floor where grains are not being moved very frequently, but sea water is continuously being pumped through. During storms, the hardground may be exposed on the sea floor and then they can be encrusted and bored. Intraclasts are commonly associated with hardgrounds. At places, they are heavily impregnated with iron minerals (**Plate VII.2**). The feature is distinct in the study area.

Plate VII.1 Photomicrograph showing micritic rim surrounding brachiopod shell fragments of bioclastic grainstone of KJH-IV facies of Jhurio Formation, Jhura dome (Plane Polarised light, X 60).

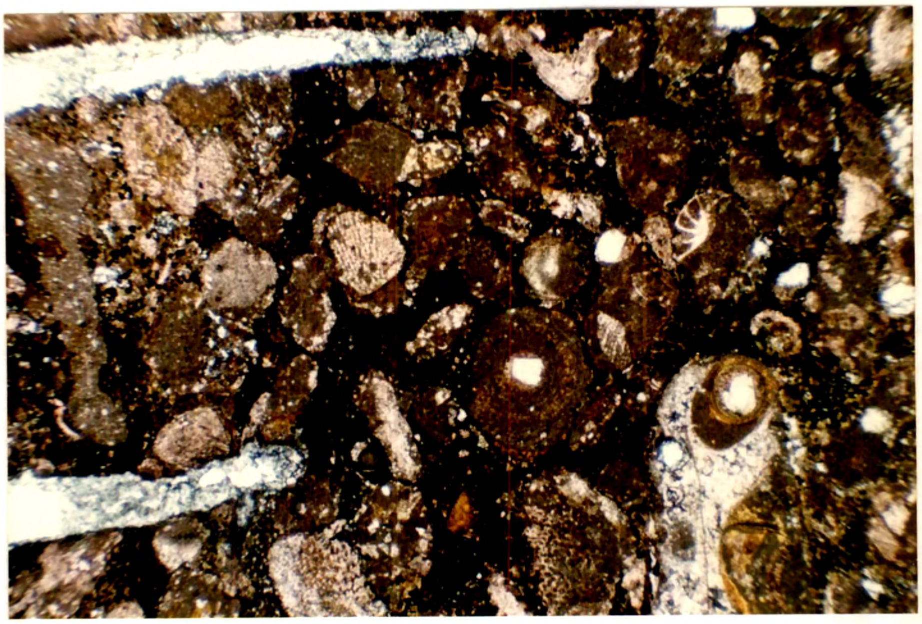


Plate VII.2 Photomicrograph showing hardground features; note the algal boring and intraclasts within pink stained non-ferroan sparry calcite and heavy impregnation of iron minerals; coralline limestone facies (KJ-I), Jhurio Formation, Jumara dome (Plane Polarised light, X 25).

3. Early lithification

The presence of intraclasts and hardground surfaces demonstrate an early lithification. Besides hardground and intraclasts, the carbonate sequences of Jhurio and Jumara formations exposed in the study area have ample evidence of early lithification. The nodular bedding of lithofacies KJ-II of Jumara dome, KJH-VA of Jhura dome and KH-I of Habo dome is due to early lithification in the muddy calcitic sediment (**Plate VII.3**). The presence of intrusive in the carbonate sequences of Jhurio formation is another evidence of an early lithification.

4. Early compaction (Pressure Solution)

The process whereby grains undergo dissolution abut their contacts is called pressure solution. Grain to grain pressure-solution must be limited to conditions where the directional pressure transmitted from grain to grain is greater than the hydrostatic pore pressure of the solution (Bathurst,1975). It generally can not take place after the precipitation of the second generation of cement, the final pore fillings, simply because the presence of this embracing material effectively prevents relative movement between grains. If pressure-solution acts after the delivery of the second generation of cement, then it does so by the formation of stylolites. On the other hand, grain to grain pressure solution can act after precipitation on the first generation of cement because a thin fringe of crystals does not prevent

Plate VII.3 Photoplate showing early lithification in the form of nodular bedding in bedded limestone facies (KJH-V) of Jhurio Formation, Jhura dome.

grain to grain movement. In this event the cement fringe is itself involved and is locally dissolved. The result of pressure solution is most clearly seen in ooids because the structure of the ooid is highly symmetrical (**Plate VII.4**). Besides pressure solution, the early compaction is expressed by reciprocal deformation of bioclasts, deformation of ooid contacts and minor spalling of outer cortical layers. **Plate VII.5** is a SEM photograph showing compaction of an ooid and details of its internal laminae.

Early compaction causes minor fracturing and these early fractures are difficult to distinguish from those of late burial origin. However, the later kind of fractures continue through the rock. **Plate VII.6** shows early fracturation of ooids in the golden oolite facies of Jhura dome.

5. Geopetal structures

Any internal structure or organization of sediments indicating original orientation such as top and bottom of strata. Evidences of this geopetal structure are seen where mud (micrite) fills the lower part of the cavity of a bioclastic chamber while sparry calcite fills the upper part (**Plate V.41**); the contact indicates an approximately level surfaces at the time of deposition. Such structures are very useful in determining original dips of unit.

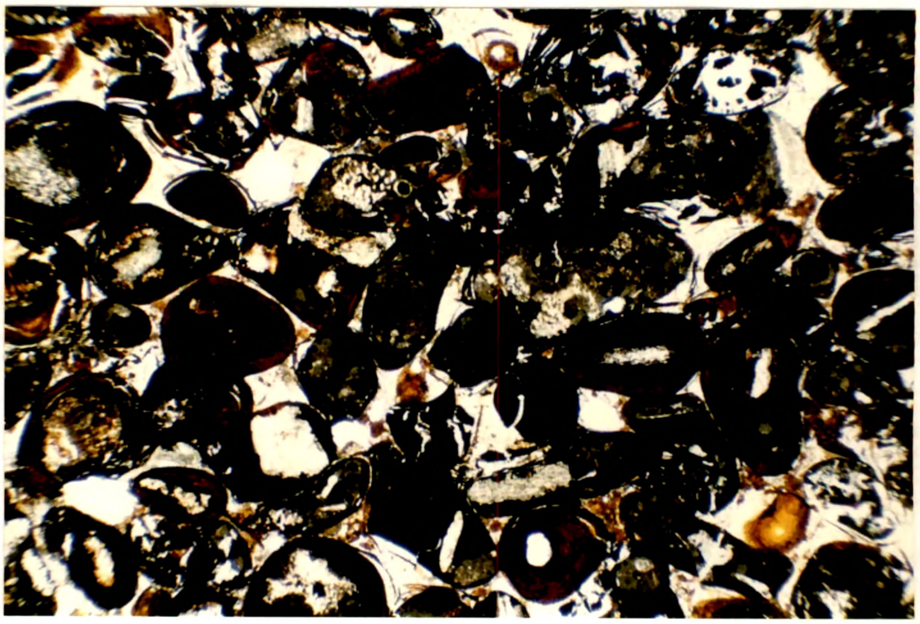


Plate VII.4 Photomicrograph of oolitic grainstone showing evidence of pressure welding, spalling and grain fracturation in KJH-III facies of Jhurio Formation, Jhura dome (Plane Polarised light X 25)

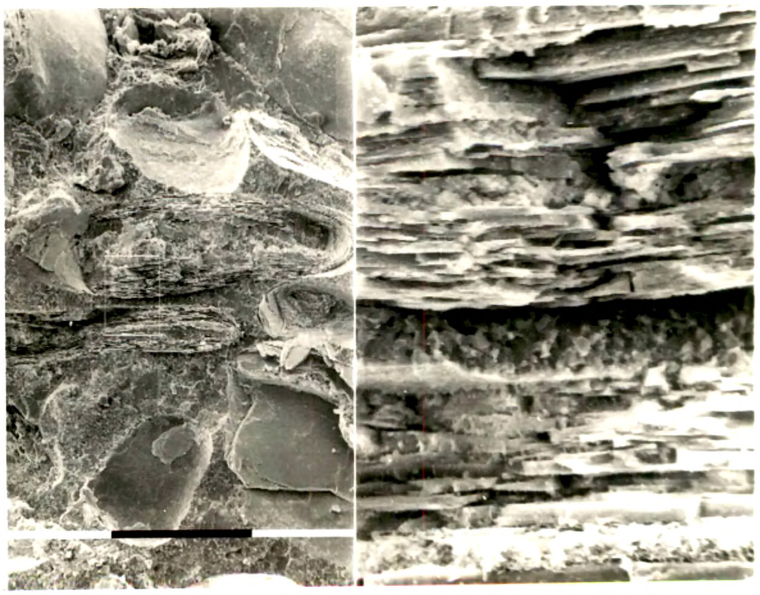


Plate VII.5 SEM photograph showing compaction of an ooid and details of its internal laminae, KJH-III facies of Jhurio Formation, Jhura dome (X 19 and X 152)

6. Early cementation

Cementation is a major diagenetic process and takes place when pore-fluids are supersaturated with respect to the cement phase. Carbonate cements form in a wide range of diagenetic environments. Aragonite, high Mg-Calcite, low-Mg calcite and dolomite are the common carbonate cements in limestones and they comprise a range of morphologies.

According to Flugel (1982), there are two kinds of cements i.e. cement 'A' and cement 'B' in many limestones because cementation takes place in successive diagenetic phases. Early cementation is represented by cement 'A'. The presence of isopachous rim cement **(Plate VII.7)** indicates an early cementation. Besides, the micritic and pelloidal cements also fall under early cementation processes **(Plate VII.8)**.

7. Dissolution of unstable grains

Carbonate sediments and cements and previously lithified limestones may undergo dissolution when pore-fluids are undersaturated with respect to the carbonate mineralogy. During dissolution, the unstable aragonitic or high magnesium constituents such as shells of pelecypods and gastropods surrounded by micritic envelopes and concentric rings of ooids dissolve and generate porosity of secondary type. **(Plate VII.7)**

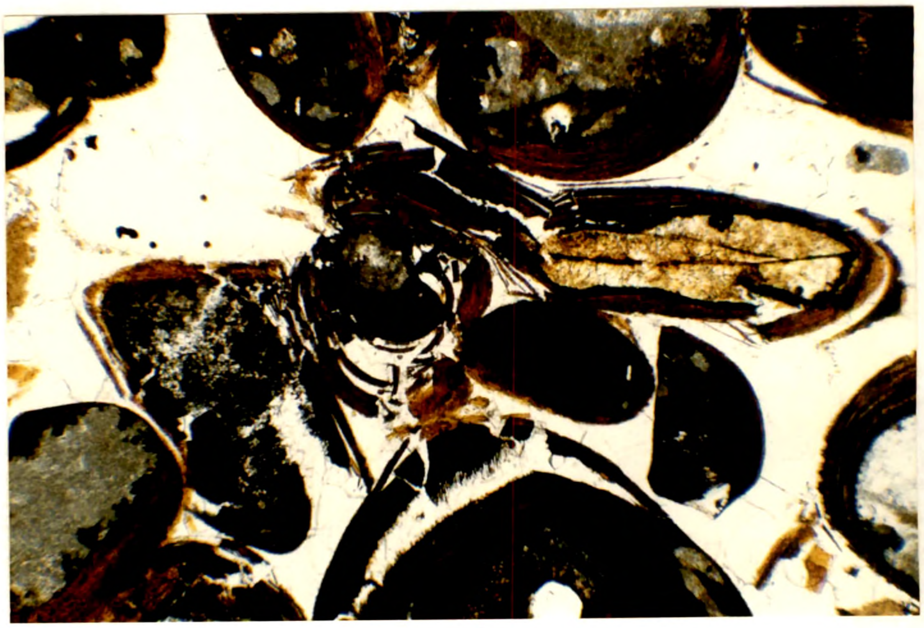


Plate VII.6 Photomicrograph showing early fracturation in the form of ooid fracturation and spalling of cortical layers of KJH-III facies of Jhurio Formation, Jhura dome (Plane Polarised light X 60)

Plate VII.7 Photomicrograph showing development of isopachous rim cement surrounding bioclastic grains within ridge sandstone facies, Jumara Formation, Jhura dome (Crossed nicols X 25)

8. **Reworking (Intraclasts)**

Intraclasts (Folk, 1959) are fragments of typically weakly consolidated sediment reworked from within the area of deposition. Reworking of subtidal sediments by storms can create intraclasts and early lithification surfaces (hardground) can be reworked in this way (Davis, 1979). These are non-skeletal grains and are common in the study area under both the formations (**Plate VII.2**).

9. **Late cementation**

The cement formed during late stages of diagenesis comes under this category. This corresponds to cement 'B' of Flugel (1982). The late cementation is represented by drusy cement and granular or blocky cement in the study area. The drusy cement or drusy mosaic fills the free spaces remaining after cementation in shallow marine environments. This is formed on account of competitive growth of crystals away from the substrate on which they nucleate. This fabric where the crystals are almost equidimensional is known as "blocky" or "equant" sparite cement (**Plate VII.9**). **Plate VII.10** is a SEM photograph showing completely sparitized shell fragment of bivalve and illustrates of how late cementation has nullified the porosity.

10. **Syntaxial overgrowth**

Syntaxial rim cement or syntaxial overgrowth is the precipitation of cement in optical continuity with the grains

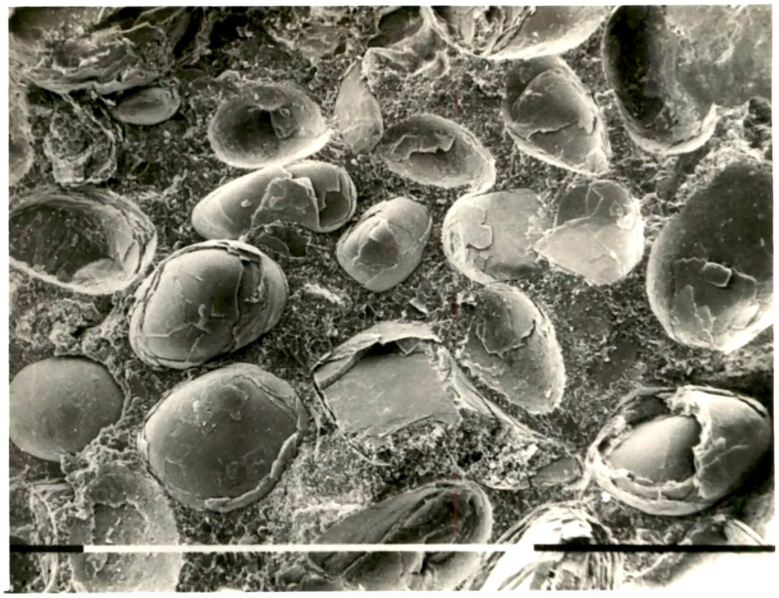


Plate VII.8 SEM Photograph of oolitic packstone with micritic cement showing an early cementation process, within facies KJH-III of Jhurio Formation, Jhura dome (X 63)

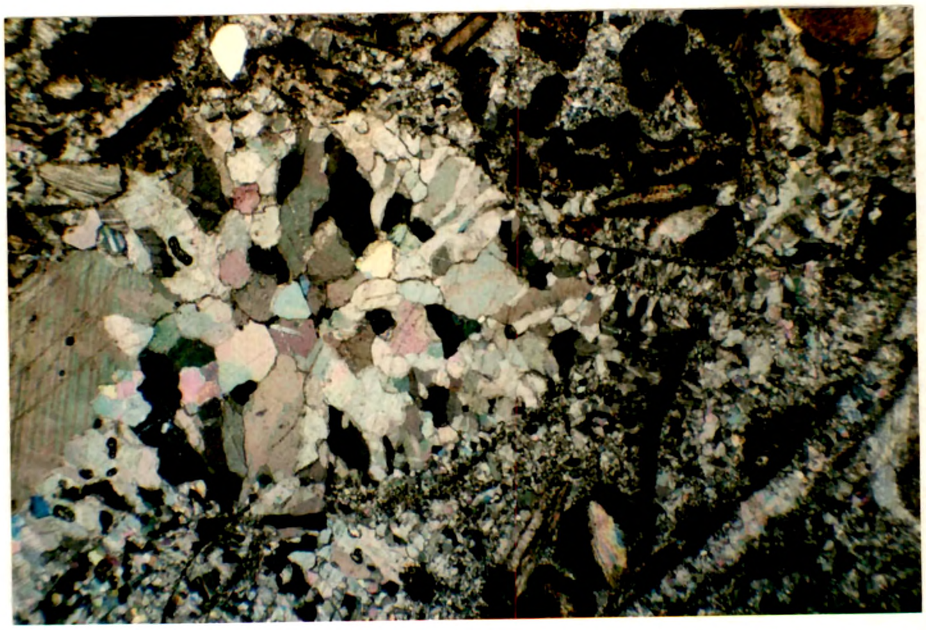


Plate VII.9 Photomicrograph showing evidence of late cementation in the form of drusy void filling sparite cement within KJH-IV facies, Jhurio Formation, Jhura dome (Crossed nicols X 25) on which they nucleate. They are more easily seen on echinoderm fragments, foraminiferal tests, molluscs and also on corals. In the study area, syntaxial overgrowth is common on crinoidal plates and echinoids **(Plate V.17)**.

11. Neomorphism

Neomorphism (Folk, 1965) is the transformation between one mineral and itself or a polymorph. The term indicates that older crystals have been consumed and replaced by new crystals of essentially similar chemical composition. In carbonate diagenesis, it includes the processes like polymorphic transformations (aragonite to calcite) and recrystallization.

The process whereby a mosaic of finely crystalline carbonate is replaced by a coarser calcite mosaic is known as aggradational neomorphism (Folk, 1965). This is seen in the study area in the form of diagenetic alteration of micrite or micron-sized skeletal fabrics to sparry calcite **(Plate VII.11 and VII.12)**.

12. Late fracturation

These fractures are produced during late diagenesis **(Plate VII.13)**. Their genesis is probably related to tectonic movements since they are often arranged in parallel sets. These fractures can be important factors for the genesis of good permeability of carbonate rocks. Besides tectonically induced fractures, there are short, thin, rather sharp edged

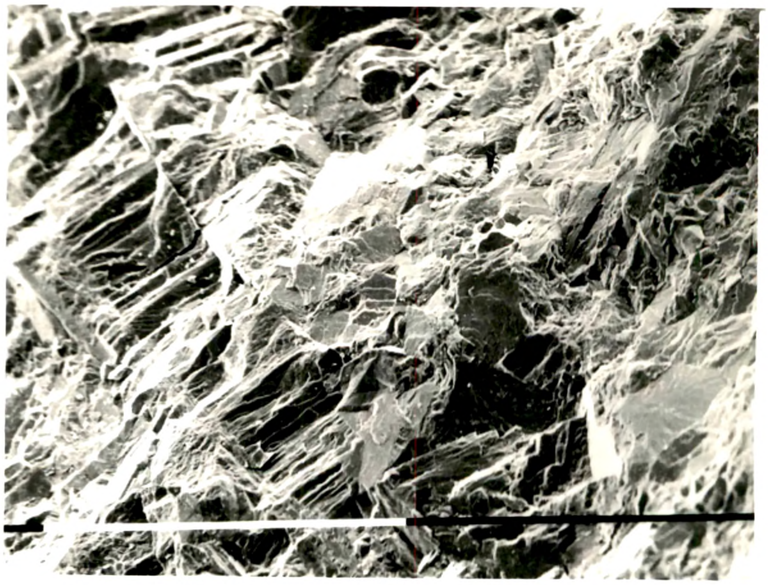


Plate VII.10 SEM photograph showing completely sparitized shell fragment of bivalve within limestone of Jumara Formation, Jhura dome; note how late cementation has nullified the porosity (X 51)

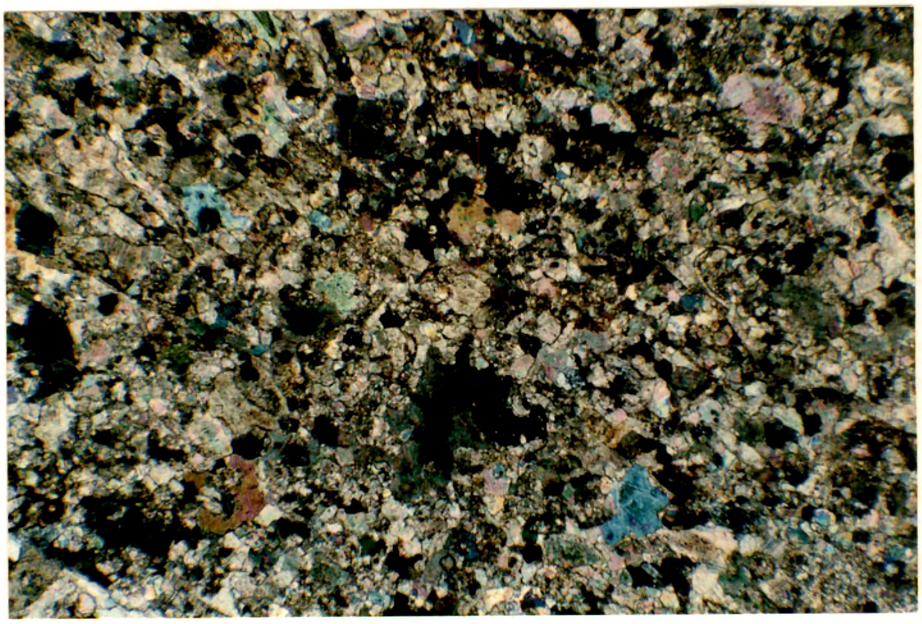


Plate VII.11 Photomicrograph showing aggradational neomorphism with the presence of relict patches of micrite within KH-I facies of Jhurio Formation, Habo dome (Crossed nicols X 60)

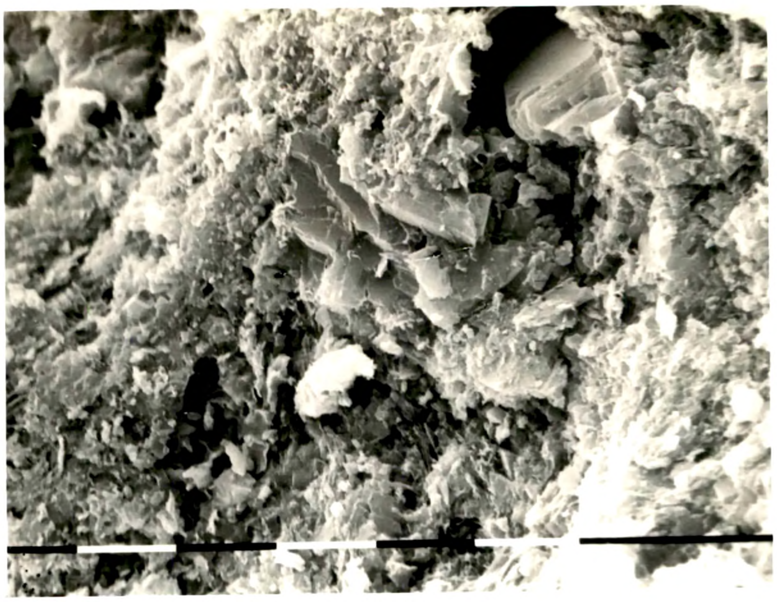


Plate VII.12 SEM Photograph showing neomorphic development of calcite crystals within micritic groundmass of wackestone of KH-I facies of Jhurio Formation, Habo dome (X 1400)

Plate VII.13 Photomicrograph showing evidence of late fracturation in the form of infilled parallel fractures within KJ-I facies of Jhurio Formation, Jumara dome (Crossed nicols X 60) fractures without parallel sets. The origin of these fractures may be due to desiccation or dehydration (Synaeresis) of carbonate mud. The intensity of these microfractures increases with increasing confirming pressure (or deep burial). Relatively micritic rocks exhibit far fewer microfractures than crystalline carbonate rocks. Most micro-fractures in non-micritic particles of carbonate rocks are intraganular.

13. **Silicification**

Silicification occurs as euhedral quartz crystals replacing cores and outer cortical layers of ooids. Besides, it may occur within the fractures and chambers of the bioclasts **(Plate VII.14)**. This may be attributed to the mixing marine-fresh water phreatic environment because of its association with the dorag-type dolomitization in case of the Jhurio formation of Habo dome.

14 **Infilling of moldic porosity**

This diagenetic feature is seen in the late stages of diagenesis where the moldic pores created by dissolution of argaonite and high Mg-calcite are filled up by sparry calcite **(Plate VII.15)**.

15. **Dolomitization**

Most of the dolomite in the geological record is of replacement origin. However, dolomite cements are common and

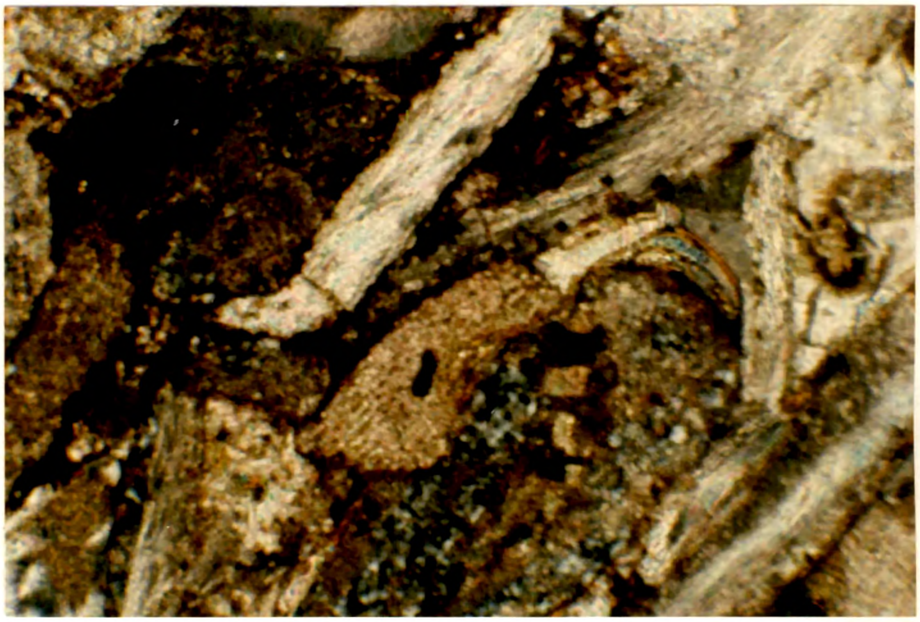


Plate VII.14 Photomicrograph of a bioclastic grainstone showing silicification within the chambers of bioclastic grains and pressure welding within KJ-I facies of Jhurio Formation, Jumara dome (Crossed nicols X 60)

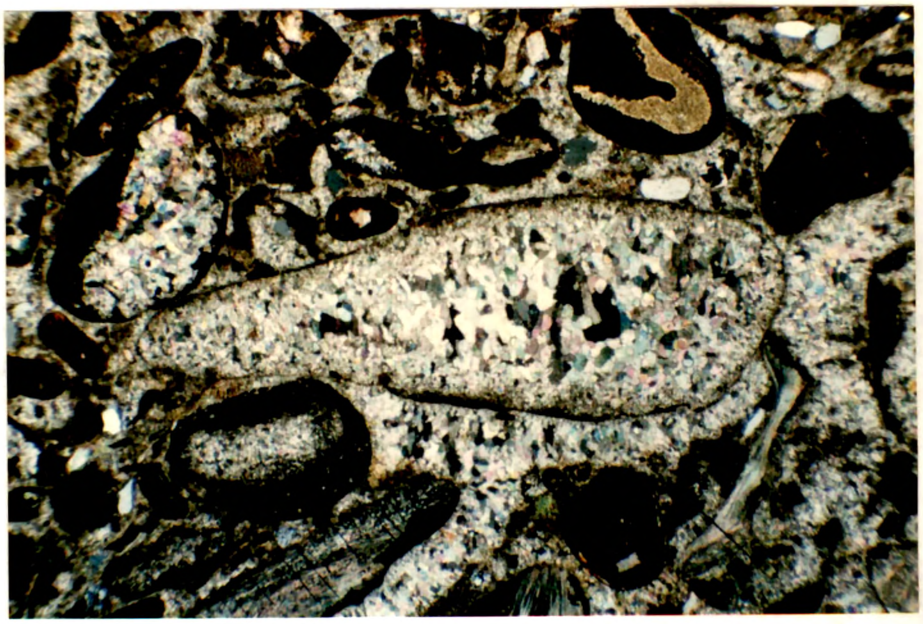


Plate VII.15 Infilling of moldic porosity by sparry calcite cement showing drusy growth and sparitized intergranular spaces within limestone of Jumara Formation, Jhura dome (Crossed nicols X 25) are precipitated directly from pore fluids during early and late diagenesis (Tucker and Wright, 1990).

The foregoing evidences suggest that the dolomites present within the Jhurio formation of Habo dome are of replacement origin and represent dolomitization under meteoric-marine mixing-zone and also burial conditions **(Plate VII.16)**. Besides dolomite, the presence of anhydrite has also been detected, however, only in the Jhurio Formation of Habo dome **(Plate VII.17)**.

The different diagenetic features, whether exhibited or not by Jhurio and Jumara Formations of the study area i.e. Jumara, Jhura and Habo dome are summarised in **Tables VII.1 and VII.2**.

From Table VII.1, it can be seen that micritization is common in Jumara and Jhura dome whereas it could not be seen in Habo dome. This may be due to only one major lithofacies (KH-I) exposed. Besides, the absence of features like pressure solution, geopetal structures and intraclasts can also be explained by the above reason. Hardground with iron impregnation is common in Jumara dome and can be attributed to its deposition under subtidal marine environment. The presence of dolomite alongwith anhydrite in the Jhurio Formation of Habo dome is significant and indicates an intertidal to supratidal environment.

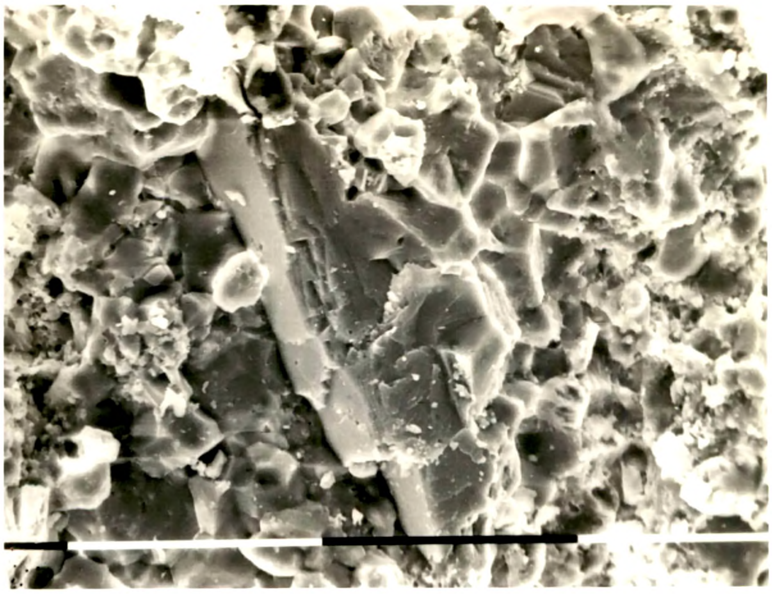


Plate VII.16 SEM Photograph of a dolomitic wackestone showing the development of dolomite crystals by replacement within KH-I facies of Jhurio Formation, Habo dome (X 360)

Plate VII.17 Photomicrograph of dolomitic wackestone showing presence of anhydrite crystals alongwith rhombohedral dolomites (Crossed nicols X 230)

Table VII.1: DIAGENETIC FEATURES OBSERVED IN JHURIO FORMATION OF JUMARA, JHURA AND HABO DOME

STUDY AREA / DIAGENETIC FEATURES	JUMARA DOME	JHURA DOME	HABO DOME
MICRITIZATION	———	———	×
HARDGROUND WITH IRON IMPREGNATION	———	×	×
EARLY LITHIFICATION	———	———	———
EARLY COMPACTION (PRESSURE SOLUTION)	———	———	×
GEOPETAL STRUCTURE	———	———	×
EARLY CEMENTATION	———	———	———
DISSOLUTION OF UNSTABLE GRAINS	———	———	———
REWORKING (INTRACLASTS)	———	———	×
LATE CEMENTATION	———	———	———
SYNTAXIAL OVERGROWTH	———	———	———
NEOMORPHISM	———	———	———
LATE FRACTURATION	———	———	———
SILICIFICATION	———	———	———
INFILLING OF MOLDIC POROSITY	———	———	———
DOLOMITIZATION	×	×	———

Table VII.2 : DIAGENETIC FEATURES OBSERVED IN JUMARA FORMATION OF JUMARA, JHURA AND HABO DOME

STUDY AREA / DIAGENETIC FEATURES	JUMARA DOME	JHURA DOME	HABO DOME
MICRITIZATION	—	—	—
HARDGROUND WITH IRON IMPREGNATION	—	—	—
EARLY LITHIFICATION	—	—	—
EARLY COMPACTION (PRESSURE SOLUTION)	—	—	—
GEOPETAL STRUCTURE	—	—	—
EARLY CEMENTATION	—	—	—
DISSOLUTION OF UNSTABLE GRAINS	—	—	—
REWORKING (INTRACLASTS)	—	X	X
LATE CEMENTATION	—	—	—
SYNTAXIAL OVERGROWTH	—	—	—
NEOMORPHISM	—	—	—
LATE FRACTURATION	—	—	—
SILICIFICATION	—	—	—
INFILLING OF MOLDIC POROSITY	—	—	—
DOLOMITIZATION	X	X	X

As mentioned earlier, the Jumara Formation is well exposed in all the three domes with maximum exposure at Jumara dome. These are subjected to extensive diagenesis, hence, most of the features are commonly observed in all the three domes (Table VII.2). The absence of dolomitization throws light on their environment of deposition.

The diagenetic features discussed above indicate a particular diagenetic environment as shown in **Table VII.3**.

Trace element studies assume vital importance in interpreting the diagenetic environment alongwith the study of stable isotopes of carbon and oxygen. The most significant among trace elements are strontium (Sr) and magnesium (Mg) because metastable suites from modern shallow marine environments are dominated by aragonite (Sr rich) and magnesian calcite (Mg rich). Stabilization of these shallow marine carbonates to calcite and dolomite involves a major reapportionment of these elements between the new diagenetic carbonates and the diagenetic fluids.

Strontium is taken up to maximum concentration of about 10,000 ppm in aragonite. Aragonite precipitated in warm shallow seas is likely to contain between 2500-9500 ppm of Sr. When marine sediments of aragonitic composition are transformed to calcite (low in Mg) during mineral stabilization in the near surface meteoric realm, where waters are low in Sr, it is depleted in the resulting

Table VII.3 : DIAGENETIC FEATURES WITH REFERENCE TO THEIR ENVIRONMENT IN STUDY AREA
(Based on Carrozi, 1991)

DIAGENETIC ENVIRONMENT / DIAGENETIC FEATURES	MARINE PHREATIC	FRESH WATER PHREATIC	MIXED MARINE FRESH WATER PHREATIC	BURIAL
MICRITIZATION	▬▬▬			
HARDGROUND WITH IRON IMPREGNATION	▬▬▬			
EARLY LITHIFICATION	▬▬▬			
EARLY COMPACTION (PRESSURE SOLUTION)	▬▬▬			
GEOPETAL STRUCTURE	▬▬▬			
EARLY CEMENTATION	▬▬▬			
REWORKING (INTRACLASTS)	▬▬▬			
DISSOLUTION OF UNSTABLE GRAINS		▬▬▬		
LATE CEMENTATION		▬▬▬		
SYNTAXIAL OVERGROWTH		▬▬▬		
NEOMORPHISM		▬▬▬		
LATE FRACTURATION		▬▬▬	▬▬▬	▬▬▬
SILICIFICATION	▬▬▬	▬▬▬	▬▬▬	
INFILLING OF MOLDIC POROSITY		▬▬▬	▬▬▬	▬▬▬
DOLOMITIZATION			▬▬▬	▬▬▬

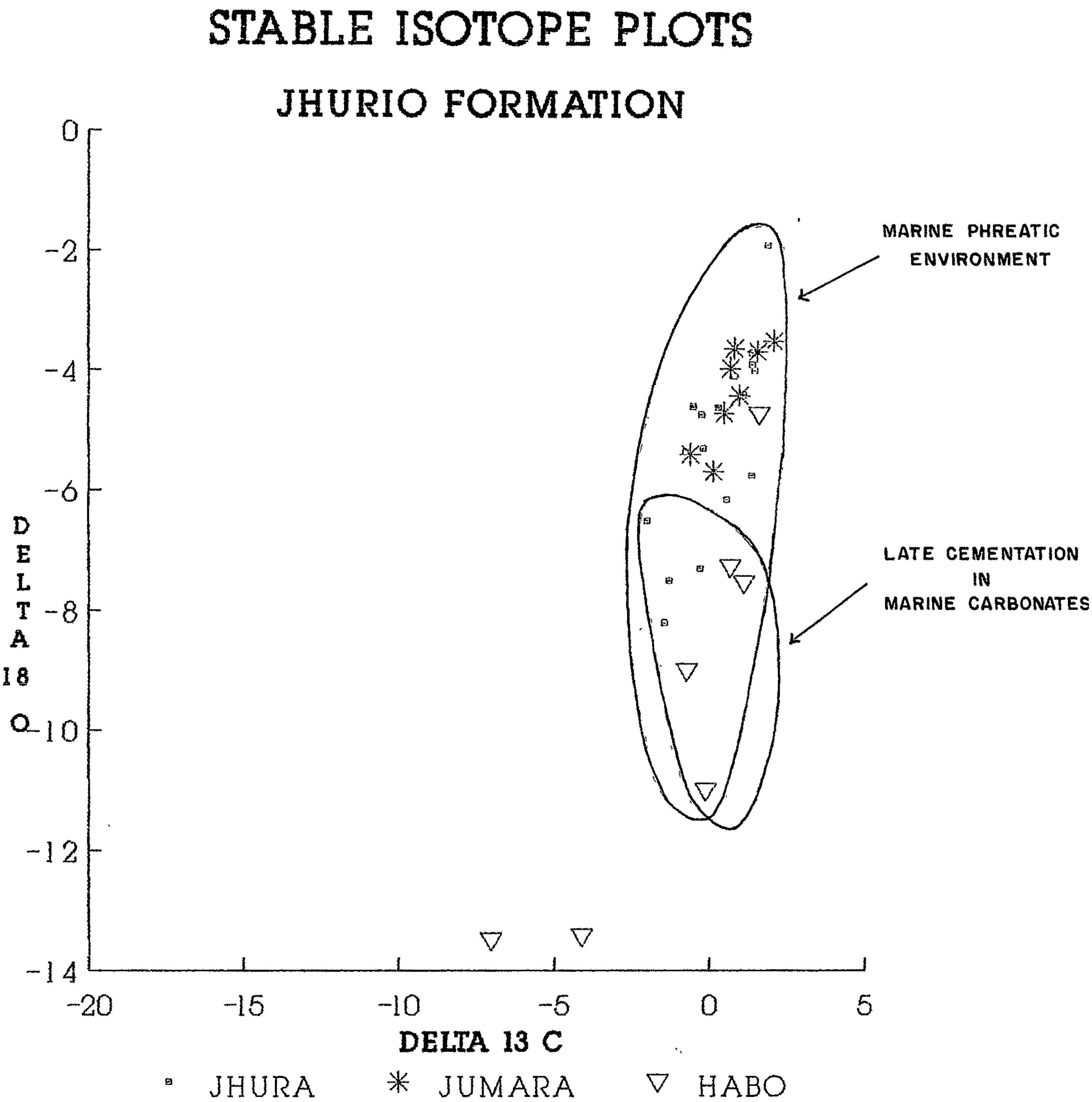
limestone. In Jhurio formation of the study area the concentration of strontium varies from 752 ppm to 2211 ppm with average concentration of 1463 ppm, whereas in Jumara formation the concentration is low and varies from 225 ppm to 1608 ppm with an average concentration of 612 ppm. This may be because of its stratigraphic position and complete exposure to the meteoric diagenetic environment. Similar to Sr, Mg also shows a depleting trend with diagenesis. However, the trend is not significant in the case of Jhurio and Jumara Formation.

Marine carbonate sediments have very low levels of iron and manganese. Modern aragonitic sediments in tropical warm shallow-marine waters have low Mn and Fe (-20 ppm) concentration (Milliman, 1974). In Jhurio Formation, the concentration of Fe (319-5723 ppm; mean 2182 ppm) and Mn (280-984 ppm; mean 525 ppm) suggests appreciable gain of both during diagenesis. Similarly, in Jumara Formation, the concentration of Fe (480-2324 ppm; mean 1129 ppm) and Mn (389-1113 ppm; mean 682 ppm) indicates late stages of diagenesis. This increased value of Fe and Mn in the Jhurio and Jumara Formation of the study area may be due to extensive meteoric diagenesis. The higher concentration of Fe over Mn may be due to higher partition coefficient of Fe than Mn.

Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotope data have become an integral part of most modern studies of carbonate diagenesis. The oceans form a relatively well mixed carbon reservoir, so marine carbonate should typically have a ^{13}C value around zero. The variation should be relatively minor (a few per mille) compared to the variations in non-marine waters.

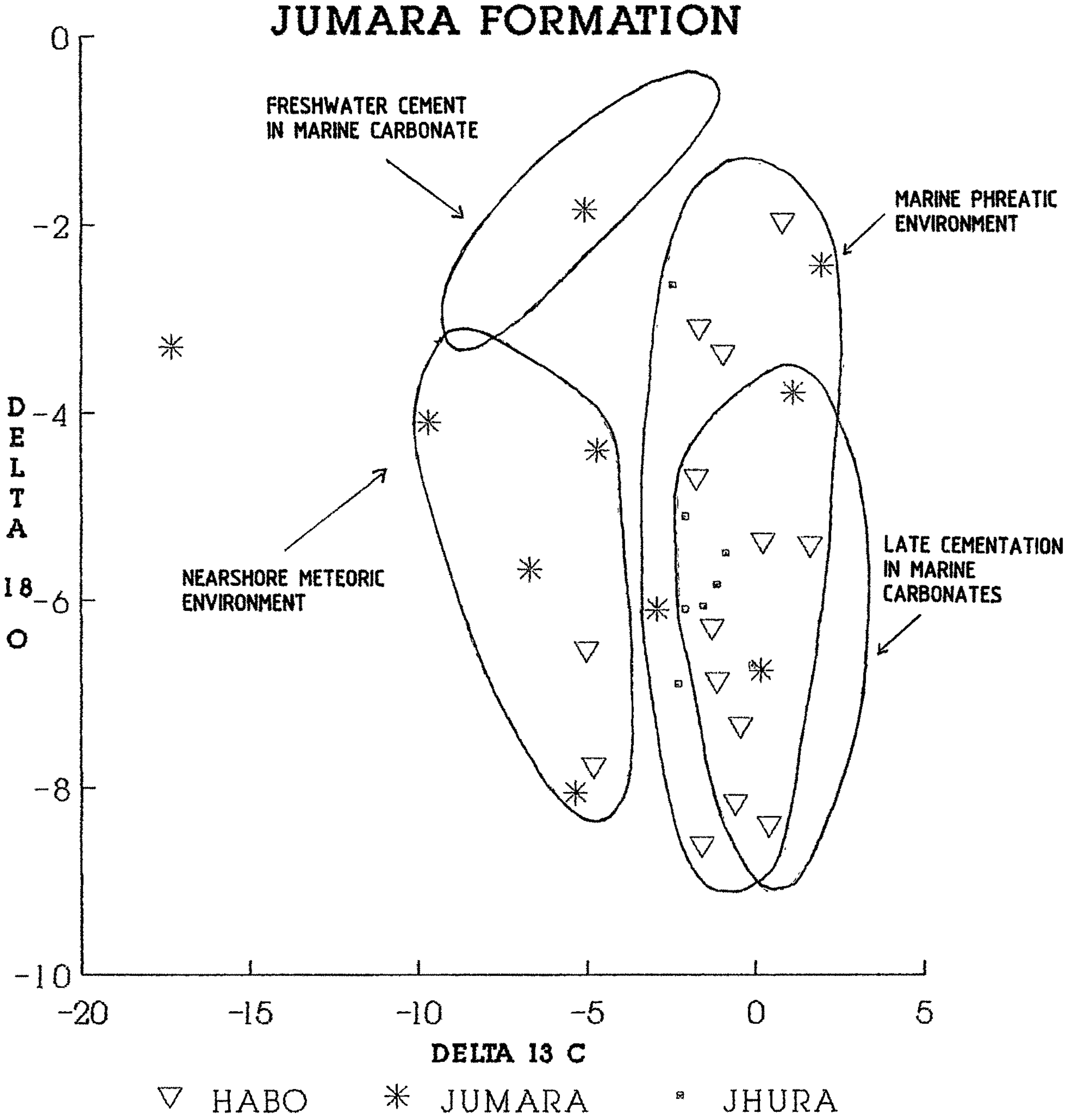
Shallow marine limestones commonly show a small range of $\delta^{13}C$ values (a few $^{o}/oo$ around 0) compared to a pronounced change towards lighter $\delta^{18}O$ values (from 0 to -15 $^{o}/oo$; Hudson, 1977). This range is due to a variable mixture of original marine carbonate and diagenetic alterations and/or addition. The enrichment of ^{16}O has been equated with the diagenetic component being added at progressively higher temperature with increasing burial, with evolving $\delta^{18}O$ of the pore waters or a combination of both.

The Jhurio formation of the study area has indicated $\delta^{13}C$ value ranging from 2.11 to -2.01 with an average of 0.51, and hence represents a shallow marine environment. However, the $\delta^{18}O$ value varies from -1.9 to -11.01 with an average of -5.82. This may be due to diagenetic alterations. **Figure VII.2** shows a plot of $\delta^{13}C$ and $\delta^{18}O$ values. From the figure, it can be seen that the Jhurio formation at Jumara dome are subjected to less diagenetic alterations in comparison to Jhura and Habo domes.



STABLE ISOTOPE PLOTS
JHURIO FORMATION
MARINE PHREATIC ENVIRONMENT
LATE CEMENTATION IN MARINE CARBONATES
0
-2
-4
-6
-8
-10
-12
-14
DELTA 18 O
-20
-15
-10
-5
0
5
DELTA 13 C
JHURA
JUMARA
HABO

STABLE ISOTOPE PLOTS
JUMARA FORMATION



This has already been supported by microfacies analyses and insoluble residue studies (Ref. Fig.V.7 and VI.1)

The Jumara formation of the study area has shown the $\delta^{13}C$ value ranging from 1.99 to -9.7 with an average of -1.95, and hence represents diagenesis in marine, meteoric and burial environment. However, the $\delta^{18}O$ value varies from -1.84 to -8.62 with an average of -5.42. This may be due to diagenetic alterations/additions. **Figure VII.3** shows a plot of $\delta^{13}C$ and $\delta^{18}O$ values. From the figure, it can be seen that the Jumara formation at Jumara dome are subjected to less diagenetic alterations in comparison to Jhura and Habo domes. Besides, the impact of meteoric diagenesis is more in the Jumara formation of Jumara and Habo domes.

POROSITY

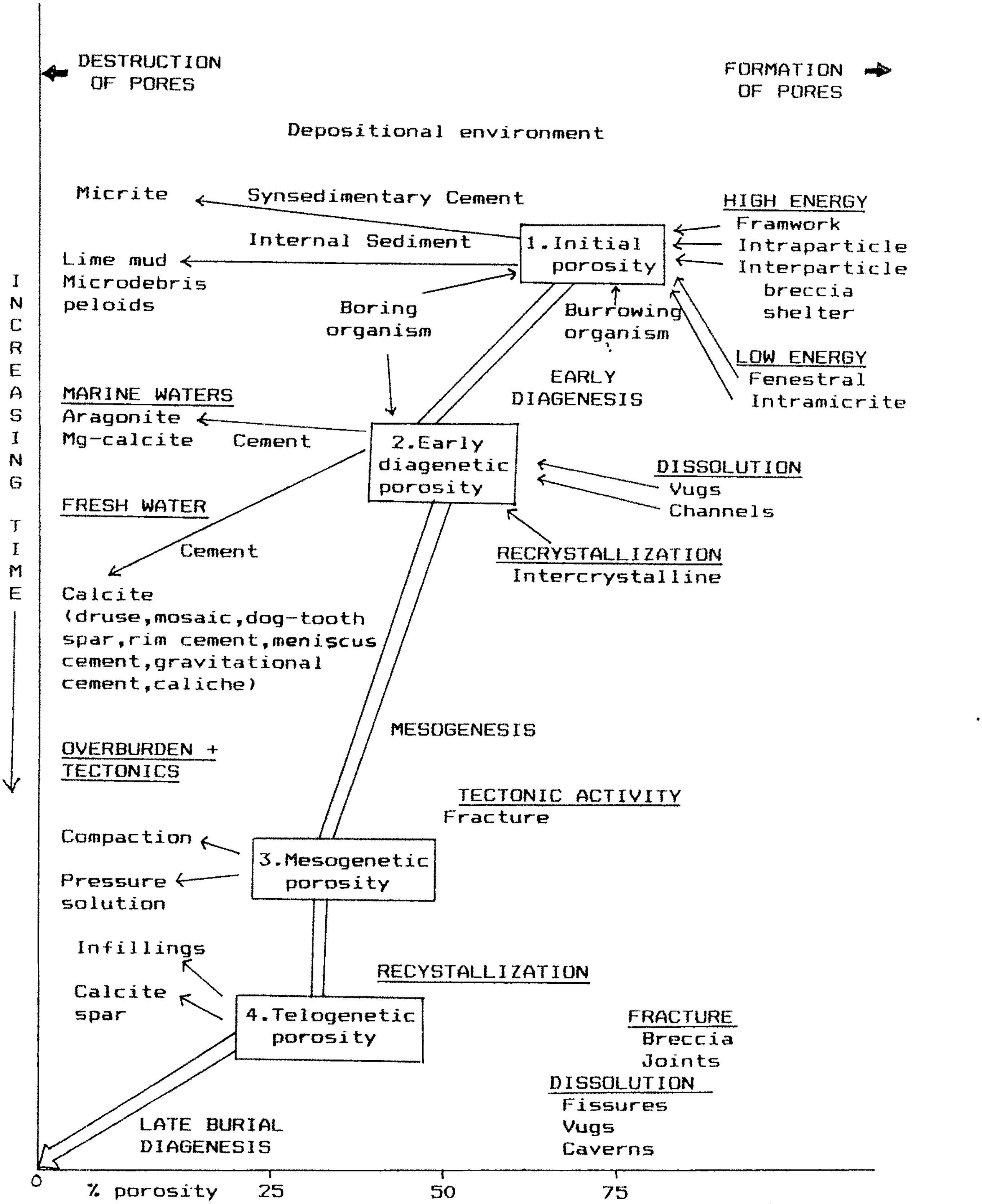
Understanding the reservoir characteristic of the carbonate rocks is of prime interest for petroleum geologists. Unlike sandstones, great heterogeneity is found in the quality and nature of pores and the petrophysical characteristics of carbonate rocks. During diagenesis carbonate sediments may gain or lose porosity. With increasing depth of burial, there is generally decrease in porosity (Schmoker and Halley, 1982), but there are late processes of dissolution and fracturation which can restore higher porosity values. The understanding of porosity formation and occlusion is another major aim of diagenetic studies which is also taken up by the author.

The initial carbonate porosity can be as great as 60-70%, particularly in lime mud and reef frame work. This original porosity is usually reduced by early diagenetic cementation, compaction, pressure solution and late stage cementation **(Fig.VII.4)**. Knowledge regarding porosity evolution in lateral and vertical sequences of carbonate rock is essential to predict the favourable zones of potential reservoir in a sedimentary basin. The origin and types of porosity are important considerations because different environmental and diagenetic setting favour different pore formation. The description of various kinds of pores, their sizes and geometries within the rocks of the study area are described below as per the widely accepted classification of Choquette and Pray (1970). Two main categories of porosities which exist are primary porosity and secondary porosity.

1. **Primary Porosity:** The primary porosity forms during the deposition of the sediments. The different types of primary porosity observed in the study area are:

i) **Intraparticle Porosity**

These pore spaces occur within the particles viz. pores in skeletal fragments caused due to disappearance of soft organic parts. Such porosity is usually found in ancient shallow water carbonates and is generally associated with arid climate. In the study area, this has been destroyed due to intense cementation in the later stages of diagenesis **(Plate VII.18)**.



Relationship between the stages of Diagenesis and Creation or Destruction of Porosity (After Reechmann and Friedman,1982)

FIG.VII 4

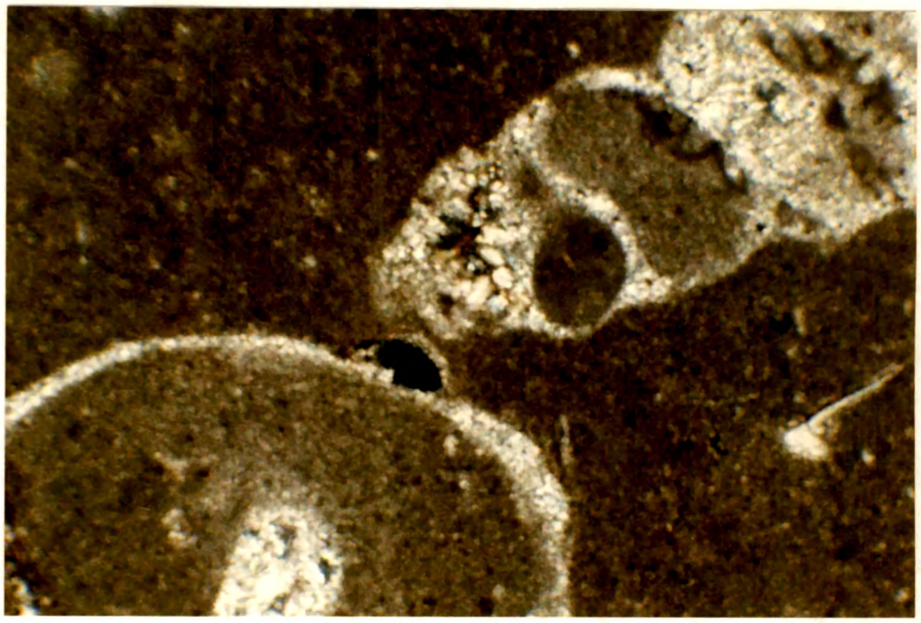


Plate VII.18 Photomicrograph showing filled up intraparticle primary porosity within the chambers of gastropod shell, KJ-III facies of Jhurio Formation, Jumara dome (Crossed nicols X 60)

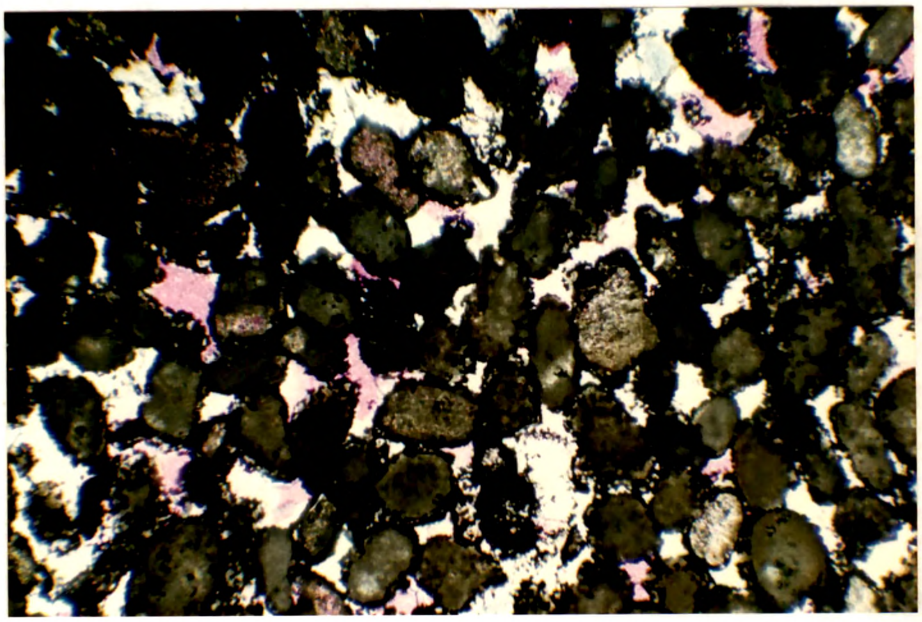


Plate VII.19 Photomicrograph of a pelloidal grainstone showing interparticle porosity (pink colour); mostly destroyed by late cementation within KJH-V facies of Jhurio Formation, Jhura dome (Crossed nicols with gypsum plate X 60)

ii) Interparticle Porosity

The pore spaces occurring between the particles similar to sandstones are categorised as interparticle type. The shape of the pores vary greatly and is homogeneous only when particles are uniform in shape and size. This porosity is preserved in deep water carbonates, away from the fresh water source and thick shale deposits. In the present study, such porosity is observed in the clastic facies interbedded with the carbonate facies as well as in allochthonous type of carbonate rocks such as pelloidal grainstone and packstone (**Plate VII.19**).

iii) Shelter Porosity

Pore spaces occurring below the large skeletal particles are classed under this category. This kind of porosity is common in packstones abounding in large molluscan shells, foraminifera or corals (**Plate VII.20**). The porosity is common in the Jhurio Formation of Jumara and Jhura dome.

2. **Secondary porosity:** This is formed after the deposition and following types are seen in the study area.

i) Intercrystalline Porosity

This type of porosity occurs in between the crystals and is usually displayed in dolomites. Most of the dolomites are of replacement origin and the origin of porosity is due to the growth of randomly oriented rhombs coupled with dissolution of interstitial $CaCO_3$ which has not been replaced. It is formed due to action of Mg^{++} rich brines

Plate VII.20 Photomicrograph showing shelter porosity within KJ-I facies of Jhurio Formation, Jumara dome (Crossed nicols X 25)

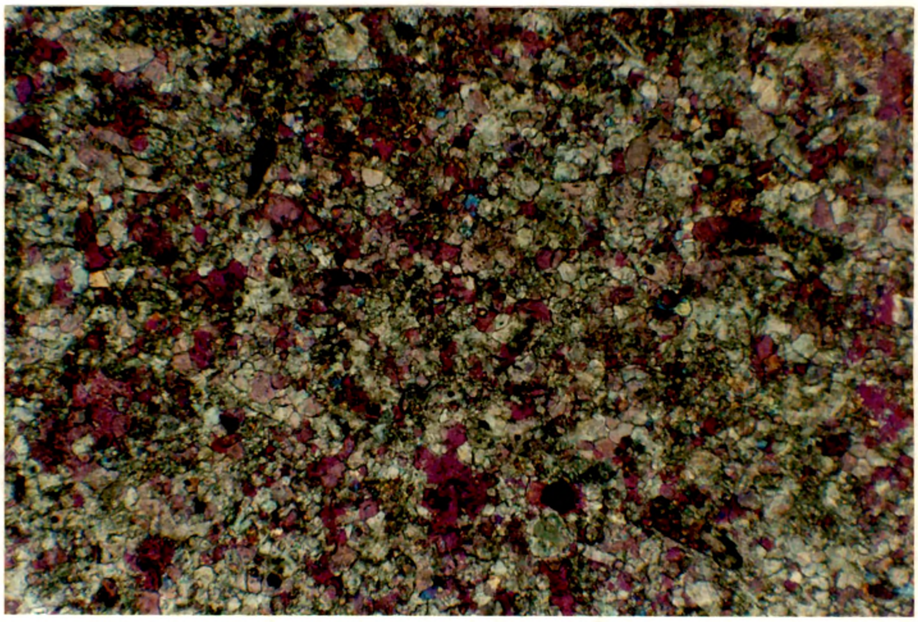


Plate VII.21 Photomicrograph showing intercrystalline porosity (pink colour) within fine calcitic grainstone of KH-I facies, Jhurio Formation, Habo dome (Crossed nicols with gypsum plate X 60) under arid climatic conditions (**Plate VII.21**). The porosity is observed in the Jhurio Formation of Jhura and Habo dome.

ii) **Moldic Porosity**

It is formed by selective removal of primary constituents such as ooids, bivalve shells, evaporite minerals, etc. The selective removal is done through leaching in fresh water phreatic and vadose environments or in deep burial conditions due to dewatering of shales. Such porosity is common in the Golden oolite facies of Jhurio formation and Dhosa oolite facies of Jumara formation (**Plate VII.22**).

iii) **Vug and channel Porosity**

This is resulted from dissolution but may not bear any relationship to the initial rock texture. The voids formed are of irregular shape and size and may or may not have interconnections (**Plate VII.23-24**). Caverns are larger forms of vugs whereas, channel porosity is distinguished from vugs by the geometry of pores. It is formed in fresh water vadose environment.

iv) **Fractures and breccia porosity**

It is common in dolomites which are susceptible to tectonic stresses. Limestones tend to yield pressure solutions under such conditions. Fracture porosity grades into secondary breccia porosity with increasing displacement, disruption and collapse of strata. Fracture porosity may greatly contribute to the increase in the permeability

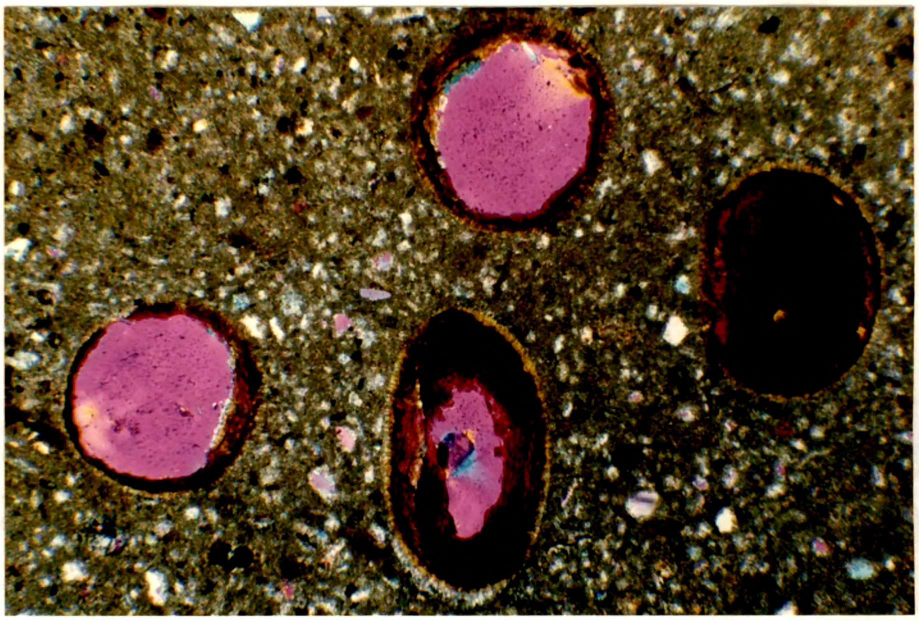


Plate VII.22 Photomicrograph of oolitic wackestone showing development of oomoldic porosity (pink colour) within Dhosa oolite facies of Jumara Formation, Jumara dome (Crossed nicols with gypsum plate X 60)

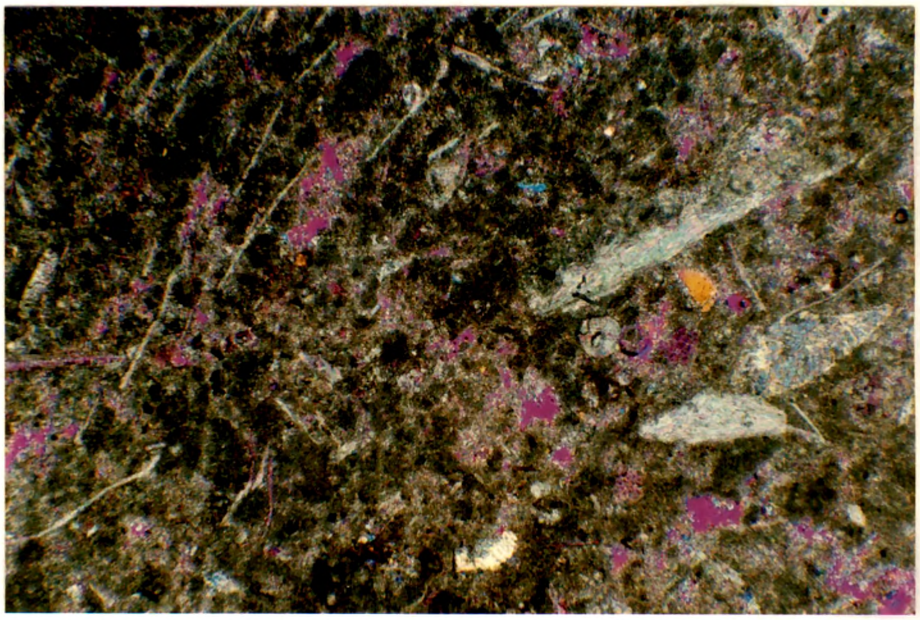


Plate VII.23 Photomicrograph showing vugs and channel porosity (pink colour) within pelloidal wackestone of KJH-V facies of Jhurio Formation, Jhura dome (Crossed nicols with gypsum plate X 60)

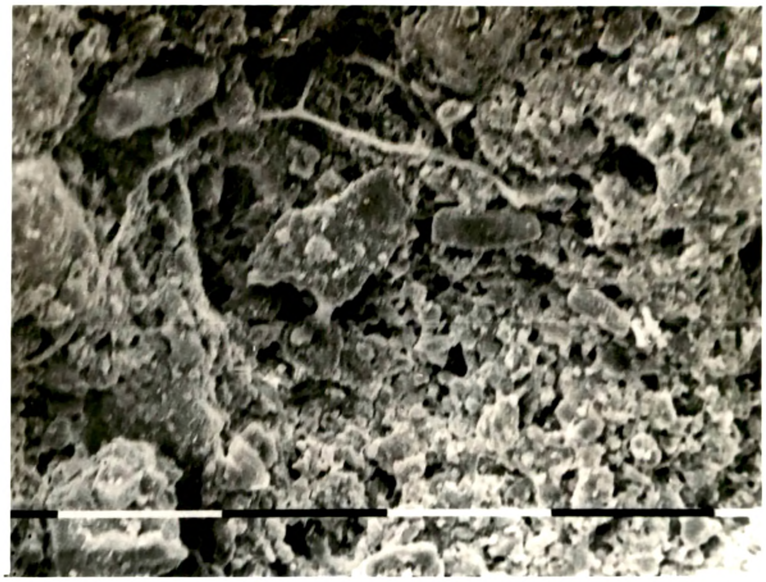


Plate VII.24 SEM Photograph showing vugs and channel porosity within KJH-IV facies of Jhurio Formation, Jhura dome (X 230)

Plate VII.25 Photomicrograph showing filled in fracture porosity within wackestone of grey limestone facies of Jumara Formation, Jumara dome (Crossed nicols X 25)

Plate VII.26 SEM photograph showing fracture porosity within limestone and marl facies of Jhurio Formation, Jumara dome (X 1300) channels **(Plate VII.25-26)** and is formed due to subsurface faulting and folding and also due to solution of evaporite, stylolitization and fluid expulsion.

From the above, it can be seen that the primary porosity present in the study area is destroyed by effects of diagenesis. However, secondary porosity is observed within the carbonate facies of Jumara as well as Jhurio Formation. The development of this diagenetic porosity is better in the Jhurio Formation. However, the lateral variation is erratic due to variation in the intensity of meteoric diagenesis. Based on microfacies and later diagenetic studies, the Jhurio Formation appears to suggestive of possessing a better carbonate reservoir quality.