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Non-marine Paleo gene sequences, Salta Group, Northwest Ar gentina

Secuencias Paleógenas continentales, Grupo Salta, Noroeste Ar gentina

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RESUMEN

Los depósitos de edad paleógena forman la culminación de la cuenca distensiva originada desde el Cretácico inferior hasta el Eoceno en el noroeste argentino. El desarrollo del *rift* presenta extensión regional y abarca parte de la sedimentación ocurrida en forma contemporánea en Bolivia, Paraguay y Chile.

Durante el desarrollo de cuenca con subsidencia termal, se formaron tres secuencias deposicionales constituidas por las Formaciones Mealla, Maíz Gordo y Lumbrera, que integran el Subgrupo Santa Bárbara del Grupo Salta. Estas unidades presentan características sedimentológicas similares que le confieren cierta ciclicidad a este período.

La distribución de los sedimentos y la asociación de facies del Subgrupo Santa Bárbara señalan una cuenca cerrada con sedimentación aluvial hacia los bordes y formación de lagos en el área central.

En la Formación Mealla se han reconocido cuatro asociaciones de facies (FA) que en gran medida identifican los ambientes sedimentarios que la integran. En posiciones de bordes de cuenca, por ejemplo sobre el borde del arco Traspampeano, se han identificado las asociaciones de facies 1 y 2 (FA1 y FA2) formadas por las litofacies Gm, Gt, Gp, Sm, Sp, Sm, Se, Fm, Fl, Fsc y P. Se ha interpretado un ambiente de abanicos aluviales proximales a distales con buen desarrollo de las facies de llanura de inundación y formación de paleosuelos carbonáticos. Hacia el centro de la cuenca se reconoció la asociacion de facies FA 3, integrada por Sp, St, Sr, Fm y P que indican sistemas fluviales arenosos interpretados como ríos entrelazados arenosos y meandrosos de grano fino. La FA 4 representa la deposición en medio subácueo, integrada por las litofacies F, Sw, Cm, E y Bs e interpretada como lago salino a lago abierto de agua dulce.

En la Formación Maíz Gordo el esquema es muy similar. Hacia los bordes de cuenca se reconoció la asociación de facies FA5, integrada por las litofacies Gm, Sm, St, Gh, Gp y Sp, e interpretada como abanico aluvial proximal y ríos entrelazados profundos. Lateralmente se reconoció la asociación de facies FA 6, formada por las litofacies Sp, St, Sr, Fm, Fl y P que representa la formación de ríos entrelazados arenosos. En el centro de la cuenca se identificaron las asociaciones de facies FA 7 y FA 8, integradas por las litofacies

Fm, Bs, Go, Ll, F, Lwl, Sw y P que indican sedimentación subácuea de tipo lacustre con extensa formación de facies litorales carbonáticas e internas de tipo meromíctico.

La Formación Lumbrera representa la culminación de la sedimentación en el Grupo Salta, caracterizada por sedimentación de tipo pelítico y frecuentes paleosuelos carbonáticos en el área con sedimentación aluvial. Está integrada por las asociaciones de facies FA 9, Sp, St, Se, Fm y P e interpretada como ríos meandrosos de arena gruesa, FA 10, Sp, St, Sr, Ss, Se, Sh, Sl, Fl y Fm cuya asociación representa ríos meandrosos finos en los que se distinguen los depósitos de sobrebanco, albardón y desborde. En el centro de la cuenca se reconocieron las FA 11 y FA 12, integradas por las litofacies St, Sr, F, Sw, Fm, Ll y Bs que representan la acumulación en un sistema lacustre clástico de tipos holomíctico y meromíctico.

El contenido paleontológico tanto de palinomorfos como de vertebrados revela variaciones climáticas fluctuantes desde situaciones de aridez hasta condiciones de mayor humedad, lo que sustenta las interpretaciones sedimentológicas realizadas. En la base de cada unidad se ha interpretado condiciones de aridez que pasan gradualmente a situaciones de mayor humedad hacia el tope.

Palabras clave: Paleógeno. Sedimentación continental. Noroeste Argentino. Grupo Salta.

ABSTRACT

Deposits of Paleogene age form the culmination of the distensive basin developed from Lower Cretaceous up to Eocene times in Northwest Argentina. The rift development shows a regional extension, and includes part of the sedimentation which occurred contemporaneously in Bolivia, Paraguay and Chile.

During development of the sag basin, three depositional sequences were laid down. These were the Mealla, Maíz Gordo and Lumbrera Formations, which make up the Santa Bárbara Subgroup of the Salta Group. These units present similar sedimentological characteristics, which gives this period a cyclic arrangement.

The sedimentary distribution and the arrangement of facies point to a closed basin, with alluvial sedimentation toward its borders, and the formation of lakes in its central area.

Each unit shows a particular pattern of river systems, from perennial sand-gravel bed braided streams to fine-grained meandering streams, and pattern of the lake originated there. It is recognized that each lacustrine basin started to develop under shallow conditions in an arid climate, and then evolved to deeper lakes, which reached stratification of the water mass.

The paleontologic content, especially the palinomorphs, records these fluctuating climatic changes, from arid situations to more humid conditions.

Keywords: Paleogene. Non-marine sedimentation. Northwest Argentina. Salta Group.

INTRODUCTION

Although the stratigraphic and sedimentologic characteristics of Salta Group are well documented, scarce sedimentological descriptions were carried out in Paleogene rocks of Santa Bárbara Subgroup.

In this paper we document a synthesis of the sedimentary evolution of Santa Bárbara Subgroup. Data come from outcrops where more than 25 stratigraphic sections were studied in detail in the Alemanía, Metán and Lomas de Olmedo sub-basins. Numerous data were obtained from previous papers carried out specially in subsurface. Sedimentary facies and facies associations and contact surfaces are analyzed with the paleontological record in order to propose a model of paleoenvironmental reconstruction for the formations of Santa Bárbara Subgroup.

The Cretaceous-Paleogene rocks in Northwest Argentina are of regional extent, and at present cover an area of approximately 150,000 km^2. Deposits of these units have been recognized in the Puna, the Eastern Cordillera, sub-Andean Ranges and Chaco-Pampean Plain (Fig. 1).

These sedimentary rocks were first described by Brackebusch (1891) who named them the "Salta System" and assigned them to the Cretaceous period. From then on, numerous works on the subjects of sedimentology, stratigraphy, paleontology, structures and geophysics have been carried out in the area of this basin. With the increase in knowledge, the Cretaceous-Paleogene depositional cycle was designated the Salta Group (Brackebusch, 1891; nom. subst. Turner, 1959), and divided into three Subgroups on the basis of the predominant lithologies and changes in the colors of sediments (Fig. 2), namely: the Pirgua Subgroup (Reyes and Salfity, 1973), Balbuena Subgroup (Moreno, 1970) and Santa Bárbara Subgroup (Moreno, 1970).

During the Cretaceous and Paleogene an intracontinental type rift basin developed in Northwest Argentina, in which continental sedimentary rocks accumulated, together with basaltic and ignimbritic volcanics. The distensive process also affected parts of the territories of Bolivia, Paraguay and Chile.

The origin of the distension has been explained as a consequence of deep crustal attenuation, brought about by contemporary subduction processes taking place to the west, between the Nazca and South American plates.

Numerous works have dealt with the rift fracture model (Bianucci et al., 1981; Bianucci and Homovc, 1982; Chiarenza and Ponzoni, 1989; Fraga and Introcaso, 1990; Kress, 1995, among others).

Grier (1990) studied the kinematics of the rift faults, and the following inversion during the Andean compressive tectonics. She also pointed out the importance of the listric type faults in the geometry of the basin, whereas the oblique and transverse faults would not be so significant.

Recently, Cristallini et al. (1998), on the basis of studies of seismic lines in the southern part of the basin, proposed an assymetric model, with a main listric detachment fault which deepens eastward, and a set of domino faults toward the west. This proposed model for the southern portion of the basin coincides with that proposed by Kress (1995) for the Lomas de Olmedo sub-basin.

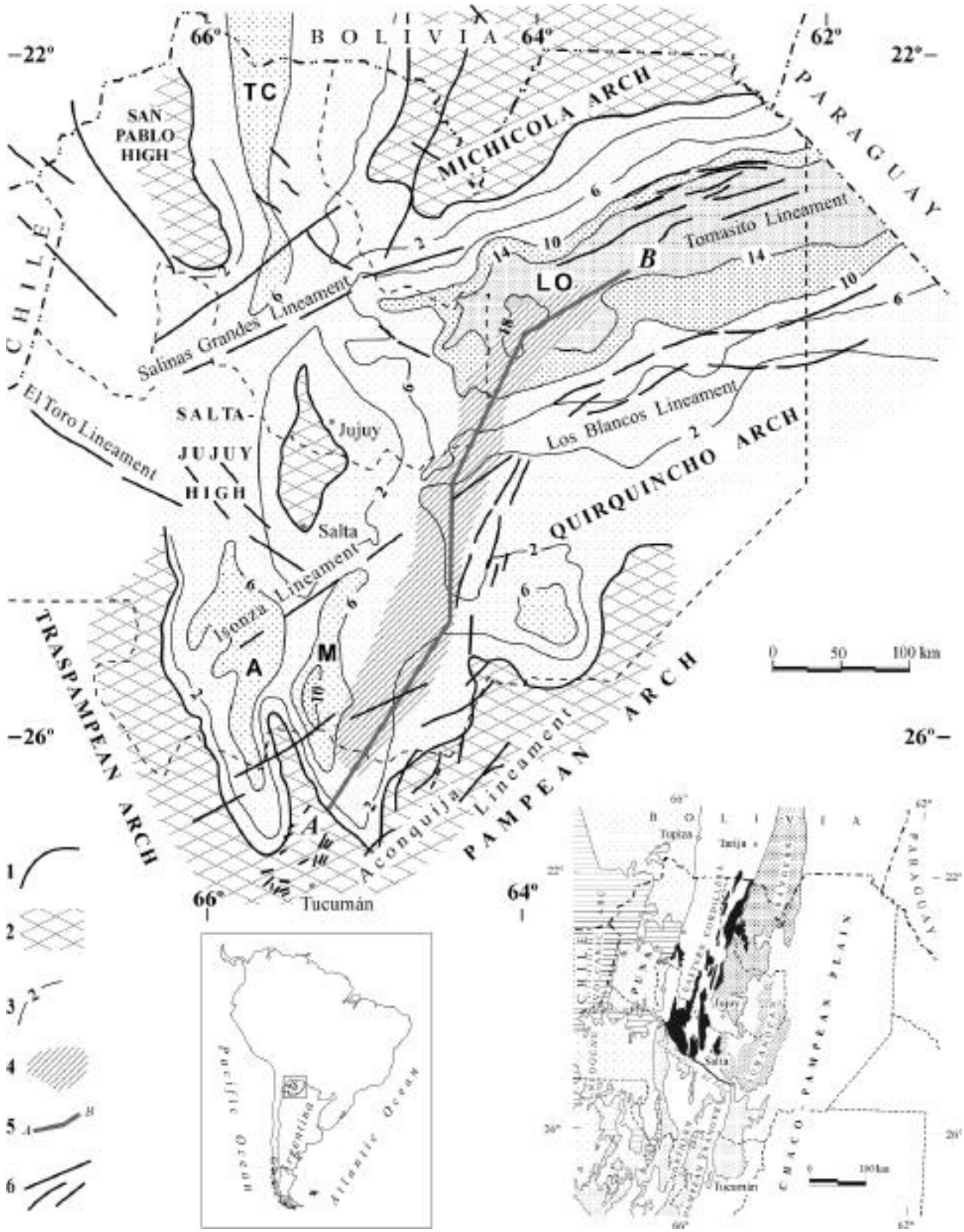
The geometry of the basin was governed in particular fashion by the rejuvenation of ancient Precambrian and Paleozoic lineaments, such as the El Toro, Aconquija, Salinas Grandes, Tomasito and Los Blancos lineaments, which affected units of the pre-Cretaceous basement (Fig. 1). In the northern portion of the basin the basement consisted of relatively younger units toward the north and east, from Cambrian to Upper Paleozoic and Jurassic? rocks. To the south of the El Toro lineament the basement was exclusively made up of Precambrian metamorphic rocks (Puncoviscana Formation and equivalents), and occasional Paleozoic granites (Salfity and Marquillas, 1994).

In the mid-section of the rift, a horst block designated the Salta-Jujuy (Salto-Jujeña) high developed, and remained lifted with little or no subsidence during the remainder of the evolution of the basin, acting as a geographic barrier between the sub-basins (Fig. 1). During the post-rift stage this high was progressively overlapped by sediments.

The Salta Group basin shows a typical rift-filling sequence, fining upward both strata and grain size, going from high energy facies to low energy facies (Fig. 3). The first stage of synrift development ranges from Kimmeridgian? to Late Campanian times, and relates entirely to the Pirgua Subgroup (Figs. 2 and 3), made up of the La Yesera, Las Curtiembres and Los Blanquitos Formations (Reyes, 1972; Reyes and Salfity, 1973). This period is characterized by the formation of isolated grabens, containing red conglomeratic deposits originated by conspicuous debris flows and mass flows, laterally associated with lacustrine systems (Boso et al., 1984; Sabino et al., 1998). The geometry of these units is irregular (Fig. 3), with frequent lateral wedging out and the appearance of sedimentary gaps (Gómez Omil et al., 1989). The greatest thicknesses recorded occur in the hanging wall, and are often as much as 3000 m thick (Boso et al., 1984; Cristallini et al., 1998).

In contemporary fashion, two volcanic events took place which resulted in the extrusion of basalts and ignimbrites. The first effusion produced peralkaline lavas and alkaline trachytes, emplacement into the La Yesera Formation and concentrated in lateral positions of the basin in association with faults (Galliski and Viramonte, 1988). The age of this pulse was dated at 128-112 Ma (Valencio et al., 1976). The second pulse consisted of alkaline basalts which expanded over the Las Curtiembres Formation, and was dated 78-76 Ma (Reyes et al., 1976; Valencio et al., 1976).

From the Maastrichtian onward, the diminishment of tectonic activity brought about a sharp deceleration of subsidence and, consequently, a diminishing accomoda-


66°
BOLIVIA
64°
62°
22°
TC
SAN PABLO HIGH
MICHICOLA ARCH
PARAGUAY
Tomasito Lineament
LO
B
Salinas Grandes Lineament
El Toro Lineament
SALTA-JUJUY HIGH
Jujuy
Salta
Los Blancos Lineament
QUIRQUINCHO ARCH
Lizoaza Lineament
A
M
TRASPAMPEAN ARCH
Aconquija Lineament
PAMPEAN ARCH
0 50 100 km
26°
Tucumán
1
2
3
4
5
6
Pacific Ocean
Argentina
Atlantic Ocean
Tupiza
Tarija
Tejeria
Salta
CHACO PAMPEAN PLAIN
100 km

MEALLA FORMATION

ARCHITECTURAL ELEMENTS	FACIES ASSOCIATION	LITHOLOGY	STRUCTURES	INTERPRETATION
SG,GB,CH OF	FA 1: Gm,Gt,Gp Sm FA 2: Sp,Sm,Se Fm,Fl,Fsc,P	Fine gravel to coarse sand, clast-soport with rip-up clast red silt and level of carbonates.	Massive with erosional scours imbrication, horizontal bedding Pedogenetic features like concretion, root marks and reducing motles.	Alluvial fans with hiperconcentrate flows and sheet flows(1). Overbank deposits, carbonates swamp and paleosols
CH, LA,SB OF,CS	FA 3: Sp,St,Sr Fm,P	Medium to fine sand with silty matrix. Red silt and mud	Fining upward beds, cross bedding tabular foresets and scours, climbing ripples. Paralel lamination and bioturbation.	Perennial fluvial systems with mixed load. sandy braided and fine meandering rivers with thick overbank deposits
L	FA 4: F, Sw,Cm Bs,E	Green and gray mudstones and silt interlayered with fine levels of fine sand. boundstones stromatolitic Level of salt	Paralel lamination and bioturbation. Wavy and lenticular bedding	Perennial saline lake to open fresh water lake.

Table I. Architectural elements and lithofacies descriptions of Mealla Formation. (1) Type 2 of Blair and McPherson (1994). See table III for legend.

Tabla I. Elementos arquitecturales y descripción de litofacies de la Formación Mealla. (1) Tipo 2 de Blair y McPherson (1994). Leyenda en la tabla III.

tion of the sediments which silted up the existing topography, and transgressively overlapped its borders (Groeber, 1953; Salfity, 1980).

The change from the synrift stage to the postrift stage is evidenced by a clearly defined flooding surface. The first deposits laid down are those of the Balbuena Subgroup, made up of the Lecho, Yacoraite and Olmedo Formations (Figs. 2 and 3).

The facies association is interpreted as being that of sandy braided river systems and isolated dune fields, with calcrete paleosols on which a stable and restricted body of water developed. This brought about the deposition of thick beds of oolitic grainstones, mudstones, wackestones and stromatolite boundstones (Marquillas, 1985). This flooding of the basin was contemporaneous with the marine transgression which occurred during the Maastrichtian-Paleocene, over a great part of the southern area of the South American continent (Camacho, 1967; Zambrano, 1987; Riccardi, 1988, among others).

The ending of the postrift stage is seen in the Santa Bárbara Subgroup, made up of the Mealla, Maíz Gordo and Lumbrera Formations. The development of the basin (Fig. 2) was interrupted by renewed tectonic activity and the formation of the present foreland basin (Grier et al., 1991).

SANTA BARBARA SUBGROUP

The deposition of these sedimentary rocks is recognized as being the final postrift period, and corresponds to an interior sag basin (Harding, 1984). The evidence from outcrops and the subsurface points to a tabular geometry for these units and lateral conformity of a regional nature (Figs. 2 and 3). However, detailed studies -especially of the western margin - reveal continuous rejuvenations of the fluvial systems, which in part have been interpreted as being the result of tectonic activity (Gómez Omil et al., 1989). Over the Traspampean arch (Fig. 1), the sequences show evidence of erosion and sedimentary rejuvenation events, which brought about

Figure 1. Location map showing regional distribution of Santa Bárbara Subgroup and main lineaments and arches. 1- Inferred basin edge, 2- Structural high, 3- Isopach line (thickness in hundreds of meters), 4- Los Gallos uplift, 5- Cross section along Los Gallos uplift (see Figure 3), 6-Lineament. Sub-basins: TC: Tres Cruces, LO: Lomas de Olmedo, M: Metán, A: Alemanía (based on Salfity and Marquillas, 1994).

Figura 1. Mapa de ubicación y distribución de la cuenca del Subgrupo Santa Bárbara y principales lineamientos y arcos. 1- Borde inferido de cuenca, 2- Alto estructural, 3- Línea isópaca (espesores en cientos de metros), 4- Umbral de Los Gallos, 5- Corte paleogeográfico a lo largo del Umbral de Los Gallos (veáse Figura 3), 6- Lineamiento. Subcuencas: TC: Tres Cruces, LO: Lomas de Olmedo, M: Metán, A: Alemanía (basado en Salfity y Marquillas, 1994).

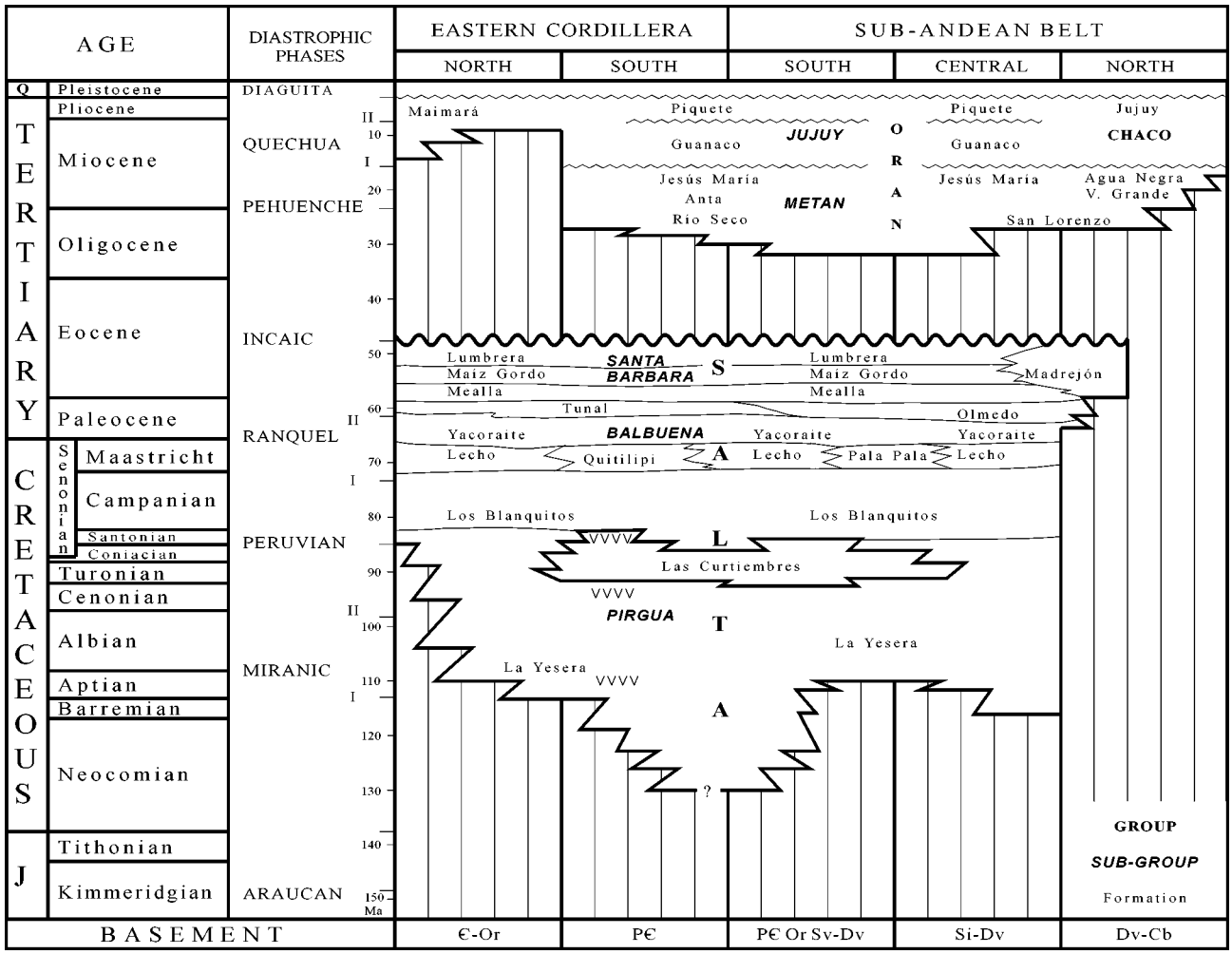


Figure 2. Stratigraphic chart showing the main unconformities of Salta Group (after Salfity and Marquillas, 1994).

Figura 2. Cuadro estratigráfico y principales discordancias del Grupo Salta (según Salfity y Marquillas, 1994).

uneven distribution of the units and the formation of proximal alluvial fans.

In the regional sense, the three Formations which make up the Santa Bárbara Subgroup show environmental similarities and the same pattern of facies distribution.

Mealla Formation

This unit is characterized by its red to purple color, which clearly distinguishes it from the underlying unit (the Yacoraite or Tunal/Olmedo Formations) and the overlying Maíz Gordo Formation. The basal contact is paraconformable with the Yacoraite or Tunal/Olmedo Formations, discordant with the Puncoviscana (Precambrian -Cambrian) and Mendieta (Devonian) Formations, and unconformable with the Cerro Amarillo (Paleozoic) granite. The upper contact is paraconformable with the Maíz Gordo Formation. The thicknesses most frequently found in this unit vary from 100 to 150 meters (Fig. 4), although, depending on locality, thicknesses have been measured ranging from only a few dozen meters, such as occurs on the Cachipunco and Las Víboras highs, to several hundred meters, in the Alemanía and Lomas de Olmedo (Fig. 3) sub-basins (Moreno, 1970).

The closed geometry of the basin brought about a fairly symmetrical facies pattern. As a result, toward the bor-

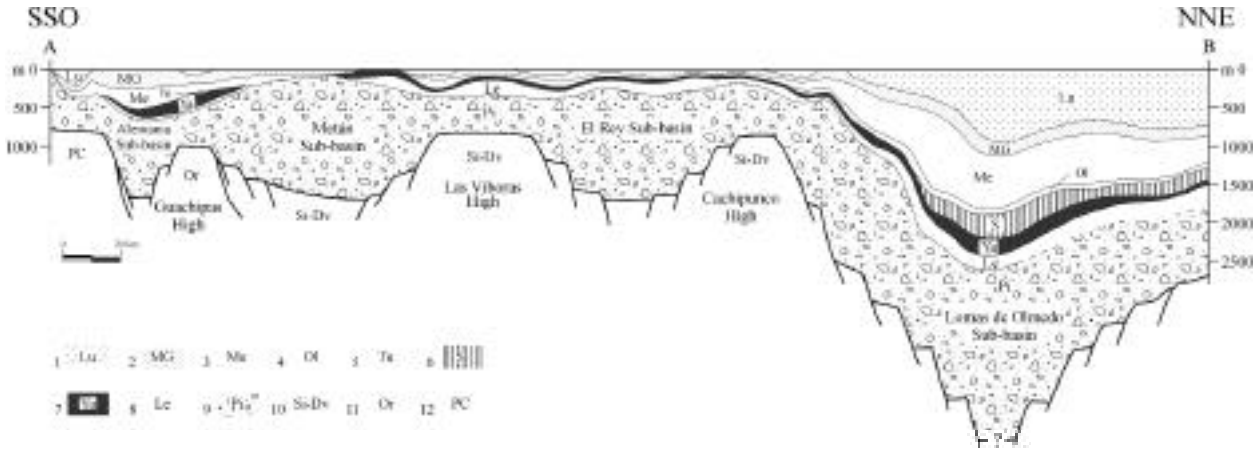


Figure 3. Paleogeographic section of Salta Group basin. Datum: top of Lumbrera Formation. 1- Lumbrera Formation, 2- Maíz Gordo Formation, 3- Mealla Formation, 4-Olmedo Formation, 5-Tunal Formation, 6- Saline Member, 7-Yacoraite Formation, 8-Lecho Formation, 9- Pirgua Subgroup. Pre-Cretaceous basement: 10- Silurian and Devonian, 11- Ordovician, 12- Precambrian. See Figure 1 for location of the section (based on Salfity et al., 1993).

Figura 3. Corte paleogeográfico del Grupo Salta nivelado al techo de la Formación Lumbrera. 1- Formación Lumbrera, 2- Formación Maíz Gordo, 3- Formación Mealla, 4- Formación Olmedo, 5- Formación Tunal, 6- Miembro Salino, 7- Formación Yacoraite, 8- Formación Lecho, 9- Subgrupo Pirgua. Basamento precretácico: 10- Silúrico y Devónico, 11- Ordovícico, 12- Precámbrico. En la figura 1 se muestra la ubicación de la sección (basado en Salfity et al., 1993).

ders of the basin the lithology was coarsely clastic (Fig. 5-A), being medially to finely conglomeratic, then diminished progressively in grain size toward the center of the basin. It has been observed that in locations near the source area (e.g., the western and southern rims) alluvial fans were formed, with a predominance of mass flows and hyperconcentrated flows (Fig. 4, FA1), associated with flood plains on which extensive carbonate paleosols developed (Fig. 4, FA2)

In positions nearing the inner portion of the basin, flowing streams which formed channelled systems were predominant, ranging from fine-grained (Fig. 4, FA3) meandering rivers (Palma et al., 1986) to sand bed braided rivers (Table I).

In the middle of the basin a lacustrine body of regional extent was formed. The predominant lithologies are purple to reddish claystone and siltstone, generally massive or having parallel laminations and intercalated stromatolite boundstones (Fig. 4, FA4). Levels showing biotubation and the development of paleosols are frequent. Strata of halite interbedded with red claystones have been recorded in the Lomas de Olmedo sub-basin (Cazau et al., 1976). These facies assemblages are indicative of a hydrologically closed lacustrine basin of a perennial saline lake type (Table I).

The top of this unit is marked by the "Faja Gris" (Mädel and Moreno, 1973, in Cazau et al., 1976), consisting of gray to dark green claystone, sandstone and limestones (Fig. 4, FA4), all of regional extent (Fig. 5-B), which is interpreted as being an open freshwater lake. This level is shown in seismic lines by a strong reflector, which can be identified throughout the basin and has been assigned a chronostratigraphic value (Gómez Omil et al., 1989).

Fossil Record

This unit contains the remains of mammals of the *Henricosborniidae* family, *Simpsonotus praecursor* and *S. major*, Pascual et al. (1978), attributed to the Riochican Mammal-Age (Early Paleocene to lower Late Paleocene, see Fig. 6), through comparison with Patagonian units (Pascual et al., 1981). There are also remains of the Pelomedusidae family, indet., Fernández et al. (1973); Gasparini and Báez (1975); Báez and Gasparini (1977). It also holds numerous palinomorphs, especially those preserved in the "Faja Gris", whose assemblages in paleocommunities point to a continental lacustrine environment under arid conditions. The level (Quattrocchio et al., 1997) was assigned to Selandian stage (Middle Paleocene).

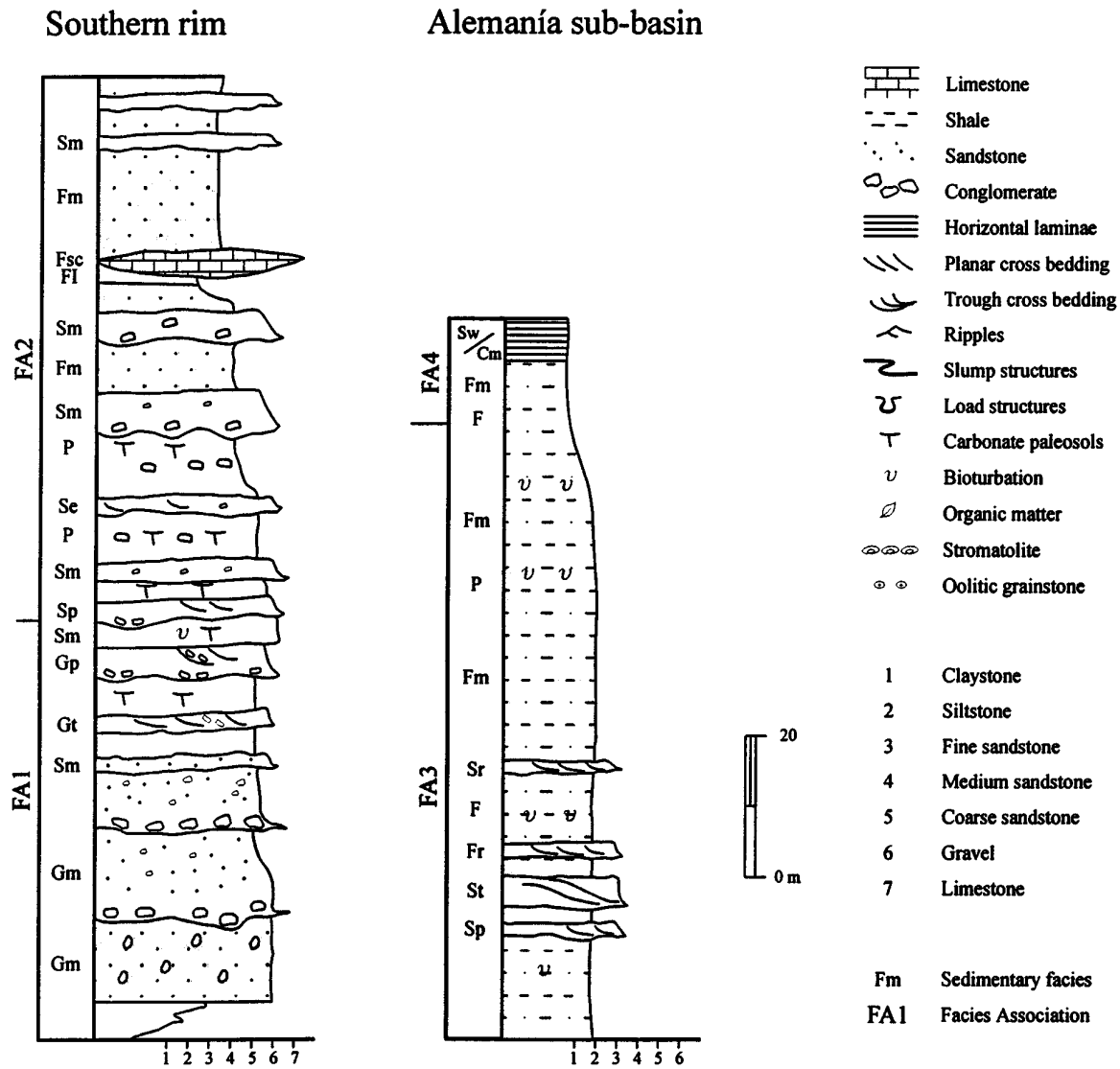


Figure 4. Measured section, sedimentary facies and facies association of Mealla Formation in Alemanía sub-basin near Traspampean arch.

Figura 4. Columnas estratigráficas, facies sedimentarias y asociación de facies de la Formación Mealla en la subcuenca de Alemanía próximo al arco Traspampeano.

Maíz Gordo F ormation

This unit differs from the foregoing by its green and gray coloring, and its frequent limestone levels. It is characterized by green and purple claystones and siltstones, with interbedded fine white sandstone and calcareous levels (Fig. 7). Toward the borders of the basin, sandstones and conglomeratic sandstones are predominant and the siltstones are completely subordinated.

The characteristic thicknesses of the Maíz Gordo Formation range from 150 to 200 meters. However, in points near the supply areas thicknesses of as much as 250 meters have been measured; while in the subsurface of the Lomas de Olmedo sub-basin, this Formation (Fig. 3) reaches a 500-meter thickness (Gómez Omil et al., 1989).

The Maíz Gordo Formation shows a greater regional extension than the underlying Mealla Formation, which points clearly to an onlap of the first-mentioned unit. On

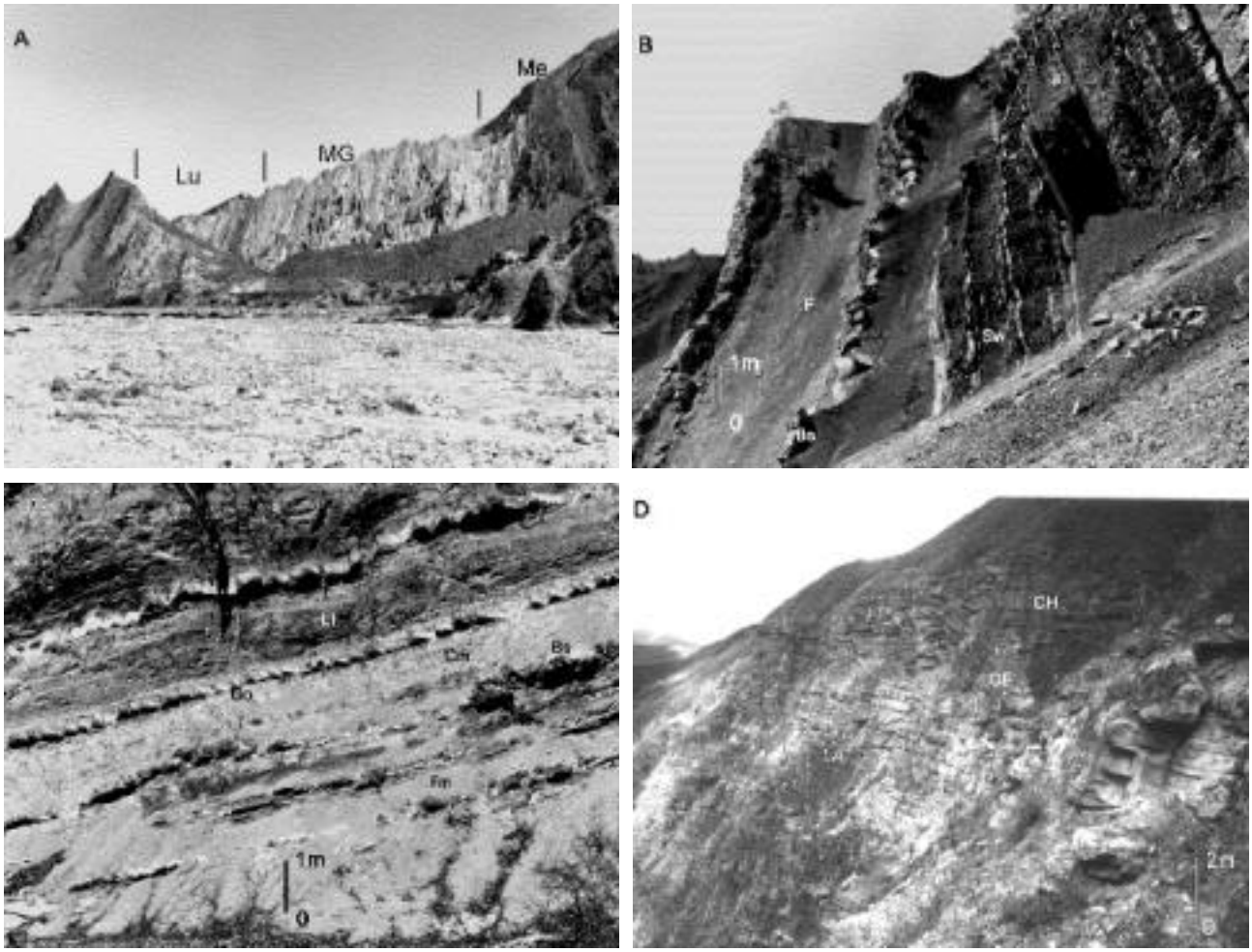


Figure 5. A- Coarse-fluvial facies of Santa Barbara Subgroup near Traspampean arch. Lu: Lumbrera Formation, MG: Maíz Gordo Formation, Me: Mealla Formation. B- Lacustrine facies (Faja Gris) of Mealla Formation. C- Clastic-carbonate lacustrine facies of Maíz Gordo Formation. D- Fine meandering fluvial facies of Lumbrera Formation. Keys see table III.

Figura 5. A- Facies fluviales conglomeráticas del Subgrupo Santa Bárbara próximo al arco Traspampeano. Lu: Formación Lumbrera, MG: Formación Maíz Gordo, Me: Formación Mealla. B- Facies lacustres (Faja Gris) de la Formación Mealla. C- Facies lacustres clástico-carbonáticas de la Formación Maíz Gordo. D- Sistema fluvial meandroso fino de la Formación Lumbrera. Leyenda en la tabla III.

the edges of the basin conglomeratic river systems developed, with sporadic alternations of hyperconcentrated flows. On the southwest border of the basin, where this unit lies on the pre-Cretaceous basement, restricted alluvial fans were formed, with predominantly detrital flows (Table II, FA5). In general, the marginal facies are characterized by braided fluvial systems of mixed load (Fig. 7, FA6, and Table II).

The most notable development in this unit is that of the lacustrine system, with mixed siliceous-carbonate sedimentation, defined as a lake of the low gradient ramp margin type (del Papa, 1994).

On the shore zones, small deltaic systems and extensive mud flat were formed, with the development of paleosols and surface exposure of breccias.

The characteristic sedimentation in the lacustrine system consists of laminated mud- limestones, boundstones with organic matter formed in a closed lake of meromictic type (Fig. 7, FA7). To a lesser degree, there are alter-

MAIZ GORDO FORMATION

ARCHITECTURAL ELEMENTS	ASOCIACION DE FACIES	LITHOLOGY	STRUCTURES	INTERPRETATION
SG,GB,CH, SB	FA 5: Gm,Sm,St Gh,Gp,Sp	Coarse to fine, angular, clast-soport gravel Pebbly to coarse sand with silty matrix	Cross bedding, imbrications, tabular foresets.	Proximal facies of alluvial fans. Mass flow and hyperconcentrate flows. Deep braided rivers with alternate bars
SB, CH,OF	FA 6: Sp,St,Sr Fm,Fl,P	Medium to fine, white sand. Red silt with levels of very fine sand	Diagonal cross bedding, tabular foresets and small scours. High energy horizontal lamination, climbing ripples.	Sandy braided rivers with mixed load, perennial type with sand flat or compound bars migration(1)
L	FA 7:Fm,Bs,Go Ll, F FA 8:Lwl,Bs,F Fm,Sw,Go,P	Dark green to gray mud with organic matter Fine levels of fine sand. Wackestones and oolitic grainstones. Stromatolites.	Horizontal laminae. Lenticular and wavy bedding. Ripples. Bioturbation.	Lake with broad, carbonates litoral facies to internal meromictic type

Table II. Architectural elements and lithofacies descriptions of Maíz Gordo Formation. (1) Cant and Walker, 1978; Miall, 1982. See table III for legend.

Tabla II. Elementos arquitecturales y descripción de litofacies de la Formación Maíz Gordo. (1) Cant y Walker, 1978; Miall, 1982. Leyenda en la tabla III.

nating bars of oolitic grainstones and wackestones, with wavy and lenticular bedding (Fig. 7, FA8, and Table II). The facies assemblage indicates a shallow lake with fresh to salt alkaline water, having a well developed carbonate shore zone (Fig. 5-C) (del Papa, in press).

The sequence of sedimentary facies reveals a cyclic arrangement, and registers subtile flooding (claystone deposits with thin beds of basal oolitic grainstones), and progressive shallowing (del Papa, 1992) of the bedrock (wavy and lenticular stratification and growth of stromatolites).

Fossil Record

The remains of reptiles have been found in the Maíz Gordo Formation, as well as those of the Pelomedusidae family, *Podocnemis argentinensis*, Cattoi and Freiberg (1958), Osteichthyes, and Teleostei of the Callichthydae - *Corydoras revelatus*, Cockerell (1925) - and Poecilliidae - indet., Cione (1977) - families. It should also be mentioned that this unit is the bearer of a rich insect (Cockerell, 1925; 1926; 1936) fauna (Coleoptera).

Lutetian

Among the palinomorphs, Poroses - Cricotriporites cf. Guianensis, Leidelmeyer (1966); *Corsinipollenites menendeii*, Quattrocchio (1978a); *Echistephanoporites* sp. cf: *E. alfonsi*, Leidelmeyer (1966) - and Fungi - *Inapertisporites* sp. A, Quattrocchio (1978b) - are of chronostratigraphic importance, being indicative of the Upper Paleocene and the Lower Eocene (Volkheimer et al., 1984).

Figure 6. Correlation chart between Paleogene epochs and stages with South American Mammal Ages.

Figura 6. Cuadro de correlación entre épocas y edades paleógenas con las Edades mediante Mamíferos de América del Sur.

The Maíz Gordo Formation is attributed to the Riochican-Casamayoran Mammal-Ages (Fig. 6), in view of its stratigraphic location with respect to the Mealla and Lumbrera Formations (Pascual et al., 1981).

Lumbrer a Formation

The Lumbrera Formation underlies the Maíz Gordo Formation through a para-conformity. The upper contact is marked by a sedimentary discontinuity of erosional and angular unconformity type, throughout the region (Schlagintweit, 1937), over which the sedimentary rocks of the Orán Group (Fig. 2). were laid down (Gebhard et al., 1974).

Lithologically, this unit is made up of reddish to red claystones and siltstones, usually massive or showing bioturbations and paleosols development. To a lesser extent it also contains green and gray claystones, yellowish limestones, and fine sandstone (Fig. 8). On the edges of the Traspampean, San Pablo and Michicola arches the predominant lithologies are coarsely clastic (Fig. 5-A), being made up of micaceous medium sandstones and coarse sandstones.

This is the thickest formation in the Santa Bárbara Subgroup, ranging in general from 300 to 450 meters (Fig. 3). In the eastern part of the basin the Los Gallos high, having a NNE elongation, has been recognized. Along this swell the Neogene sediments of the Orán Group lie disconformably on eroded levels of the Lumbrera Formation, or else directly on the Maíz Gordo Formation or even older units of the Salta Group (Figs. 1 and 3). The erosive events have been assigned to the Incaic diastrophic phase (Fig. 2), which is a reflection of the first compressive tectonic events to take place after the laying down of the Salta Group, and which brought about the uplift of part of the basin, with the consequent erosion of its cuspidal parts (Salfity et al., 1993).

In the areas near the rim of the basin, this unit differs from those which underly it by a having a greater development of its fluvial systems. Wide channels, containg multiple episode fill with conglomeratic lag deposits, can be distinguished. These are interbedded with thick levels of flood plain facies, characterized by a frequent and continuous carbonate paleosols development (Fig. 8, FA9, and Table III).

Toward the interior of the basin, meandering fluvial systems were formed, with a predominance of overbank deposits (Fig. 5-D). In this area the occurrence of levee and crevasse events and the formation of load structures and slumps of decimetric proportions are outstandingly evident (Fig. 8, FA10, and Table III).

In the innermost parts of the basin, lacustrine systems of meromictic characteristics were formed; these have been identified informally as the "Faja Verde". In the Alemanía area two lacustrine levels have been recorded: the lower one, named "Faja Verde I", has the least thickness (generally about 10 meters), and the upper, or "Faja Verde II", is the thickest (between 20 and 30 meters). When only one level is recognized it is cor-

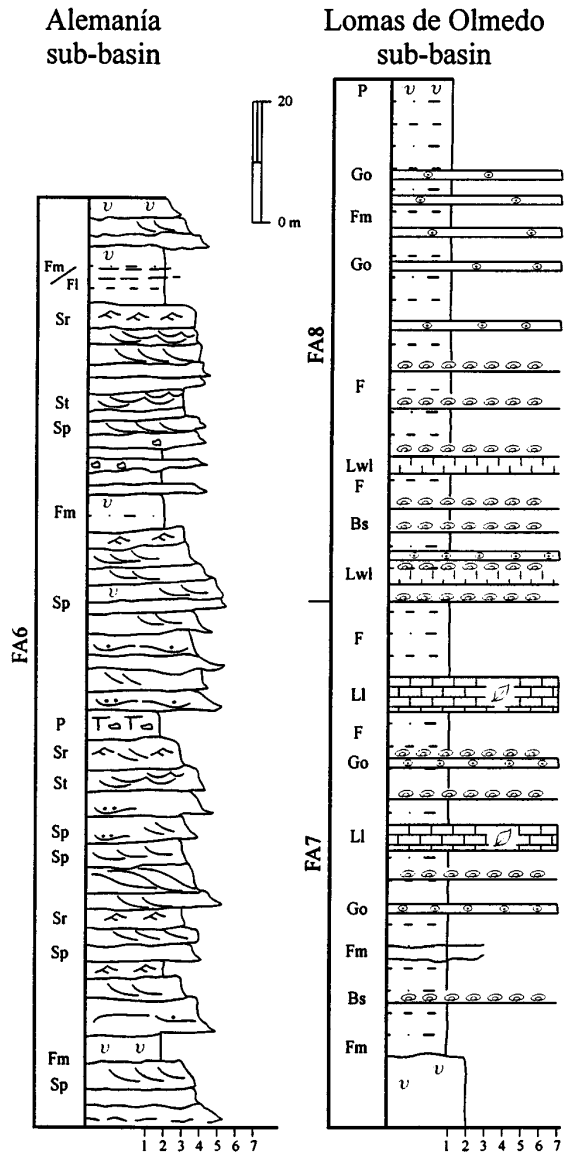


Figure 7. Measured sections, sedimentary facies and facies association of Maíz Gordo Formation in the Alemanía and Lomas de Olmedo sub-basins. Keys see figure 4.

Figura 7. Columnas estratigráficas, facies sedimentarias y asociación de facies de la Formación Maíz Gordo en las subcuencas de Alemanía y Lomas de Olmedo. Leyenda en la figura 4.

LUMBRERA FORMATION

ARCHITECTURAL ELEMENTS	FACIES ASSOCIATION	LITHOLOGY	STRUCTURES	INTERPRETATION
CH, SB	FA 9: Sp,St	Gravel to coarse sand with gravel lags	Scours, irregular, fining-upward beds.	Coarse sandy meandering rivers.
OF	Se, Fm,P	Reddish silt with levels of limestones	Imbrication. Massive silts with rhizoliths and concretions	Flood plain with paleosols.
CH, SB,LA,LV CR,CS,FF	FA 10: Sp,St,Sr Ss,Se,Sh,Sl Fl,Fm	Fine, white, sand. Red silts interbedding with sand	Lateral accretion. Scours lamination. Climbing ripples. Horizontal laminae. Massive deposits, bioturbation, load structures and slumps	Fine meandering rivers with thick overbank deposits. Crevasse and crevasse splay deposits.
L	FA 11: St, Sr, F Sw,Fm	Dark green to gray mud with organic matter.	Fine bedding with horizontal laminae.	Clastic lake of holomictic to meromictic types
	FA12: St,F, Sw Ll, Bs	Fine sand interbedding with mud. Isolated, domic boundstones.	Wavy to lenticular bedding. Wave ripples.	

Architectural elements according to Miall 1985, 1996	Lithofacies classification (Miall 1978, 1982) and lacustrine lithofacies
SG: Sediment gravity flows deposits	Ll: Laminites
GB: Gravel Bedforms and bars	Sw: wavy sandstones
CH: Channels	Bs: Boudstones stromatolitic
SB: Sandy Bedforms	Fm: Massive mud
DA: Downstream Accretion deposits	Lwl: wavy and laminated limestones
LA: Lateral Accretion deposits	Cm: Massive limestones
OF: Fine Overbank	F: mud and silt
CR: Crevasse Channel	Go: oolitic grainstones
CS: Crevasse Splay	P: Paleosols
L: Lacustrine environment	E: Evaporite

Table III. Architectural elements and lithofacies descriptions of Lumbrera Formation.

Tabla III. Elementos arquitecturales y descripción de litofacies de la Formación Lumbrera.

related with Faja Verde II. Although these two layers were at first considered to be sedimentologically similar, detailed studies have revealed significant differences between them. The first lacustrine episode is restricted in area, the sedimentation is predominantly clastic (Fig. 8, FA11), and the water mass predominantly holomictic. The most frequent association is deltaic-lacustrine in nature.

On the other hand, the second lacustrine episode shows well-developed littoral and internal lake facies. The internal lake sedimentation is characterized by levels up to 20 meters thick, made up exclusively of laminated mudstones with a high organic content, indicating anoxic bottom conditions (Fig. 8, FA12).

The depositional environment defined for the Lumbrera Formation is one of proximal to distal meandering river systems, and distributary (deltaic) systems related to lakes. The lacustrine system is interpreted to be of regional extent, with a predominantly clastic sedimentation and bituminous shales deposited under reducing conditions and anoxia, which favored the preservation of the parallel laminations and the organic matter in them (Table III).

Fossil Record

The Lumbrera Formation is the unit which has the largest paleontologic content in the Santa Bárbara Subgroup. Osteichthyes of the Poeciliidae family, indet., Pascual et al. (1981), and the Lepidosirenidae family, Lepidosiren paradoxa, Fernández et al. (1973) have been mentioned. In the Reptilia class, specimens of the Pelomedusidae family, Gasparini and Báez (1975), Crocodylidae? and Sebecidae families, Pascual et al. (1981), have been recorded. Among the mammals which have a chronostratigraphic value, Marsupialia, Bonaparthriidae, *Bonapartherium hinakusijum*, Pascual (1980), Notoungulata of the Oldfieldthomasiidae and Isotemnidae families, Pascual et al. (1981), and Astrapotheria Astrapothedae, *Albertogaudrya? carahuasensis*, Carbajal et al. (1977),

Notohippidae Eomorphippus sp, Mulé y Powell (1998) have been mentioned, pointing to a Casamayoran to Mustersan Mammal-Age (See Fig. 6).

The Faja Verde has provided a diversity of palinomorphs, studied by Quattrocchio (1978a,b), and Quattrocchio and Volkenheimer (1990). Insect fossils (Cockerell, 1926; Murature de Sureda and Alonso, 1980) have also been recognized. Naón (1998) points out the well-preserved state of insect wing cases, among which she refers to the Carabide and Curculinoidae families. Through her study of the paleoentomologic fauna, she describes an environment having abundant vegetation and a stable and placid body of water.

Age

On the basis of the fossil record, especially that of the vertebrates, the Mammal Ages proposed are: the Riochican (Upper Paleocene-Selandian) for the Mealla Formation; the Riochican-Casamayoran (Uppermost Paleocene-Thanetian to Early Eocene-Ypresian-Lutetian) for the Maíz Gordo Formation (Quattrocchio et al., 1997), and the Casamayoran to Mustersan (Mid to Late Eocene-Bartonian-Priabonian) for the (Pascual et al., 1981 and Mulé and Powell, 1998) Lumbrera Formation (See Fig. 6).

CONCLUSIONS

During a time-lapse which covered practically the whole of the Paleogene, an extensive sag basin developed in Northwest Argentina. The characteristic sedimentation was of a non-marine type and, with the exception of the southwest border of the basin, no paleogeographic changes were recorded. The lithofacies and facies associations show a fining-upward pattern for each unit from gravel and coarse sand to shale facies.

The sedimentary environments interpreted for the laying down of the Mealla Formation include: the base of the unit are integrated by alluvial fans governed by detrital and hyperconcentrate flows and/or braided streams in the alluvial zones and saline lake in the inner part of the basin. To the top of the unit, the environments changes to sandy meandering rivers and open fresh water lake (Fig. 6-I).

A very similar scheme is interpreted for the Maíz Gordo Formation, which is differentiated by its fluvial development involving rivers of the perennial sandy braided type from coarse at the base to fine sand at the top. In the

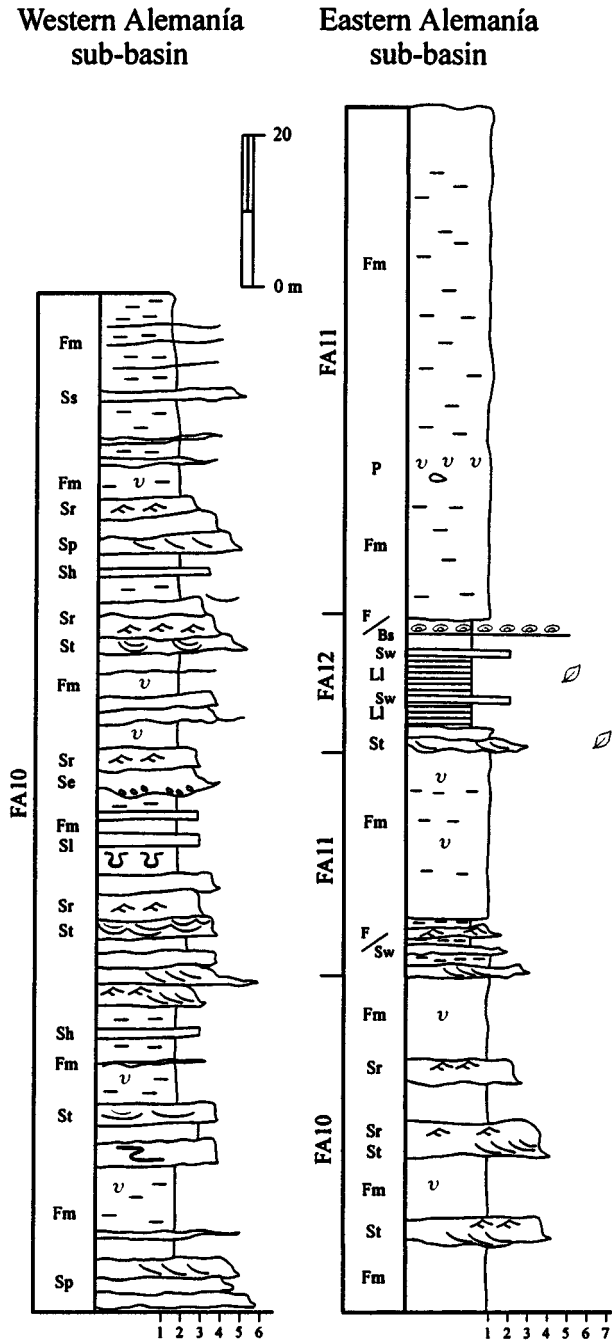


Figure 8. Measured sections, sedimentary facies and facies association of Lumbrera Formation. Alluvial facies of western Alemanía sub-basin and lacustrine facies of eastern Alemanía sub-basin. Keys see figure 4.

Figura 8. Columnas estratigráficas, facies sedimentarias y asociaciones de facies de la Formación Lumbrera. Facies aluviales en el área oeste de la subcuenca de Alemanía y facies lacustres en el área Este de la subcuenca de Alemanía. Leyenda en la figura 4.

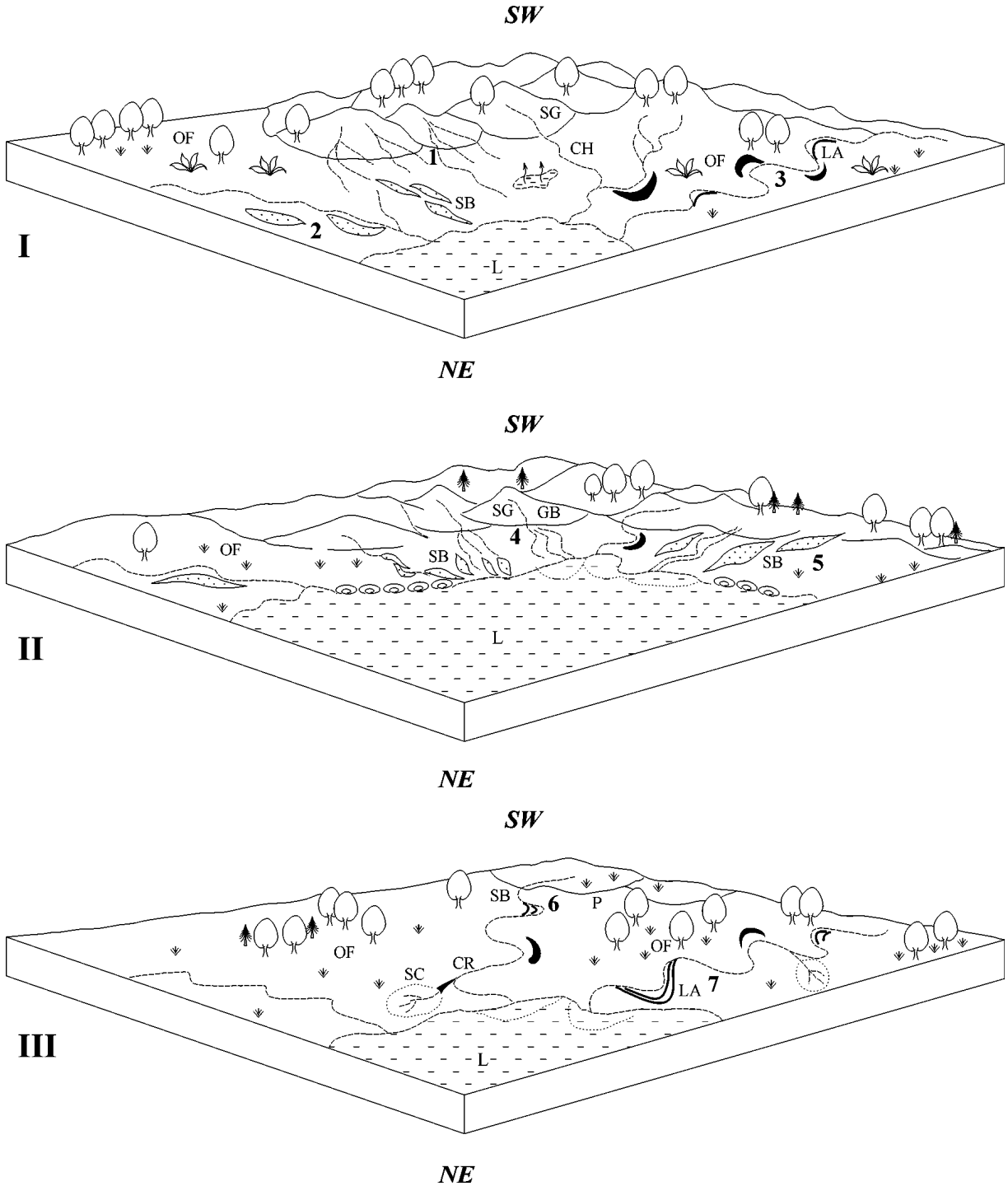


Figure 9. Block diagrams showing paleogeographic reconstructions. I- Mealla Formation, 1-alluvial fans, 2- braided streams, 3- meandering rivers. II- Maíz Gordo Formation, 4-alluvial fans, 5- perennial sandy braided rivers. III-Lumbrera Formation, 6- coarse sandy meandering rivers, 7- fine meandering rivers. See table III for legend.

Figura 9. Bloques-diagrama con reconstrucciones paleogeográficas. I- Formación Mealla, 1- abanicos aluviales, 2- fluvial entrelazado, 3- ríos meandrosos. II- Formación Maíz Gordo, 4- abanicos aluviales, 5- ríos entrelazados arenosos perennes. III- Formación Lumbrera, 6- ríos meandrosos de arena gruesa, 7- ríos meandrosos de grano fino. Leyenda en la tabla III.

inner basin a lake system being of carbonate type, with a wider distribution in space and time than that developed in the Mealla sequence. The facies and facies assemblages show a broad, carbonate litoral environment and deep water meromictic type in the internal environment (Fig. 6-II).

The Lumbrera Formation is characterized by a predominantly fine-grained sedimentation, the permanent formation of paleosols, and a restricted development of its fluvial facies. A coarse sandy to fine meandering river system with thick flood plain sequences has been recognized in its fluvial environment, specially near the Transpampean arch. The first lacustrine system or "Faja Verde I" has a restricted spread, and is holomictic type associated at deltaic systems. The second one or "Faja Verde II" has a regional spread and represent a deeper lake with thick facies of clastic meromictic type with bituminous shales (Fig. 6-III).

The sedimentary column of Santa Bárbara Subgroup shows a recurring pattern of facies and sedimentary environments, which gives it a cyclic arrangement characteristic of this period. The study of palinomorphs and sedimentary facies assemblages suggests climatic fluctuations, ranging from arid conditions during the laying down of the base of the Mealla Formation to greater humidity in the Faja Gris, which is the roof of this unit. This climatic cycle is repeated during the deposition of the Maíz Gordo and Lumbrera Formations.

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