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PETROGRAPHY AND DIAGENESIS OF THE LIDAM FORMATION (CARBONATE UNITS)–FROM SELECTED WELLS IN SIRT BASIN, LIBYA

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دراسة مجهرية لصخور تكوين الليدام — حوض سرت ليبيا

محمود البكاي

قسم تكوين الليدام إلى وحدتين رئيسيتين هما : وحدة صخور الحجر الجيري ، ووحدة صخور الدولوميت . هاتين الوحدتين تمثلان بوضوح صخور مترسبة في بيئة سطح مدى ، أي ما بين المد والجزر، وتتكون من ثلاث مناطق بيئية هي : منطقة السبخة ، منطقة مغمورة بالماء ، ومنطقة ما بينها .

من الظواهر الدالة على البيئة السبخية هي الطبقات الطولية المنظمة والغير منظمة ، طبقات الطحالب ، الجبس ، الدلمته ، وغياب الحفريات البحرية . أما الظواهر الدالة على وجود البيئة ما بين السبخة والمنطقة المغمورة فهي طبقات رقيقة من الطحالب ، الجبس ، الحجر الرملي ، الدلمته ، بعض الحفريات الشوكية وغيرها . أما بالنسبة للظواهر التي تشير إلى البيئة المغمورة كلياً بالماء هي وجود حفريات دقيقة بحرية مثل الشوكيات ، فوراميينيفيرا ، اوستراكودا وغيرها .

المسامية والنفاذية في المناطق البيئية الثلاثة لهذا التكوين غالباً ما تكون ثانوية تكونت من جراء ذوبان المواد القابلة لذلك والغير مدلمته ، أما بالنسبة للمسامية والنفاذية الأولية فقد أنسدت نتيجة للدلمته ، وترسب المواد اللاحمة بين الحبيبات .

ABSTRACT

The Lidam Formation is divided into two units: limestone unit and dolomite unit. These units exhibit clearly tidal flat setting of supratidal, intertidal and subtidal.

The most indicative features of supratidal environment is the regular and irregular laminae (aggregates of pellets) algal mat, anhydrite, replacive dolomite and absence of marine fauna. This particular supratidal environment is present in Masrab high, As-Zahra–Hofra Platform, Beda Platform and Kotla Graben wells P16–59, Z1-59, 3V1-59, F8-59 and F10-59.

The intertidal environment is dominated by algal laminae, anhydrite, quartz and dolomite with echinoderm fragments, ooids and pellets. This environment is present in Ajdaby Trough and Gatter Ridge in wells 5N1a-59, E1-57 and 001-11. The subtidal environment is characterized by mudstone and wackestone facies with abundant marine fauna e.g. echinoderm fragments, ostracods and foraminifera.

Locally at D1-32 L1-32, 01-32, C1-NC57, D1-NC57 wells, (Azahra–Hofra Platform), and DD2a-59 (Ajdabya Trough) oolitic grainstone with peloids and bioclasts are abundant with indication possibly of shallow shoals reflecting high energy conditions. From the lateral distribution of the Lidam Formation one can conclude that the supratidal and intertidal environments were formed mainly on highs, during the Cenomanian transgression (Vail et al., 1977).

Porosity of intertidal and supratidal environments of the Lidam Formation is mostly secondary, generated by dissolution of materials survived from dolomitization. However, primary porosity either in subtidal or intertidal-supratidal environments had been totally occluded during cementation stage of diagenesis.

Dolomitization of matrix, marine cementation and dissolution are the most diagenetic stages which took place in the different environments of the Lidam Formation in the Sirt Basin.

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INTRODUCTION

The Cenomanian period began with marine transgression advancing from the north and NW towards the south (Klitzsch, 1981). The Cenomanian strata in the Sirt Basin are principally carbonates and shales. These carbonates (Lidam Formation) are widely spread and extending over much of the Sirt Basin. Its thickness varies in structurally high and low areas. Barr and Weegar (1972) concluded that the maximum thickness of the Lidam Formation is more than 600 feet in the middle of the Zella Trough, but the actual maximum thickness is more than 1000 feet in the south Zella Trough (D1-85 well). This formation was deposited in a shollow marine environment (Barr & Weegar 1972).

The Lidam Formation unconformably overlaps various units including the Nubian Formation, the Bahi Formation, and Igneous-metamorphic basement. It is usually overlain by the Upper Cretaceous Etel Formation or its equivalent Argub Formation with apparent conformity. The Lidam formation is considered as Cenomanian in age by Barr & Weegar (1972), who recognised that the rare microfossils of this formation consist mainly of ostracods, miliolids and large benthonic foraminifera, *Ovalveolina Ovum (d'Orbigny)*. This later species is diagnostic of Cenomanian age.

The conclusion in this paper is based on the data collected from selected wells scattered in a wide range all over the Sirt basin.

LITHOLOGICAL TYPE

North West Sirt Basin-North Zella Trough and Azahra–Hofra Platform

The lower part of this Formation is medium to coarse, laminated dolomite with quartz grains scattered through dolomite indicating a local mixing with the underlying sands of the Bahi Formation, and abundance of glauconite pellets. The middle part of the Lidam Formation, in this region, is mainly well cemented oolitic limestone interlaminated with very fine irregular laminae of shale. The dominant bioclasts being echinoderms, brachiopods and molluscs. The upper part is fine, laminated dolomite with anhydrite nodules and glauconite.

South Central Sirt Basin–Beda Platform and Kotla Graben

The lower part of the Lidam Formation, in this area (wells F8-59 and F10-59), is mainly dolomitized limestone, with sand grains indicating a local mixing with the underlying sands. The upper part of the formation consists of a well cemented pellet calcarenite. The pellets exhibit indistinct rings suggestive of an algae origin. Subordinate constituents of this facies include ooids, algae, and miliolids and rare quartz grains.

South East Sirt Basin-Masrab High and Agedabia Trough

The lower part of the Lidam Formation, in this region, is argillaceous dolomitized mudstone with anhydrite (nodular and chicken-wire texture). Pyrite nodules are also observed within this lithology. The dominant bioclasts being echinoderms. This dolomitized mudstone is highly porous in some intervals. The upper part of the Lidam Formation is mudstone partially dolomitized with nodules of anhydrite and interlaminated shale. Pressure solution is quite common. This lithology is overlain by chicken-wire anhydrite which, probably, grades upward to the Etel Formation of Turonian age.

THIN SECTION MICROSCOPY

General Statement

The lithology of the cored interval in the different areas were assessed from the microscopic examination of 131 thin-sections taken from core samples and cuttings at different depths. These samples were collected from specific horizons in order to provide information concerning the lithological variation and reservoir potential of carbonates, evaporites and clastics present in the sequence.

Skeletal Allochems

Echinoderms: Whole crinoids and fragments have been either totally and/or partially replaced by dolomite or still in original condition, i.e. calcite composition (Fig. 1). Some of these crinoids form nucleous of ooids (Fig. 2), while others have a calcite overgrowth cement showing an optical continuity with the grains.

Mollusca: Long shells display prismitic or foliated structure at depth 6934–6935 feet in well D1-32, some of these shells have overgrowth cement. There are also long shells displaying crossed lamellar structure. At depths 10080 feet 5 inches in well P17-59 and in well Z1-59 at depth 10980 feet, the shell fragments of Mollusca have completely been dissolved out and replaced by anhydrite and dolomite (Figs. 3 and 4). At depths 10690 and 10709 feet in well 5N1a-59 there are long bivalve shells preserving original mineralogy and structure.

FIG. 1. Photomicrograph showing echinoderm plates.

FIG. 2. Photomicrograph showing echinoderm being as nucleus of ooids.

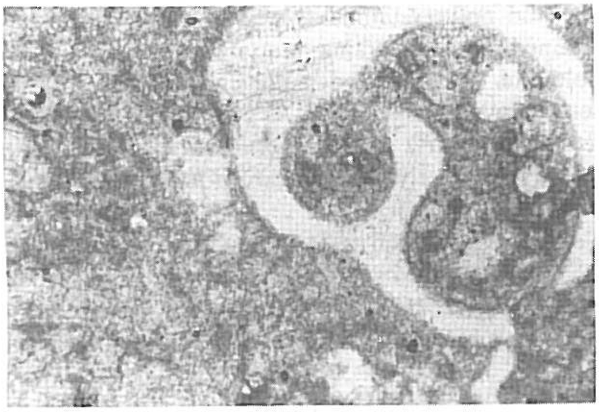

FIG. 3. Photomicrograph showing gastropod shell, replaced by dolomite and anhydrite.

Gastropods: Transversal sections through a single gastropods occur. All traces of the original wall structure have been obliterated during inversion either to dolomite or calcite, but the recognizable outlines are preserved (Fig. 2).

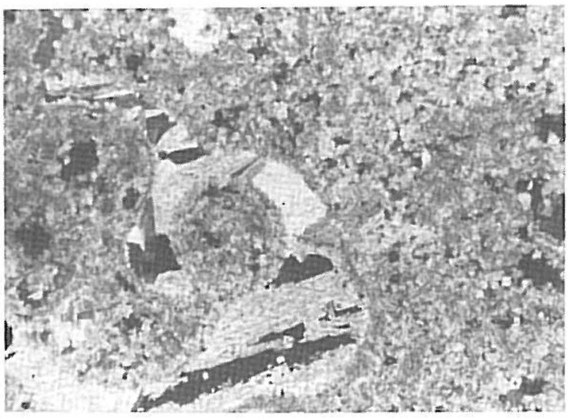

FIG. 4. Some as Fig. 3, but under X.N.

There are also transverse sections of gastropod that have been dissolved out and totally replaced by anhydrite, but their recognizable outlines are preserved. At depth 10690 and 10695 feet in well 5N1a-59, gastropods are partially replaced by dolomite and/or ferroan calcite.

Ostracods: Pairs of valves showing common overlap of one valve over the other exist. Between the valves single crystals of ferroan and non-ferroan calcite or dolomite as a cement phase (Fig. 5) are present. Other ostracods valves were observed in well D1-32 at depth 7122–7137 feet and in well 5N1a-59 at depths 10690, 10695 and 10709 feet, these valves have been totally replaced either by calcite or dolomite, but the recognizable outlines are still visible.

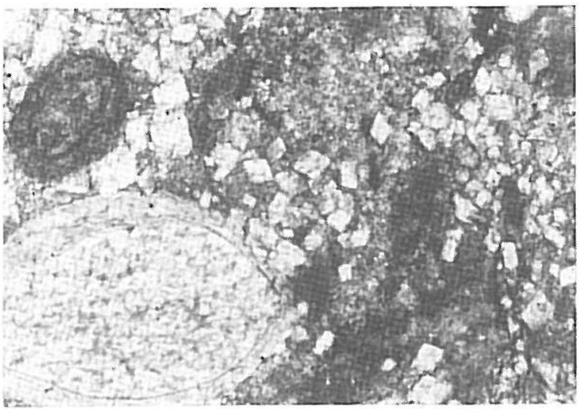

FIG. 5. Photomicrograph showing two halves of ostrocods, and single crystal of calcite and/or dolomite between them.

Foraminifera: In well F10-59 at depth 7606 feet the chambers of globigerinid Foraminifera are filled with calcite, while the chambers of miliolid Foraminifera are filled with neomorphic spar. At depth 10009–10009–10010 feet in well P9-598, benthonic uniserial Foraminifera have either been dissolved out leaving moldic porosity or partially occluded by dolomite. The dominant skeletal grains in well 5N1a-59 at depth 10690, 10695 and 10709 feet are miliolid and benthonic uniserial Foraminifera. These chambers are generally filled with ferroan calcite. In well N1-32 at depths 5360–5370, 5400–5410, 5440–5450 and 5470–5480 feet, Foraminifera are small and replaced by dolomite. At depth 6975–6976 feet in well D1-32 the miloilid Foraminifera are present as nucleous of ooids within interclasts, their walls have largely been micritized (micrite envelope), and some pores are also filled with sparite. Globigerinids are common in the lower part of the Lidam Formation in well D1-32.

Algae: Not very well developed and laminated blue-green algal mat have been observed in wells P6-59 and P11-59 at depths 10166, 10167 and 10131 feet respectively. These blue green algae are characterized by pelletal texture, irregular lamination (Fig. 6). Well preserved coralline algae are common in the middle and upper part of the Lidam Formaton in D1-32 well.

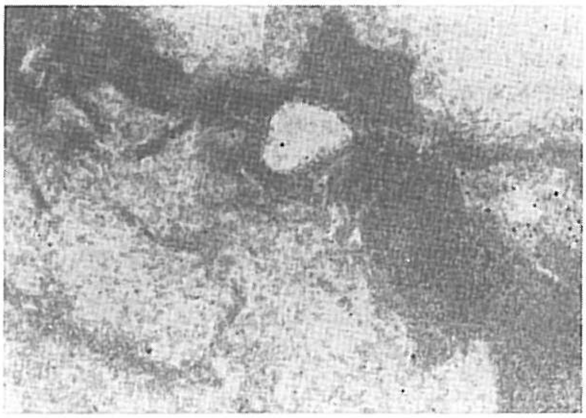

FIG. 6. Photomicrograph showing algal laminae.

Microfossils: At depth 7226-7228 feet in well D1-32 the spherical microfossils (Calcispheres) are well defined, which are difficult to distinguish from uniserial Foraminifera or spherical algal balls. The chambers of these grains are filled either with ferroan calcite or ferroan dolomite.

Non-Skeletal Allochems

Pellets: These grains are observed throughout the dolomite facies; these grains are oval and well rounded. Some elongate micritic grains, have partially been replaced by dolomite. They are probably of Foraminifera or fecal origin.

Stromatolites: Pellets are aggregated together into laminae making stromatolites structure or algal mat associated with anhydrite (Fig. 6).

Peloids: Present in the whole dolomite facies, they are large, rounded and micritized grains, probably of foraminifera or algae origin. Some of these grains are unaffected by dolomite and the micrite of others are slightly aggrading to neomorphic spar.

Incompletely Micritized Particles: At depth 10695 feet in well 5N1a-59, the incompletely micritized particles have low magnesium calcite in the centre and micrite at the outer.

Ooids: In well D1-32 at depth 6975, 6993–7007 and 7029–7058 feet the oolids are well rounded and/or oval, showing concentric and radial structure. Some of these ooids enclose Foraminifera, echinoderm plates and/or a single crystal of calcite or dolomite as a nucleous (Fig. 2).

Interclasts: In well D1-32 at depths 6934, 6975 and 6933–7007 feet and in well 5N1a-59 at depths 10690 and 10695 feet, the interclasts are not very common. They are large, rounded and subrounded micritic grains. They enclose some clastic grains and skeletal fragments, e.g. echinoderm fragments, Foraminifera, ooids, small micritic grains and glauconite grains. Some of these grains are cemented by calcite.

Non-Carbonate Grains

Quartz: Most of the Lidam carbonates contain fine to coarse sand grade, rounded to angular unicrystalline and polycrystalline as well as strained and unstrained detrital grains scattered throughout the dolomite. Well formed authigenic quartz are observed in well 5N1a-59 at depths 10690 and 10695 feet. The quartz percentage increases with depth where the underlying formation is mainly sandstone.

Feldspar: At depth 6974 and 6978 feet in well D1-32, some of the feldspar grains are partially altered to clay, whereas, the rest are largely unaffected. Some strained grains (only one set of twin lamellae) are observed in wells P9-59 and Z1-59 at depths 10051 and 10989 feet respectively.

Glauconite pellets: The glauconite pellets are common in the north-west (D1-32 well). They are moderately to well sorted and are usually larger than the dolomite crystals and quartz grains. The glauconite pellets are mainly well rounded to elliptical with rare irregular and narrow cracks. They occur in three different colours; grass-green pellets, light green pellets and brownish-yellow pellets.

PETROGRAPHY AND ENVIRONMENT OF DEPOSITION

The Lidam Formation in the Sirt Basin can be divided into two major units (Fig. 7).

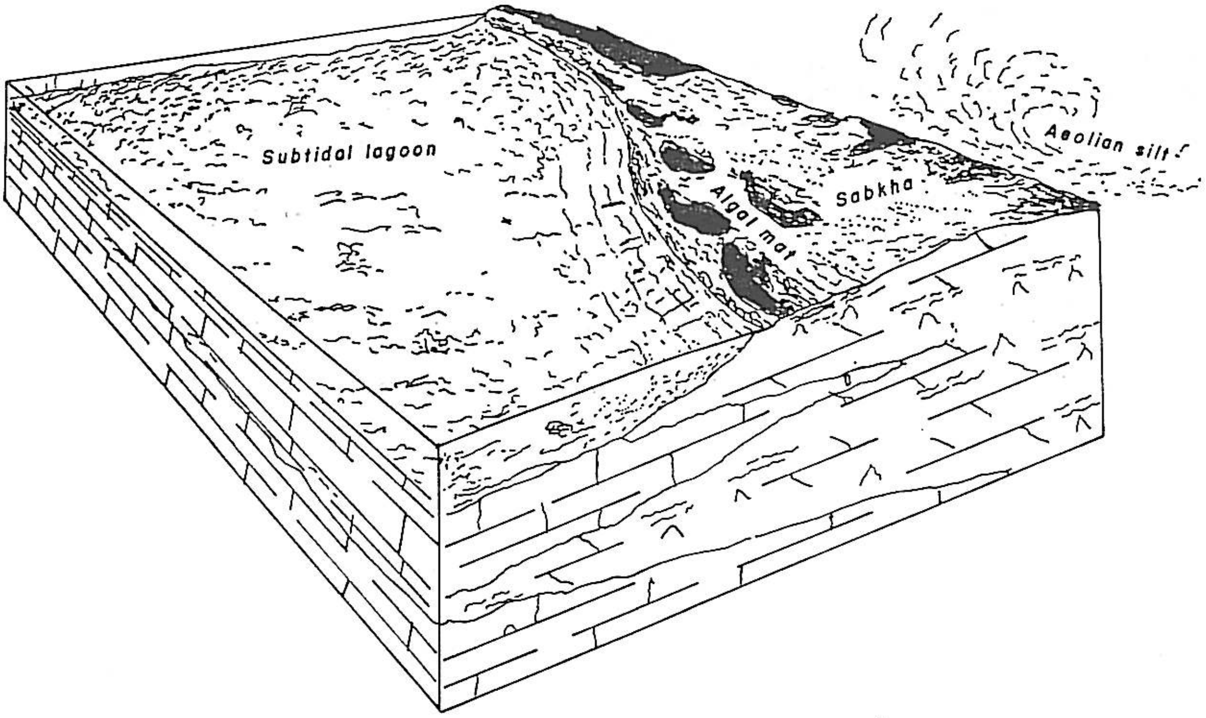

FIG. 7 Idealized Environmental Reconstruction for sedimentation of the Lidam Formation.

The Upper Lidam Limestone Unit

The upper limestone unit has been recognized in the Masrab High and Agedabia Trough, South East Sirt basin (wells 3V1-59 and 5N1a-59), and in the Zella Trough and Azahra-Hofra platform (D1-32 Well).

Petrography: For the unit as a whole, particle assemblages are dominated by diverse fauna comprising molluscs, gastropods, echinoids, ostracods and Foraminifera. Non skeletal allochems are represented by ooids, peloids and pellets, but intraclasts also occur locally. Trace amounts of quartz sand grains and variable clays are the only non-carbonate components. Presence of primary porosity at some intervals; generally the porosity in this facies is scarce.

Primary fabrics: The dominant depositional fabric is wackestone, grading into mudstone with a decrease in alochems. Poorly defined packstone intercalations are present in 3V1-59 and 5N1a-59 Wells. In Well D1-32 the facies show horizons of grainstone. The limestone are generally massive and unbedded, bioturbation is apparent in Well 5N1a-59. Fine scale lamination is preserved in the upper part of limestone facies in this well; suggesting very low energy deposition.

Environment of Deposition: The limestone unit broadly represents carbonate sedimentation in a normal marine shallow subtidal environment (Fig. 8), the biota is diverse and indicates hospitable substrates. The environment was predominantly one of low energy, but the local packstone and grainstone intercalations indicate periods of moderate turbulence and winnowing of lime-mud. More lithological variation is apparent in wells 3V1-59, 5N1a-59 and D1-32. The vertical successions in these wells display broad similarities, especially towards the top of the facies, where evidence of incipient regression is apparent (Wilson, 1975). The sequence takes an upward-shallowing aspect. In these wells there are an upward gradation from packstones with interclasts into wackestones, suggesting decrease in the contemporary energy of the environment towards the top of the facies. Laminated calcareous and unfossilliferous shales form intercalations with the limestone, and the biota in the latter reveals a drastic decrease in diversity. The origin of the shales is uncertain, but they are probably very localized deposits of topographically controlled, restricted lagoons.

The Lower Lidam Dolomite Unit

The contact between the Lower Dolomite Unit, in the wells selected for this study, and the overlying upper limestone unit is everywhere fairly abrupt. The

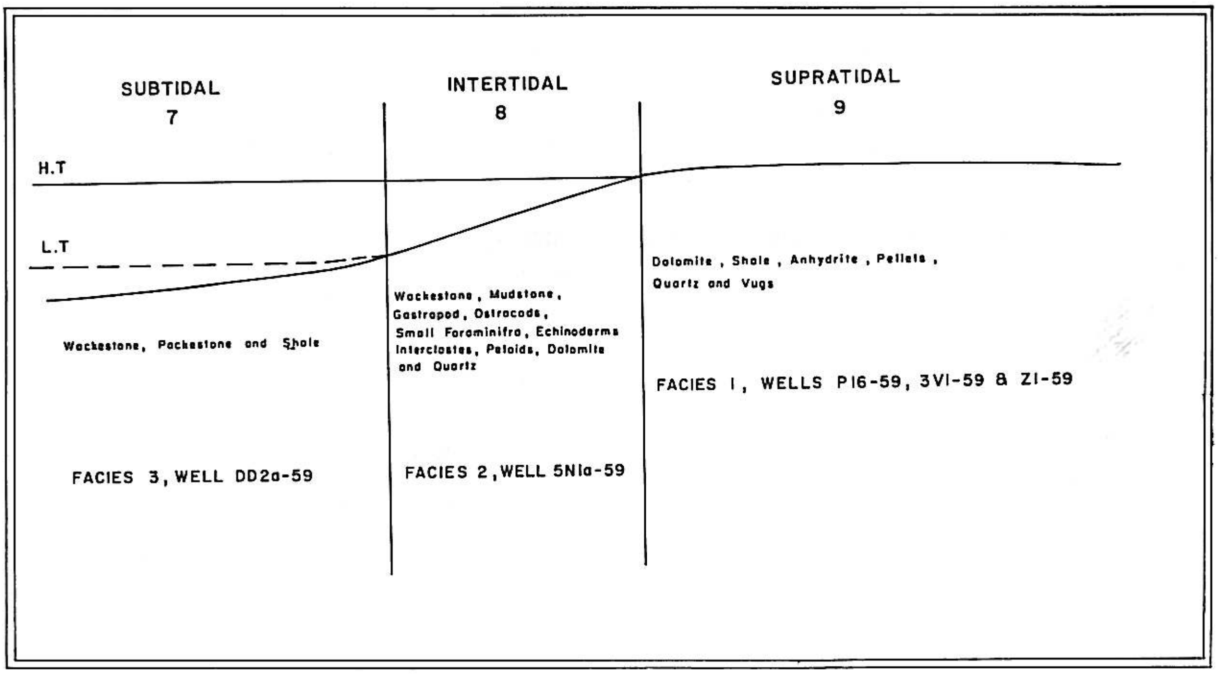

FIG. 8. Generalized Depositional Model for the Lidam Formation.

facies display thin development towards the centre of the troughs and thickest towards the platform.

Petrography: Uniform, microcrystalline "aphantic" to finely crystalline dolomites are the dominant lithologies. Particle assemblages (whether preserved or as relicts) are sparse. Skeletal allochems are representative of low density biota of ostracods, echinoids and algae, while non-skeletal allochems are dominated by abundant fecal pellet materials. Peloids are not widespread. Non carbonate constituents comprising fine sand to silt grade, detrital quartz and clasts of siliciclasts clay, are abundant in 5N1a-59, F8-59 and D1-32 wells rare phosphatic nodules and very common glauconite pellets are also present.

Primary Fabrics: The dominant depositional fabric before dolomitization was probably massive mudstone (argonite lime-mud). Discrete burrows are present. These, often, have fillings of pellets and bioclasts producing pockets of wackestone/packstone (wackestone whole-rock fabric are rare). Algal boundstones representing algal mat developments are abundant in some wells, e.g. F10-59 or P16-59. These are characterized by wavy, buckled laminae or microdolomite. The primary trapped sediments are generally strong pelletal lime-mud, or pelmicrite packstone with small admixture of clay. Associated with these boundstone horizons are nodules of "primary" felted lath anhydrite. The anhydrite, regularly, forms thick cloudy bedded developments displaying well formed chicken-wire structure.

Environment of Deposition: The change form limestones into diagenetic dolomites is indicative of the onset of regression and fairly rapid establishment of supratidal sabkha. Slight variation is provided by 5N1a-59 where an apparent absence of algal boundstone and evaporites suggests that the immediate area did not actually become emergent. But the fabrics present (intense bioturbation, abundant fecal pellets) suggest a nearshore subtidal "lagoon", sufficiently close to the shore line, for diagenetic dolomitization to have been effective. Relatively thick supratidal sequence were build up in A1-17, N1-32, 3V1-59 and F8-59 wells. In 5N1a-59 and D1-32 wells "subtidal", the transgression introduced bioturbation, large interclasts, well cemented ooids and sparse fauna and pushed the shoreline back such that diagenetic dolomitization became less intense. In D1-32 and 3V1-59 wells, the anhydrite algal boundstone fade and gave way to massive dolomites with thin intercalations dolomitic shale; these may represent topographically restricted lagoons generated by the first floodings of the supratidal which stands up as massive/laminated non-evaporitic dolomites with bioturbation fabrics and abundant quartz silt, this lithology is interpreted as a low intertidal flat.

DIAGENESIS

The initial sediments micrite and clay, consisted of skeletal allochems (composed mainly of argonite and calcite), and non-skeletal allochems (ooids, pellets and peloids). Ditrital grains such as quartz, feldspar, pyrite and glauconite are also present. Most aspects of limestone diagenesis (post depositional changes), can be related to this plan of hydrological zones (Fig. 9). As limestones pass, from their place of origin through them, under the influence of changes in sea level or progradation of the land, then each environment of change places upon the rock fabric.

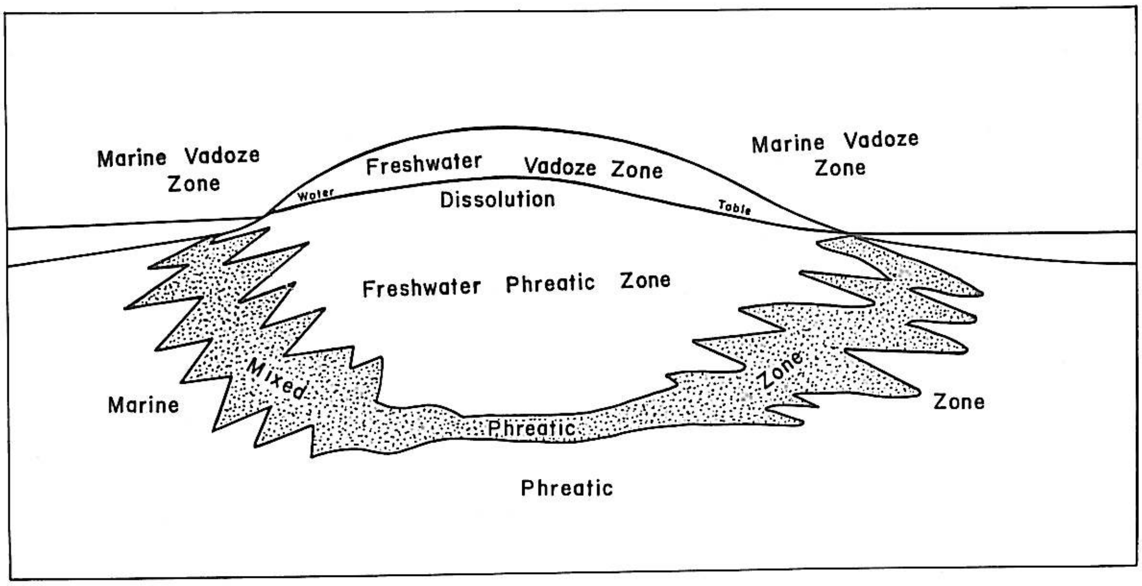

FIG. 9. Major hydrological zones important in carbonate diagenesis.

Terminology

(a) Where all the rock pore-space is filled with water, then the rock is said to inhabit a PHREATIC ZONE (Longman, 1980, 1981). If the water is fresh, this is the Freshwater Phreatic Zone. If the water is brakish, this is the Mixed Phreatic Zone. Phreatic zone extends from beneath the sea to a depth of rock beneath the land, which lies under the Water Table. The transition from marine to fresh occurs over the mixing or mixed phreatic zone.

(b) Where all the pore space is not completely filled with water all the time, but is occasionally filled with air, the rock inhabits the VADOZE ZONE (Longman, 1981).

Marine Phreatic Zone: The active marine phreatic zone is nearest to the seabed, here the water is pumped through the sediments and cementation by aragonite and high-Mg calcite takes place.

Mixed Phreatic Zone: This zone is narrow, but moves backward and forward through the sediment in response to rainfall. Though cementation is not the only process that takes place here, dolomitization is thought to be significant. This variety of dolomite is generally coarsely clean and ferroan crystalline, and the process is very effective leaving little calcite unaltered. As a result, this sort of dolomite is a cement phase. Formation of stylolites (pressure solution) also takes place in this zone.

Freshwater Phreatic Zone: This is the most important diagenetic zone where rapid cementation and dissolution takes place.

Dissolution: Local dissolution of skeletal grains, non-skeletal grains and relict micrite took place and created different types of porosity.

Cementation: In the saturated active zone, rapid cementation by fringe low-Mg calcite, phreatic ferroan calcite, equant calcite spar and also by anhydrite took place. The water contacts the water table from the vadoze zone having passed down through limestones; it may therefore, be at a variable degree of $CaCO_3$ saturation, depending on the time spent in migration. Solution is therefore, common in the uppermost regions of the phreatic zone.

Dissolution is intense and creates large vugs similar to the freshwater vadoze zone.

Freshwater Vadoze Zone: This zone passes upwards into the soil zones. Calcrets and other deposits may form distinctive units. Evaporation also is important, so the precipitation of calcite took place at the grain contacts (meniscis cement).

Marine Vadoze Zone: In this limited zone environment, beachrock develops. Here, aragonitic microcrystalline cements may blind the deposits. Aragonite and some high-Mg calcite are the major cement types. Evaporation (anhydrite of felted lath, chickenwire and nodules structure) and early dolomitization (diagenetic dolomite) of xenomorphic to hypidimorphic crystal shape and xenotoic to hypidiotopic texture. This dolomite (pervasive and saddle), which replaced the original sediments, is the most dominant control in this zone.

POROSITY

Types

Porosity is diminished or lost through diagenetic changes e.g. cementation, compaction, dolomitization and pressure solution. Porosity in the Lidam Formation can be divided into two main types according to Choquette and Pray (1970).

Fabric Selective

(a) *Intercrystalline porosity:* This type occurs between dolomite crystals; it is better developed where dolomite is coarsely crystalline (Fig. 10). This type of porosity is created by dissolution of survived micrite and calcite in fresh water phreatic zone.

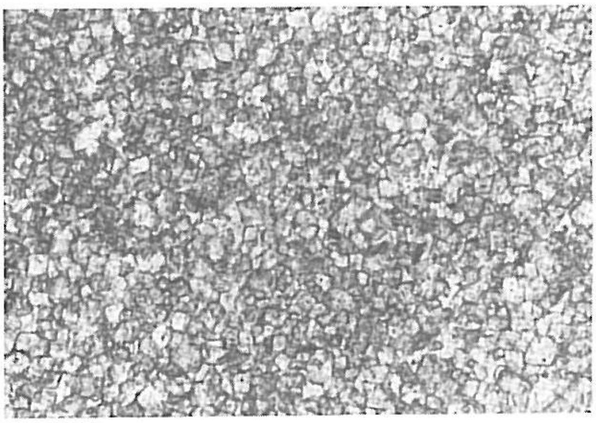

FIG. 10. Photomicrograph showing intercrystalline porosity within dolomatized mudstone.

(b) *Moldic porosity:* It is formed by selective, but extensive, removal of predominantly aragonitic pellet materials. As a result, only relicts of the pellets remain, because micrite commonly fills the interstices between the pelletal grains. The molding porosity, which is more in the intertidal environment, is considered to be comparatively unimportant and ineffective porosity.

(c) *Intraparticle or interskeletal porosity:* This type of porosity is primary. It is present within individual skeletal particles, in miliolid Foraminifera in particular, where the individual chambers remain unfilled in a high energy subtidal environment, e.g. in well F10-59 at depth 7606 feet.

Non-Fabric Selective

(a) *Vuggy porosity:* This type of porosity is generated by leaching out of micrite, calcite, cement and/or bioclasts leaving vugs or by the enlargement of intercrystalline porosity.

(b) *Channel porosity:* This type of porosity is likely solution enlarged fractures. It occurs in wells A1-17 and F8-59 at depths 5776 and 6596–6958 feet respectively.

Distribution

The development of porosity in the Lidam Formation is largely controlled by dolomitization, compaction and freshwater phreatic leaching or dissolution. Generally, good secondary porosity is present in wells located on the highs or platform, but poor or absent in wells located within throughs. However, poor porosity at the supratidal and intertidal environment and moderate to very good porosity at subtidal environments. The most common types of porosity in the Lidam Dolomite is intercrystalline occuring between the dolomite crystals. It is the result of pervasive dolomitization, in some intervals calcite cement has reduced the porosity. Vuggy porosity is the second most common type in the Lidam dolomite. This type of porosity has resulted from dissolution of calcite and anhydrite and/or by solution enlarged intercrystalline porosity. Moldic and intraparticle porosities are developed in subtidal environment (shallow shoals) where the currents are strong enough to winnow away the intertidal micrite particles. The chambers of some skeletal allochems, e.g. Foraminifera remain unfilled.

RESERVOIR QUALITY

Porosity in the Lidam Formation (mainly secondary) has been generated by dissolution of the original lime-mud, which survived from dolomitization or by the dissolution of calcite and anhydrite crystals. The diagenetic changes has also destroyed the primary porosity such as in Well D1-32, where the cement has totally occluded interparticle porosity in the shallow shoal sediments.

Good secondary porosity in Well A1-17 at depths 5644–5655 feet and 5668–5713 feet, but the remaining clay has reduced permeability, so poor reservoir quality is inferred. In Well F8-59 at depth 10829 feet the secondary porosity is quite good and connected by throats, therefore, good permeability and good reservoir quality is inferred. Generally there is absence of porosity in the limestone unit because of diagenetic changes, so the reservoir quality is poor. Secondary porosity is well developed and connected in some intervals of the dolomite unit, and good reservoir quality is inferred.

SUMMARY

The core material of Cenomanian age collected from the different wells scattered throughout the Sirt basin is divided into two units; summarized as:

1. *Limestone Unit:*

This unit, as a whole, is dominated by oolitic limestone, cemented by ferroan calcite and dolomite (oosparite grainstone and biomicrite wackestone/ mudstone) with common galuconite pellets. It is deposited in moderate to high energy environment.

2. *Dolomite Unit:*

This unit is characterized by diagenetic laminated and pervasive dolomite, with good porosity at some intervals. Nodules and chicken-wire structure of anhydrite also occur within the dolomite unit. This unit represents sedimentation in a restricted marine environment.

The petrographic description of samples collected from the different depths, show that the dominant primary depositional fabric before dolomitization is that of massive mudstone, subsequently subjected to arid sabkha type shoreline diagenesis. The dominant type of porosity in the dolomite facies is secondary (intercrystalline and vuggy), created by dissolution of the survived matrix in freshwater phreatic zone. These porosities are partially occluded by cement and remanent matrix.

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