Carbonate ramp facies at the Calabozo Formation (Middle Jurassic), Mendoza, Argentina

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ABSTRACT

The limestones of the Calabozo Formation of early Callovian age, crop out in the Neuquén Basin, southwestern Mendoza Province, Argentina. Facies/microfacies analysis at Arroyo El Plomo, west of Malargüe, shows that the limestones of the Calabozo Formation originated during a transgressive /regressive episode over the delta-margin facies of the Lajas Formation (late Bajocian-Callovian), with a change from siliciclastic to carbonate sedimentation. An extensive layer of floatstone marks the beginning of this stage. Within a ramp environment, a well represented mid-ramp subenvironment can be distinguished, consisting of a subtidal facies arrangement (wackestones, packstones, packstones with channels and floatstones) and an inner ramp subenvironment, characterized by a system of ooidal bars (grainstones) with tidal channels (floatstones) and predominantly intertidal facies passing into peritidal, and supratidal facies (boundstones). Three shallowing-upward cycles were recognized, the lower and middle ones being characteristic of the mid- ramp. The upper cycle is the best developed and consists of a middle ramp lower hemicycle and an inner ramp upper hemicycle. The Calabozo Formation is capped by deposits corresponding to a supratidal environment with restricted circulation, on top of which the evaporitic succession of the early Callovian Tábanos Formation is developed.

Keywords: Lmestones, Palaeoenvironmental analysis, Callovian, Neuquén Basin, Argentina.

RESUMEN

Facies de la rampa carbonática de la Formación Calabozo (Jurásico medio), Mendoza, Argentina. Las calizas de la Formación Calabozo (Caloviano inferior) afloran en el sudoeste de la Provincia de Mendoza, Argentina, dentro del ámbito de la Cuenca Neuquina. En el presente trabajo, se realiza el análisis facial/microfacial de esta unidad en la localidad del arroyo El Plomo, el que permitió inferir las condiciones de sedimentación y el modelo de rampa carbonática local. Las calizas de la Formación Calabozo representan un episodio transgresivo sobre las facies deltaico-marginales de la Formación Lajas (Bajociano tardío-Caloviano), como así también un cambio del régimen

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sedimentario silicoclástico a carbonático. El inicio de esta etapa se manifiesta por un nivel de 'floatstone' de amplia extensión areal. En el ambiente de rampa se distinguieron el subambiente de rampa media que es el mejor representado y está compuesto por un arreglo de facies submareales ('wackestones', 'packstones', 'packstone' con canales y 'floatstones') y el subambiente de rampa interna, caracterizado por un sistema de barras ooidales ('grainstones'), con canales mareales ('floatstones') y con predominio de facies intermareales que pasan a perimareales hasta supramareal ('boundstones'). En la evolución de la rampa se diferenciaron tres ciclos con tendencia somerizante. Los ciclos inferior y medio son característicos de la rampa media. El ciclo superior es el mejor desarrollado y, en él, se distinguen un hemiciclo inferior, de rampa media y un hemiciclo superior, de rampa interna. La Formación Calabozo culmina con depósitos de ambiente supramareal de circulación restringida, sobre los cuales se desarrolla la sucesión evaporítica de la Formación Tábanos del Caloviano inferior.

Palabras claves: Calizas, Análisis paleoambiental, Caloviano, Cuenca Neuquina, Argentina.

INTRODUCTION

The Calabozo Formation crops out in the Neuquén Basin of southern Mendoza Province, Argentina. This unit is exposed from Río Salado in the north, to the Bardas Blancas region, in the south. It is represented by relatively thin and isolated outcrops formed by bioclastic and ooidal limestone beds. Even though there is large bibliography on the analysis of the Jurassic-Cretaceous sequences, there are few studies on the Calabozo Formation, probably due to its restricted distribution. Dessanti (1973, 1978), described the carbonate beds exposed in Arroyo Calabozo, in the neighbourhood of Cerro Puchenque, and introduced the name 'Calizas de Calabozo' and dated them as Oxfordian. He assigned them a thickness of 50 m because levels belonging to La Manga Formation were included (Legarreta and Gulisano, 1989, and Legarreta *et al.*, 1993). Palma and Lo Forte (1999) described cyanophites in the limestones beds of Arroyo Calabozo. Palma *et al.* (2000a, b) carried out sedimentological, microfacial and diagenetic studies in southern Mendoza, but the exact geographic location of the studied outcrops was not indicated. Cabaleri *et al.* (2001), analysed the sedimentology and geochemistry of Calabozo Formation in Arroyo La Vaina.

The presence of ammonites in beds underlying these limestones at the type section (Riccardi, 1984; Riccardi and Westermann, 1991) dated them as early Callovian (see also Legarreta *et al.*, 1993; Gulisano and Gutiérrez Pleimling, 1994; Legarreta and Uliana, 1996; Uliana *et al.*, 1999).

Jurassic-Cretaceous successions in southern Mendoza indicate relative changes at the base level which, according to Legarreta *et al.* (1993) and Legarreta and Uliana (1999), are due to tectonic activity superimposed on eustatic changes. The Calabozo Formation originated during the first Jurassic transgressive-regressive cycle recorded in the Neuquén Basin.

The Calabozo Formation lies conformably on the Lajas Formation (late Bajocian-Callovian), which is formed by calcareous sandstones and conglomerates accumulated in shallow-water marine conditions, with deltaic facies intercalated with tongue-shaped marine bodies of carbonaceous shales (Gulisano and Gutiérrez Pleimling, 1994; Legarreta and Uliana, 1999). Laterally, to the southwest of Bardas Blancas, the Calabozo Formation lies with an erosional contact on the sandy beach facies of the Bardas Blancas Formation (Upper Toarcian-Lower Bajocian) (Gulisano, 1981; Legarreta *et al.*, 1993).

Towards the end of the early Callovian, evaporites of the Tábanos Formation accumulated on top of the limestones of the Calabozo Formation, attesting for the complete dessication of the basin, possibly due to isolation caused by the magmatic arc located to the west (Legarreta and Uliana, 1996).

This paper deals with a facies/microfacies analysis and the reconstruction of the palaeoenvironmental model of the Calabozo Formation in the Arroyo El Plomo area, near the Cuchichenque mine (Fig. 1), Mendoza Province, Argentina. This study forms part of a larger project, on the sedimentology and geochemistry of carbonate units of the Neuquén Basin in southwestern Mendoza.

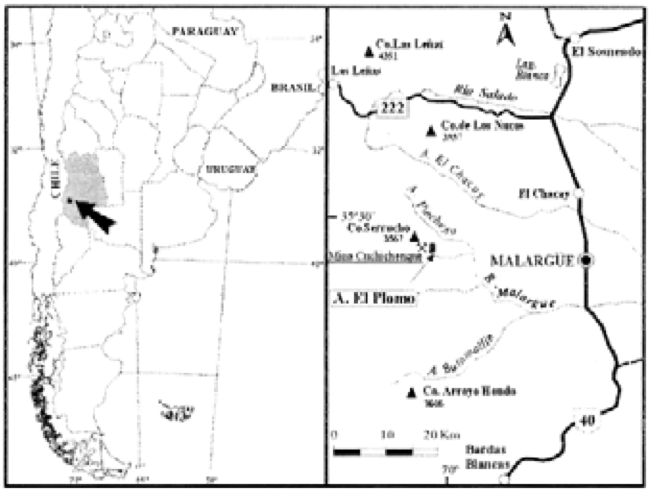

FIG. 1. Location map showing the area under study.

METHODOLOGY

Sedimentological and palaeontological analyses are based on detailed field observations along two profiles 1,000 m apart (Profile 1: 8 m, Profile 2: 4 m) (Fig. 2). Sedimentary structures were examined on a cm/dm scale and samples were collected in order to make thin sections and polished surfaces. Microfacies data were obtained from thin sections by quantitative analyses performed by point counting (500 points *per* every 7.5 cm^2 of section). The results allowed the determination of different facies/ microfacies which, together with the field data, enabled the authors to correlate between the profiles.

DEPOSITIONAL ENVIRONMENT

Analyses of the Arroyo El Plomo sections indicate that limestones of the Calabozo Formation were deposited on an extended ramp (*sensu* Ahr, 1973; Read, 1985, Burchette and Wright, 1992; Wright and Burchette, 1996). Facies associations are indicative of mid and inner ramp subenvironments.

MID- RAMP

The mid-ramp (Wright, 1996) facies association is made up of wackestones, packstones, packstone with channels and floatstones. There are no mudstones and the micrite is preserved in the wackestone and in some packstone layers. This mid-ramp facies association is widely developed in Profile 1, but in Profile 2 is only found in the lower levels (Fig. 2).

The characteristic components of this environment are ooids, intraclasts and bioclasts. Extrabasinal fragments have an irregular quantitative distribution in the different microfacies and reach a maximum in the floatstone facies.

The base level of **silici-intraclastic floatstone (FF1)** (Pl.1, a) spreads with varying thickness over the whole area under study, presenting a slight wedging in the neighbourhood of the Cuchichenque mine. This facies is made up mainly of siliciclasts (45%) with evidence of reworking. The size of the coarse particles (volcanic rock fragments) ranges between 5 and 19 cm in diameter. The fine-grained fraction, with an average size of 12 mm, is represented by quartz, plagioclase and potassium feldspar together with sandstone clasts. The texture is clast-supported and normally graded. Particles are oriented parallel to bedding, with imbrication in

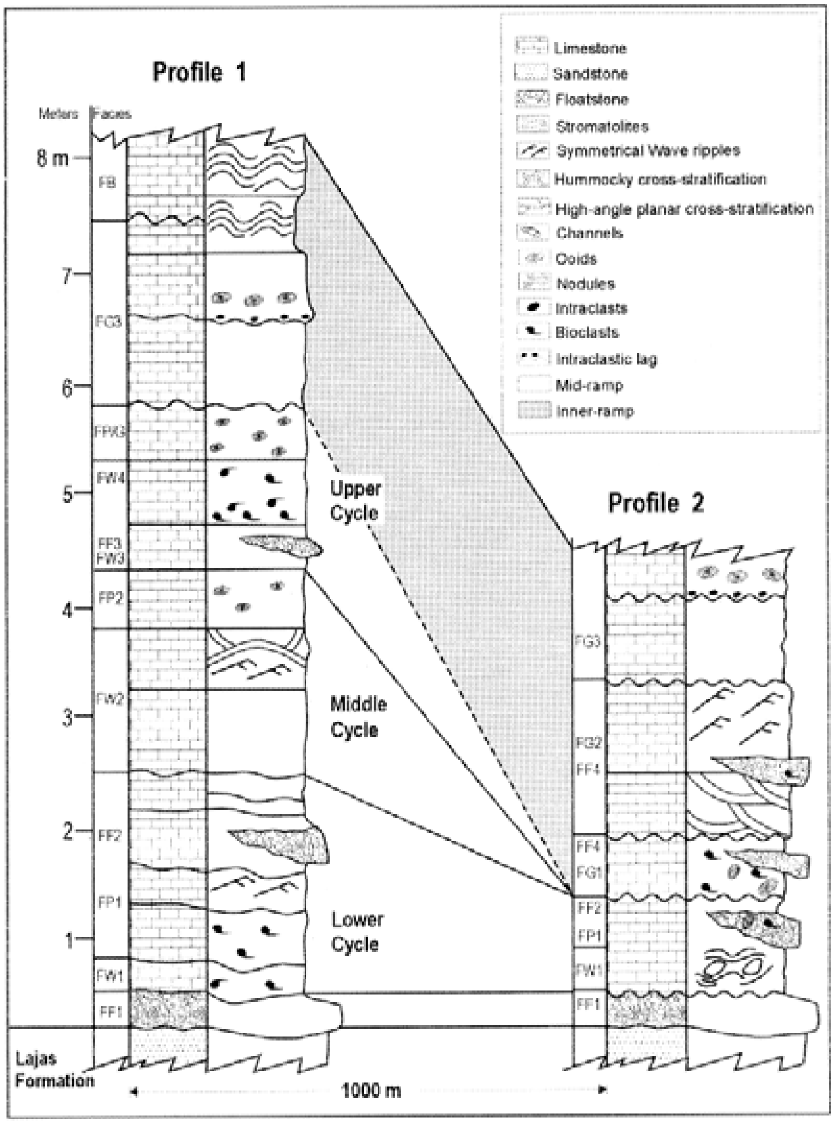

FIG. 2. Facies distribution and lithostratigraphic correlation scheme of the two studied profiles. The lines indicate the three shallowing-upward cycles that affected the ramp.

some areas. Intraclasts (15%) have different origins, some being composed of homogeneous micrite or microsparite with remains of filamentous algae; but most are cortoids with a well-defined dark micrite coat. Bioclasts (5.5%) consist of broken shells and dasycladacea algae. Ooids are rare (1%).

At approximately 2 m from the base of Profile 1, there is evidence of a major channel into which minor channels flowed, also identified in Profile 2, near the Cuchichenque mine. The main channel consists of an **oointraclastic floatstone (FF2)** (Pl. 1, b) composed of ooids (25%), intraclasts (15%) and siliciclasts (15%). The texture is clast-supported and the particles are poorly sorted. Bioturbation, mainly burrows, is common.

The **peloidal wackestone facies (FW1)** (Pl. 1, d-e), characteristic of the lower levels of the succession, is represented by well-rounded micrite peloids (15%), in part of faecal origin, of approximately 200 to 300 μm, radial concentric ooids (10%), micrite or other microfacies intraclasts (5%), siliciclasts (5%) of well-rounded quartz and feldspar crystals and lithic fragments. Very fragmented bioclasts (5%) are also present, consisting of brachiopods, echinoderms, corals, poorly preserved foraminifera and dasycladacea algae.

The **biointraclastic wackestone facies (FW2)** (Pl. 1, f-g), is found in the section ranging from 2.50 to 3.80 m. It consists of bioclasts of bryozoans, bivalves (*Weyla*), fish scales, gastropods and *Girvanella* (15%), together with intraclasts (8%), ooids (5%), peloids (5%) and siliciclasts (1%). Sedimentary structures are dominated by wave ripples that towards the top pass into hummocky cross-lamination. In the upper half of Profile 1, at approximately 4.5 m from the base, there is an **intrabioclastic wakestone (FW3)** (Pl. 1, h) that grades into a **pelointrabiosclastic (FW4)** (Pl. 2, a), where the intraclast and peloid content increases (20%) and bioclasts are larger than in the underlying facies. Bioturbation is represented by subhorizontal perforations.

In the FW3 facies, there are lenticular bodies, 0.70 m long and 0.20 m thick, of **biointraclastic floatstone with siliciclasts (FF3)** (Pl. 1, c). The bioclasts are very fragmented and other particles (intraclasts and ooids) show evidence of erosion. The intraclasts usually are well rounded and the ooids are broken or with abraded edges. They are poorly sorted and show an inversely graded texture.

The **oobioclastic packstone facies (FP1)** (Pl. 2, b-c), cropping out in amalgamated beds, is recognised at about 1.5 and at 1 m from the base in Profiles 1 and 2 respectively. It is made up of ooids (25-10%), bioclasts (15%), faecal pellets (5%) and intraclasts (5%). Siliciclasts (1%) and peloids (1%) are scarce. Among the skeletal fragments there are echinoderms, gastropods, bryozoans, complete and fragmentary bivalve shells, foraminifera and fish scales. An increase in the ooid content is indicative of its proximity to the inner-ramp ooidal bodies.

The **bioclastic packstone facies (FP2)** (Pl. 2, d-e) is represented by beds, up to 0.80 m thick, dissected by channels with well-defined erosional bases and dominantly wave-generated structures. Components show reworking and good sorting. Bioclasts (45%) consist of oriented broken large bivalve shells together with corals, gastropods, bryozoans, echinoderms, foraminifera, ammonites and dasycladacea algae. They are associated with intraclasts (15%), black pebbles (rich in organic matter and iron oxides) and sparite intraclasts with micrite coats (cortoids). Subordinate peloids (5%), faecal pellets (3%) and ooids (3%) are also present.

The **intraclastic packstone/grainstone facies (FP/G)** (Pl. 2, f-g) consists of well-rounded intraclasts (30%). The size ranges from 50 to 100 µm and the composition is variable, mostly from other microfacies. Bioclasts (15%) are represented by bivalve shells, foraminifera, echinoderms, fish scales and dasycladacea algae, in decreasing frequency. Trapped fine sand size grains are found in the cavities of small bivalve shells, forming a geopetal fabric. Ooids (5%) are similar to those present in the grainstone facies. Bioturbation is important, including *Thalassinoides*, *Planolites* and *Teichichnus*.

INNER- RAMP

The facies association characterizing the inner ramp (Wright, 1996), consists of grainstones and boundstones. This subenvironment is found in the upper levels of Profile 1 and constitutes almost all of Profile 2 (Fig. 2).

The **grainstone facies** is divided into:

Intraclastic grainstone (FG1) (Pl. 3, a-b) dissected by lenticular channels. The grainstone facies consists of well-rounded intraclasts (40%) with dark micrite coats. Intraclasts range from 0.20 to 2 milimeters in diameter. They are of different origins, but mostly from other facies (packstones) and with shell nuclei. Bioclasts (5%) are fragmented and consist of cephalopods and gastropods shells, bryozoans and dasycladacea algae. Micritic ooids (1%) are scattered about the rock. Some levels show bioturbation, with forms similar to *Ophiomorpha*.

The channels dissecting the intraclastic grainstone (FG1) consit of matrix-supported and inversely graded **intrabioclastic floatstone (FF4)** (Pl. 2, h). They form 3.5 m long and 0.12 m thick lenticular bodies with erosional bases. The main components are poorly sorted intraclasts (30%) and bioclasts (15%) of fragmentary *Weyla* sp. valves and corals. The matrix is an intrabioclastic wackestone that in some areas grades into grainstone made of intraclasts (8%), broken ooids (5%), small bioclasts (5%), oncoids (4%) and peloids (3%). Most grains are reworked and oriented.

Ooidal grainstone (FG2) (Pl. 3, c-d) shows high-angle planar cross-stratification with current and wave ripples. Grains are well sorted and correspond to ooids (15%) with nuclei of different compositions: bivalve shell fragments, small brachiopods or intraclasts as well as radial, micrite and sparite ooids. Intraclasts (8%), with mean sizes ranging from 100 to 350 μm, are composed of micrite, sparite and other microfacies; the particles are cortoids. Bioclasts (2%) include dasycladacea algae, gastropods and bivalve shell remains.

Intraclastic grainstone with ooids (FG3) (Pl. 3, e-f). The main components are intraclasts (35%) and bioclasts (20%) of cephalopods, brachiopods, echinoderms, corals, foraminifera and dasycladacea algae. Ooids and oncoids are also found (15%). This facies is represented by beds up to 0.60 m thick with erosional surfaces overlain by intraclastic lags, which form an extended thin body (0.03 m) present in both sections.

The **boundstone facies (FB)** (Pl. 3, g-h) consists of stratiform stromatolites, present in Profile 1 over a surface of erosion and dissolution of grainstone horizons. The microbial lamination is defined by an alternation of light microsparite and dark peloidal micrite. Laminae are crenulated, subhorizontal and laterally discontinuous. A fenestral fabric characterizes the upper facies levels. It consists of alternating fenestras, empty or filled with sparite. Pores are irregular, arranged subhorizontally concordant with stratification and surrounded by peloidal grumous micrite with a high content of organic matter and disseminated iron oxides. Porosity increases towards the top of the unit, where thin evaporitic gypsum beds are more conspicuous.

PALAEOENVIRONMENTAL MODEL

The facies association identified in the carbonate succession of the Calabozo Formation at the arroyo El Plomo are characteristic of a shallow-water ramp with a mid and an inner ramp subenvirontments (Fig. 3c). Carbonate beds overlie a ravinment surface on the delta margin sandstones (Fig. 3, a, b) of the Lajas Formation. This erosional surface is recognized from south of río Salado to north of the río Malargüe and indicates a change from a siliciclastic to a carbonatic regime within the basin.

During transgression, waves and tides eroded the delta plain (Fig. 3, b) and sediments (clasts, intraclasts, extrabasinal particles) were deposited forming a clast-supported floatstone (FF1). These bodies have a tabular geometry and show a slight wedging to the east (Profile 2, near the Cuchichenque mine entrance).

Facies/microfacies analysis indicates three shallowing-upward cycles affecting the ramp: lower, middle and upper, the last consisting of a lower and an upper hemicycle. The lower and middle cycles and the lower hemicycle are defined by the mid-ramp wackestone/packstone facies association, whereas the upper hemicycle is characterized by the inner ramp grainstone/boundstone facies association. The mid-ramp subenvironment is defined between fair weather wave base and storm wave base (Burchette and Wright, 1992), (Fig. 3, c) and is best represented in Profile 1 (Fig. 2). In Profile 2 (Fig. 2), the basal levels consist of the mid-ramp association, whereas the middle and upper levels, consisting of grainstone facies with ooidal bodies, characterize the inner ramp.

The lower cycle begins with a peloidal wackestone (FW1), formed under low-energy conditions that represent periods of quiet water circulation in the basin. The basinal and extrabasinal particles were transported by tidal currents and there is no evidence of wave activity. The grain association, frequently cortoids and biota, suggests shallow water conditions. Intraclast characteristics indicate a peritidal facies provenance. A particular feature of wackestone levels is bioturbation, mostly of the *Cruziana* icnofacies.

This facies is overlain by oobioclastic packstone facies (FP1), indicating that shallow water conditions were established on the ramp. High energy conditions are shown in the upper levels, by wave-generated structures, indicating a prevailing south-westerly flow, and by very fragmentary skeletal particles. This facies is dissected by a distributary tidal channel system (FF2) that transported sediments from marginal to basinal areas.

The middle-cycle facies and the biointraclastic wackestone levels were formed in a storm-influenced environment, under high energy and shallow water conditions (Wright and Burchette, 1996; Nichols, 1999). Particles are eroded and bioclasts are highly

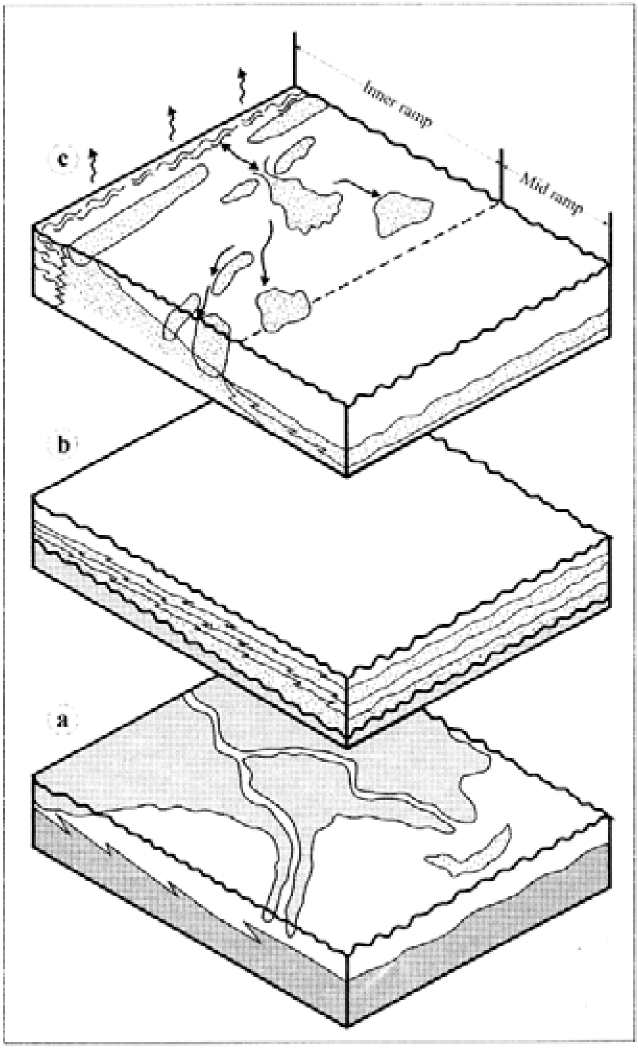

FIG. 3. Schematic representation of palaeoenvironmental model of the Calabozo Formation in the Arroyo El Plomo area; **a-** delta plain (Lajas Formation) previous to the development of the ramp, not analysed in this paper; **b-** maximum flooding surface and base floatstone levels of the Calabozo Formation. Settlement of highstand conditions and middle ramp facies association; **c-** morphology, structures and facies associated to the mid and inner ramps.

reworked. Amalgamated beds, megaripple structures produced by wave oscillation and hummocky cross-stratification are often found, which could be the result of storm-generated flows (Cheel, 1991; Cheel and Leckie, 1993).

The bioclastic packstone facies (FP2) was formed in shallow water ramp areas under fair weather wave oscillation. This facies (FW2), compared to the underlying wackestone, shows a higher percentage and greater size of bioclasts. The material is very fragmented and well sorted. Trace fossils of *Planolites* and *Palaeophycus* are present in this environment.

The upper cycle is the most widespread and shows a facies succession indicating a shallowing trend. Taking into account its thickness and that it attests to more conspicuous shallow water conditions than the previous cycles, it is subdivided into a lower hemicycle, including a mid-ramp facies (FW3, FW4, FF3 and FP/G), and an upper hemicycle, defined by an inner ramp facies (FG3 and FB). At the base of the lower hemicycle, the particle association and the biota of the intrabioclastic (FW3) and pelointrabioclastic wackestone (FW4) levels indicate quiet shallow water conditions. In the FW3 facies a small channel system (FF3) developed, indicating water discharge from the inner towards the mid-ramp, possibly due to a temporary increase in the amount of water received or captured by the basin. The mid-ramp facies is capped by a bioturbated intraclastic packstone/grainstone (FP/G). The environment shows moderate to low energy levels, affected by currents. The trace fossil association is a soft substrate ichnofacies, where sorting is poor to fair and depositional rate is preferably low (Pemberton *et al.*, 1992).

The inner ramp subenvironment (Fig. 3, c) extends from the high tide wave base to the fair weather wave base (Burchette and Wright, 1992), and is affected by waves and tidal currents (Reading, 1987). This subenvironment is better developed near the Cuchichenque mine entrance (Fig. 2, Profile 2), where a group of ooidal bar facies (FG2) and grainstones, formed in high energy environments (FG1 and FG3), are found on top of the mid-ramp facies (lower cycle).

In Profile 1 (Fig. 2) this subenvironment is represented by the upper hemicycle of the topmost shallowing-upward cycle (upper cycle). This hemicycle consists of intraclastic grainstones with ooids (FG3). The upper levels alternate with peritidal microbial beds. The succession ends with stromatolitic mats (FB), developed over an erosional surface truncating grainstone beds. Benthic microbial communities grew in shallower areas of the ramp and underwent recurrent episodes of subaerial exposure and evaporation with gypsum precipitation.

Near the entrance to the Cuchichenque mine (Fig. 2, Profile 2), the mid-ramp lower hemicycle facies are not present and are replaced by carbonate ooidal bodies from the inner ramp upper hemicycle. The ooidal bodies form elongated bars that are sometimes dissected by small tidal channels (FF4). These channels are filled by sediments deposited by currents coming from the inner ramp and marginal areas. In relatively low energy levels, a high density of *Ophiomorpha* burrows is present.

The inversely graded, well-sorted intraclastic grainstone beds (FG1) that grade into ooidal grainstone (FG2) indicate high-energy depositional conditions, which is typical of intertidal areas. The biota and ichnofacies association denote a normal marine environment with a sandy type mobile substrate under shallow and turbulent waters affected by currents (Pemberton *et al.*, 1992).

The top of the upper levels in Profiles 1 and 2 indicates evidently shallow water conditions on the ramp, and deposition of ooid rich intraclastic grainstones. In this facies an erosional surface and an intraclastic lag is also present, which may have formed in a wave dominated shoreface, similar to lags formed during forced regressions (Hunt and Tucker, 1995; Plint, 1998; Posamentier *et al.*, 1992).

The microbial facies (FB) are not found near the Cuchichenque mine, as an erosional surface truncates the upper beds.

CONCLUSIONS

The carbonate facies cropping out in the arroyo El Plomo area were deposited on a delta plain (Fig. 3a) forming a pre-ramp, for the transgression during which the Calabozo Formation sedimentation commenced. On the substrate formed by delta margin facies of the Lajas Formation, which represent a maximum flooding surface, the basal floatstone was deposited (FF1) (Fig. 3b). These levels are present in different localities from south of the río Salado to north of the río Malargüe.

During the subsequent highstand, prograding parasequences developed. In its initial phase, the highstand condition produced subtidal facies characteristic of a mid-ramp subenvironment, which are present throughout the area.

The mid-ramp (Fig. 3c) is better represented in the western sector (Fig. 2, Profile 1), where three different shallowing-upward cycles are identified: the lower and middle cycles are typically mid-ramp, whereas the upper cycle is characterized by a different facies association. Thus, the lower hemicycle of the upper cycle was formed in the subtidal areas of the mid- ramp and the upper hemicycle in the intertidal, peritidal and supratidal areas of the inner ramp.

The lower cycle, identified in both profiles, shows a slight decrease in thickness towards the entrance to the Cuchichenque mine (Profile 2) and is represented by the FW1 and FP1 facies. The floatstone facies (FF2) characterizes the tidal channel fills that retransported sediments from basinal and extrabasinal areas.

The middle cycle is formed by the FW2 and FP2 facies. It is found in Profile 1 and is missing towards the east, near the Cuchichenque mine (Profile 2). This indicates a strong shift from low energy subtidal environment facies, characteristic of the mid-ramp, to high energy intertidal environment facies, characteristic of the inner ramp.

The upper cycle is the most extensive unit and indicates a well defined regressive stage. It comprises the inner ramp subtidal facies with a small channel system (FW3 and FF3) and subtidal facies (FW4 and FP/G) (lower hemicycle) and the inner ramp intertidal, peritidal and supratidal facies (upper hemicycle). FG3 and FB in Profile 1 and FG1, FG2 and FG3 in Profile 2 represent the facies of this last hemicycle. The mid-ramp lower hemicycle facies wedge out and disappear towards the east (Profile 2), where they are replaced by the upper hemicycle facies. This suggests the predominance of a high energy intertidal environment in the eastern sector. In this environment, ooidal bodies (FG1 and FG2) were formed, and were under constant wave and current activity that caused erosion and the development of channel bars. These channels (FF4) trapped the sediments resulting from destruction of the ooidal bodies and enabled the material to be transported between the peritidal and subtidal areas.

Progradation of the marginal facies took place over the whole area and the increasingly shallower conditions favoured the development of peritidal to supratidal environments of the upper hemicycle (FG3 and FB). Restriction of the basin becomes more evident towards the top of the Calabozo Formation with the deposition of restricted circulation facies, on top of which the evaporitic succession of the Tábanos Formation developed.

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PLATES 1-3

PLATE 1

Figures (a-h) Mid- ramp facies of the Calabozo Formation, thin sections of the different types of floatstone and wackestone facies.

a FF1. Silici-intraclastic floatstone. Siliciclasts are the dominant components: quartz and tabular plagioclase crystals, and igneous rock fragments. Rounded intraclasts of homogeneous micrite, the smaller ones show thin dark micrite coats (cortoids). Scale bar: 500 µm.

b FF2. Oointraclastic floatstone. Radial and micrite ooids. Well-rounded micrite and sparite intraclasts. Siliciclasts: quartz, plagioclase and feldspar crystals and rock fragments. Grains are well sorted and show a clast-supported texture. Scale bar: 500 µm.

c FF3. Biointraclastic floatstone, with siliciclasts. Bioclasts of bivalve shells, echinoderms, intraclasts of micrite/ microsparite and of microsparite with sparite and dolomite crystals, siliciclasts: rock fragments and quartz. Scale bar: 500 µm.

d FW1. Peloidal wackestone. Micrite peloids, faecal peloids, well-rounded intraclasts, made of micrite with organic matter and of other microfacies, siliciclasts of quartz and rock fragments, ooids replaced by sparite. Scale bar: 500 µm.

e FW1. Peloidal wackestone. Transverse section of a foraminiferous, micrite peloids, ooids with feldspar nucleous, igneous rock fragment. Scale bar: 500 µm.

f FW2. Biointraclastic wackestone. Ooid with sparite nucleous, concentric ooid, well-rounded intraclasts, faecal peloids. Scale bar: 100 µm.

g FW2. Biointraclastic wackestone. Bioclast corresponding to a fish scale remain. Scale bar: 500 µm.

h FW3. Intrabioclastic wackestone. Bioturbation canal cutting through intraclasts and bioclasts. Scale bar: 500 µm.

PLATE 1

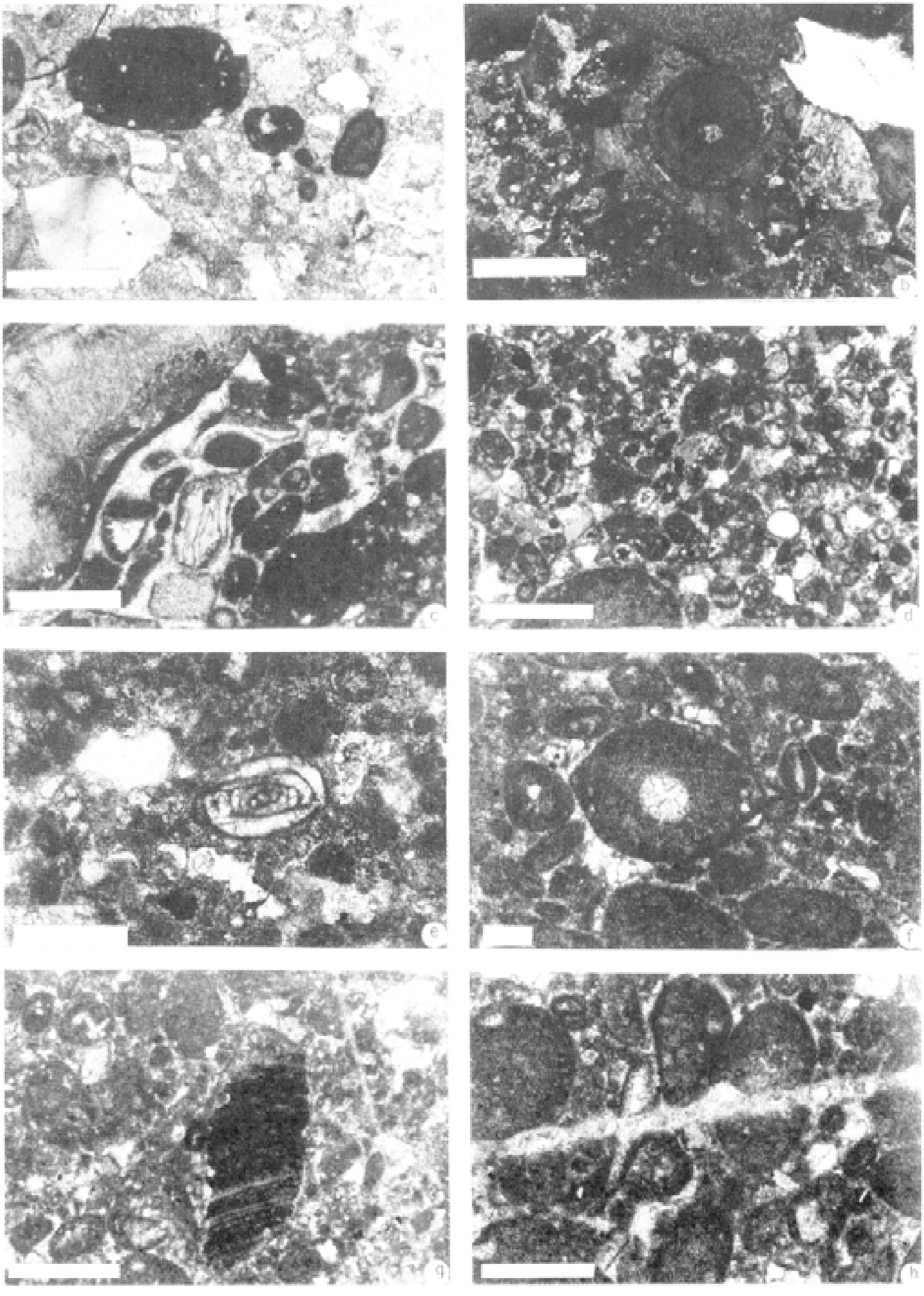

PLATE 2

Figures (a-h) Mid-ramp facies of the Calabozo Formation, thin sections of the different types of wackestone and packstone facies.

a FW4. Peloidal-intrabioclastic wackestone. Gastropod remains, fragments of bivalve shells, peloids, faecal peloids, small intraclasts. Scale bar: 500 μm.

b FP1. Oobioclastic packstone. Concentric ooids with sparite nucleous, micrite/microsparite intraclasts, micrite peloids, quartz and feldspar siliciclasts and rock fragments. Scale bar: 100 μm.

c FP1. Oobioclastic packstone. Foraminifera fragment, bioclasts with micrite coat, ooids, intraclasts, siliciclasts and bioturbation canal. Scale bar: 100 μm.

d FP2. Bioclastic packstone. Bioclasts, gastropod section, sparite intraclasts with micrite edges, peloids. Scale bar: 100 μm.

e FP2. Bioclastic packstone. Fragments of bivalve shells, micrite intraclasts, concentric ooids, cortoids. Scale bar: 100 μm.

f FP/G. Intraclastic packstone. Well-rounded intraclasts of micrite and of other facies, foraminifera. Scale bar: 100 μm.

g FP/G. Intraclastic packstone. Section of foraminifera, reworked bioclasts, intraclasts. Scale bar: 500 μm.

h Inner-ramp facies. FF4. Intrabioclastic floatstone. Intraclasts, broken ooids, siliciclasts, bioclasts. Peloidal micrite. Scale bar: 500 μm.

PLATE 2

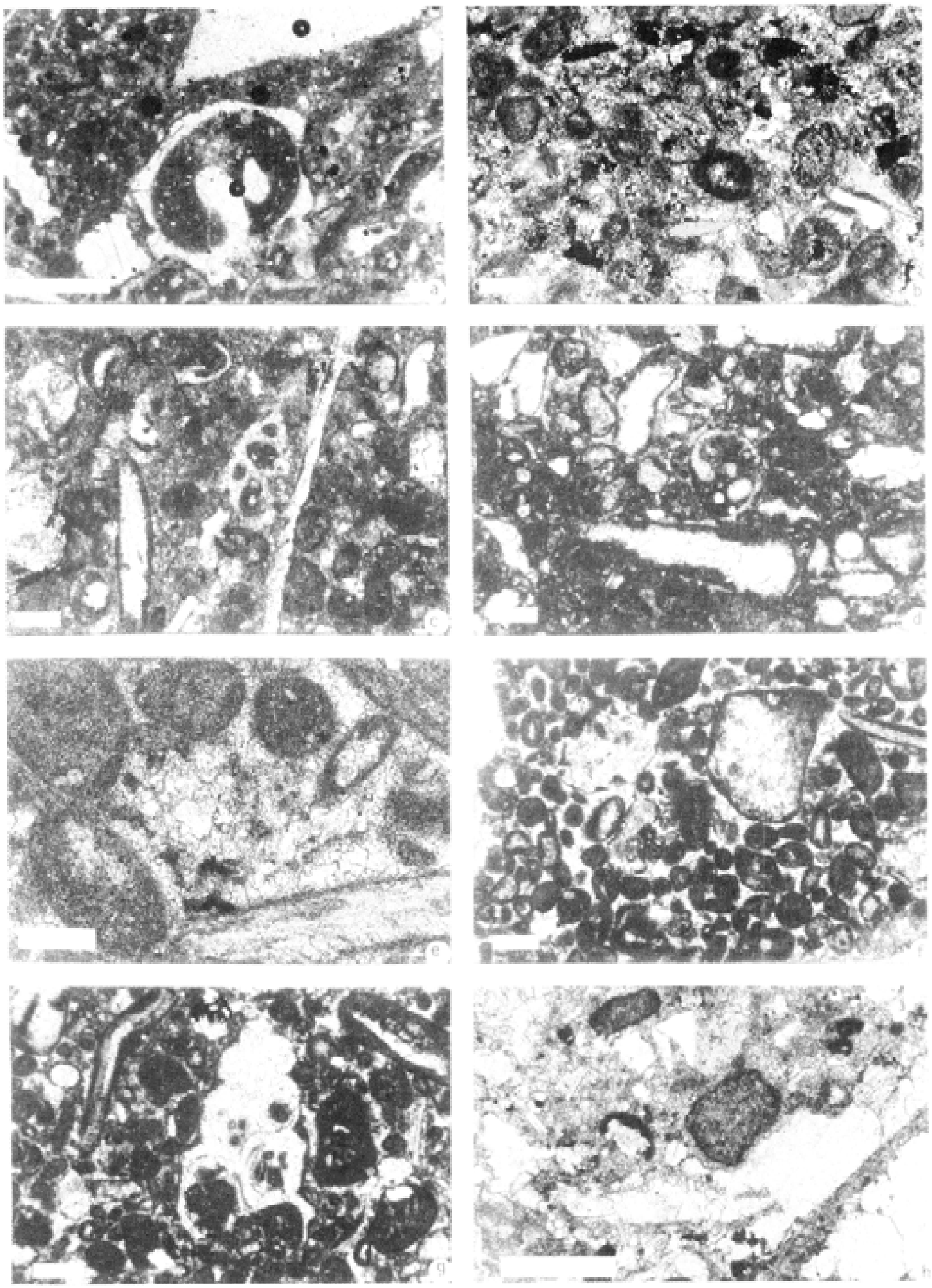

PLATE 3

Figures (a-h) Inner-ramp facies of the Calabozo Formation, thin sections of different types of ooidal body and stromatolitic boundstone facies.

a FG1. Intraclastic grainstone. Sparite-filled ooid with micrite coat, micrite intraclasts, peloids. Scale bar: 500 µm.

b FG1. Intraclastic grainstone. Reworked gastropod with micrite coat. Scale bar: 500 µm.

c FG2. Ooidal grainstone. Concentric ooids with nucleous of brachiopod, of micrite and of sparite.Reworked bioclasts, peloids, oncoids. Scale bar: 100 µm.

d FG2. Ooidal grainstone. Transverse section of dasycladacea alga crossed by microstilolite, peloids, micrite intraclasts. Scale bar: 100 µm.

e FG3. Intraclastic grainstone with ooids. Section of gastropod, ooids, oncoids and intraclasts. Scale bar: 100 µm.

f FG3. Intraclastic grainstone with ooids. Bioclasts represented by bivalve shells and vertebrate remains. Scale bar: 500 µm.

g FB. Stromatolitic boundstone facies. Subhorizontal microbial lamination, with crenulated contours; micrite laminae with iron oxides can be seen in the upper sector. Scale bar: 500 µm.

h FB. Stromatolitic boundstone facies. Contact between the stromatolitic level and the gypsum laminae. The stromatolite is made up of dark peloidal-grumous-micrite laminae with scattered black pebbles. Scale bar: 500 µm.

PLATE 3