Diagenetic Evaluation of La Luna Formation at Tachira and Merida States, Western Venezuela

Egleé Zapata[1]; María A. Lorente [2], Olga Rey [1]; Víctor Padrón [1]

[1]Universidad Central de Venezuela, Faculty of Engineering, School of Geology, Mines and Geophysics.
[2]PDVSA Exploration and Production

1.- Introduction

La Luna Formation, from the Late Cretaceous, has been considered the most important hydrocarbon source rock in western Venezuela and possible one of the most productive of the world. Even it importance, their biostratigraphy, diagenesis and sedimentological characterization are not well known.

This deposits are represented by marine sediments of fine grain: "black-shale", composed essentially of clay and carbonatic mud, with an abundant fossil fauna of foraminifera in association with phosphate, chert, pyrite and glauconite. Some fish bones and mollusk of thin walls remains, enrich the fossil assemblage.

With the purpose of evaluate diagenetically this formation, two surface sections were chosen in Merida and Tachira states. This sections are almost complete and not affected tectonically (Fig. 1).

By detailed sampling (every 50 cm.), a total of two hundred and five (205) samples where collected, for the elaboration of petrography sections and 102 samples for electronic microscope studies.

Petrographycally, lithotypes with muddy texture were identified, classified according to Dunham (1962) as packstones, wackestones, and mudstones and in a minor proportion grainstones. The electronic microscopy evaluation allows to precise the composition relationships of the rocks. The whole study shows early diagenetic process of micritization, phosphatization, pyritization, cementation, etc.; and compaction effects by burial diagenesis.

2.- Lithostratigraphy:

La Luna Formation, in the studied sections, is characterized by the presence of black calcareous shale interbedded with black limestones and in a minor proportion, thin layers of chert. Two intervals can be recognized: the lower one is characterized by a very compacted black calcareous shale with concretions of a variable size (from 0.03 to 1.50 m) and very thin chert levels, the limestones levels are very rare and thin. The upper interval is characterized by limestones interbedded with black shales, concretions and chert levels are scarce.

The top of the formation is characterized by the presence of a phosphate and glauconite level recognized as Tres Esquinas Member.

3.- Petrography and diagenesis

The samples and petrographic sections were described with the purpose of compile the greater amount of diagenetic evidence that can be easily seen such as concretions (with diversity in size, form and distribution), highly compaction grade, fracturing (the presence of microfractures filled and open) without presence of stylolites, low primary porosity and secondary porosity by dissolution and mineralization (presence of phosphates, glauconite, pyrite, etc.)
By microscopic studies, a lithologic assemblage of muddy texture can be recognized, represented by a fine fraction of abundant terrigenous clay and carbonate mud, in which the grains are usually distributed with loose contacts, becoming occasionally punctual contacts . The coarsest granular component is represented by planktic and benthic foraminifera assemblage, distributed with variable abundance and diversity throughout the sections in proportions that varies between 10% and 35%. Other components of the rocks are represented by small percentages of fishbone and mollusk remains (less than 15%). Phosphates, pyrite, silicates, sulphates and organic matter, are important components in low proportion.

4.- Petrography Characterization

Each of the components are describe below:

Matrix: The muddy and granular carbonate matrix of La Luna Formation, has a montmorillonite-smectite matrix plus carbonate mud, with lower percentages of organic matter. Petrographically this group is hard to identify and it is appreciated as a very dark and pseudomorphous mass. By electronic microscope (rock section) examination, little clay flakes assembled with carbonate mud and some times with chert were recognized. It is possible, eventually, to appreciate effects of microspar recrystallization and pseudospar . This matrix is dense, dark colored in proportions up to 50 %.

Fossils:
Foraminifera: They are in proportions that varies between 10% and 35%, the calcareous foraminifera shells present their original texture very well preserved. They can be found complete, or as loose chambers and very few are broken. Their size vary from middle to fine sand. Characteristically they are displayed forming bands or laminas of light color inside the dark matrix, generating a thin lamination that is typical in these sequences. The chambers of this fossils can be partial or totally filled with equigranular calcite and sintaxial cements, kaolinite-chert, pyrite, organic matter; or they can be empty. Recrystallization effects in these walls are scarce and very localized, like the micritization effects.
Mollusks: The mollusk remains are distributed with no order in the rocks, they present, in the majority of the cases, tabular geometry parallel to the lamination. This mollusk remains , with a size of 0.5 to 1.5 mm, belong to the *Inoceramus* genus. Usually they are affected by diagenetic process of neomorphism of homoaxial inversion, allowing maintain their magnesium calcite texture. Others can present pyritization and/or phosphatization and frequently present bioerosive effects of micritization.
Fish bones: The majority of fish remains are altered by phosphatization and/or pyritization and in some occasions by sulphatization phenomenon. Also can be associated to organic matter. They have a cavern aspect, in a variety of sizes that give a bad sorting to the rock. They are frequents along the sequence, in both sections, in low proportions (<10%), reaching greater proportion (15%) towards the top (Tres Esquinas Member).

Organic Matter: It is found as pores fillings with an amorphous structure, in a percentage of 4%. Petrographycally it was not recognized. The dark color of the matrix presupposes its existence, however, the electronic microscope observation established an abundance in clay and an scarce presence of organic matter.

Autigenic Minerals: The autigenic minerals observed in order of abundance are: carbonates, sulphurs silicates, phosphates and sulphates.
Carbonates Minerals: Calcite and dolomite are present as cements
Calcite:It is the most abundant autigenic mineral, principally presented as different cement types: equigranular, blocky, prismatic enlarged, sintaxial, “dogtooth spar” and rhombohedric.
Cements:
Equigranular: Inside the foraminifera chambers,(intragranular) with sizes smaller than 150μ, with a crystalline texture and irregular edges.
Blocky: Present as intragranular type occupying the internal parts of the foraminiferal chambers with anhedrals crystals with a size smaller than 250μ. between the foraminifera shells with a size smaller than 300μ and also well cristallized in small extension fractures.
Enlarged prismatic:It is recognized associated to “cone in cone” structure levels and concretions. It size is larger than 500μ and can be macroscopically observed. This type of cement is frequent along the whole intercalation of shale section with concretions, in both sections.
“Dogtooth spar”:It has been formed by subhedral calcite crystals, with intermediate fabrics of pointing tendencies. Usually they are observed in partially dissolve cavities or pores, where it is developed with clean and defined edge crystals up to 120μ., occasionally they are associated with pyrite.
Sintaxial: They have been developed as crystals in optical continuity to foraminifera and in cavities and patches over the matrix, with a difficult petrographic visualization.
Rhombohedric t: Posterior to the equigranular cementation, it is present with an opaque texture in rhombohedric defined cleavages. It is observed inside foraminifera walls and isolated in the matrix.

Dolomite: It is present only at Tres Esquinas Member as rhombohedric and anhedric crystals, in both sections, with a size from 80µ to 100µ, associated to glauconite and phosphates.
Sulphurs: With a wide distribution along the two studied sections, they are represented by pyrite and sphalerite in proportions from 1% to 10%.
Pyrite: Preferentially, it is presented with a framboidal texture and eventually with an euhedral habit. The pyrite crystals are distributed in the micritic-clay matrix, inside the pores, in fossil cavities, in phosphatized remains of fish bones and associated to some cements.
Sphalerite: It has an euhedral habit, ocurrs associated to pyrite in a higher proportion.
Silicates:
Glauconite: It is presented in a granular form or fitted to the preexisting structures, distributed in proportions lower than 4% at the basal part of the sequence, reaching notorious proportions at Tres Esquinas Member (20%), as cement in association with phosphates, carbonates and pyrite (Fig. 3A and B).
Silica: It occurs as cement, forming bands of a gray-bluish color , with an undulatory concentric extinction (chalcedony) or in small gray-white and black prisms, in association with the matrix or as silicifications in foraminifer chambers associated to kaolinite.
Phosphates:
Collophane: It is present as neomorphic replacement in the matrix and also in the fish bone remains and in some mollusks. In general it is associated to sulphates and sulphurs.
Sulphates: They are associated to phosphates as barium sulphate and partial replacement of phosphatic fish bones remains.

5.- Diagenetic Processes

Bioerosion: It comprises boring and micritization. Both are observed with little frequency and they are referred to the action of organisms (bacteria, fungi, etc.), over the shells of foraminifer and mollusks.

Compaction: In the studied sections, the compaction is expressed by: fossil concentrations in bands with micrite lenses, laminations, preferential orientation of thin mollusk remains parallel to laminations, low porosity (<6%) and hardness of the rock.

Cementation: In both sections the following types of cements where recognized: a) blocky calcite cement (between particles of fossils), b) equigranular blocky calcite cement (intragranular), c) glauconite cement inside the fossil chambers and intergranular, d) enlarged prismatic calcite cement (“cone in cone” and concretions), and g) rhombohedric cement in foraminifer walls.

Replacements: The following replacements were observed: pyritization, silicification, glauconitization, phosphatization, sulphatization and dolomitization.

Dissolution: The process is non selective and generates vug porosity, lower than 5%.

Neomorphism and Recrystallization: Neomorphism of homoaxial inversion, occurs in mollusk shells, with the preservation of the original fibrose texture, replaced by low magnesium calcite more stable than the high magnesiun original shells. This process involves the carbonate mud matrix which it is transformed in micrite by loss of magnesium. Micritic recrystallization process to pseudospar are minor, also like the scarce recrystallization of fossils shells.

6.- FINAL REMARKS:

La Luna Formation diagenesis, for the sections objective of this study, is mainly represented by early diagenetic processes, with little evidence of a burial diagenesis. Some of the important aspects of the diagenetic evaluation will be discuss below:

1. The presence of a clay matrix made by an abundant proportion of montmorillonite-smectite and carbonated mud, with an original texture not recrystallized, in conjunction with the existence of a foraminiferal fossil fauna very well preserved indicate a low diagenetic grade in the studied sections. (Fig. 2A and B).

2. The effects of silicification associated to fossil cavities are related to early diagenetic replacements during marine depositional in presence of organic matter. The last one works as absorbent in the separation of the silica in a solution or colloidal suspension, before its reduction. Kaolinite associated with chert in the fossil cavities filling, evidences a relation of contemporaneousness of this process and genetic affinity (Fig. 3C and D). The silica cement (chert) represents penecontemporaneous sedimentation with compaction, as a product of fluid expulsion from the matrix.
3. The presence of framboidal pyrite and anhedral and euhedral sphalerite, in reductive conditions, can be explained by the mobility of elements classically enrichers of the organic matter, such as zinc, capable of simultaneous incorporation in the interior of the pyrite in depositional environments typically resistant to anoxic sulphurous conditions (Huerta-Diaz., 1990 and Morse, 1992 cit. in Mongemont *et al*., 1996) (Figs. 2C and D).
4. The presence of barium sulphate in association to phosphates suggests a high content of phosphorus and barium ions during la Luna sedimentation (Mongemont *et al*., 1996)(Figs. 3E and D)
5. The process of transformation of the organic matter associated with the changes of metals trapped with the sediments during diagenesis, could be incorporated to new phases such as sulphurs, or they can also be absorbed in carbonates or philosilicates (Disnar, 1980; cit. in Mongemont *et al*. 1996); in consequence the sediments would keep this information in their traces elements.

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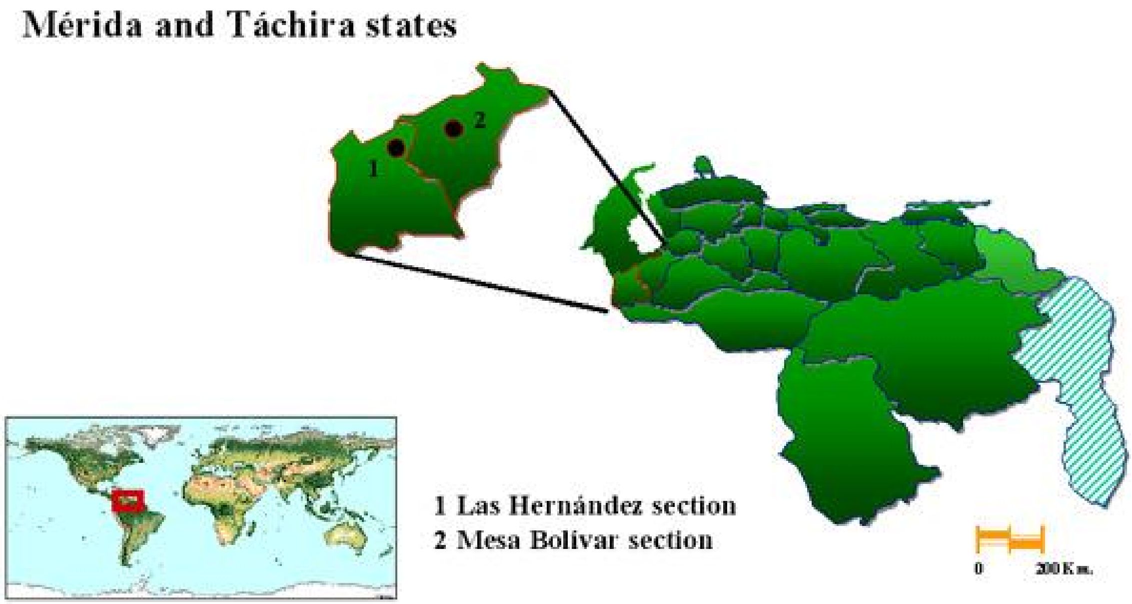

Fig. 1.- Location map of the study area

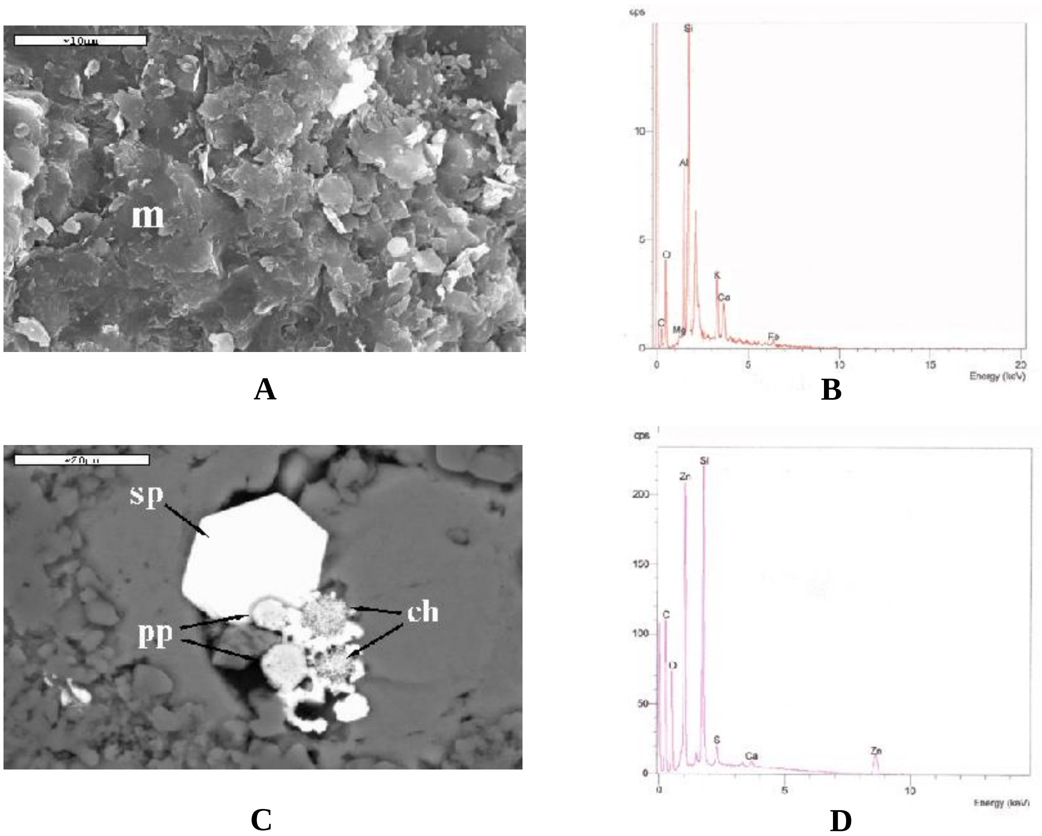

Fig. 2.- Rocks components: A) Montmorillonite-smectite matrix (m); B) Montmorillonite-smectite matrix spectrum; C) Sphalerite (sp), euhedric phramboidal pyrite (pp) and chert (ch); D) Sphalerite spectrum.

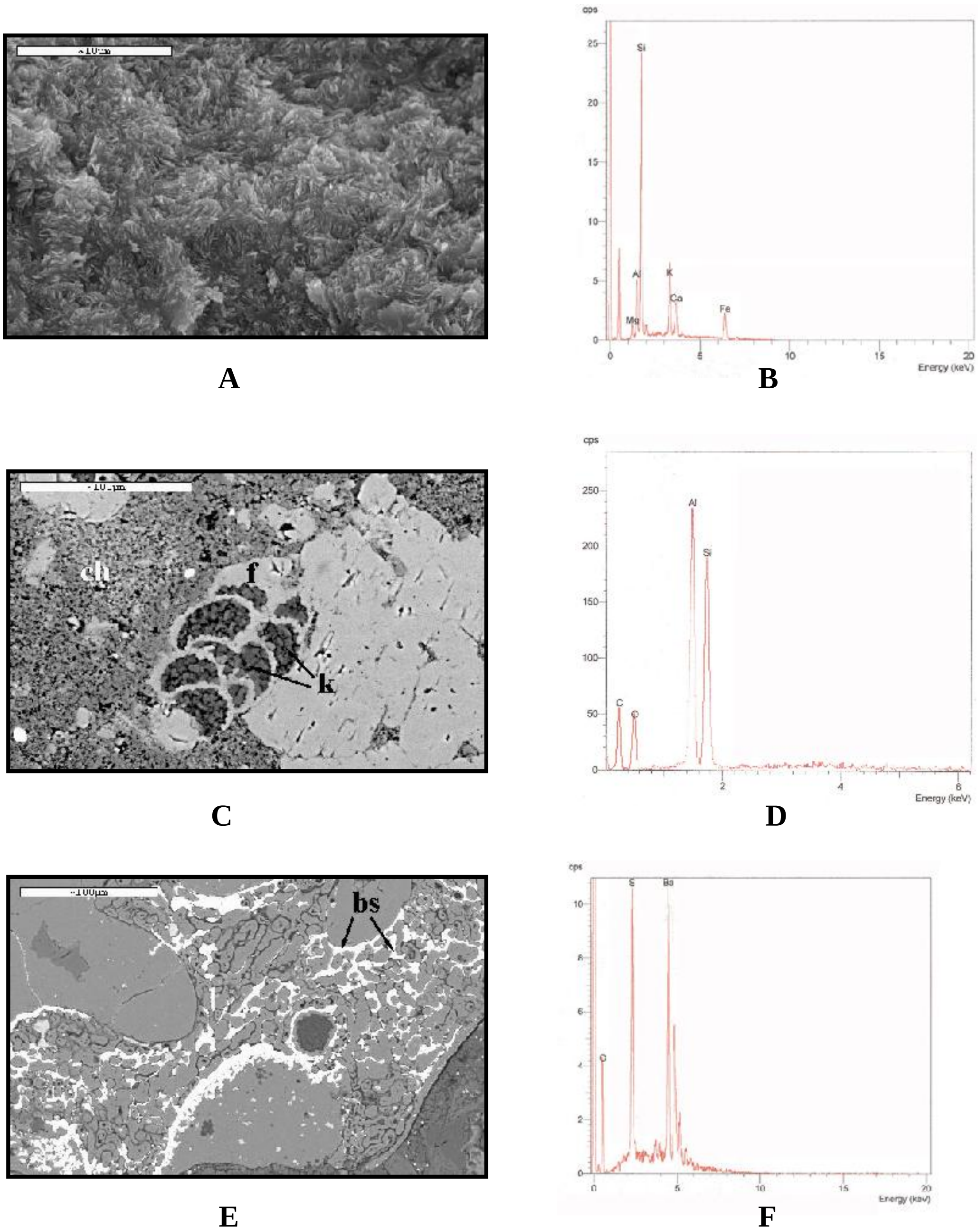

Fig. 3.- Rock components: A) Glauconite (g); B) Glauconite spectrum; C) Kaolinite cement (k) filling a *Bolivinoides* sp. in a chert (ch)–micrite (mic) matrix; D) Kaolinite spectrum; E) Barium sulfate (bs) in bone fish; F) Barium sulfate spectrum.