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Microfacies Study of Dissolution and Precipitation in Littoral Deposits on the Western Coast of Baja California Sur (Mexico)

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ABSTRACT

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The study area, located on the western coast of Baja California, in its south-central portion, discloses several outcrops of well-preserved marine deposits at various elevations and thicknesses which are attributed to a series of Quaternary marine transgressions. The paleolittoral deposits form a belt parallel to the present coastline, and in some places there are as many as nine of these belts with heights between 5 and 90 m. The microfacies study provided an understanding of various diagenetic processes which have taken place in these deposits. The deposits consist mainly of well-consolidated sandstones and beach conglomerates, with both macrofauna and microfauna. The microfauna has been reworked and broken. These diagenetic processes took place in a mainly subaerial environment. The lithification began usually in a shallow marine environment and continued after the emergence under the influence of fresh water and variations of the water table, which led to the dissolution of the organic carbonates, mainly fossil shells. The oldest deposits show evidence of several dissolution phases and successive recrystallization of the cement, also the epigenesis of quartz and feldspar grains as well as caliche production as a result of Quaternary climactic changes.

ADDITIONAL INDEX WORDS: *Beach conglomerate, macrofauna, microfacies, microfauna, marine terrace, paleolittoral deposits.*

INTRODUCTION

The west coast of Baja California is one of the few places in Mexico where there are traces of old coastlines, represented in the landscape as marine terraces of littoral deposits and erosion benches, which testify to the high marine levels reached by the transgressions that originated from fluctuations of sea level during the glaciations and deglaciations which have occurred since the Pliocene.

A determinant factor for the conservation of these coastal deposits is the recent tectonic activity that has affected the peninsula (ORME, 1972; ORTLIEB and MALPICA, 1978; ORTLIEB, 1978; MALPICA, CELIS and ORTLIEB, 1980.)

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The study area is located on the Pacific coast in its central-south portion (Figure 1) where, at various elevations of lateral extent, the Quaternary deposits are well-preserved.

MARINE TERRACES

The paleolittoral deposits are present as belts parallel to the present coast, with nine of them in some places as between Bahiá Asunción and Punta San Hipólito. The height of the top of such belts increases from the shore towards the interior, from +5 to +100 m. The deposits are in part dissected and transverse cut by fluvial erosion, as to the east of Bahiá Asunción, or are covered by alluvium as to the north of Punta Prieta.

Generally, around 5 m above sea level, there is a terrace that consists of a littoral marine deposit but

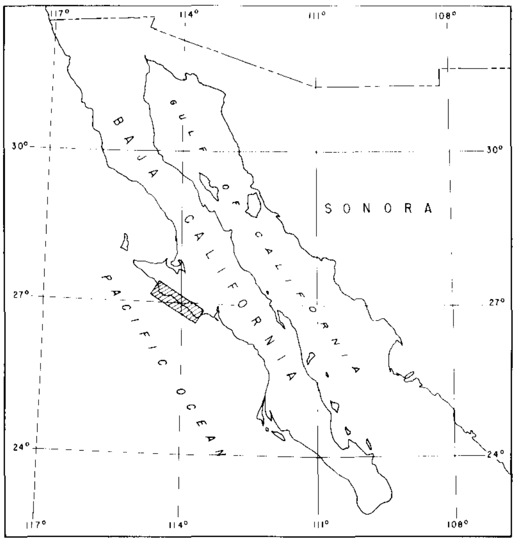

Figure 1. Location of the study area.

in some places, as at Punta Asunción and to the northeast of Punta Prieta, it includes a layer of alluvial sediments. At the basement of these deposits a beach conglomerate can be interpreted as the product of a transgression; overlaying it there are consolidated littoral deposits, and at the top are less-consolidated beach deposits of coarse sand with well-preserved fauna, considered to be late Pleistocene (ORTLIEB, 1979).

The most extensive terrace in this region (Figure 2) varies in elevation between +15 and +20 m, with a thickness between 3 and 10 m (MALPICA *op. cit.*), and contains a coquina rich in *Tivela stultorum*, which ORTLIEB (1978, 1979) has informally labelled the "*Tivela stultorum* coquina". The difference of altitude is due to regional and local tectonic movements (ORTLIEB *op. cit.*). This deposit extends through several kilometers. It is constituted of loose and semiconsolidated sand, well-lithified sandstones, calcarenites and calcirudites. In some parts is observed a thin calcareous crust or calcrete. It presents changes of lateral facies varying from high-energy beach sand to clay-silt sand that corresponds to protected beaches or bays.

In almost all of its extent the stratification is slightly inclined towards the sea, characteristic of most beach deposits. Generally these deposits are close to the present coast, associated with an erosion terrace. It is inferred that these deposits can be correlated with a transgression dated between 200,000 and 250,000 years in some other parts of the world and which corresponds to the last interglacial period of the middle Pleistocene (BUTZER, 1974).

In the same way, there are other littoral deposits at elevations of 20, 35, 45 and 50 m, also well-consolidated and with calcareous crusts, mainly in the top, which does not happen in the lowest terrace. Generally they are present as calcarenite or calcirudite facies with fauna in the process of dissolution. These deposits contain a fauna of *Cardium* sp., *Donax* sp., *Ostrea* sp., and *Tivela stultorum*. Lithologically they resemble the 15-20 m level of the *Tivela stultorum* coquina with a greater degree of consolidation.

It can be observed thus that the deposits of marine terraces of lowest elevations are less consolidated than the higher deposits, so that it is considered that subaerial processes have acted on the latter during the longest periods.

The study of the microfacies provides insight into the various diagenetic processes that have acted on these deposits and that are determinant factors for the lithification of some horizons and for the formation of calcareous crusts (calcrete). The consolidation of the deposits results from a complex process in which dissolution and precipitation phenomena have taken place in a subaerial environment.

DESCRIPTION OF THE DISSOLUTION PHENOMENA

In each of the samples studied (18), two dissolution phases are seen that are due mainly to a meteoric alteration that will be described below. One of them is represented by the dissolution of carbonate elements, the other affecting silicaceous elements. Within the first phase was observed the dissolution of shells of organisms consisting mainly of mollusks (gastropods, pelecypods) and foraminifers. The diagenetic process starts with the formation of a micritic cover; later, the cracks in the shells that result from collisions that they have undergone, favor the aragonite dissolution as well as a micritic replacement. As the shell dissolution increases, it leaves a space determined by its original contours and in some cases some part of the original shell is preserved. As can also be observed in some deposits (*e.g.*, 3 km to the east of Bahiá Asunción, in the Arroyo Camaleón, 10 km to the south of Rancho San Rafael), there is sometimes a complete dissolution of the shells, leaving only the internal and external molds of the organisms.

The second phase of dissolution was observed in

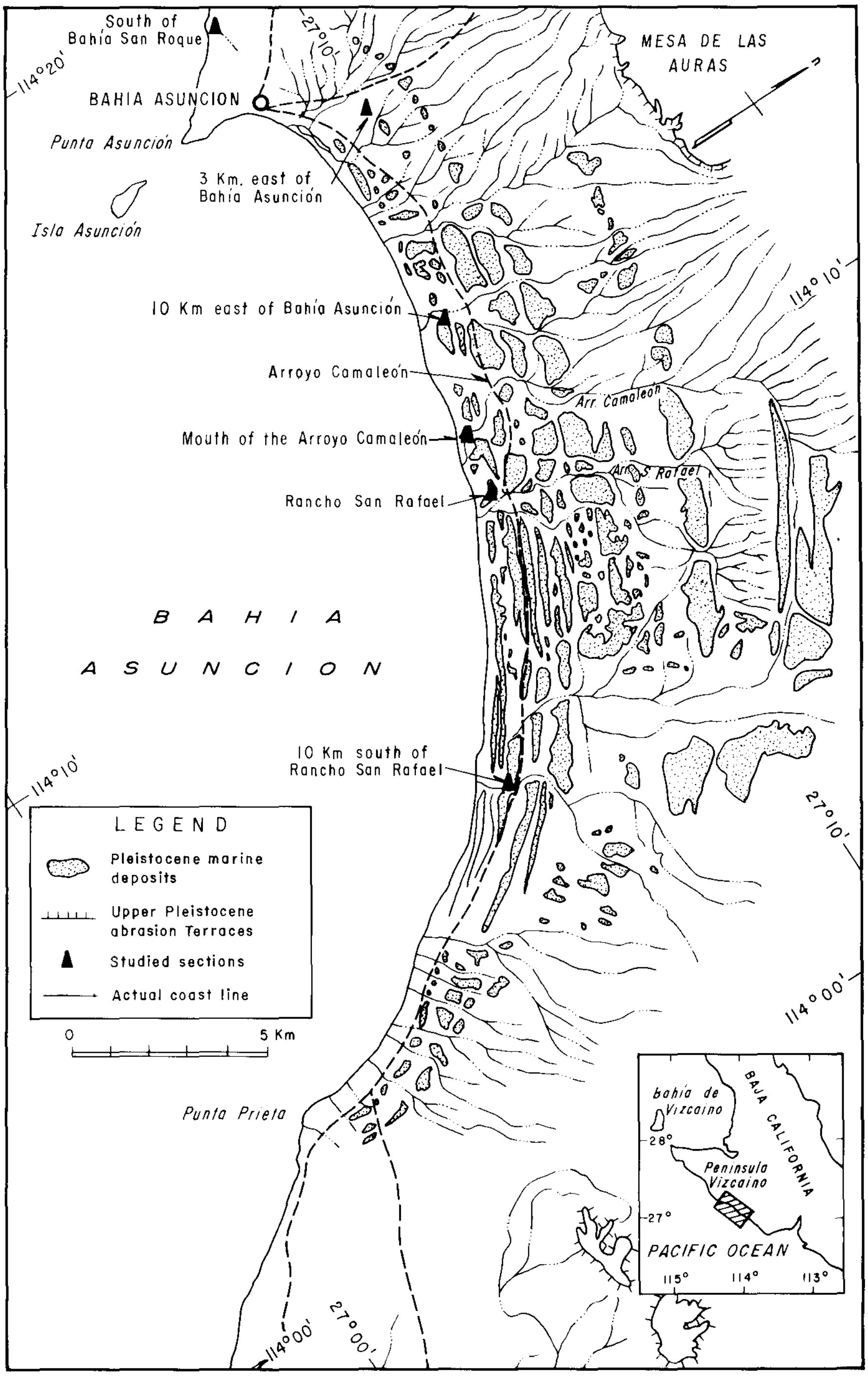

Figure 2. Location of study sections, marine deposits, and terraces.

the matrix that was originally constituted of micrite, but in the dissolution phases it is frequently replaced by espatite. In most of the cases, the matrix dissolution gives rise to an intergranular porosity.

The phenomena we have just described are frequently initiated as a result of the dissolution of the carbonates in contact with meteoric water and with ground water or meteoric water at shallow depths.

At the present time, it is in this subaerial or shallow-water marine environment that the carbonates generally undergo diagenetic processes of dissolution/precipitation type (FRIEDMAN, 1964; BATHURST, 1973; LUCAS *et al*, 1976). The subaerial phase is the "epidiagenesis" of FAIRBRIDGE (1979). The process is as follows: the calcite and aragonite are easily dissolved under the action of fresh water. The amount of carbonate taken into solution rises at the same time as the amount of CO_2 in the water increases (AUBOIN *et al*, 1975). This low alkaline water has thus a tendency to acquire a low pH due to the liberation of the H+ ions, being transformed this way into a corrosive water (ELF-AQUITAINE, 1977).

In this environment organic fims are oxidized. The aragonite is progressively dissolved, until a small micritic cover is left (BATHURST, 1971, 1973; FRIEDMAN, 1973). Such dissolution often produces a secondary porosity within the matrix. At the same time that the aragonite is dissolved, a non-magnetic calcite is formed (espatite), the precipitates replacing successively the intergranular and intragranular spaces, in the form of drusy calcite (PURSER, 1973; ELF-AQUITAINE, 1977).

In the second dissolution phase, the one that involves silica, two forms were observed with diverse development stages. The most common dissolution is the one that is present when small cracks that already existed are filled with micrite starting from the periphery of the grains. Later the dissolution is extended, forming a dense anastomosed net within the coarser grains (Figure 3). The most advanced dissolution phase leads to an actual grain disintegration, leaving its original contours delineated by the contact between the matrix micrite and the espatite from the intragranular neoformation which replaces the thin vein of the initial micrite.

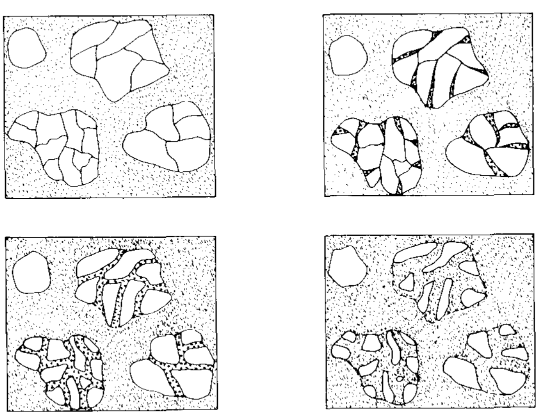

Figure 3. Stages that show the fragmentation process by dissolution.

The other dissolution type observed is one that starts in the periphery of the grain and which progressively leads to its reduction until all that is left is a small remnant of the original grain, bordered by espatite. As in the former case, the original contour of the grain is in some samples preserved by a micritic aureole.

Both cases appear to be related to an epidiagenetic phenomenon, that is, to a mineralogic modification that affects the grains under near-surface non-marine hydrologic conditions. This process consists of a molecule-by-molecule replacement in which the crystallographic net of the original grain is preserved (PETTIJOHN *et al*, 1972).

According to MILLOT *et al* (1959), the silica is susceptible to solution by waters with a relatively high pH, of the order of 9. This type of pH can often be found in ground water, especially in semiarid regions (FRIEDMAN, 1973). It is important to notice, that these processes seem to be related to the presence of primitive organisms (bacteria, fungi, etc.) that considerably modify the physico-chemical conditions of the environment.

DESCRIPTION OF THE PRECIPITATION PHENOMENA

We have seen that in a subaerial environment, the water of percolation plays an important role, causing the dissolution/precipitation processes which concern mainly the calcite and silica.

The calcite precipitation takes place as micrite and as espatite. Two types of micrite were observed; one chemically precipitated, probably in the intergranular spaces and a secondary one observed in the crusting and micritization periods. The most common observed case is the one in which the matrix is formed by a micrite that corresponds to an homogenous carbonate mud that might have fragments of microorganisms or clay particles. This is generally observed in the wackestone and packstone samples.

The secondary micrite is present in several forms: as a thin cover around some grains more or less micritized; in the form of a uniform crust around the grains in the case of rocks with a grainstone or packstone texture; in uniform or laminar crusts, including small nodules; and in calcareous crusts associated with the growth of algae. The small parallel layers, alternatively dark and clear, form stripes of micritite and espatite respectively.

The espatite presents different aspects, depending on where it is observed. Inside the intragranular spaces it can be observed forming rhomboid crystals in the form of "dog teeth", or as a geodic calcite (BATHURST, 1958), or as small calcite crystals, or as a mosaic which DUNHAM (1969) called cement in the shape of a meniscus. Inside the intergranular spaces it is present in the form described above or in the form of a regular mosaic which seems to fill the cavities.

The silica is observed in some cases in a partial epidiagenetic replacement of feldspar grains by the silica which can start in the grain peripheries or in some cracks of the grains.

INTERPRETATION

A matrix could have had its origin within the same environment as that of the deposit, being influenced in this case by marine water supersaturated with calcium carbonate (BATHURST, 1973). In the same way the micritic covers and the several micritizations of the grains can be started in this environment.

Afterwards, when the sediments are more or less consolidated they are exposed and submitted to the action of the subaerial environment. This is produced within the vadose zone and under the effect of the meteoric water, somewhat alkaline, due to the dissolution of the micritic matrix and the aragonite of the shells of organisms. At this stage the grains become covered by uniform micritic crust (BATHURST, 1971; ELF-AQUITAINE, 1977).

In the phreatic zone there is a permanent circulation of alkaline water that helps the dissolution of the silica or the precipitation of carbonates. Within this zone the cementation seems to become more important. The enrichment of these waters with $CaCO_3$ due to the processes that we have already explained favors the precipitation of the espatic calcite.

The first phase of the cementation is the development of crystals with the shape of "dog teeth". Afterwards the precipitation and growth of the carbonate in the shape of drusy mosaics reduces the intergranular porosity (ELF-AQUITAINE, 1977).

The caliche (calcrete) crusts are produced by the dissolution of the shell carbonates under the direct action of meteoric water followed by the percolation in the vadose zone and carbonate precipitation in the fluctuation zone of the phreatic level.

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□ RESUMEN □

El área de estudio se localiza en la costa Oeste de la Baja California, en su parte Sur-Central, disponiendo varios depósitos marinos en buen estado de conservación a diferentes cotas y con distintos espesores, lo cual se atribuye a las distintas series de la transgresión Cuaternaria marina. Los depósitos paleo-litorales se disponen a modo de cinturas paralelos a la actua linea de costa, presentándose en lugares hasta nueve de los citados cinturones con alturas entre 5 y 90 metros. El estudio de las microfacies permite conocer los procesos diogenéticos que se producen en estos depósitos, que están constituidos por areniscas y conglomerados bien consolidados con macro y microfauna, estando esta última removida y rota. Estos procesos tienen lugar principalmente en un ambiente anaerobio. La litificación comienza normalmente su desarrollo en las profundidades marinas y continua, una vez producida la emergencia, bajo la acción del agua dulce, cambiando las caracteristicas fisico-quimicas del agua, lo produce la disolución de los carbonatos orgánicos principalmente de los fósiles. Los depósitos más antiguos evidencian varias fases de disolución y sucesivas recristalizaciones del cemento, asi como la epigénesis de los granos de cuarzo y feldespato y la producción de caliches como resultados de los cambios climáticos cuaternarios.

□ ZUSAMMENFASSUNG □

Das in der Westküste Baja Californias Forschungsgebiet bringt viele Anstehen von gut erhaltenen Seelagerstätten ins Licht, die auf verschiedenen Höhen und in verschiedenen Dichten zu finden sind und mit einen Reihenfolge der Quartärseeauflagerungen zuordnen sind. Die Palaeostrandlagerstätten bilden einen Gürtel parallel zu die aktuelle Küste; bei vielen Stellen gibt es bis zu 9 Gürteln, die zwischen 5 und 90 m Höhe. Die Mikrofazieforschen liefert ein Verständnis für verschiedenen Diagenetikprozesse, die in dieser Lagerstätten stattfunden worden sind. Die Lagerstätten bestehen überhaupt aus Sandstein und gut kompakte Strandkonglomeräte; die bieden enthalten Mikro- und Makrofauna. Die Mikrofauna ist wiedergebildet und zerbrochen worden. Diese Diagenetikprozesse sind unter eine überhapt anärobische Umgebung stattfunden. Die Versteinung hat normalerweise in einer seichten Seeumgebung angefangen, und ist nach der Auftauchen vom Süsswasser und Grundwasserspiegelveränderungen beeinflusst, der die Auflösung der organischen Karbonaten–hauptsächlich Fossilschalen–gewirkt haben. Die älteste Lagerstätte legen Zeugnis für vieler Auflösungen und Wiederkristallisierungen der Bindung ab, auch der Epigenese der Quarz- und Felspatekörner und Kalische-Herstellung als Folge der quatärischen Klimaveränderungen.