

# MINERALOGY AND DIAGENESIS OF THE MFAMOSING LIME- STONE, SE. NIGERIA

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## ABSTRACT

Mineralogical and diagenetic studies of the Mfamosing Limestone show that it is mineralogically stabilized with calcite (62.71 – 49.58%) as the dominant mineral and quartz (15.86 – 0.55%) as the subordinate mineral. The diagenetic fabrics, events and environments include dissolution, dolomitization, isopachous cementation, porosity occlusion and rejuvenations and precipitation. Carbonate diagenesis indicates physical and chemical transformation of the limestone from the time of deposition through burial under vadose, phreatic, mixed, shallow and deep conditions to uplift and karst development.

**KEY WORDS:** Mfamosing, Mineralogy, Diagenesis.

## INTRODUCTION

The Mfamosing Limestone is located on the Calabar Flank in SE Nigeria (Fig. 1). It is arcuate in shape and rims the Precambrian Oban Basement Complex. This carbonate body was deposited during the first marine transgression in the South Atlantic in Mid-Albian times.

The primary objective of this paper is to extend our knowledge of this carbonate body beyond the Mfamosing type section, which hitherto has received considerable attention in biostratigraphy (Dassauvage, 1968, Fayose, 1986, Ramanathan and Kumaran, 1981), depositional environments (Reijers and Petters, 1987; Nair et al, 1982, Akpan, 1990), diagenesis (Oti and Koch, 1990) and chemical analysis (Ekwueme, 1985). To achieve the above objectives, mineralogical and petrographic examination of the limestones samples were carried out. This allowed for the determination of its mineralogical constituents and evaluation of diagenetic textures, events and environments. Also, attempts have been made to relate its burial history to the diagenetic imprints observed.

## METHODOLOGY

The study involved field sampling as well as petrographic and mineralogic analyses. Sampling was undertaken along the depositional strike which covered a distance of about 135km. Major sample locations included, Mfamosing (type section, Reijers and Petters 1987), Odukpani, Okoyong Usang Abasi, Ikot Okpora, Agoi Ibami, Etankpini, Agbung and Obarekai (Fig. 1).

The Zeiss petrologic microscope was used to study both polished and thin sections. Measurements were made using a calibrated eye piece and a stage micrometer. Standard staining method of Katz and Friedman (1965) was used to distinguish between iron-poor and ferroan calcite, iron-poor and ferroan dolomite.

Mineralogical studies consist of subjecting composite (channel) samples to XRD analyses. Characteristic XRD peaks were interpreted using Brindley and Brown (1980).

## REGIONAL GEOLOGY

Structurally, the Calabar Flank represents a part of the founded southern Nigeria continental margin (Fig.1). It is dominated by a system of NW-SE trending step fault that resulted in the formation of a horst (Ituk high) and graben (Igang Trough) structure. The Igang Trough for most part of its depositional history was the site of active clastic sedimentation while the Ituk high was a stable carbonate platform where about 450m of the Mfamosing Limestone accumulated (Reijers and Petters, 1987).

Sedimentation started in the Calabar Flank with the deposition of fluvio-deltaic clastics of probably Aptian age on the Precambrian Crystalline basement complex, the Oban Massif (Fig. 1). These sediments belong to the Awi Formation (Adeleye and Fayose, 1978).

The earliest marine transgression into the Calabar Flank and the Benue trough occurred in the Mid-Albian times with the deposition of platform

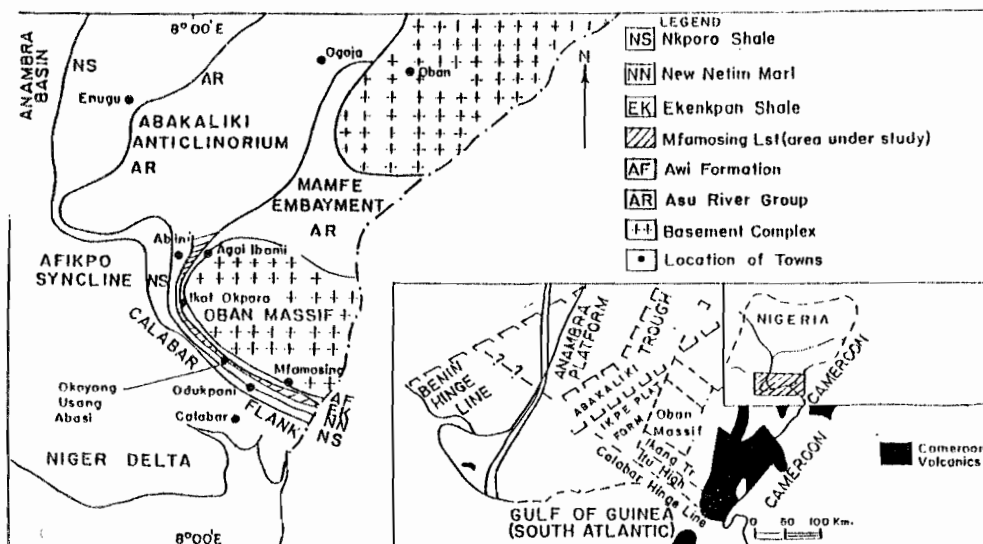


Fig. 1 : Geological Map of south-eastern Nigeria (Modified after Nyong, 1995)

Inset : Location Map and structural elements of the Calabar Flank and adjacent areas (After Nyong and Ramanathan, 1985)

carbonates of the Mfamosing Limestone. This limestone unit was deposited in a variety of depositional environments and displays microfacies types ranging from algal stromatolitic/oncolidal boundstone, oolitic-pelloidal packstone, gastropod bioclastic grainstone to highly fossiliferous packstone (Essien, 1995). The limestone unit is underlain by the Awi Sandstone.

The Mfamosing Limestone is overlain by a thick succession of black to grey shale, the Ekenkpon Shale. This thick shale unit is characterised by minor intercalations of marl, calcareous mudstone and oyster beds. The Ekenkpon Shale is a product of two transgressive cycles in the Late Albian-Cenomanian

and Late Turonian.

The Ekenkpon Shale is overlain by a thick marl unit, the New Netim Marl (Petters et al, 1995). The marl unit is nodular and shaly at the base and is interbedded with thin layers of shale in the upper parts. Foraminiferal (Nyong, 1985) and coccolith evidence (Perch-Nielson and Petters, 1981) suggest Early Coniacian age for this marl unit. The New Netim Marl is overlain by carbonaceous dark grey shales of the Nkporo Formation (Late Campanian – Early Maastrichtian) (Reyment 1965). This shale unit is interbedded with thin bands of marlstones and gypsum.

TABLE 1: CARBONATE MINERALOGY OF THE MFAMOSING LIMESTONE AT DIFFERENT LOCALITIES

S/NO	LOCALITIES	SAMPLE NO.	CALCITE (%)	QUARTZ (%)	FELDSPAR		LOSS IN IGNITION (LOI)%
					ALBITE (%)	OLIGO-CLASE (%)	
1.	MFAMOSING	MF 1	56.42	2.22	-	-	41.36
2.	"	MF 2	53.63	7.90	0.42	-	38.47
3.	ODUKPANI	OD 1	62.72	0.70	-	0.5	36.08
4.	"	OD 2	56.66	0.55	-	-	42.79
5.	OKOYONG USANG ABASI	OU 1	57.48	1.67	-	-	40.85
6.	"	OU 2	49.94	3.60	-	-	41.46
7.	IKOT OKPORA	IKO 1	53.88	4.72	-	-	41.40
8.	"	IKO 2	53.90	15.86	-	-	30.24
9.	AGOI IBAMI	AB 1	49.58	12.65	-	-	37.77
10.	"	AB 2	53.75	6.11	-	-	40.14
	MAX		62.72	15.86			42.79
	MIN		49.58	0.55			30.24
	AVERAGE		54.72	6.10			39.06

The Nkpore Shales cap the Cretaceous succession in the Calabar Flank and is overlain by a pebbly sandstone unit of the Tertiary Benin Formation.

**CARBONATE MINERALOGY**

A summary of the carbonate mineralogy of the limestone under investigation at various sampled localities is as shown in Table 1. Typical XRD patterns obtained from some sampled localities (Ikot Okpora, Odukpani and Mfamosing) are as shown in Fig. 2

Calcite is evidently the dominant mineral in the Mfamosing Limestone. The non-carbonate constituents are mainly quartz and some traces of feldspar. The average amount of calcite recorded in the samples is about 54.72%, while that of quartz is 6.10%. 39.06% is the average value recorded on loss on ignition. The quantity of calcite in this carbonate body ranges from 62.72% in pure limestone at

Odukpani to 49.58% in the sandy variety obtained at Agoi Ibami. The amount of quartz varies from 15.86% to 0.55% while the loss on ignition ranges from 42.29 to 30.24%.

Thin section turned red on exposure to a mixture of Alizarine red S and K ferricyanide mixture. This indicates that the dominant calcite in the Mfamosing Limestone is of ferroan calcite variety.

**DIAGENESIS**

The various diagenetic fabrics, processes and events observed in the Mid-Albian Mfamosing Limestone are inferred from diagenetic imprints based on petrographic studies. Evidence of early stages of diagenetic processes in this carbonate body includes: micritization, isopachous/syntaxial rim cementation, leaching, generations of cements, dissolution and

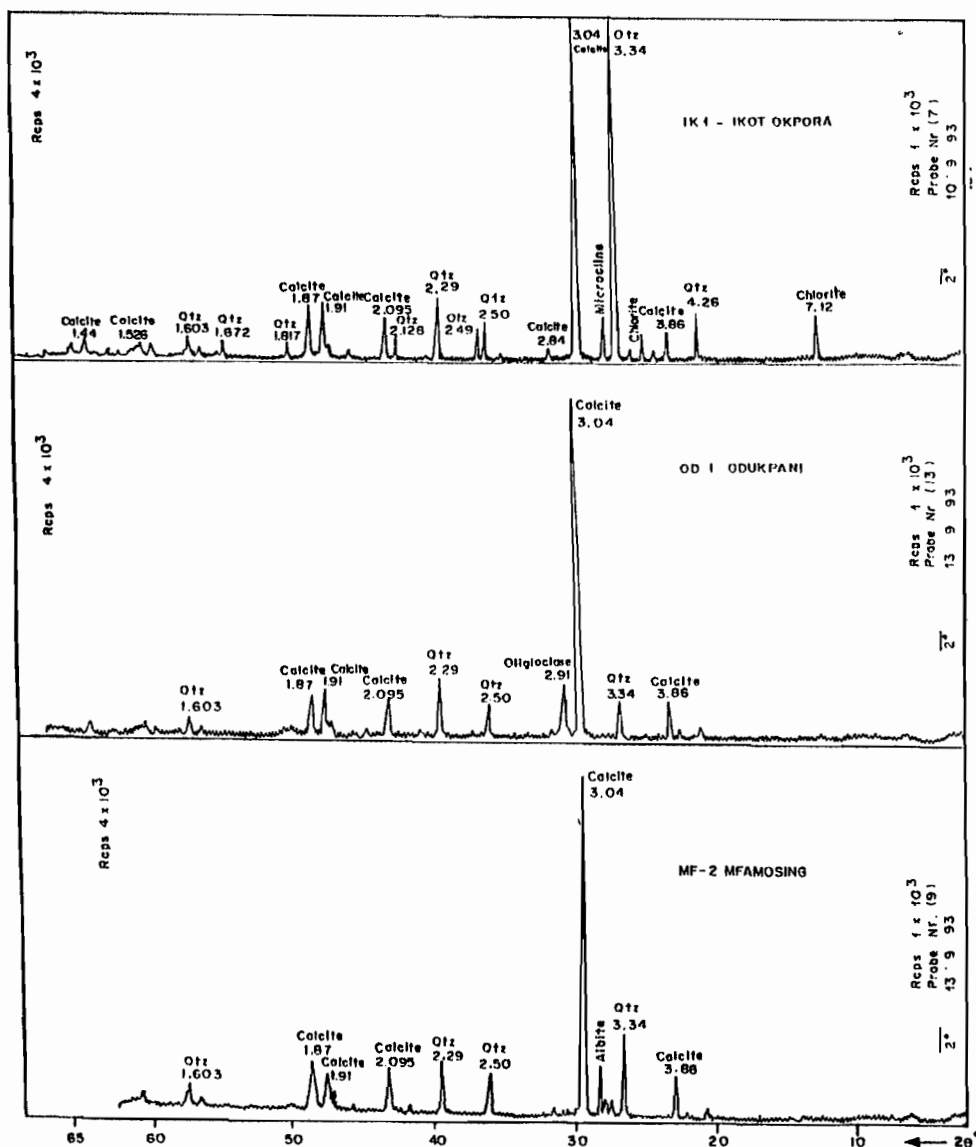


Fig. 2: Typical mineralogical X-ray diffraction patterns of the Mfamosing Limestone at Ikot Okpora, Odukpani and Obarekai

neomorphism. The late diagenetic stages caused dolomitization, stylolization and karstification.

The inferred diagenetic sequence of the Mfamosing Limestone is as shown in fig.3 while the observed diagenetic events and interpreted diagenetic environments are shown in fig.4. Petrographic studies reveal imprints of vadose, meteoric, phreatic and submarine diagenesis. Generally, the limestone exhibits bulk diagenetic characteristics independent of limestone microfacies type.

Diagenetic Environment Events	Vadose	Meteoric Phreatic Zone	Deep Meteoric Phreatic Zone	Mixed Fresh H <sub>2</sub> O Marine Phreatic Zone	Marine
Micritization					—
Isopachous cementation					—
Initial Cementation	—				
Cementation by equant calcite		—			
Neomorphism		—			
Syntaxial rim		—			
Dolomitization			—	—	
Stylotization			—		
Dissolution	—	—			

Fig. 3: Diagenetic events and interpreted diagenetic environments

Micritization (Bathrust, 1966) represents the earliest indication of diagenesis in this limestone unit (Plates 1 and 2). It occurs as a result of boring by endolithic algae and fungi, causing widespread and wholesale destruction of all types of grains, skeletal fragments, oolites and pelloids. The processes of micritization are known to occur in shallow stagnant marine phreatic zone especially at the sediment/water interface (Kobluk and Risk, 1977).

Isopachous cementation represents the earliest diagenetic event in the Mfamosing Limestone. It varies from very thin rim (Plate 3) to bladed morphology (Plate 4). This constitutes the first generation of cement which is followed by equant, interlocking mosaic calcite cement (Plate 4) which coarsens towards the center. The first generation of cement suggests deposition in a submarine diagenetic environment. Records similar to the second generation of cement observed in this limestone are abundant in geologic history (Bathrust, 1971; Jacka and Brand, 1971). It represents early cementation in a freshwater phreatic diagenetic environment (Loucks, 1977). Reprecipitation of preferentially dissolve allochemical particles represent the third generation of cement.

Syntaxial rims (overgrowth) which are in optical continuity with echinoid fragments envelopes pre-existing grains forming fabric and occludes porosity. Longman (1980) has indicated that syntaxial outgrowths forms more rapidly in a freshwater phreatic diagenetic environment.

Dolomitization which represents one of the late diagenetic events of the Mfamosing Limestone was observed as subhedral to rhombohedral crystals (Plate

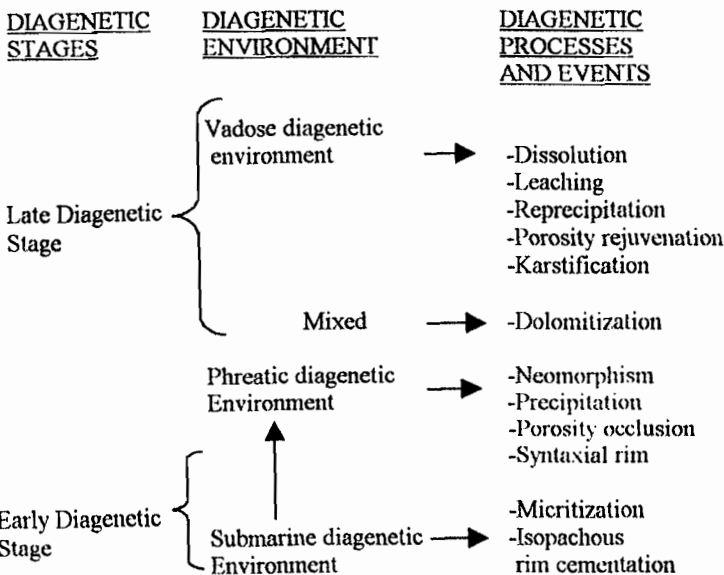
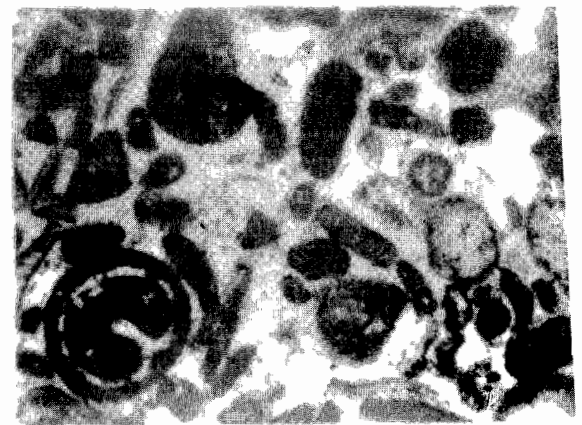
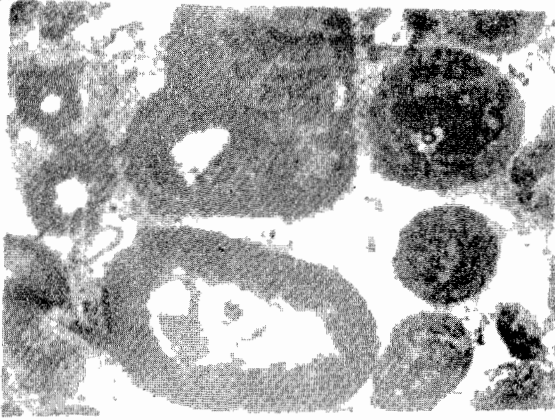


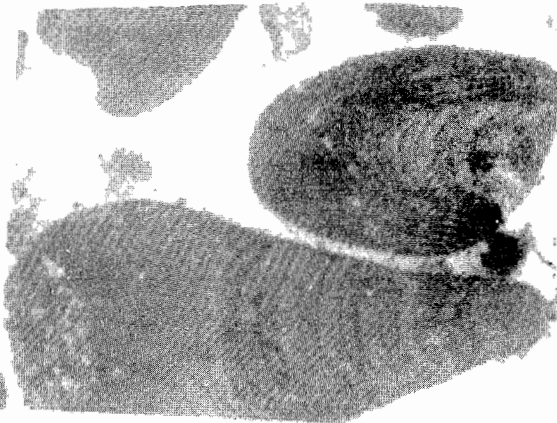
Fig. 4. Tentative diagenetic model for the Mfamosing Limestone



1. Photomicrograph of the intra-bioclastic grainstone test, echinoid fragment, coralline algae with admixture of coated grains and pelloids. Note the micritic rims of most of the allochems due to algal boring. sample from quarry face, calcemco Quarry face, type section, Mfamosing Limestone (PPL - x40).



2. Photomicrograph of the intra bioclastic grainstone packstone microfacies showing pelloids, grapestone, superficial ooids and highly - spired gastropod in the nucleus of a coated grain. Sample taken from the face, Calcemco Quarry, types section, Mfamosing Limestone (PPL -x40).

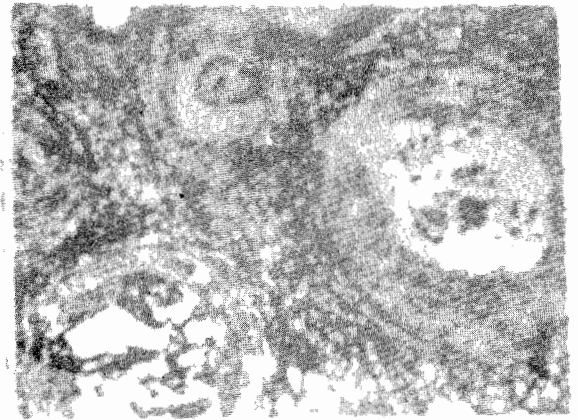


3. Photomicrograph of large smoothly rounded fragments of articulating coralline algae in a sparry matrix. Note the isopachous rim cement around an algal fragment. Sample taken from quarry, Calcemco Quarry, type section, Mfamosing Limestone (PPL - x40).

5) in both the cement and allochems, indicating a post cementation process. Ions for dolomitization may have been derived from water expelled from the overlying Ekenkpon Shales. The transition of this carbonate body through mixed meteoric-marine phreatic diagenetic environments may be a contributory factors (Bodiozamani, 1973). Similar case studies have been reported in the Pleistocene Hopegate and Folmoth Formations in Jamaica (Land, 1973a, b). Also, magnesium released by high-magnesium skeletal grains such as Coralline algae during diagenesis could serve as a magnesium ion source for dolomitization.

Two phases of compaction in the Mfamosing Limestone were inferred from petrographic studies. These are the physical and chemical compaction. Physical composition involves breaking of grains and compaction of allochems while the chemical compaction is evident both as pressure solution at grain contact and multiple microstylolite-horsetail.

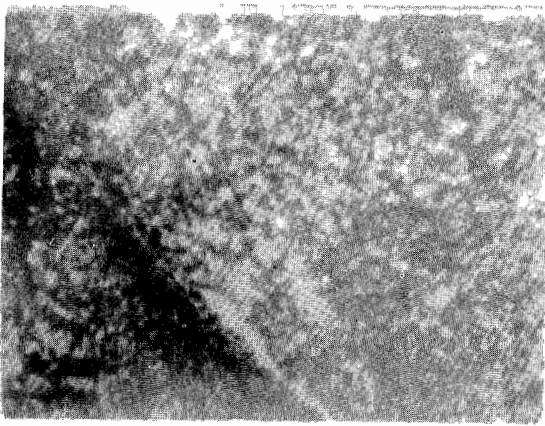
Stylolites are a common feature in the limestone under study especially in the southern part of the area under investigation (Mfamosing, Etankpini and Agbung). They are products of post-consolidation intrastratal solution (Pettijohn, 1975). In the Mfamosing Limestone, stylolites occur both within the limestone units and along lithologic (Microfacies) boundaries. Their surfaces are stained with seams of



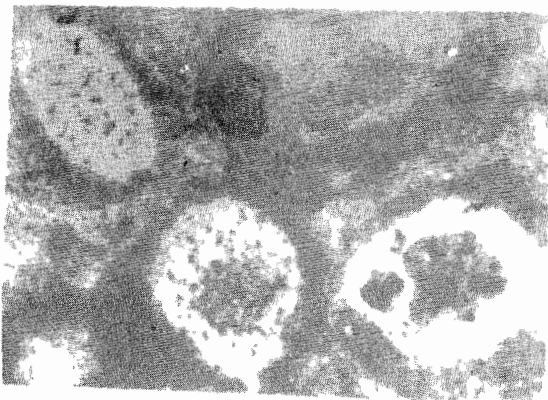
4. Photomicrograph of the oolitic-pelloidal packstone microfacies showing oolite with dissolved nucleus. Note the bladed isopachous rim cement followed. Sample taken from the quarry face, type section, Mfamosing Limestone (PPL - x40).



5. Photomicrograph of the Mfamosing Limestone showing subhedral to euhedral dolomite crystals growing in a micritic matrix. Sample was taken from an outcrop, Odukpani area, SE Nigeria (PPL - x40).



6. Photomicrograph of the Mfamosing Limestone showing neomorphism of both the matrix and allochem constituents. Sample was taken at Etankpini village, SE Nigeria (PPL - x40).



7. Photomicrograph of the Mfamosing Limestone showing solution-enlarged oomoldic porosity formed due to the preferential dissolution of ooids (pore spaces in white with small pecks). Sample was taken at Agbung village, SE Nigeria (PPL - x40).

insoluble organic matter residues. These seams are considered to be formed as a result of intrastatal solution, removing the calcareous constituents and concentrating the insoluble residue (Barrat, 1964). The stylolites observed in the field are generally parallel to bedding planes. The widespread and roughly horizontal stylolites suggest that stylolitization was as a result of pressure. Similar studies on the front Range of Wet Mountain in Colorado concluded that stylolite seems parallel to bedding plains indicate stress of load (Black and Roy, 1949).

Neomorphism is a dominant diagenetic process in the Mfamosing Limestone. Most of the allochems are characterized by neomorphic fabric. In most cases, the original delicate fibrous structure of the carbonate skeleton have been replaced by interlocking

neomorphic calcite. The neomorphic spars abut and transect both the allochems and the matrix (Plate 6). In some cases, it obliterates most of the internal structures of skeletal grains leaving behind dusty, micritic relics from which their original geometry can be inferred.

Diagenesis, depositional environment and fabric are the determinants of the types and distribution of porosity in the Mfamosing Limestone. The basic porosity types encountered are: moldic - Plate 7 (oomoidic and crittermoldic), vuggy, channel, fracture and compound. Moldic porosity is fabric-selective whereas the rest are not. The porosity types in this carbonate buildup are exclusively secondary. Primary porosity having been occluded by incipient cementation and compaction. The burial history of the Mfamosing unit appears to have followed a definite pathway of porosity development during subaerial exposure in the vadose diagenetic environment and destruction in the phreatic diagenetic environment.

#### DISCUSSION:

Mineralogical analysis of the Mfamosing limestone reveals high amount of calcium carbonate. This is responsible for such diagenetic processes as dissolution, leaching, cementation, neomorphism, stylolitization, porosity occlusion and rejuvenation.

The burial history of the Mfamosing Limestone tends to have followed a definite pathway as evidenced by the products of burial diagenesis. A tentative diagenetic model of the Mfamosing Limestone is shown in Figure 4.

Initial deposition of this limestone during eodiagenesis began in the submarine diagenetic environment as evident in incipient cementation producing isopachous rims. Longman (1980) and Macintyre (1977) have shown that isopachous rim cementation is diagnostic of a submarine diagenetic environment.

Diagenetic imprints of intense leaching, dissolution, formation of molds and vugs suggest subaerial emplacement of this carbonate body in a vadose diagenetic environment. These have been attributed to the action of undersaturated percolating freshwater in the vadose diagenetic environment which is slightly acidic and hence take into solution material of calcium carbonate composition (Friedman, 1965).

The transition of this carbonate body from the submarine to the vadose diagenetic environment through the phreatic and mixed diagenetic environment is very significant. It marked the phase of porosity occlusion and intense neomorphism. The phreatic diagenetic environment is generally saturated with calcium carbonate and this enhances intense neomorphism and precipitation (Friedman, 1964).

The final emplacement of the limestone unit in

a vadose diagenetic environment marked a phase of porosity development and karsitification. The rejuvenated porosity is entirely secondary and basically telegenetic (Choquette and Pray, 1970) since the pore spaces were developed postdepositionally during which the long buried limestone unit was subjected to subaerial and subaqueous erosion. The dominantly ferroan calcite identified by staining of this limestone gives credence to this.

## SUMMARY AND CONCLUSION

Deduction from X-ray diffractograms show that the Mfamosing limestone is mineralogically stabilized. Calcite is the major mineral constituent with varying amounts of quartz and feldspar. Diagenetic studies indicate overprinting of diagenetic events and environments. Diagenetic events in the Mfamosing limestone is evident as isopachous rim cementation, neomorphism, chemical and physical compaction, dissolution-reprecipitation, stylolitization, dolomitization, porosity occlusion and development. Diagenetic imprints show that this limestone unit evolved through a submarine, phreatic and vadose diagenetic environments. Basic porosity types encountered are moldic, vuggy, channel and compound types. These are basically secondary in origin. Porosity development is basically telegenetic i.e the pore spaces are developed during the post-depositional time interval in which the long burial limestone is influenced significantly by processes associated with subaerial and subaqueous erosion.

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