

ITUZAINGÓ FORMATION. A KEY FOR THE INTERPRETATION OF UPPER TERTIARY STRATIGRAPHY, MESOPOTAMIA-CHACO PARANÁ BASIN, ARGENTINA

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RESUMO

Quatro anos de estudos sedimentológicos de detalhe permitiram reinterpretar o esquema estratigráfico do Terciário Superior da Região Mesopotâmica. O presente autor encontrou, sobre a base do estudo sedimentológico da Bacia Mesopotâmica-Chaco Paranaense, uma nova possibilidade de interpretar a seqüência estratigráfica, em relação às idéias que se empregavam anteriormente. A Formação Ituzaingó tinha sido interpretada como continental (fluvial), por vários autores, sobre a base de uma fauna fóssil não diagnóstica de invertebrados, sempre presentes na parte superior da Formação. Esses fósseis têm um amplo "biocrón" no Cenozóico. A Formação Paraná infrajaz a Formação Ituzaingó. A idéia de uma discordância de erosão entre as Formação Paraná e Ituzaingó foi, geralmente, aceita. A Formação Paraná leva uma abundante fauna fóssil de invertebrados datados no Mioceno Médio. Aceita-se, geralmente, que as

Formações Toropí e Yupoí descansam sobre a Formação Ituzaingó em todas as partes. A relação estrutural seria de discordância de erosão. As Formações Toropí e Yupoí tem sido datadas de idade Pleistocena, sobre a base de restos de ossos de vertebrados. A interpretação que eu assumo para esses restos, é que, os mesmos jazem em terrenos Quaternários, e que, em todo caso, são alóctonos dos pelitos das Formações Toropí e Yupoí. Tenho realizado estudos de detalhe em relação aos seguintes temas: arquitetura, granulometria, morfoscopia, petrografia, medição de paleocorrentes, microscopia de varredura eletrônica, difratometria de raios-x, perfis sedimentológicos de detalhe, correlações de perfurações e estudos mediante processamento digital de imagens. O estudo arquitetural revelou a presença de estratificação cruzada “hummocky”, feixes de marés (ou “tidal bundles”), estratificação cruzada tipo “espinha-de-peixe” (“herringbone”), estratificação cruzada bipolar, acapamento lenticular, acamamento “flaser” e vários tipos de estratificações onduladas. Estes estudos permitiram dar-me conta que existe a possibilidade de outro ambiente deposicional, diferente ao proposto até agora, continental para as Formações Ituzaingó, Toropí, Yupoí e Puelches. Propus, então, uma origem marinho rasa (“intermarés”) para todas estas Formações e uma idade Miocena Média (12-14 Ma). Este evento seria consequência do ingresso do Mar Paranaense e, entre as “litofácies” das Formações mencionadas existira uma interdigitação. A Formação Puelches, uma unidade de subsuperfície, próxima à Formação Paraná, interpreta-se como pertencente a esta “litofácies” areno argilosa, típica de um ambiente marinho litoral. Um trabalho prévio interpretou a mesma como de origem fluvial e de idade Pliocena-Pleistocena. Assim, propôs-se a existência de uma discordância erosiva entre a Formação Paraná e a Formação Puelches. As Formações Paraná, Ituzaingó, Toropí, Yupoí e Puelches estão compostas por mais de 80 % de areia e 20 % de argilas.

Nas mesmas encontra-se presente um contacto brusco, mas irregular, de uma frente de ferricretização, especialmente na fácies arenosa. Este fenômeno físico-químico levou a interpretar de forma errônea o esquema estratigráfico, já que assumia-se que isto era uma discordância de erosão (a frente de ferricretização). Em alguns lugares a ferricretização gerou arenitos, os quais constituem um “ferruginous duricrust”. Este se formou no Pleistoceno Superior-Holoceno.

Também está presente, nos afloramentos, em todas as partes, a calcretização. A ferricretização e a calcretização, ambos processos secundários, mascaram as características primárias físico e químicas das fácies areno-argilosas. As Formações Paraná, Ituzaingó, Toropí, Yupoí e Puelches possuem uma mesma origem, marinho litorânea e a mesma idade, Mioceno Médio. Estas Formações constituem um corpo mantiforme (“blanket”) de aproximadamente 1.500 quilômetros de extensão no Noreste da Argentina e possuem uma espessura ao redor de 300 metros. Elas estão compostas somente por fácies de areias finas a muito finas, brancas a cinza claro e argilas cinzas. Quando a ferricretização está presente, os sedimentos mudam suas cores, pela alteração de óxidos férricos, e tomam cores como vermelho, avermelhado ou ocre, amarelo, púrpura, castanho e preto. Em poucos casos, a alteração é muito intensa e as areias são convertidas em arenitos vermelhos ou pretos. Nestes casos, as estruturas sedimentárias primárias tratativas estão sempre presentes. Todas essas unidades geológicas são sincrônicas e podem se correlacionar com outras similares aflorantes no Brasil, Paraguai, Uruguai, Perú, Bolívia, Colômbia, Venezuela e as Guianas. Elas se originaram durante a ingressão dos Mares Amazônico e Paranaense.

Palavras chave: Formação Ituzaingó, Sedimentologia, Ambiente Sedimentar, Bacia Mesopotamia-Chaco Paranaense, Argentina

SUMMARY

Four years of sedimentological detailed study led me to reinterpretate the Upper Tertiary Mesopotamia region stratigraphic scheme.

Upon a detailed sedimentary environment analysis of the Mesopotamia-Chaco Paraná basin, I made a different interpretation about previous ideas of the several units present at this morphostructural domain. The Ituzaingó Formation was interpreted as continental (fluvial) in origin by several researchers based on an insecure fossil fauna of invertebrates, always present at the top of the layers. These fossil fauna has a broad and extend biochron over the Cenozoic time. The Paraná Formation infralies the Ituzaingó Formation. The idea of an erosion unconformity between them was strongly proposed. The Paraná Formation carries marine fossil fauna of invertebrates dated as Middle Miocene. It generally is accepted that Toropí and Yupoí Formations rest over Ituzaingó Formation elsewhere. The structural contact was assumed as an erosional unconformity surface. Paraná Formation was dated by fossil invertebrate fauna as Middle Miocene. Toropí and Yupoí Formations were dated as of Middle to Upper Pleistocene based on fossil vertebrate fauna. I assumed that the position of these fossils vertebrate fauna of is of alloctonous for the Toropí and Yupoí muddy formations and I propose that the fossil vertebrate fauna is in Holocene sediments. I carried out detailed studies which include: architectural, granulometric and morphoscopic analysis, petrographic data, paleocurrent measurements, scanning electron microscopy, diffractometric x-ray measurements, detailed sedimentologic profiles, drill hole correlations and remote sensing digital processing image analysis. Architectural analysis allowed me to distinguish the following internal sedimentary structures: hummocky cross stratification, tidal bundles, herringbone cross stratification, lenticular bedding, flaser bedding, bipolar cross stratification and several types of wavy stratifications. These studies led me to realize that the sedimentary environments and specially the relationship between these units are different from previously proposed studies. I propose a common shallow littoral marine origin (intertidal) for all these units in a Middle Miocene age, synchronous with the Paranense Sea ingression (12-14 MA) and an interdigitation between sand and mud lithofacies. A subsurface

unit, near Paraná Formation, the Puelches Formation, is interpreted as belonging to this sandy-muddy typical shallow marine lithofacies, despite of a previous work, that accepted a fluvial origin for this unit. An erosion unconformity was also proposed between Paraná and Puelches Formation. The Paraná and Ituzaingó Formations are composed by some 80 % friable arenaceous facies and of about 20 % of muddy facies. This is a typical heterolithic succession. A neat but irregular ferricretization forehead is present, specially, in the sandy lithofacies. This physico-chemical phenomena led previous authors to a misinterpretation of the stratigraphic scheme. My results show that the contacts between forehead ferricretization in the sandy lithofacies was assumed as an erosion unconformity, which is not the case. In some place, the ferricretization formed ferrigenous sandstones, which I called ferrigenous duricrust. This is of a very recent age of about Upper Pleistocene-Holocene times. Calcretization is also present in the outcrops. All these secondary processes hid the primary physical structures and chemical composition of the sandy-muddy lithofacies. Paraná, Ituzaingó, Toropí, Yupoí and Puelches Formations are suggested to have the same origin (intertidal) and the same age, Middle Miocene. They constitute a blanket body of about 1500 kilometers in extension at the northeastern portion of Argentina and have of approximately 300 meters of thickness. They are composed only by medium, fine to very fine white sands and grey to beige mud lithofacies. When alteration is present (ferricretization), the sediments change its colours to reddish or yellowish, sometimes purple, brown or black. In a few cases the alteration (ferricretization) is very intense, then the sands are converted into reddish to black sandstones. In this case, primary sedimentary tractive structures were always recognized. These units, Paraná and Ituzaingó Formations are synchronous and may be correlated with other similar outcrops at Uruguay, Brasil, Paraguay, Bolivia, Perú, Ecuador, Colombia, Venezuela and Guyanas. They were formed during the Paranense-Amazon Seas.

Keywords: Ituzaingó Formation, Sedimentology, Depositional Environment, Chaco Paraná-Mesopotamia Basin, Argentina

INTRODUCTION

From the point of geomorphologic view, the area of study is a vast plain called "Llanura Chaco Pampeana-Mesopotamia". Its average above sea level is of 45 to 65 meters.

The studied area may be seen in Figure 1 and 2.

Some researchers have studied Paraná, Ituzaingó, Toropí, Yupoí and Puelches Formations (D'ORBIGNY, 1946, FRENGUELLI, 1920, 1937, BONARELLI & LONGOBARDI, 1929, DE ALBA, 1953, HERBST, 1969, 1971, HERBST & SANTA CRUZ, 1985, 1995, IRIONDO & RODRIGUEZ, 1972, JALFIN, 1988, SANTA CRUZ, 1972). Excepting Paraná Formation (Miocene), the others formations were considered continental (fluvial) in origin. Their age range from Lower Pliocene to Upper Pleistocene.

Paraná Formation is considered to be marine in origin based upon fossil fauna invertebrate rests. *Ostrea patagonica*, d'Orb. and *Ostrea parasitica*, d'Orb., defined the environment and age of this layers, among many other invertebrate remains.

Although previously suggested, an erosion unconformity between Paraná and Ituzaingó Formations has never been proved (HERBST & SANTA CRUZ, 1985, 1995).

The vertical relations among Ituzaingó, Toropí and Yupoí Formations are believed to be unconformity surfaces (HERBST, 1969, 1971, HERBST & SANTA CRUZ, 1985, 1995).

I have studied Ituzaingó Formation in detail from 1994 to 1998. From this date until now, I have taken more than 20,000 measurements on these units.

Studies were made in the following themes: architectural, facies analysis, granulometric and morphoscopical, petrographic data, x-ray diffractometry, paleocurrent measurements, detailed sedimentologic profiles, scanning electron microscopy, drill hole correlations, study of the contacts and analysis with remote sensing digital image processing.

Once the processing of these data was complete, I concluded with a different idea from previous theories.

METHODS

On the field of sedimentology, several lines of methods of study were used for a better understanding of the depositional model system and age of formation.

Field methods were architecture and facies analysis, paleocurrent measurements, detailed sampling and profiles, detailed studies of vertical relations and type of contacts between sand and mud. Internal contacts in the sand beds were always remarked.

To obtain very good outcrops, many artificial cuts on the badlands and gullies were made in order to take precise measurements and then obtain reliable data at the cleaned gullies slopes. Several different types of primary tractive sedimentary structures were observed and drawn out in paper.

A lot of photographs with general and detailed primary sedimentary tractive structures views were captured using a suitable reflex camera and special zoom and filters. Different contact orders were discriminated, and all types of discontinuity surfaces were drawn.

Natural and artificial outcrops were undertaken to measure paleocurrents. Measurements were done only on planar cross bedding in order to avoid mixed directions among different types of structures.

The contacts between friable, fine to very fine, white to clear grey sands and dark grey to beige mud intercalations (lenticular) were revealed by detailed profiles.

Measurements for cyclicity studies (rhythmites) were made out. At the laboratory, time series were analyzed by means of the Fast Fourier Transformations.

On the other hand, I studied the samples under the polarizing microscopy, magnifying glass, classical granulometrical analysis, x-ray diffractometry and scanning electron microscopy.

I compared field drawings with amplified photographs. These photographs were passed through computational filters and effects. Softwares used are easily accessible in all parts of the world. Final results were extracted from field drawing and effect treated photographs. Remote sensing and digital image processing were done over satellite imagery, LANDSAT 5 with IDRISI software, using several band combinations, with many false colour compositions, filterings and stretchings.

DESCRIPTION

The Ituzaingó Formation is composed by beds of sands (80 %) and intercalation of muds (20 %).

The exact thickness remains unknown but the probable average is of about 250 to 350 meters. Only 30 meters are visible in the outcrops of the Mesopotamia region, always in the left margin of the Paraná river. This is probably because block faulting reactivation on Holocene time (FRENGUELLI, 1920, 1922, 1937, TORRA, 1993, 1994, 1996).

The friable sandy lithofacies are very well sorted, very well rounded, fine to very fine in grain size and white to clear grey in colour. This is the case when they are unaltered by ferricretization, calcretization and incipient silicification.

When the opaque minerals are altered by ferricretization there is an oxidation of magnetite, which is converted into limonite of various tones of colours. Reddish ones prevail over yellow, orange, brown, black and purple. The result is a "ferruginous duricrust" (BATES & JACKSON, 1987).

The contacts with the pelitic (mud) lenticular intercalations are very well defined. Geometrically, muddy lithofacies beds are wholly lenticular in shape.

Primary sedimentary tractive structures are recognized in the beds of friable, fine to very fine, white to clear grey sands. They are the following in order of frequency: planar cross stratification, wavy stratification, tidal bundles, hummocky cross stratification, herringbone cross stratification, flaser beddings, bipolar cross stratification and lenticular bedding. Figures 3, 4, 5 show some details.

Planar cross stratification and tidal bundles prevail in sets of 20 to 80 cm in thickness. Generally, they are limited by wavy stratification, in beds of about 5 cm to 20 centimeters. Bipolar cross stratification is very common too.

There are doubts about the presence of tempestites, because they are not completely recognized until now. Lines of mud paracasts, until 20 cm in diameters, are often above Hummocky Cross Stratification (HCS) structure.

The thickness of the sandy lithofacies ranges from 10 cm to 80 cm when unaltered. The sands are fine to very fine, well sorted, very well rounded, white to clear grey sand beds.

These sandy beds carry primary tractive sedimentary structures well developed and never mentioned before (TORRA, 1997a).

When they are altered, no visible structural limits are distinguished. The sand beds are massive. In this case, the primary tractive sedimentary structures very well recognized in the lower section of the outcrops white sand beds, were destroyed for ferricretization, calcretization,

scarce silicification and recent meteoric weathering. In few cases, when the sands are converted into really sandstones, the primary tractive sedimentary structures are present. Tidal bundles stratification predominate and bipolar cross stratification is frequent.

Petrographically, the sand beds are composed for more than 95 % of quartz clasts (mono – and polycrystalline quartz, Qm + Qp), some feldspars (mainly microcline) and accessory minerals as muscovite, tourmaline, hornblende, cyanite, sillimanite, augite, calcadony, opale, augite and epidote. May be for it is a very fine sand lithics are absent. Opaque minerals are magnetite (which predominate), very fine, well rounded, sometimes until 3% of the average composition. Titanomagnetite and ilmenite are also present in minor quantities. The fabric is clearly unimodal, with point contacts and no visible matrix.

According to PETTIJOHN *et al.* (1987) classification scheme, the sand is a quartzarenite, a supermature sand.

Pelitic (muddy) lenticular intercalations are massive. In the case that they are unaltered, diffractometrical analysis reveal that illite is the predominant clay mineral in percentage. On the other hand, when the muddy facies is altered, montmorillonite and kaolinite are more common and illite disappears.

Thickness of the muddy beds range from 1 cm to 4 meters. Colours are dark grey and beige, sometimes greenish.

The logs registered in the drill-holes reveal a monotonous alternancy of fine to very fine, white to grey beds of friable sandy lithofacies intercalated with greenish mud layers. This pattern is continuous until the depth of 230 m, as in the drill-hole “Corrientes Nº 1” (INCYTH, 1977). Other drill-hole logs, ranging 40 m to 65 m in depth, reveal exactly the same pattern. The drill-holes mentioned are scattered over about an area of approximately 150,000 square kilometres at Corrientes Province. Figure 2.

The study of oil drill-holes, reveal that this similar pattern may be identified at least 250 to 350 m in depth, according to the place and situation in the "Llanura Chaco Pampeana-Mesopotamia region". After this depth (more than 350 meters), the lithology seems to be the same although some changes of colour, may be due to diagenetic effects or depositional variations in the sedimentological environment may be present there.

The Paraná Formation is a geologic unit that appears at the south of the Mesopotamia region of Argentina, near Paraná city (Figure 2).

It is composed by predominantly pelitic (muddy) lithofacies with intercalations of fine to very fine, very well rounded, very well sorted, reddish to white sandy lithofacies. Ferricretization and calcretization phenomena are always present in both the sandy-muddy lithofacies but it is not so evident as in the north part of the Mesopotamia region and south of the Paraguay country.

The thickness of muddy lithofacies are 60 cm to 4 meters while the thickness of intercalated fine sands are 20 cm to 100 centimeters thick. The contacts between these lithofacies are planar neat. The sand beds are lenticular in shape but very extensive (more than 2,000 or 3,000 meters).

The pattern of the outcrops at the Paraná gullies are very similar to those of the northern part of Mesopotamia region, where sand of beds and muds are called Ituzaingó Formation. In this region, 600 km to the south of Corrientes city, near Paraná city, the pattern is very similar, changing the predominancy of one lithofacies over the other (muds for sands).

In this place, the mud carried out a fossil fauna invertebrates. *Ostrea patagonica*, d'Orb. and *Ostrea parasitica*, d'Orb. are present among another invertebrates at the Paraná gullies and surrounding areas. These invertebrates were dated from Middle Miocene age (DEL RIO, 1991).

It was supposed that Paraná Formation infralies Ituzaingó Formation (HERBST, 1971, HERBST & SANTA CRUZ, 1985, 1995). It was

inferred an erosion unconformity although it was never proved (TORRA, 1998b).

The Toropí and Yupoí Formation outcrop in the north of the Mesopotamia region. These Formations were created by HERBST (1971) in order to solve a complex stratigraphic problem.

They are composed of silty-muddy layers (clear to dark grey) and intercalations of fine to very fine, very well rounded, well sorted, reddish to yellowish sands. The whole thickness ranges between 3 m and 6 meters.

The contacts between sands and muds are hidden by ferricretization, calcretization and meteoric weathering although they appear to be conformable when the outcrops are cut and cleaned out with a spade. The thickness of mud layers are 20 cm to 40 cm and the fine sand ones are of about 5 to 20 centimeters.

HERBST (1971) and HERBST & SANTA CRUZ (1985, 1995) believes that the relation of these two units (Toropí and Yupoí Formations) with the supposed infralying Ituzaingó Formation is represented by an erosion unconformity but according to new researches made in the area, the contacts appear to be clearly in perfect structural conformity (TORRA, 1997a, 1998a,b).

Both units, Toropí and Yupoí Formations are assigned to Quaternary age upon the basis of fossil vertebrate fauna (HERBST, 1971, HERBST & SANTA CRUZ, 1985, 1995). Although the presence of these vertebrates are of Pleistocene age, the sediments that contains the bones are older than the fossil fauna according to new investigations (TORRA, 1998c).

I thought the vertebrates, which lies on the "top most levels of the beds of Toropí and Yupoí Formations" are the results of swamped into the thin silt-mud beds when they died under very wet conditions. Indeed, they may be alloctonous to the silty-muddy sediments.

At the end of this section, I shall consider a subsurface unit situated near the Mesopotamia region, toward the south of Paraná city. This is Puelches Formation (SANTA CRUZ, 1972).

This was recognized in the drill-holes cuttings at south of the Santa Fé and north of the Buenos Aires provinces, both limiting with the Mesopotamia region. See Figure 2.

It is composed by medium, fine to very fine, very well rounded, well sorted, yellow, grey or white sands. Scarce layers of muddy beds were recognized. Its thickness is of approximately 60 meters. The Quaternary loessic sediments supralies it and its supposed bottom part supralies the sandy-muddy sediments of Paraná Formation.

INTERPRETATION

There are five units structurally and horizontally disposed all along of about 1,000 km in length at the Mesopotamia region.

The outcrops are never more than 30 meters of exposure although they continue, in depth at least for a minimum of 230 meters.

Unconformities was never proved until now (TORRA, 1997a, 1998a,b,c,d).

The composition of only two lithofacies appearing, given us all the impression that they are laterally interdigitated, geared or tongued. Middle Miocene invertebrate fossil fauna (*Ostrea sp.*, etc.) were recognized in muddy Paraná Formation. Pelitics and sand sediments, in the fossil record, are common in marine littoral platforms and shelves (PROTHERO, 1997, PROTHERO & SCHWAB, 1997, TUCKER, 1994).

However, the origin of these two lithofacies is generally attributed to fluvial origin in which Paraná River was the agent of transport and producing the deposits of mud and supermature sands. The age is attributed

to belonging to Pliocene until Upper Pleistocene (DE ALBA, 1953, HERBST, 1969, 1971, HERBST & SANTA CRUZ, 1985, 1995, JALFIN, 1988).

Based upon the detailed sedimentological studies carried out during four years in the field of all Mesopotamia region, and in the laboratory, processing real data obtained from good exposures, and the study of bibliography about old logs of drill-holes, the author would like to express another point of view.

Paraná Formation, situated at the bottom of the supposed sequence, has been given a Middle Miocene age as mentioned above. Its lithofacial composition is predominantly mud over sand. None unconformity was proved with the supposed supralyings formation (Ituzaingó). Ferricretization and calcretization inferred on Upper Pleistocene-Holocene age (TORRA, 1998c) are present elsewhere. The irregular or neat forehead of ferricretization causes a visual effect that seems an unconformity. However, the detailed examination shows that this contact is not an erosion unconformity (TORRA, 1998a).

The supposed unconformities mentioned before are always the irregular or neat forehead of oxidizing (ferricretization) present in the sandy and muddy lithofacies elsewhere.

In the Middle Miocene a very vast and extensive marine ingression, called the "Paranense Sea", covered all Chaco Paraná and Mesopotamia basins and great part of South América as suggested by RÄSÄNEN *et. al.* (1995) and RAMOS & ALONSO (1995). Figure 10.

A great number of measurements of paleocurrents made over all these formations gives us a bimodal design. This model was only sometimes polymodal or bimodal oblique, but never unimodal which is the typical case for fluvial systems (TUCKER, 1994). Bimodal design is more frequent in tidal systems where tidal currents dominate the depositional system (TORRA, 1998d,e). Figure 6.

Studies of time series analysis on tidal bundles strongly suggests a deposition controlled by tides currents (TORRA, 1997b). Recurrent periodicity encountered was approximately 14 and 28 days. Figures 7 and 8.

The study with SEM showed typical v-shaped percussion marks in the monocrystalline, rounded and high sphericity clasts of quartz (Qm), indicating possible high-energy beach environment (KRINSLEY & TAKAHASHI, 1962, 1964, KRINSLEY, *et al.*, 1964, KRINSLEY & MARGOLIS, 1969, TUCKER, 1994).

Vertical continuity without unconformities, is proved by means of a drill-hole log reaching the 230 m in depth. Monotonous succession of sandy and muddy lithofacies are present. It is an outstanding heterolithic succession.

Remote sensing data shows a clear lithology horizontal continuity of all these units along the Mesopotamia region and the south of the Paraguay. The external limits of the basin can be seen perfectly in the satellite images. It is present in the east of the Mesopotamia region, where volcanic Mesozoic rocks outcrops intercalated with thin beds of aeolian supermature sandstones. This was a positive region from Paleozoic age. It is necessary to look the tone and the texture to appreciate the space distribution of this great unit like a "manteau". To the west of the Paraná River the sandy-muddy lithofacies disappear by effect of the Holocene regional faulting (TORRA, 1993, 1994, 1996).

The supermature sands and associated muddy lithofacies sometimes are characteristic of beach environment in intertidal to subtidal environments (PROTHERO, 1997, PROTHERO & SCHWAB, 1997, TUCKER, 1994).

Mud dropped when water slack. The change in speed of flow currents and the possible change of sea depth conditions are the probable reasons why mud beds are in the order of meters.

Many bibliography exist about this theme as AIGNER, (1985), ALLEN, (1980, 1984), ALLEN & UNDERHILL, (1989), DALRYMPLE, (1984, 1992), SMITH, REINSON, ZAITLIN & RAHMANI, (1991), VISSER, (1980), WALKER, (1985a, b, c), WALKER, (1990), WALKER, DUKE & LECKIE, (1983) and WALKER & GUY PLINT, (1992). They treated in detail many outstanding aspects of modern and ancient intertidal-subtidal environments in very selected places.

CONCLUSIONS

After the analysis of these data, I concluded that the problem of Paraná, Ituzaingó, Toropí, Yupoí and Puelches Formations may have another interpretation, with regards to its depositional environment system.

My opinion is that these formations constitute an unique sedimentologic sequence with some smooth facial changes. Unconformities are not present.

This large geologic unit, may have been deposited as submarine accretional bars during the ingression of the "Paranense Sea" (Middle Miocene) in extended tide-dominated plains. The muddy lithofacies, was deposited when the sea level changed and the depth was increased or the speed of flow currents turned to a minimum.

Ferricretization and calcretization, recent phenomena in this area (TORRA, 1998e), hidden and destroyed textural characteristics and other important sedimentologic properties as marine internal structures in the friable sands.

A summary of the stratigraphic scheme proposed may be seen in Figure 9. Relation with Paranense Sea may be reported in Figure 10.

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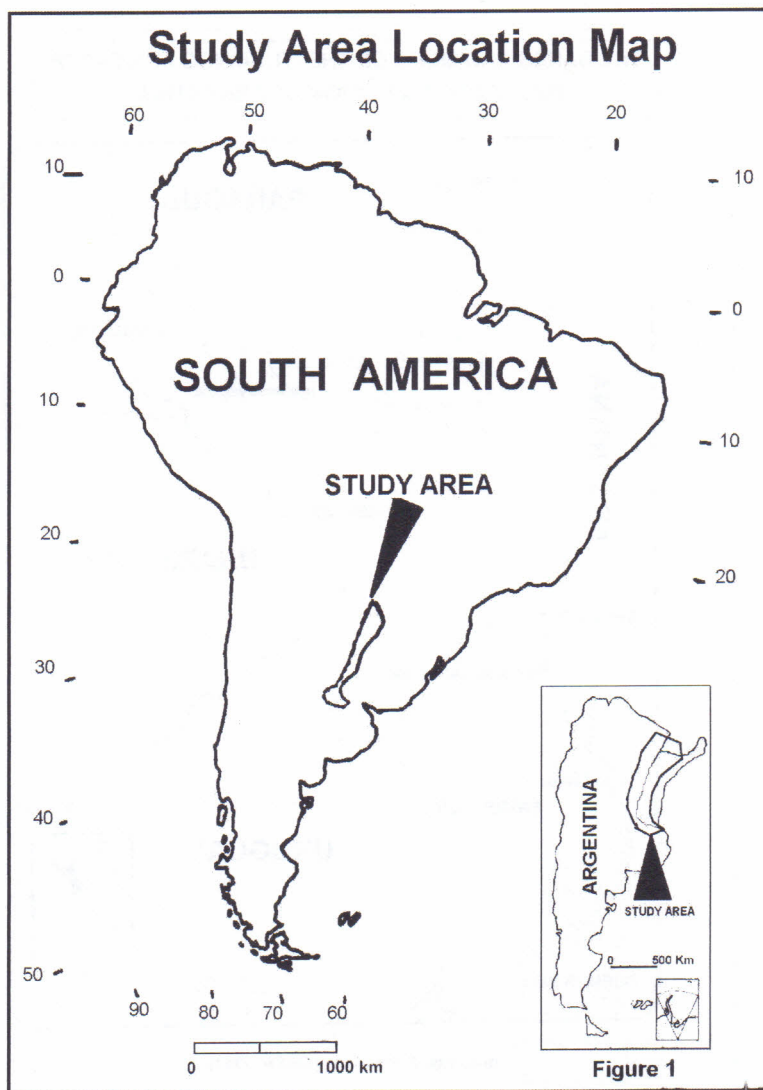


FIGURE 1. A map showing the study area in South America continent.

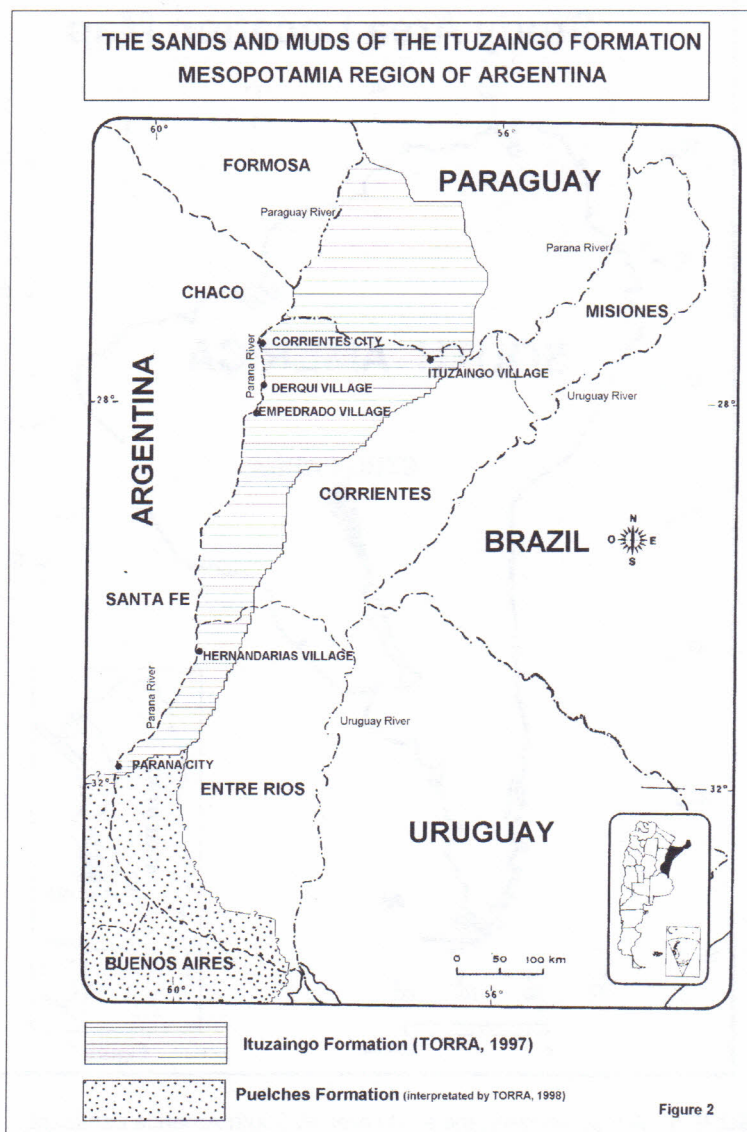


FIGURE 2. A map showing the distribution along Mesopotamia region and Paraguay of the Ituzáingó and Puelches Formations.

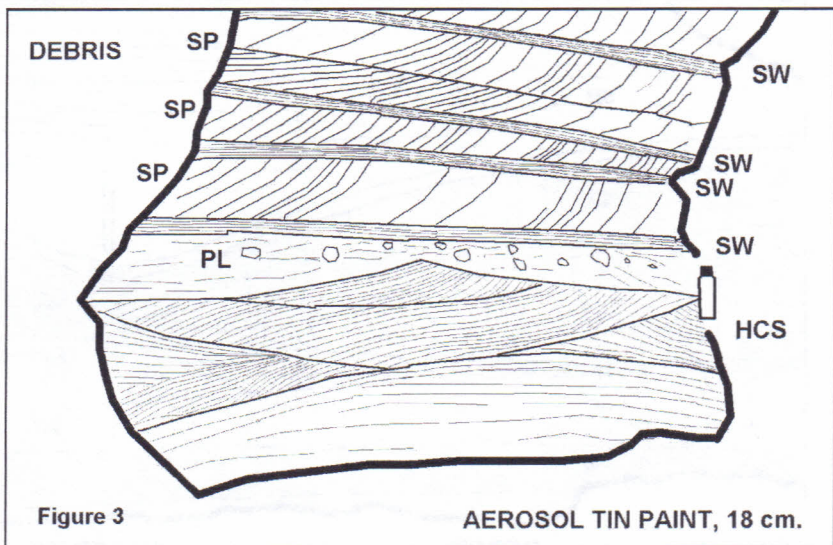


FIGURE 3. Hummocky cross stratification (HCS). SP: Planar cross stratification. SW: wavy stratification. PL: line of mud paraclasts.

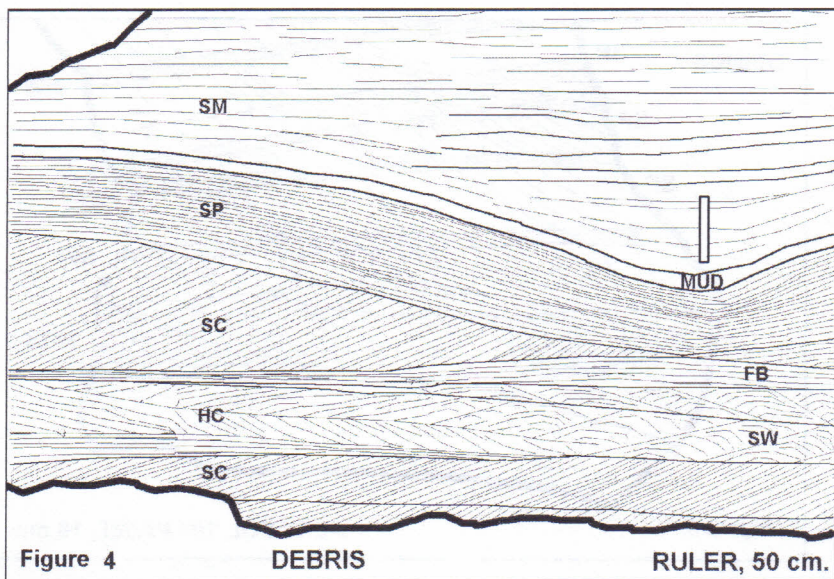


FIGURE 4. Herringbone cross stratification (HC). SW: wavy stratification. SC: planar cross stratification. FB: flaser beddings. SP: planar lamination. MUD: a convex pelitic bed (illite rich), in a subaqueous interdune channel.

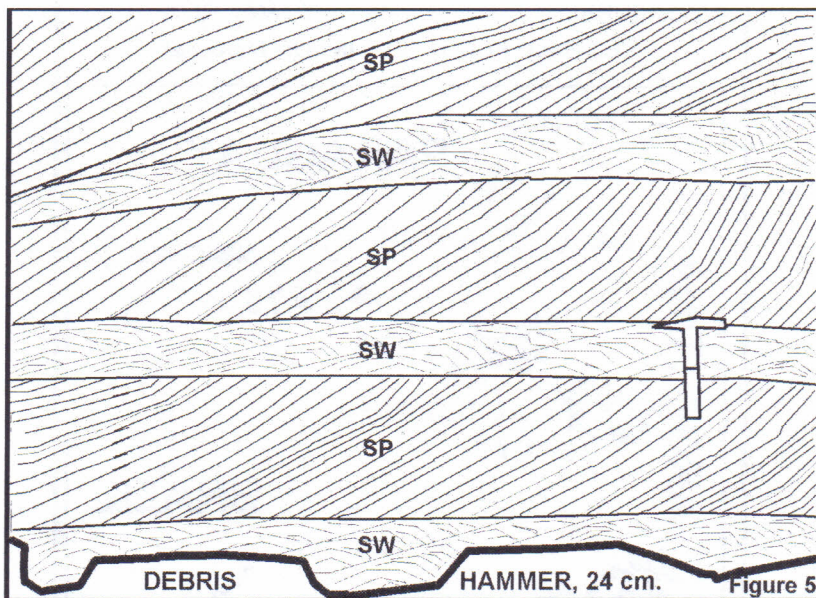


FIGURE 5. Tidal Bundle framework. SW: wavy stratification. SP: planar cross stratification.

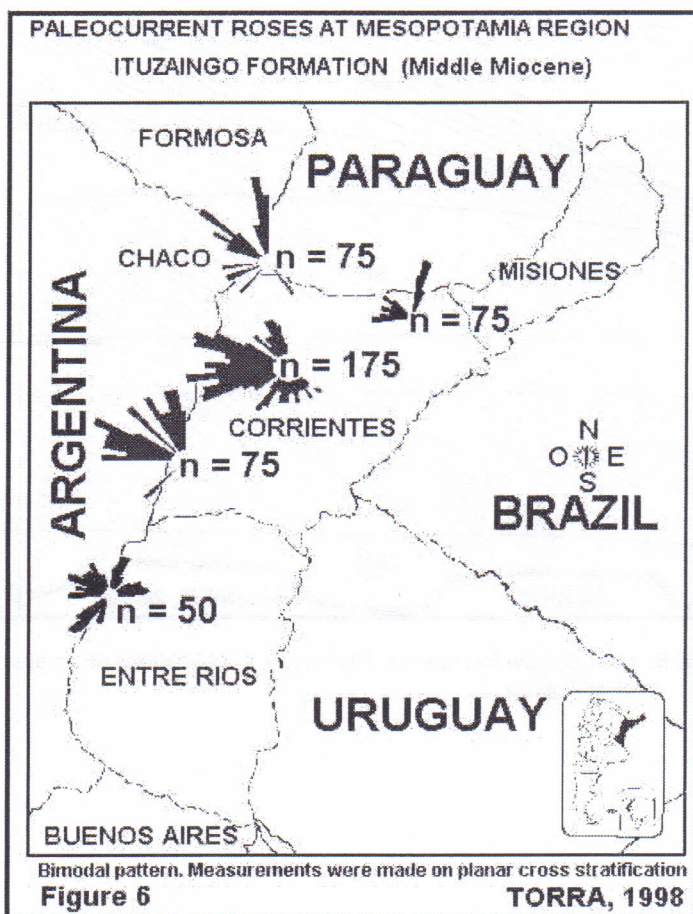


FIGURE 6. A map showing paleocurrent roses along Mesopotamia region. Bimodal or polymodal pattern predominate. None of river unimodal pattern exist.

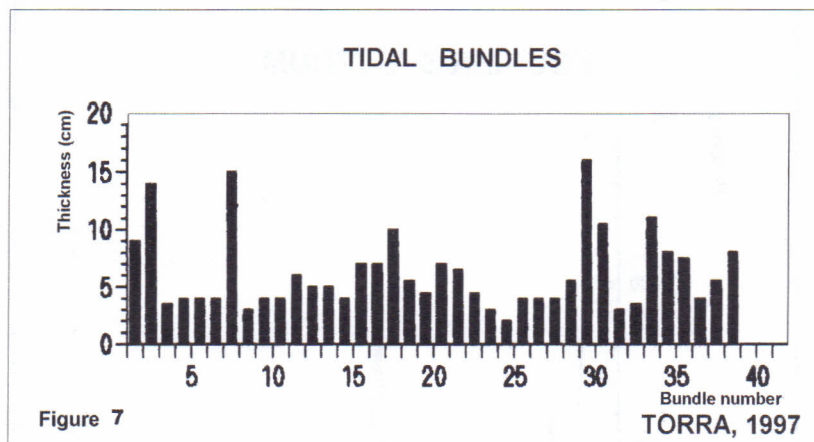


FIGURE 7. A diagram showing behaviour of thickness bed of tidal bundles.

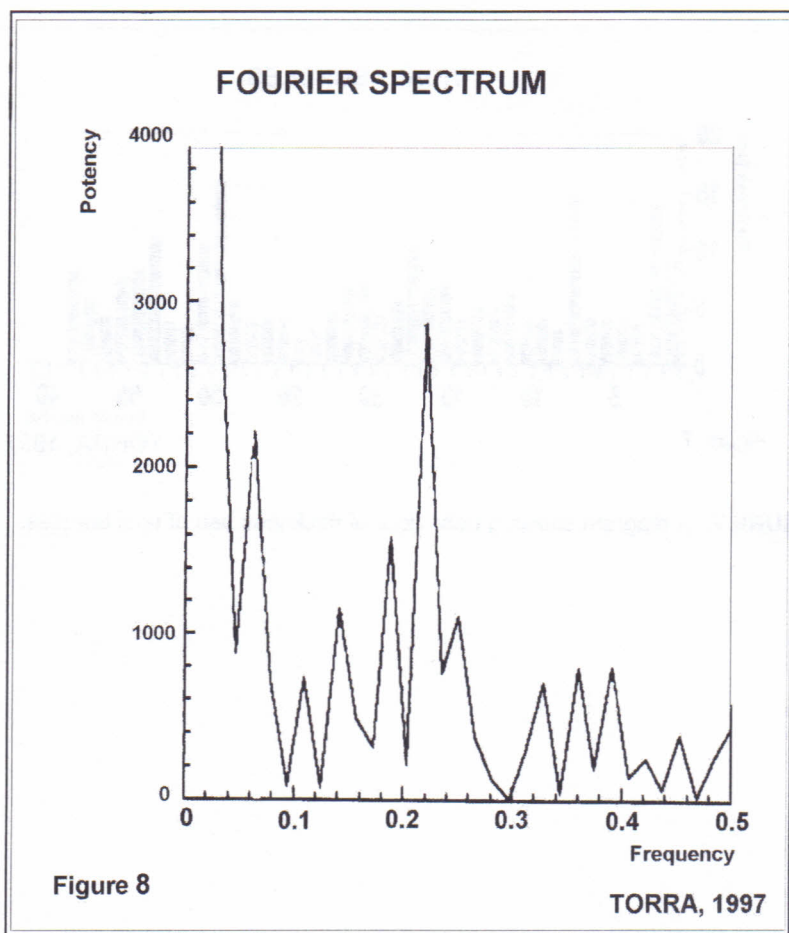


FIGURE 8. A diagram showing Fourier Spectrum after applied the Fast Fourier Transformation analysis. Ciclycity is of about 28 and 14 days, indicating possible tide regime. Other cycle, of about 7 day, may indicate marine storms.

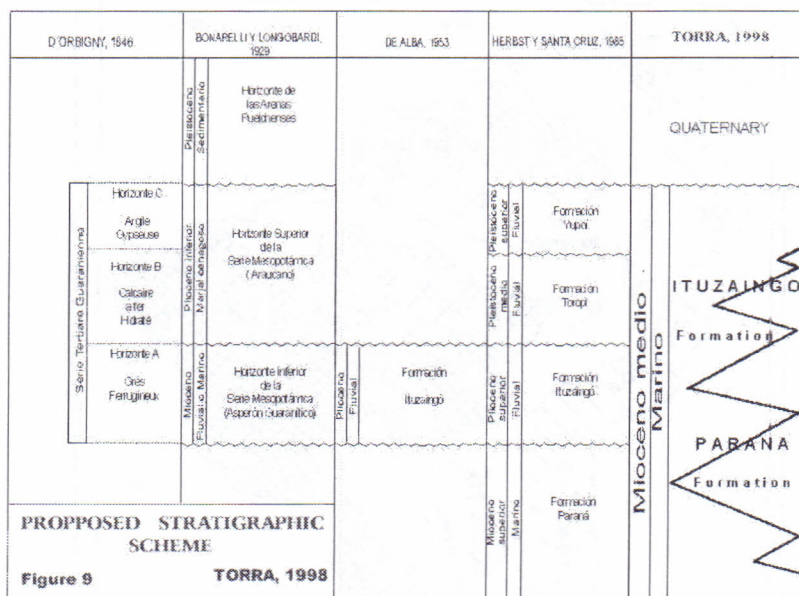


FIGURE 9. A schematic draw which show the proposed stratigraphic picture for Upper Tertiary Mesopotamia Region.

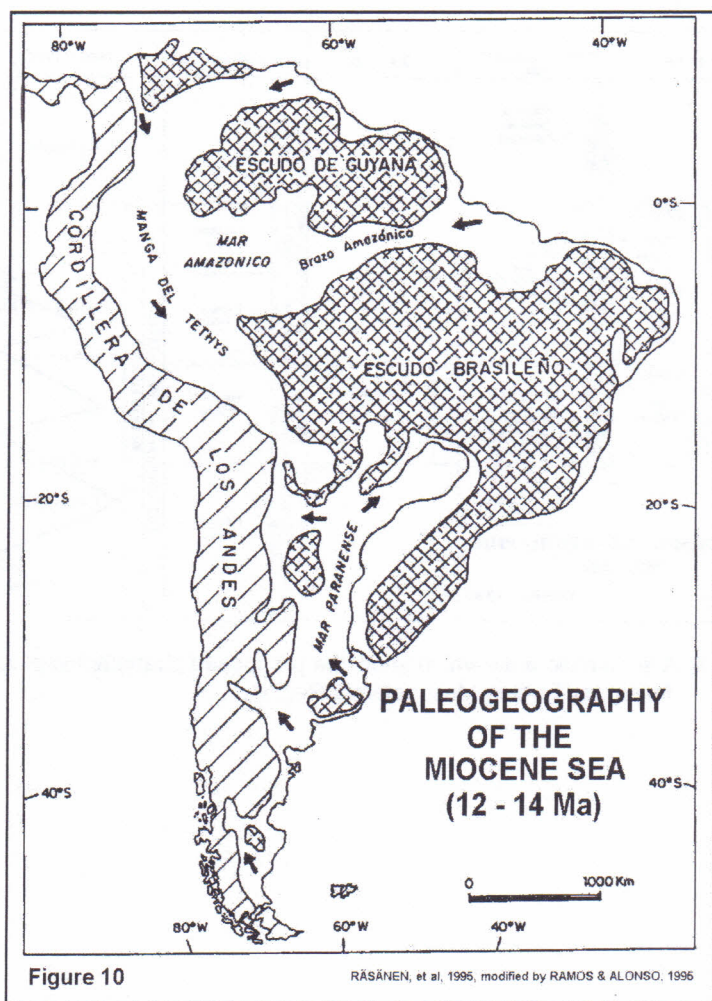


FIGURE 10. A general view of the Miocene Sea embracing a great part of South America.