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Hybrid coastal edges in the Neuquén Basin (Allen Formation, Upper Cretaceous, Argentina)

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ABSTRACT. The Allen Formation records the first Ingression Atlantic to the Neuquén Basin during the Late Cretaceous. The definition of lithofacies and facies associations interpretation for stratigraphic sections in Paso Córdoba and Salitral Moreno area, Río Negro, Argentina allowed to establish the depositional system that characterized this transgression in the northeastern edge of the Basin. In this paper we present sedimentological analysis of conglomeratic, sandstone, heterolithic and pelitic facies, which allowed the interpretation of tidal channels (TC), intertidal flats (ITF), storms-influenced tidal flat (SITF), subtidal flat (STF) and shoreface deposits (SF) parts of the depositional environment. These deposits represent a sedimentary records preserved example of hybrid systems, in which, the base of the sequence has greater tidal influence, while the upper portion is dominated by wave action. The paleocurrent data indicating a NNW-SSE direction to the shore and correlations and spatial distribution of facies associations propose paleogeographic and paleoenvironmental interpretations to Malargüe Group base. Then in this paper the relationship of this coastal environment presents with wind systems previously defined in this area for the Allen Formation.

Keywords: Sedimentary paleoenvironment, Tidal channels, Intertidal flat, Subtidal flat, Hommocky, Upper Cretaceous, Malargüe Group, Argentina.

RESUMEN. Márgenes costeros híbridos de la Cuenca Neuquina (Formación Allen, Cretácico Superior, Argentina). La Formación Allen registra la primera Ingresión Atlántica a la Cuenca Neuquina, durante el Cretácico Superior. La definición de litofacies y la interpretación de asociaciones de facies para las secciones estratigráficas de esta formación en el área de Paso Córdoba y Salitral Moreno, Río Negro, Argentina, permitieron establecer el sistema depositacional que funcionó durante esta transgresión en el borde noreste de la cuenca. En este trabajo se presenta el análisis sedimentológico a partir de la descripción de facies conglomerádicas, de areniscas, heterolíticas y pelíticas, las cuales permitieron la determinación de depósitos de canales de mareas (TC), planicies intermareales (ITF), planicie mareal con influencia de tormentas (SITF), planicie submareal (STF) y cara de playa (SF). Estos depósitos representan un ejemplo más de registros sedimentarios preservados de sistemas híbridos, en los cuales la base de la secuencia tiene mayor influencia de las mareas, mientras que en las secciones superiores predomina la acción del oleaje. Los datos de las paleocorrientes indicando un rumbo NNO-SSE para la línea de costa y las correlaciones y distribución espacial de las asociaciones de facies permiten ajustar las interpretaciones paleogeográficas y paleoambientales de la base del Grupo Malargüe. Además en este trabajo se sugiere la vinculación de este ambiente costero con los sistemas eólicos anteriormente definidos para el área de la Formación Allen.

Palabras clave: Paleoambiente sedimentario, Canales de mareas, Planicie intermareal, Planicie submareal, Hammocky, Cretácico Superior, Grupo Malargüe, Argentina.

1. Introduction

The correct definition of the depositional environments is an essential component of basin analysis, especially in oil basins where it is of great interest to have detailed sedimentological studies that contribute to regional correlation and characterization of the various units that comprise it, in particular in sections of the stratigraphic column characterized by transitional environments where continuity is highly variable and difficult to predict. The Neuquén Basin, located in west-central Argentina (Fig. 1A, B, and C) between 34°-41°S and 66°-71°W, is the leading oil and gas producing sector in the country. The Allen Formation of the Malargüe Group (Fig. 1D) is one of the units that forms the basin's stratigraphic sequence and, recently, has provided a wide variety of fossils which have been of great interest to paleontological studies. However, the knowledge we have regarding the sedimentary paleoenvironments that characterized this lithostratigraphic unit is still limited in many areas of the basin.

The definition to date is that the Allen Formation records a continental to marine sedimentation coinciding with the first Atlantic transgression during the Late Cretaceous. The variety and arrangement of fossils found suggest some complexity in estimating the layout of the coastline, although the depositional environments recognized so far in this formation, such as estuaries and tidal flats (Andreis *et al.*, 1974; Barrio, 1990; Armas and Sánchez, 2011), brackish lakes (Salgado *et al.*, 2007) and aeolian fields (Armas and Sánchez, 2013) in part allow the corresponding paleogeography to be established. This work contributes to this last aspect and presents the interpretation of the sedimentary system linked to a transitional environment with variations in the influence of tides and the action of waves.

The differentiations in coastal depositional environments caused by waves and tides have been defined since the early 70s by Galloway (1975), Wright (1977) and Hayes (1979) with their classification diagrams, among others. Dalrymple and Zaitlin (1992) suggest the definition of tidal flats as environments dominated by tides with a gentle slope and little influence of waves, unlike beach or shoreface environments, in which the slopes are greater and are subject to strong wave action. Although existing models of shoreface depositional systems rarely consider the effects of tides, this occurs in a wide range of coastal systems and presents great variability controlled by relative changes in sea level, the influence of storm and fair-weather waves and tides (Dashtgard *et al.*, 2012). What is certain is that among these coastal environments there are considerable mixtures of energies which are given very little study. However, some tools such as the identification of muddy heterolithic facies, including flasser, wavy and lenticular stratification or the deposits generated by storm waves, including hummocky cross stratification are essential to distinguish the dominant power (wave or tidal, respectively) of the sedimentary paleoenvironment (Yang *et al.*, 2005). A term which has emerged in recent times is the reference to hybrid depositional systems, which occur where the influence of waves, seas and rivers overlap (Boyd *et al.*, 1992; Dalrymple and Zaitlin, 1992; Basilici *et al.*, 2012).

The aim of this paper is to present detailed sedimentological study conducted for the Allen Formation by showing the types of paleoenvironments that occurred with the onset of the Atlantic ingression on the eastern edge of the basin, and thus contribute to the definition of the paleogeography of the Upper Cretaceous.

The research was carried out in Río Negro's northeastern area (Fig. 1C), by conducting a detailed survey of continuous stratigraphic sections of up to 2 km along the north side of the Salitral Moreno (pSM Fig. 2) and in the vicinity of the town of Paso Córdoba (pPC1 and pPC2 Fig. 2). In addition to preparing sedimentological profiles and photomosaics mapping of sedimentary bodies, research includes the identification and interpretation of lithofacies-essential units that allow the characterization of sedimentation paleoenvironments. The definition of these lithofacies involves combining observations made about spatial relationships and internal characteristics (lithology and sedimentary structures) with comparative data from other studies of stratigraphic units, particularly from studies of modern sedimentary environments (Walker, 1990). Furthermore, in this work, the interpreted lithofacies were grouped into facies associations, considering genetically related features and sedimentary features including geometry, continuity and shape of the lithologic units (Miall, 1984). This definition of facies associations in conjunction with the statistical analysis of paleocurrent data make it possible to create a model of deposition for the Allen Formation.

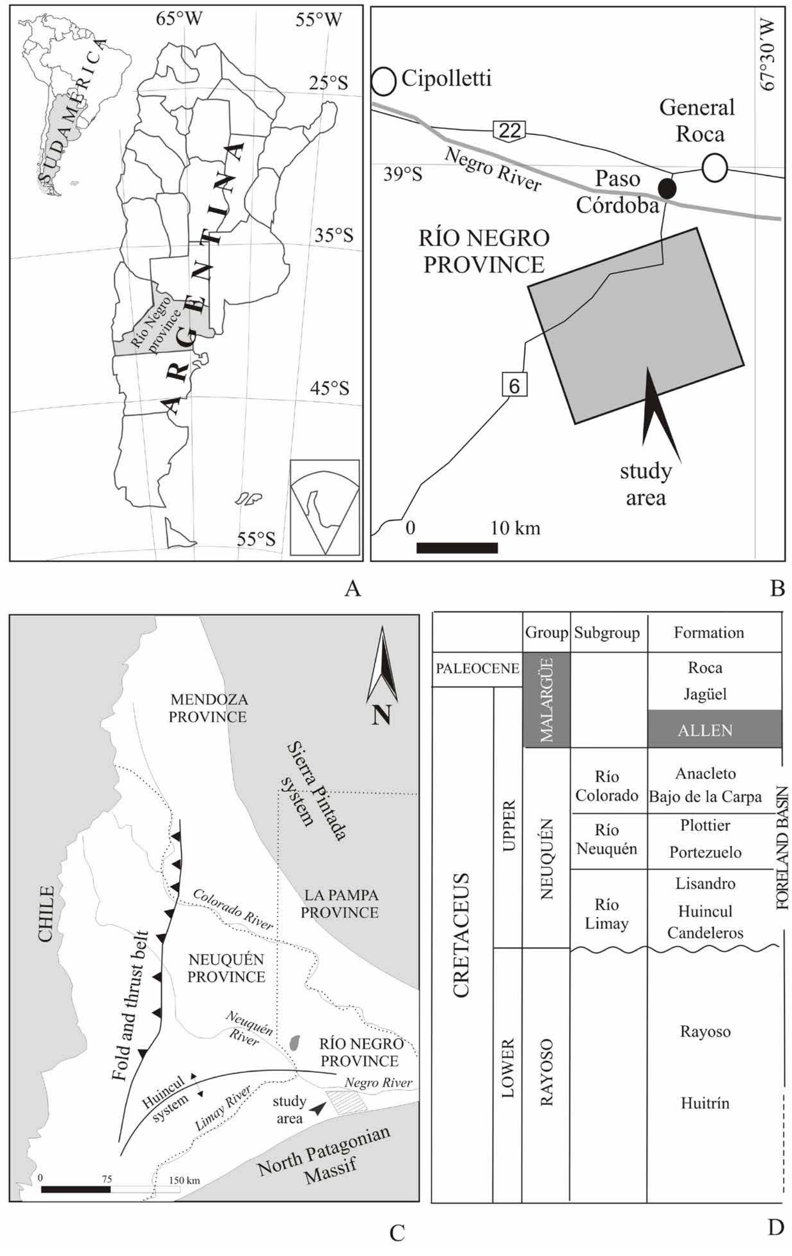

FIG. 1. Geographic location of the study area and Stratigraphic table. **A.** Location of Río Negro province, Argentina and South America; **B.** Study area in the Río Negro province; **C.** Neuquén Basin; **D.** Stratigraphic table of the Cretaceous of the Neuquén Basin.

2. Geological environment

The Allen Formation is part of the stratigraphic sequence that fills the Neuquén Basin. From the Triassic period to the present, the active subduction and development of the magmatic arc on the western edge of Gondwana controlled the geological evolution of the basin. During the first phase of syn-rift, the low rate of subduction of the proto-Pacific plate generated a regional continental intraplate extension. At this stage the basin was filled with continental and volcaniclastic deposits (Vergani *et al*., 1995; Howell *et al*., 2005). Later, in the post-rift phase, the development of an active subduction zone associated

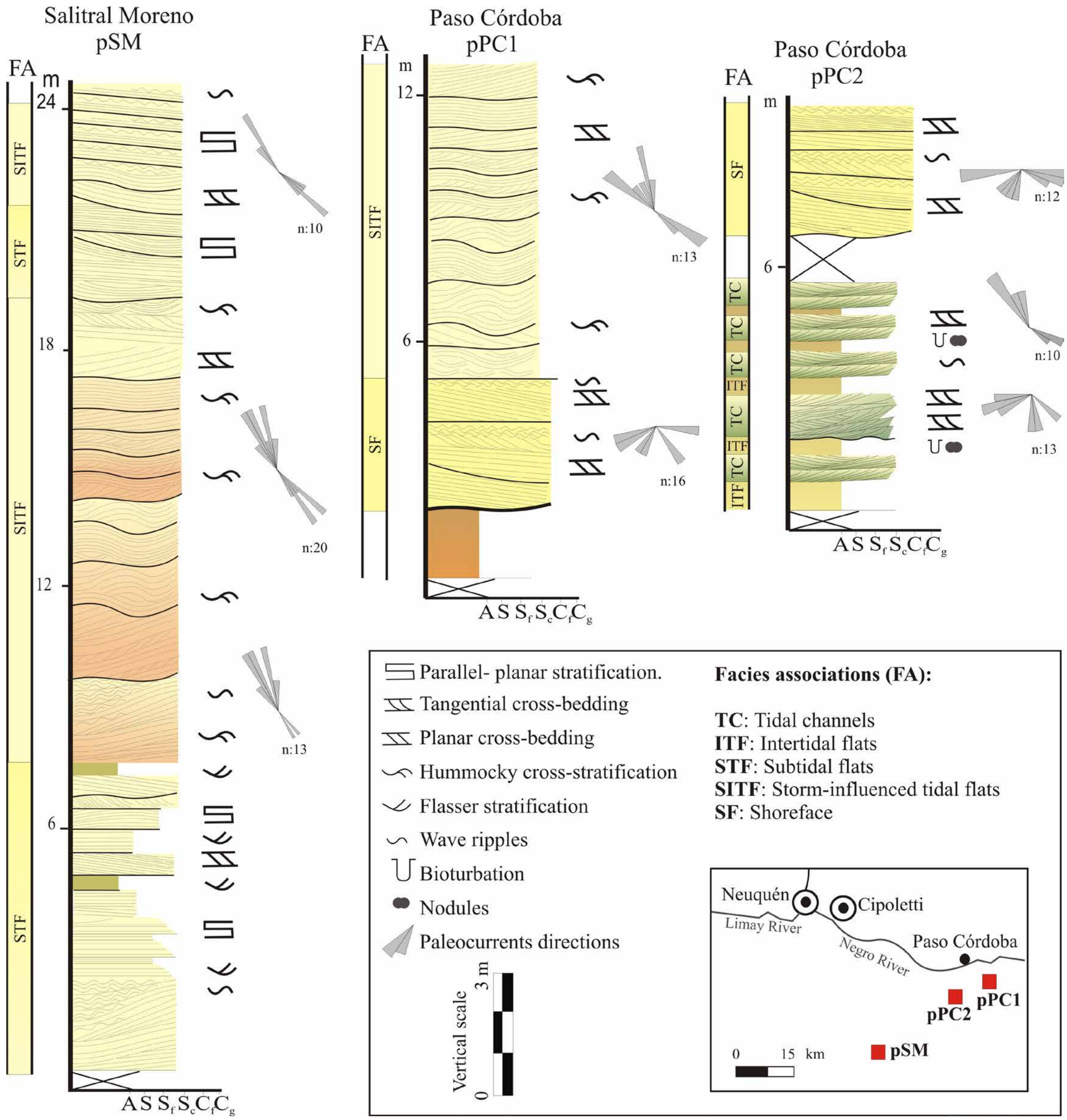

FIG. 2. Sedimentological profiles with the facies associations defined in the Allen Formation in Salitral Moreno (pSM) and Paso Córdoba (pPC1 and pPC2) area.

with the evolution of a magmatic arc which generated backarc subsidence produced deposits of marine and continental sediments (Franzese *et al.*, 2003; Howell *et al.*, 2005). In the earliest stages of the development of the foreland basin in late Cretaceous is linked to a decrease in the angle of slab subduction produced by compression and flexural subsidence (Vergani *et al.*, 1995; Ramos, 1999) and the uplift of the thrust belt. This stage is marked by the deposit of the Neuquén Group (Tunik *et al.*, 2010; Aguirre Urreta *et al.*, 2011) with a continental sedimentation and a transitional environment (Armas and Sánchez, 2011) linked to the first Atlantic transgression into the basin, of which the Malargüe Group offers the greatest evidence (Fig. 1D). The Andean tectonic finally caused the complete folding and uplift of the Mesozoic succession, exposing the wide variety of depositional environments (Franzese and Spalletti, 2001; Howell *et al.*, 2005).

3. Stratigraphy of the area

The Allen Formation is the lower unit of the Malargüe Group (Fig. 1D) and is considered to be late Campanian to early Maastrichtian based on foraminifera (Ballent, 1980) and magnetostratigraphic (Dingus *et al*., 2000) studies. The stratotype of this formation was defined by Uliana and Dellapé (1981) in eastern area of the Bajo de Añelo, where the relation between base and top is clearly exposed. The deposits are mostly clastic interbedded with banks of limestone and layers of anhydrite (Uliana and Dellapé, 1981) for which Barrio (1990) defined continental and shallow marine facies associated with semiarid conditions. The interpreted sedimentary paleoenvironments range from purely continental such as ephemeral lacustrine, aeolian and fluvial systems to coastal marine paleoenvironments with development of estuaries and tidal flats (Salgado *et al*., 2007; Armas and Sánchez, 2011, 2013), followed by a lagoon sedimentary stage from marsh to sea with carbonate precipitation in an area protected from waves, ending with a retraction leading to the accumulation of evaporites (Page *et al*., 1999; Barrio, 1990). The fossil record shows that this formation includes vertebrate skeletal remains, dinosaur eggshells, theropod teeth, remains of birds, scutes from turtles and crocodiles, lungfish teeth, indeterminate plant impressions, freshwater ostracods and fresh and salt water pelecypods (Uliana and Dellapé, 1981; Hugo and Leanza, 2001; Coria *et al*., 2007; Salgado *et al*., 2007).

Allen Formation deposits record the first Atlantic ingression (Uliana, 1979), and this transgressive process was accompanied by a gradual subsidence of the basin with the development of a low-gradient intercontinental coastal plain or barrier beach (Andreis *et al*., 1974; Uliana and Biddle, 1988).

4. Facies analysis

The assessment of the 10 lithofacies presented in Table 1 is the result of the facies analysis, and the code used for their designation was based on the criteria outlined by Miall (1996) for fluvial facies, with the addition of a third capital-letter ‘T’ in reference to tidal environment. Thus, the first letter refers to the particle size, the second to the sedimentary structure and the third to the type of agent. The definition of lithofacies makes it possible to group them in “hierarchical units”, by determining the different facies associations.

4.1. Facies associations

4.1.1. Facies associations: Tidal channels (TC)

This association is composed of the GtT, StT and ShT lithofacies (Table 1) comprising lenticular bodies with maximum thicknesses varying between 0.40 and 1.2 m, limited by gently undulating and planar surfaces. GtT and StT facies associated with three-dimensional gravel and sandy bedforms alternate at levels of 10 to 15 cm and present planar, tangential to the base and/or sigmoidal cross stratification (Figs. 3A, B). The foresets of cross stratification vary between 0.15 and 0.70 m with dip angles from 8° to 20°. Thin mud drapes are preserved on these with variations in thickness (from 0.01 m to 0.05 m) and continuity, alternating with the sandy sets (Fig. 3B).

The paleocurrents are bipolar, but with a predominant direction (pPC2-Fig. 2), and reactivation surfaces have a very low angle (Fig. 3D). The heterolithic of climbing ripple lithofacies (HrT) characterize the base of stratification and are affected by syn-sedimentary or slightly post-depositional deformation, covering thicknesses ranging between 0.05 and 0.80 m. The strata forming this association are interbedded with HfT (Fig. 3C), HlT, HrT and FlT lithofacies corresponding to intertidal flat deposits defined below (Fig. 3D).

Interpretation: The lithofacies of this association are primarily assigned to a variety of hydrodynamic regimes. The general characteristics match those described as the product of the migration of sinuous and straight-crested sand ripples under conditions of bidirectional currents, with the presence of a dominant flow and a subordinate one (Mowbray and Visser, 1984). The sigmoidal sets in particular are generated by vortices in the flow separation area related to the acceleration and subsequent deceleration of the tidal flow. The alternating layers of sandstone and claystone reflect ebb and flow cycles in tidally dominated environments (Plink-Björklund, 2005). The sandy sets are deposited in the strong flow of the dominating current, while the mud layers correspond to the period of slack water where the flow velocity decreases and allows the deposition of suspended materials (Mellere and Steel, 1995). The presence of mud layers, the bipolarity of the paleocurrents and the type of fill allow interpreting this association as tidal channels with multiepisodic fill due to medium-scale migrating dunes where

TABLE 1. DESCRIPTION AND INTERPRETATION OF THE LITHOFACIES DEFINED IN THE ALLEN FORMATION.

Lithofacies	Descriptions	Interpretations
GtT	Fine grained, regular sorted clast to matrix supported conglomerate with tangential cross-bedding at the base. Bodies of tabular and in wedge geometry up to 0.4 m thick with net wavy and erosive base.	Three-dimensional bedforms.
ShcsT	Coarse to medium grained, well sorted sandstone with hummocky cross-stratification of large scale and swalley cross-bedded, with wavelengths from 2 to 5 m. Bodies up to 1.2 m thick and lateral extension up to 30 m. Internally strata show planar lamination set from 0.007 m to 0.02 m thick and very fine mud drapes.	Combined action of high energy flows and storm events.
ShT	Fine grained sandstone and siltstones with parting lineation, low angle planar cross-bedded (5°) and parallel stratification to quasiplanar lamination with set from 0.01 m to 0.05 m thick. Bodies tabular up to 1 m thick with wavy base.	Upper flow regime, transition from dune to planar layer.
StT	Medium to fine grained, well sorted sandstone with tangential/ sigmoidal cross-bedding and planar cross-bedding with mud drapes. Bodies of tabular or in wedge geometry up to 3.5 m thick with net and erosive base. Paleocurrents directions show bipolar distribution.	Migration of 3D and 2D bedforms under bidirectional current conditions with the presence of a dominant flow and subordinate flow.
SpT	Coarse to medium grained, well sorted sandstone with planar and asymptotic base cross-bedding, and planar lamination. Bodies of wedge geometry up to 0.5 m thick and lateral extension up to 8 m.	Migration of straight crest bars in shoreface.
SrT	Coarse to medium grained, well sorted sandstone with climbing, asymmetric and symmetric in phase ripples. The ripples presents distinctive internal structure characterized by chevron-like laminations and rounded crest. The wavelengths vary from 0.03m to 0.15 m. Bodies tabular up to 0.35 m thick with net base.	Wave ripples.
HfT	Very fine grained sandstone and mud with flasser and lenticular bedding. Bodies of tabular and in wedge geometry up to 0.7 m thick.	Tidal currents with fluctuation in flow rates.
HrT	Very fine grained sandstone and mud with climbing ripples lamination gradually varying from type I to type II (Allen 1984). Bodies of tabular geometry up to 0.5 m thick.	Fluctuation in aggradations/ downstream migration rates bedforms, from subcritical flows tabular (type I and II) to supercritical flow (type III).
HlT	Very fine grained sandstone and mud with parallel lamination. Bodies of tabular geometry up to 0.7 m thick.	The sandstone deposited during peak tidal flow and the mud drapes deposited during slackwater periods.
FlT	Siltstone and mud with parallel lamination. Bodies of tabular geometry up to 0.5 m thick with net base.	Deposition by decantation.

the HhT lithofacies represents the final event of filling up (Reading, 1996; Neuwerth *et al*., 2006). It is suggested that these channels were dominated by high-energy currents and bimodal stratification with a predominant direction reflects the direction of a dominant current and a subordinate one (Plink-Björklund, 2005). In the regional paleogeographic reconstructions for the area (Sellwood and Valdés, 2006), the first can be associated with flow events, followed by periods of slack water that allows the deposition of the suspended load parallel with the foreset surface that generates the mud drapes (Yokokawa *et al*., 1995; Ghosh *et al*., 2004). During the ebb tibe, generated structures are exposed, and according to their intensity can erode or not the mud drapes. The changes in the dip angles recorded by the foresets are related to changes in the transport of the bed load for short periods, related to the semidiurnal/diurnal variations (Mowbray and Visser, 1984; Richards, 1994).

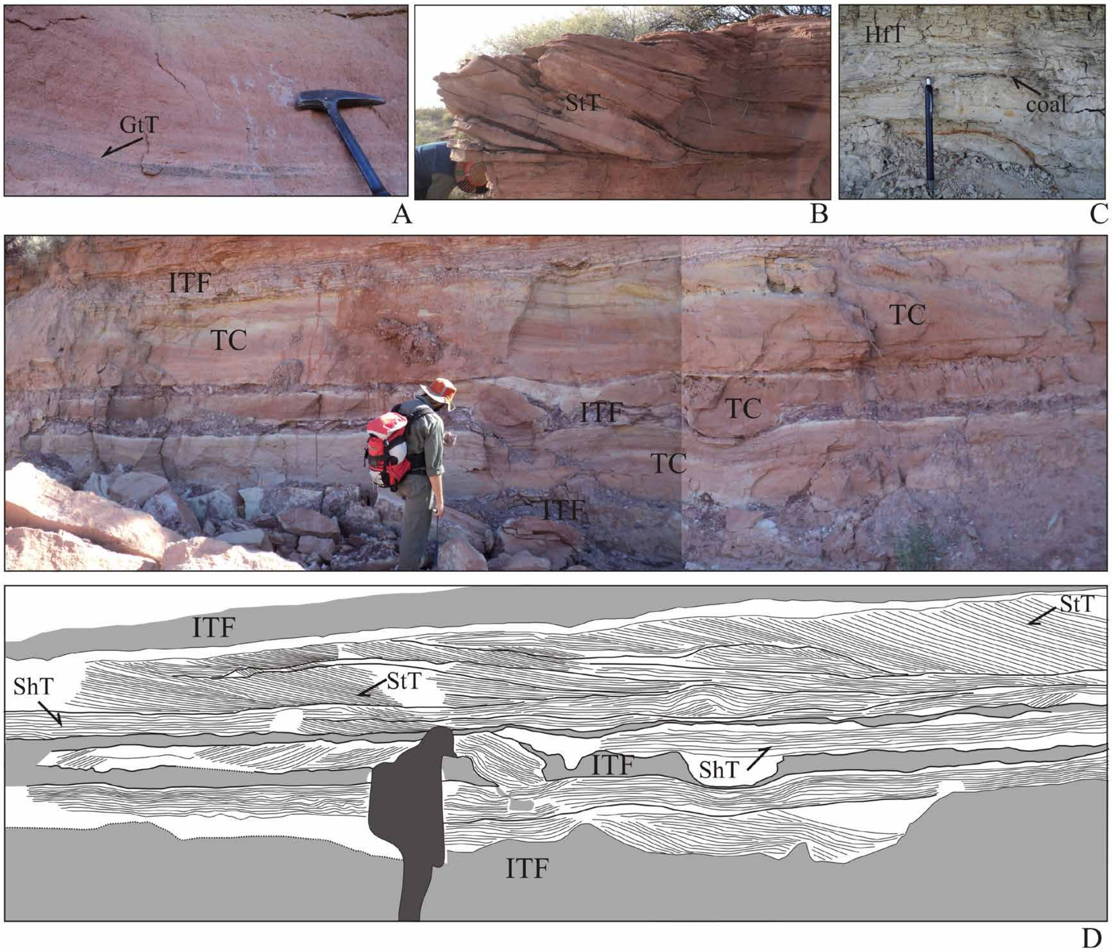

FIG. 3. Facies associations: Tidal channel (TC) and intertidal flats (ITF): **A.** GtT lithofacies in tidal channel; **B.** StT lithofacies in tidal channel, show sigmoidal set and mud drape; **C.** HfT lithofacies with millimeter coal levels. **D.** Outcrop and lithofacies identified in Tidal channel (TC) and Intertidal flats (ITF).

4.1.2. Facies association: Intertidal flats (ITF)

This association is characterized by the predominant presence of heterolithic facies, including HfT, HrT, HlT and FlT lithofacies (Table 1). These are arranged with a recurring alternation, presenting few bioturbations, root molds, and continuous levels or cemented or carbonate nodules; also, common are violet and ocher colored patches or sheets, as well as millimetric levels of coal (Fig. 3C). This association forms tabular bodies ranging from 0.20 to 1.2 m in thickness with a wavy net basis interspersed with the association interpreted as tidal channels (Fig. 3D) best recorded in the southwest of the study area.

Interpretation: The characters described in this association are similar to those of the intertidal flats (Reading, 1996). Heterolytic stratification is generated by the modified flows caused by frequent beating of the sea and finely laminated sets record quadrature periods while the grouping of the thick slabs, the sicigia periods (Fan and Congxian, 2002; Eriksson *et al*., 2006). This preserved heterolithic stratification then suggests the action of flows with high variability at speeds that allow the transport and deposition of sands and mud, recurrently (Leckie and Singh, 1991).

The presence of millimetric carbonate levels make it possible to interpret events of reduced clastic input under conditions of restricted water environments associated with marshes, shallow marine or tidal flats (Holz, 2003; Munir *et al*., 2005). In particular marsh deposits are characterized by the recognition of silty-pelitic sediments rich in organic matter with lesser amounts of sandstone, and levels of calcareous levels and abundant root molds in compact layers (Lander *et al*., 1990). This is due to the fact that marshes are confined to areas above the average elevation of water (Dalrymple *et al*., 1990) and poor drainage on these elevated areas within the flats favors the preservation of organic material. Because they are reducing environments, wetlands are conducive to the development of soils with gley horizons, which is why mottling is common and abundant (Aslan and Autin, 1998).

Although the low sedimentation rate favors the action of organisms, it is possible that the conditions of salinity and low nutrient availability have been the cause of the low density of bioturbations (Weimer *et al*., 1981). The stacking of multiple units is interpreted as vertical accretion that characterizes these flats, but it is common that such provision be affected by the installation of tidal channels (Fig. 3D).

4.1.3. Facies association: Subtidal flats (STF)

This association is composed of the interbedded of 10-30 cm units constituted by ShT, SrT and HfT lithofacies (Table 1). The main feature is the domain of upper-regime sedimentary structures such as sandstone with parallel and quasiplanar lamination (Fig. 4A) and parting lineation. These units toward the top show the reworking of the wave ripples (Fig. 4B), and the increase in pelitic material and layers of gypsum more than 5 cm thick accompanied by the development of flaser and lenticular stratification (HfT). Regarding the SrT lithofacies not only does it occur at the top of the units but also in strata of up to 30 cm where the passage of symmetric and in-phase ripples to asymmetric ripples is preserved (Fig. 4A and C). The geometry of this association is tabular, with flat base and up to 3 m thick, and has an aerial extent of more than 6 km. It is mostly preserved southern part of the area, in the vicinity of Salitral Moreno and is closely associated with the facies associations interpreted below as storm-influenced tidal flats and shoreface deposits.

Interpretation: Tractive sedimentary structures whose characteristics suggest deposits of upper flow regime sand flats dominate this association (Plink-Björklund, 2005). The presence of parallel lamination in this association demonstrates the migration of low-amplitude waves on flat surfaces by currents that reached speeds of 2 m/sec and depths less than 2-3 m or the combination of storm events and tidal action (Dalrymple *et al*., 1990; Fielding, 2006). The varied bedforms and the stability field of these structures is a function of changes in the speed and size of grain for a constant water depth and temperature (Fielding, 2006). The presence of parallel stratification and parting lineation characterize the upper plane bed phase (Richards, 1994; Fielding, 2006). The latter indicates the action of micro-vortexes under conditions of high-energy fluxes, which select and deposit sand grains (Allen, 1984). The flat low-angle cross stratification corresponds to long-wavelength symmetrical dunes (Saunderson and Locket, 1983) generated in stage between an upper plane bed phase and anti-dune plane (Fielding, 2006).

Two types of processes can be the cause of the presence of lenticular and flasser stratification of this association. Tide action and the variations in the velocity of flow and ebb currents contribute to the formation of such structures and to begin to form based on the migration of ripple during the decrease in the velocity of the current of tide flows. After this phase, the relative increase in the amount of mud in suspension induces ‘decantation deposition’ to cover the topography of the bedform at a late stage. During the period of slack water, the deposition of mud will reach a maximum thickness and if the accumulation is thick enough, the layer will be preserved, since its granulometry will require high current power for its mobilization (Reineck and Wunderlich, 1968; Hawley, 1981). When the threshold speed for the remobilization of pelitic material is reached, the removal will affect the stoss side of the ripple, and again will go into suspension while the bedform migrates and the remnants located in the foresets and troughs are preserved (Fan and Congxian, 2002). This process causes the progressive burial of the mud patches, generating flasser stratification. If the rate after the slack water period did not increase, a continuous layer of mud could be preserved. Considering that for flasser stratification to take place a high supply of suspended matter is needed, another major cause could be attributed to storm action (McCave, 1970, 1971) since storms are the only ones capable of producing a considerable increase in suspended pelitic material (Hawley, 1981). The close relationship with ShT lithofacies make it possible to consider this as the most probable cause under

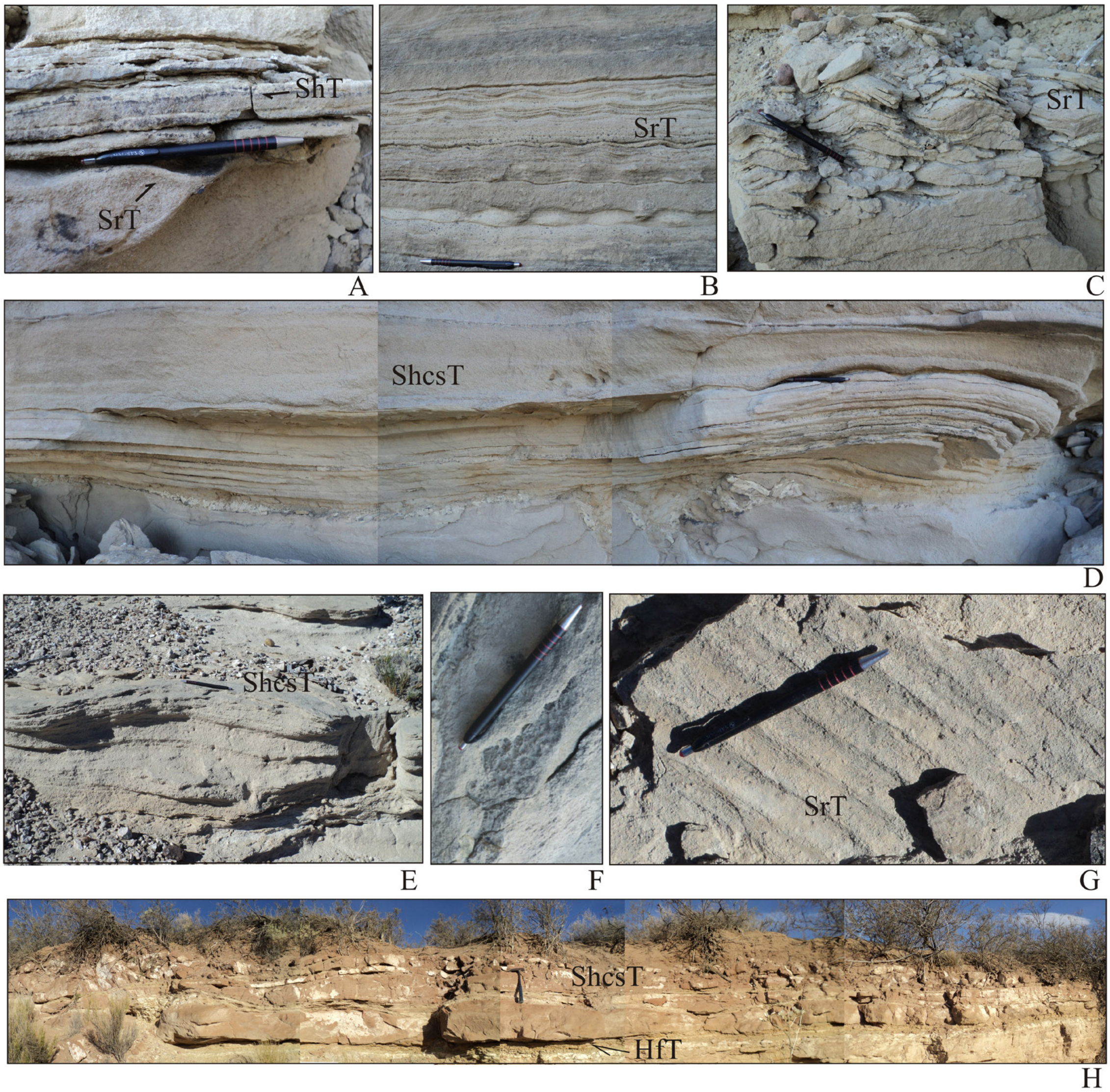

FIG. 4. Facies associations: Subtidal flats (STF): **A.** ShT and SrT lithofacies; **B-C.** SrT lithofacies. Facies associations: Storm influenced tidal flats (SITF): **D-E.** ShcsT lithofacies; **F.** Raindrop impressions; **G.** SrT lithofacies at the top of the unit; **H.** ShcsT and HfT lithofacies.

conditions of high flow rate (ShT). The origin of this association is interpreted as a sand tidal flat in a subtidal environment (Dalrymple *et al*., 1990).

4.1.4. Facies association: Storm-influenced tidal flats (SITF)

This association includes ShcsT (Figs. 4D and E) as the dominant lithofacies, interbedded with the SrT and HfT lithofacies (Table 1). The units are limited by undulating planar surfaces which, in some cases, reveal impressions of raindrops (Fig. 4F). The ShcsM lithofacies has a quasiplanar parallel stratification internally and wave ripple (SrT) toward the top, predominantly ripples in phase (Fig. 4G). While wavelength values of hummocky cross stratification are around 2 m, these structures also occur in large scales reaching wavelengths of up to 20 m. The basal contact is gently undulating, following the morphology of the underlying strata. The different units are interspersed with mud levels 0.05 to 0.15 m thick (Fig. 4H). Internally the layers show planar lamination with a set from 0.007 to 0.02 m and very thin levels of mud in some cases. The geometry of this association is tabular or wedge-shaped up to 10 m thick with an aerial extension of more than 10 km. It has a lateral and vertical relationship with the facies associations interpreted above as subtidal flat and intratidal flat.

Interpretation: This association suggests deposition by oscillatory periodic flows of high energy and high net sedimentation rate. The contact type shows that the depositional flow had low erodibility given the presence of mud covering the underlying strata, whereby the formation of the hummocky cross-stratification indicates accretion processes. In this process, sedimentation begins with the deposition of parallel plates in flat-bed phase, which initially adapt to the roof of the underlying strata and toward the top convert into weakly asymmetric shapes. The last deposited phase of sandstone correspond to two-dimensional symmetrical ripples, indicating oscillatory flow (Basilici *et al*., 2012). The presence of impressions of raindrops present in this facies association indicates its emergence during the post-storm phase. SrT development at the top of the macroforms suggests the action of waves and a high rate of sedimentation (Reineck and Singh, 1980) given the presence ripples in phase. The characteristics of this association which dominate the oscillatory flows and considering its relationship with other associations make it possible to interpret it as tidal flat deposits with strong control of storm events (Basilici *et al*., 2012).

4.1.5. Facies association: Shoreface (SF)

This association is composed of sandstone lithofacies with planar stratification (SpT) and low-angle cross stratification (ShT), and trough cross stratification (StT) to a lesser extent (Fig. 5A and B) but with little development of mud drape and strongly flattened tops. Paleocurrent directions show a bimodal and oblique arrangement (pPC1 and pPC2-Fig. 2), although conformably unimodal stacked sets predominate with direction toward the W and SW limited by low angle surfaces. The units with opposite paleoflows are stacked with a clear wedge-shaped geometry limited by undulating planar surfaces that truncate the strata. The development of wave ripplemark (Fig. 5 A, B, and C) up to 5 cm in wavelength (SrT) towards the top of each unit is characteristic. The maximum thickness is 3 m to 3 km of lateral continuity, limited by a very low angle surface with dipping toward the SE.

Interpretation: The wave-reworked, wedge-shaped lithofacies in this association can be interpreted as deposits of a shoreface environment. The bipolarity of the paleocurrents suggests alternating unidirectional currents perpendicular to the shoreline, the dominant headed toward the W and SW (towards the coast) and subordinate current to the SE. The obliquity these directions present and their bipolarity can be assigned to alternating episodes of transport toward the coast by asymmetric waves and transport toward the sea by rip currents, plus the presence of parallel lamination suggests wave wash in the shoreface zone (Colquhoun, 1995). Based on these characteristics, considering the dominance of sediment transport toward the coast, it is possible to interpret berm deposits (Hine, 1979). In these environments the low-angle cross stratification (ShT) suggests wash processes (Clifton, 1971), and the gentle slope with deposits is interpreted as a smooth surface dipping toward the sea, characteristic of shoreface. In those cases where the lamination has an opposite dipping (SpT), it is interpreted as suggesting backshore deposits, suggesting the washing of berm under storm conditions. In environments with tidal influence, significant differences in the range of these, between syzygy and quadrature, causes growth of the beach due to the aggradation of small berms on the straight section of the beach during syzygy tide. During quadrature tide in periods of fair-weather waves, the tide does not exceed the berm crest and hence the sands and gravels are deposited in the shoreface along the high-tide swash line forming a stratification consistent with the shoreface. During syzygy tide due to the increase in the tidal range, these sediments are transported toward the berm reworking the top and producing its lateral and vertical growth (Hine, 1979).

4.2. Depositional system

These facies associations that make up this depositional system hinder its definition, since there are tidal and wave influences, both controls of great importance. However, it is understood that it consists of tidal channels, tidal flats affected or not by storms and shoreface deposits.

The main development of this system's lower

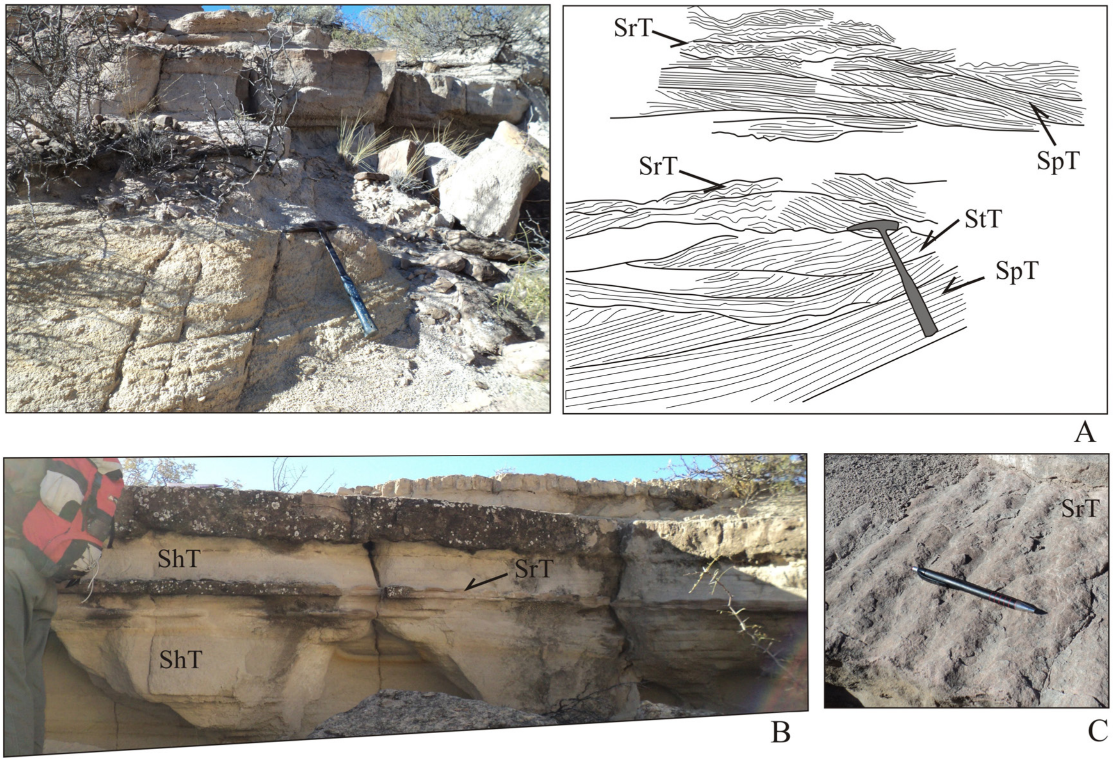

FIG. 5. Facies associations: Shoreface (SF): **A.** StT, SpT and SrT lithofacies in shoreface deposits; **B.** ShT and SrT lithofacies in shoreface deposits; **C.** SrT lithofacies at the top of the unit.

section is near Paso Córdoba, where tidal influence dominates, and to a lesser extent wave action, with deposits of intertidal (ITF) and subtidal flats (STF) and tidal channels (TC) with east-west and northeast-southeast directions (Fig. 6A), with evidence of the dominance of flow currents according to paleocurrent data (pPC2-Fig. 2). In sectors, the channels' lateral and vertical relationships with the tidal flat make it possible to infer sinuous conditions with lateral accretion.

As for the upper section of the system, the shoreface associations (SF) of the storm-influenced tidal flat (SITF) and subtidal flat (STF) are the dominant ones (Fig. 6B). The shoreface presents an arrangement of bimodal paleocurrents and further development of unimodal sets toward the W and SW, constituting the record of backshore washing. Considering that the bipolarity of the paleoflows suggests alternating unidirectional currents perpendicular to the coastline, it is estimated that it had a NNW-SSE direction. More precisely in the northern area (pPC1-Fig. 2) there is evidence of berm deposits with clear records of washing due to wave action as well as tides. To the southwest, near Salitral Moreno (pSM-Fig. 2) associated with beach deposits, there are extensive sand cords with a lateral continuity of more than 12 km and integrated by large hummocky structures whose characteristics described above make it possible to link them to storm-influenced tidal flats (SITF) in shallow marine environments, where tides and waves alike represented important controls on the dynamics. Moreover, there is the wave action evidenced by such structures and ripples, with paleocurrent data involving NNW and SE directions for the paleoflows. With respect to the tidal action, this is associated due to the presence of heterolithic cross-stratification, the mud drapes that cyclically alternate with climbing ripples, the flasser and wavy stratification, and bipolarity in the paleocurrent.

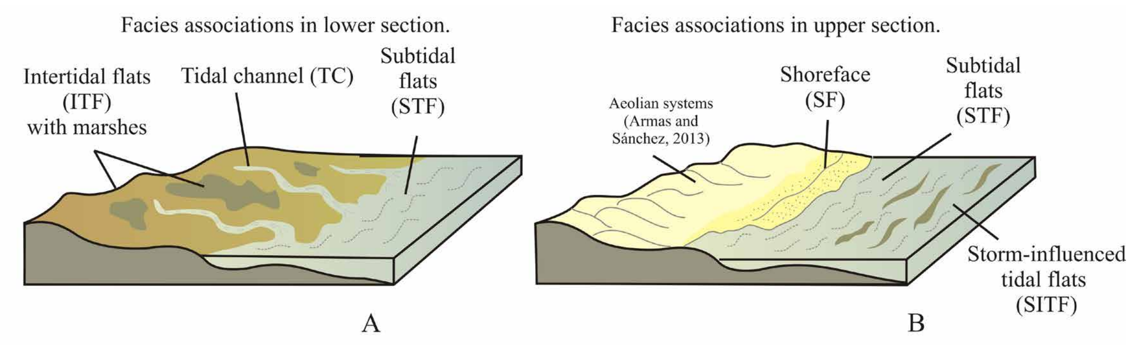

FIG. 6. Facies associations distribution in outcrop Allen Formation in the study area: **A.** facies associations in the lower sections, intertidal flats (ITF) with marshes deposits preserved, tidal channel (TC) and subtidal flats (STF); **B.** facies associations in the upper sections, shoreface (SF), subtidal flats (STF) and storm influenced tidal flats (SITF).

The characteristics of this system as a whole indicate hybrid depositional conditions, in some cases showing subaerial exposure, suggesting an intertidal environment. Therefore, a tidal flat, which toward the top dominates the influence of the waves over the tide and the development of shoreface, is defined.

5. Discussion

Although the sedimentary record is evident in the joint action of tides and waves, there is always a predominance of control over the other. Some sedimentological features are characteristic of these and as a result it is important that they be found, interpreted and preserved. For example, muddy deposits associated with tidal flats and periods of low wave energy are key tools given that the erosional remnant serves to distinguish such an environment influenced by tides. In this paper, that tool made it possible to define facies associations with strong tidal influence. The deposits may have low preservation, and occur in drape forming rhythmites, or concentrated at the base of strata as intraclasts (Plink-Björklund, 2005; Yang *et al.*, 2005). The presence of mud drape in the sedimentary record also contributes to infer periods of subaerial exposure of the plain because intense solar insolation and high temperatures promote the consolidation of muds during exposure and thus increases the potential for preservation (Anderson and Howell, 1984; Krogel and Fleming, 1998). Moreover, as mentioned in the introduction of this article, hummocky cross stratification indicates the domain of waves in the sedimentary record. It is known that the wavelength of this structure correlates with the wavelength of the wave, and tidal plains are shorter (<2m) than typical shorefaces (Amos *et al*., 1996). The smallest size is attributed to the reduction in the size of waves that occurs when waves propagate in the intertidal zone (Clifton, 1971). However, as posed by Yang *et al*. (2005), the presence of hummocky cross stratification with small wavelengths in itself would not be indicative of an intertidal origin because they have registered these structures lacustrine shorefaces where waves are small (Greenwood and Sherman, 1986).

These kinds of mixed-energy coastal environments with tidal and wave action are more common than you may think, and one of the best known is called open-coast tidal flats. In this type of environment, meso to macrotidal ranges are required, with high-energy waves; they characterized by concave upward profiles and development of tidal beaches with slopes between 0.15° and 3° (Yang *et al*., 2005). At times it can be difficult to estimate slope variations in the sedimentary record, but some clues are preserved. The increased thickness of the bar deposits suggest an increasing slope, while the presence of mud-rich flats is more likely to develop along coasts with smoother gradients. The slope determines the variation in wave energy, while the sediment grain size is also an important factor in the gradient of the coast, showing a directly proportional relationship between both controls (Yang *et al*., 2005). With respect to the gradient of the coast, in the case of the deposits used in this paper, besides the presence of muddy and heterolithic facies, and the wavelength values of the ShcsM, numerous authors from Windhausen (1914) and Wichmann (1927) to Uliana and Dellapé (1981);

Barrio (1990); Aguirre-Urreta *et al*., (2011) have indicated the existence of a shallow epicontinental seas during the Upper Cretaceous from the Atlantic transgression during the Maastrichtian, associated with the opening of the South Atlantic Ocean.

The Malargüe Group has always been interpreted as the recording of the first Atlantic ingression to the basin, although recent investigations show the influence of tides on the Anacleto Formation (top of the Neuquén Group, Fig. 1D) which along with the Allen Formation constitute the transgressive systems tract (Armas and Sánchez, 2011) in the area of Cinco Saltos (Fig. 7A and B). As mentioned above, it is difficult to define the beginning of this ingression in northwestern Río Negro due to the wide variation of fossils (continental and marine) supplied by the Allen Formation in the area. However, the interpretation of depositional systems based on the facies analysis and considering the paleogeographic reconstruction of the Upper Cretaceous according to Sellwood and Valdés (2006), it is possible to estimate some aspects of paleogeography in the central-eastern edge of the Neuquén Basin (Fig. 7). The geographical distribution of outcrops and defined facies associations propose the development of a coastal and tidal system with a NNE-SSW coastline in line with the paleocurrent analysis. The HCS is one of the most recurrent lithofacies in the system, and is associated with tidal deposits indicating deposition in shallow waters (Li *et al*., 2000; Yang *et al*., 2005). The distribution of the associations and the field relationships suggest that the best exhibitions of shoreface deposits are

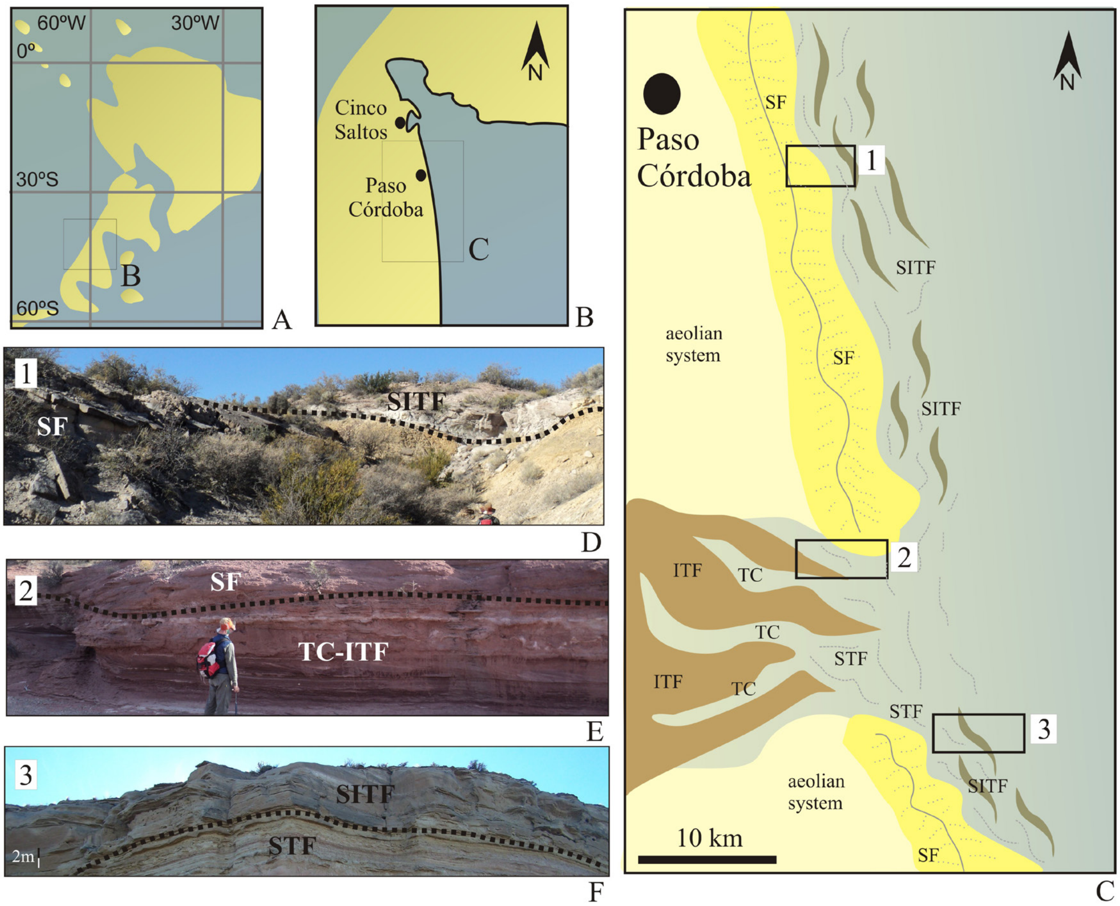

FIG. 7. **A-B.** Paleogeographic reconstruction for the Upper Cretaceous according Sellwood y Valdés (2006) and location of study area; **C.** map of facies associations distribution with geometry of coastline; **D-F.** outcrop of facies associations vertical relationships in the 1, 2 and 3 sections respectively indicated in c.

found to the north (Fig. 7C and D), while the further development of tidal channels and flats occur south of the area (Fig. 7C and E). For the latter it is important to mention that Armas (2013) postulates the development of a coastal lagoon to the northwest of the studied sections at the top of the Anacleto Formation, so it is estimated that such tidal channels are part of an inlet connecting the lagoon with the sea to the east. We could also discuss whether the basis of the sections surveyed in this paper corresponds to the Allen Formation or actually forms part of the top of the Anacleto Formation. The discontinuity of the outcrops and field relationships in the study area suggests future research for adjusting the formational boundaries, although in transitional environments like these, this goal is highly complex.

A very important feature of these coastal deposits is that they are laterally associated with large aeolian systems (Fig. 7C) identified by Armas and Sánchez (2013) in the Allen Formation in the area of Paso Córdoba. In this area, the authors interpreted a complex aeolian fluvial system and complex dunes with sinuous crests that form a 'draas', where aeolian system of transverse dunes with wet interdunes is installed, associated with a decrease in the availability of sediment (Armas and Sánchez, 2013). This change in type of aeolian system and decreased availability are associated with the increase in flooded areas to the north, due to the installation of the estuarine system in the area of Cinco Saltos (Fig. 7B) for the lower member of the Allen Formation (Armas and Sánchez, 2011) and the development of lagoons registered for the middle member in that area (Andreis *et al*., 1974). These aeolian systems are presented in concordance with the deposits studied in this paper, interpreted as tidal channel and tidal flat facies with strong wave influence, records of storm events and shoreface deposits, whose architectures are typical of epicontinental seas.

According to the tectonic history of the Neuquén Basin and sedimentological studies available to date, the deposition of Malargüe Group began at the moment Anacleto and Allen Formations came into contact (Uliana and Dellapé, 1981; Armas and Sánchez, 2011). This stage was characterized by a continued rise in eustatic level which favored the increase in accommodation and the complete installation of epeiric sea that covered much of the basin during the first Atlantic transgression. It is important to highlight that the study area for the stratigraphic period analyzed was located in the distal part of the foreland basin according to the model of Posamentier and Allen (1993), characterized by a low subsidence rate; therefore the accommodation pattern at the time of deposition was primarily controlled by the eustatic factor (Armas and Sánchez, 2011). This factor as well as an increase in the gradient of the floor of the basin toward the NE during the Late Cretaceous (Uliana and Dellapé, 1981) were the main controls on the progress of the marine systems toward continent with a subordinate influence of tectonics and subsidence on the development of the stratigraphic sequence.

6. Conclusions

In stratigraphic sections of the Allen Formation of the study area, ten lithofacies (one conglomeratic, five of sandstones, three heterolithics and one pelitic) were identified, which allowed the definition of four facies associations, which were interpreted as tidal channels, intertidal flat, subtidal flat, storm-influenced tidal flat and shoreface deposits.

This detailed sedimentological study contributes in part to the reconstruction of the paleogeography of the eastern edge of the basin for the Upper Cretaceous, revealing the arrangement of the coastline and the complexity of the transition environment during the Atlantic ingression. A hybrid coastal system of tidal flats with a large storm influence in some areas linked to aeolian systems previously defined in the study area by Armas and Sánchez (2013) is established for the Allen Formation.

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References

Aguirre-Urreta, B.; Tunik, M.; Naipauer, M.; Pazos, P.; Ottone, E.; Fanning, M.; Ramos, V. 2011. Malargüe Group (Maastrichtian-Danian) deposits in the Neuquén Andes, Argentina: Implications for the onset of the first Atlantic transgression related to Western Gondwana break-up. Gondwana Research 19 (2): 482-494.

Allen, J. 1984. Sedimentary Structures-their caracter and Physical Basis. Elsevier 1: 593. Ámsterdam.

Amos, C.; Li, M.; Choung, K. 1996. Storm-generated, hummocky stratification on the outer-Scotian shelf. Geomarine Letters 16: 85-94.

Anderson, F.; Howell, B. 1984. Dewatering of an unvegetated muddy tidal flat during exposure-desiccation or drainage? Estuaries 7 (3): 225-232.

Andreis, R.; Iñíguez-Rodríguez, A.; Lluch, J.; Sabio, D. 1974. Estudio sedimentológico de las Formaciones del Cretácico Superior del área del lago Pellegrini, Provincia de Río Negro, República Argentina. Revista de la Asociación Geológica Argentina 29 (1): 83-104.

Armas, P. 2013. La transición continental marina del Cretácico Superior en el borde oriental de Cuenca Neuquina (provincias de Neuquén y Río Negro): análisis por analogía con ambientes modernos y estudio estratigráfico secuencial. PhD Thesis (Unpublished). Universidad Nacional de Río Cuarto: 315 p.

Armas, P.; Sánchez, M. 2011. Análisis estratigráfico secuencial (Cretácico Superior) en el borde nororiental de Cuenca Neuquina, Argentina. Andean Geology 38 (1): 119-155. doi: 10.5027/andgeoV38n1-a08.

Armas, P.; Sánchez, M. 2013. Sedimentología y arquitectura de las dunas costeras de la Formación Allen, Grupo Malargüe, Cuenca Neuquina-Río Negro, Argentina. Revista Mexicana de Ciencias Geológicas 30: 65-79.

Aslan, A.; Autin, W. 1998. Holocene flood-plain soil formation in the southern lower Mississippi Valley, implication for interpreting alluvial paleosols. Geological Society of America Bulletin 110: 433-449.

Ballent, S.C. 1980. Ostrácodos de ambiente salobre de la Formación Allen, Cretácico Superior, en la provincia de Río Negro, República Argentina. Ameghiniana 17: 67-82.

Barrio, C.A. 1990. Paleogeographic control of Upper Cretaceous tidal deposits, Neuquén Basin, Argentina. Journal of South American Earth Sciences 3: 31-49.

Basilici, G.; De Luca, P.; Olivera, E. 2012. A depositional model for a wave-dominated open-coast tidal flat, based on analyses of the Cambrian-Ordovician Lagarto and Palmares formations, north-eastern Brazil. Sedimentology 5 (59): 1613-1639.

Boyd, R.; Dalrymple, R.; Zaitlin, B.A. 1992. Classification of clastic coastal depositional environments. Sedimentary Geology 80: 139-150.

Clifton, H. 1971. Orientation of empty pelecypod shells and shells fragmentes in quiet water. Journal of Sedimentary Petrology 41: 671-682.

Colquhoun, G.P. 1995. Siliciclastic sedimentation on a stormand tide-influenced shelf and shoreline: the Early Devonian Roxburgh Formation, NE Lachlan Fold Belt, southeastern Australia. Sedimentary Geology 97: 69-98.

Coria, R.A.; Cambiaso, A.V.; Salgado, L. 2007. New records of basal ornithopod dinosaurs in the Cretaceous of North Patagonia. Ameghiniana 44: 473-477.

Dalrymple, R.; Zaitlin, B. 1992. Estuarine facies models: conceptual basis and stratigraphic implications. Journal of Sedimentary Petrology 62 (6): 1130-1146.

Dalrymple, R.; Knight, R.; Zaitlin, B.; Middleton, G. 1990. Dinamics and facies model of a macrotidal sand bar complex, Cobequid Bay-Salmon River estuary (Bay of Fundy). Sedimentology 37: 577-612.

Dashtgard, S.E.; MacEachern, J.A.; Frey, S.E.; Gingras, M.K. 2012. Tidal effects on the shoreface: Towards a conceptual framework. Sedimentary Geology 279: 42-61.

Dingus, L.; Clark, J.; Scott, G.R.; Swisher, C.C.; Coria, R. 2000. Stratigraphy and magnetostratigraphic/faunal constraints for the age of sauropod embryo-bearing rocks in the Neuquén Group (Late Cretaceous, Neuquén Province, Argentina). American Museum Novitates 3290: 1-11.

Eriksson, K.; Simpson, E.; Mueller, W. 2006. An unusual fluvial to tidal transition in the mesoarchean Moodies Group, South Africa: A response to high tidal range and active tectonics. Sedimentary Geology 190: 13-24.

Fan, D.; Congxian, L. 2002. Rhythmic deposition on mudflats in the mesotidal changjiang estuary, China. Journal of Sedimentary Research 72: 543-551.

Fielding, C.R. 2006. Upper flow regime sheets, lenses and scour fill: Extending the range of architectural elements for fluvial sediment bodies. Sedimentary Geology 190: 227-240.

Franzese, J.; Spalletti, L. 2001. Late Triassic-early Jurassic continental extension in southwestern Gondwana: tectonic segmentation and pre-break-up rifting. Journal of South American Earth Sciences 14: 257-270.

Franzese, J.; Spalletti, L.; Gómez-Pérez, I.; Macdonald, D. 2003. Tectonic and paleoenvironmental evolution of Mesozoic sedimentary basins along the Andean foothills of Argentina (32°-54°S). Journal of South American Earth Sciences 16: 81-90.

Galloway, W. 1975. Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. *In* Deltas, Models for Exploration: Houston, Texas (Broussard, M.L.; editor). Houston Geological Society: 87-98.

Ghosh, S.; Chakraborty, C.; Chakraborty, T. 2004. Combined tide and wave influence on sedimentation of Lower Gondwana coal measures of central India: Barakar Formation (Permian), Satpura basin. Journal of the Geological Society 161: 117-131.

Greenwood, B.; Sherman, D. 1986. Hummocky cross stratification in the surf zone: flow parameters and bedding genesis. Sedimentology 33: 33-45.

Hawley, N. 1981. Flume experiments on the origin of flaser bedding. Sedimentology 28: 699-712.

Hayes, M.O. 1979. Barrier island morphology as a function of tidal and wave regime. *In* Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico: New York (Leatherman, S.P.; editor). Academic Press: 1-27.

Hine, A. 1979. Mechanisms of berm development and resulting beach growth along a barrier spit complex. Sedimentology 26: 333-351.

Holz, M. 2003. Sequence stratigraphy of a lagoonal estuarine system an example from the lower Permian Río Bonito Formation, Paraná Basin, Brazil. Sedimentary Geology 162: 305-331.

Howell, J.; Schwarz, E.; Spalletti, L.; Veiga, G. 2005. The Neuquén Basin: an overview. *In* The Neuquén Basin, Argentina: A case study in sequence stratigraphy and basin dynamics (Veiga, G.; Spalletti, L.; Howell, J.; Schwarz, E.; editors). Geological Society, Special Publications 252: 1-14.

Hugo, C.; Leanza, H. 2001. Hoja Geológica 3969-IV, General Roca. Provincias de Río Negro y Neuquén. Instituto de Geología y Recursos Minerales. Servicio Geológico Minero Argentino, Boletín 308: 64 p. Buenos Aires.

Krögel, F.; Flemming, B. 1998. Evidence for temperature-adjusted sediment distributions in the back-barrier tidal flats of the East Frisian Wadden Sea (Southern North Sea). *In* Tidalites: Processes and Products (Alexander, C.R.; Davies, R.A.; Henry, V.J.; editors). Society for Sedimentary Geology, Special Publication 61: 31-41.

Lander, R.; Bloch, S.; Mehta, S.; Atkinson, C. 1990. Burial diagenesis of paleosols in the Giant Yacheng gas field, People's Republic of China: bearing on Illite reaction pathways. Journal Sedimentary Petrology 61: 256-268.

Leckie, D.; Singh, C. 1991. Estuarine deposits of the Albian Paddy Member (Place River Formation) and Lowermost Shaftesbury Formation Alberta, Canada. Journal Sedimentary Petrology 61: 825-849.

Li, C.; Wang, P.; Daidu, F.; Bing, D.; Tiesong, L. 2000. Open-coast intertidal deposits and the preservation potential of individual laminae: a case study from east-central China. Sedimentology 47: 1039-1051.

McCave, I. 1970. Deposition of fine-grained suspended sediments from tidal currents. Journal of Geophysical Research 75: 4151-4159.

McCave, I. 1971. Mud layers and deposition from tidal currents: discussion of a paper by G. de V. Klein, Tidal origin of a Pre-Cambrian quartzite-the lower fine-grained quartzite (Middle Dalradian) of Islay, Scotland. Journal Sedimentary Petrology 41: 1147-1148.

Mellere, R.; Steel, R. 1995. Facies architecture and sequentially of nearshore and shelf sandbodies; Haystack Mountains Formation, Wyoming, USA. Sedimentology 42: 551-574.

Miall, A. 1984. Principles of sedimentary basin analysis. Springer, Berlin Heidelberg: 490 p. New York.

Miall, A. 1996. The geology of fluvial deposits. Sedimentary Facies, Basin Analysis and Petroleum Geology. Springer-Verlag: p. 575. Italia.

Mowbray, T.; Visser, M. 1984. Reactivation surfaces in subtidal channel deposits, Oosterschelde, southwest Netherlands. Journal of Sedimentary Petrology 54: 811-824.

Munir, U.; Baig, M.; Mirza, K. 2005. Upper Cretaceous of Hazara and paleogene biostratigraphy of Azad Kashmir, north west Himalayas, Pakistan. Geology Bulletin, Punjab University 40-41: 69-87.

Neuwerth, R.; Suter, F.; Guzman, C.; Gorin, G. 2006. Soft-sediment deformation in a tectonically active area: The Plio-Pleistocene Zarzal Formation in the Cauca Valley (Western Colombia). Sedimentary Geology 186: 67-88.

Page, R.; Ardolino, A.; de Barrio, R.; Franchi, M.; Lizuain, A.; Page, S.; Silva-Nieto, D. 1999. Estratigrafía del jurásico y cretácico del Macizo de Somún Curá, Provincias de Río Negro y Chubut. *In* Geología Argentina (Caminos, R.; editor), Anales 29 (17): 460-488, Buenos Aires.

Plink-Björklund, P. 2005. Stacked fluvial and tide-dominated estuarine deposists in high-frequency (fourth-order) sequences of the Eocene Central Basin, Spitsbergen. Sedimentology 52 (2): 391-428.

Posamentier, H.; Allen, G. 1993. Siliciclastic sequence stratigraphic patterns in foreland ramp-type basins: Geology 21: 455-458.

Ramos, V. 1999. Rasgos estructurales del territorio argentino, evolución tectónica de Argentina. Instituto de Geología y Recursos Naturales, Anales 29: 715-784. Buenos Aires.

Reading, H. 1996. Sedimentary Environments: Processes, Facies and Stratigraphy. Blackwell Scientic Publications: 688 p. Oxford.

Reineck, E.; Singh, B. 1980. Depositional Sedimentary Environments 2. Springer-Verlag: 549 p. Berlin.

Reineck, E.; Wunderlicfh, F. 1968. Classification and origin of flaser and lenticular bedding. Sedimentology 11: 97-104.

Richards, M. 1994. Transgression of an estuarine channel and tidal flat complex: the Lower Triassic of Barles, Alpes de Haute Provence, France. Sedimentology 41: 55-82.

Salgado, L.; Coria, R.; Magalhaes-Ribeiro, C.; Garrido, A.; Rogers, R.; Simón, M.; Arcucci, A.; Curry-Rogers, K.; Carabajal, A.; Apesteguía, S.; Fernández, M.; García, R.; Talevi, M. 2007. Upper Cretaceous dinosaur nesting sites of Río Negro (Salitral Ojo de Agua and Salinas de Trapalcó-Salitral de Santa Rosa), northern Patagonia, Argentina. Cretaceous Research 28: 392-404.

Saunderson, H.; Locket, F. 1983. Flume experiments on bedforms and structures at the dune-plane bed transition. *In* Modern and Ancient Fluvial System (Collinson, J.; Lewin, J.; editors), International Association of Sedimentologists, Special Publication 6: 49-58.

Sellwood, B.; Valdés, P. 2006. Mesozoic climates: General circulation models and the rock record. Sedimentary Geology 190: 269-287.

Tunik, M.; Folguera, A.; Naipauer, M.; Ramos, V.A. 2010. Early uplift and orogenic deformation in the Neuquén Basin: constraints on the Andean uplift from U-Pb and Hf isotopic data of detrital zircons. Tectonophysics 489: 258-273.

Uliana, M. 1979. Geología de la región comprendida entre los ríos Colorado y Negro, Provincias de Neuquén y Río Negro. Tesis Doctoral (Unpublished). Universidad Nacional de La Plata: ??. La Plata.

Uliana, M.; Dellapé, D. 1981. Estratigrafía y evolución paleoambiental de la sucesión Maastrichtiano-Eoterciaria del engolfamiento neuquino (Patagonia septentrional). *In* Congreso Geológico Argentino, No. 8, Actas 3: 673-711. San Luis.

Uliana, M.; Biddle, K. 1988. Mesozoic-Cenozoic paleogeographic and geodynamic evolution of Southern South America. Revista Brasileira de Geociencias 18 (2): 172-190.

Vergani, G.; Tankard, A.; Belotti, H.; Welsink, H. 1995. Tectonic evolution and paleogeography of the Neuquén basin, Argentina. *In* Petroleum basins of South America (Tankard, A.J.; Suárez-Soruco, R.; Welsink, H.J.; editors). American Association of Petroleum Geologists Memoir 62: 383-402.

Walker, R. 1990. Facies modeling and sequence stratigraphy. Journal of Sedimentary Petrology 60: 777-786.

Weimer, R.; Howard, J.; Lindsay, D. 1981. Tidal flats and associated tidal channels. *In* Sandstone Depositional Environments (Scholle, P.; Spearing, D.; editors). American Association of Petroleum Geologists Memoirs 31: 191-245.

Wichmann, R. 1927. Sobre la facies lacustre senoniana de los Estratos con Dinosaurios y su fauna. Boletín Academia Nacional de Ciencias 30: 383-405.

Windhausen, A. 1914. Contribución al conocimiento geológico de los Territorios del Río Negro y Neuquén. Anales del Ministerio de Agricultura, Sección Geología y Minería 10 (1): 1-60. Buenos Aires.

Wright, L. 1977. Sediment transport and deposition at river mouths: a synthesis. Geological Society of America, Bulletin 88: 857-868.

Yang, B.; Dalrymple, R.; Chun, S. 2005. Sedimentation on a wave-dominated, open-coast tidal flat, southwestern Korea: summer tidal flat-winter shoreface. Sedimentology 52: 235-252

Yokokawa, M.; Kishi, M.; Masuda, F.; Yamanaka, M.; 1995. Climbing ripples recording the change of tidal current condition in the middle Pleistocene Shimosa Group, Japan. *In* Tidal Signatures in Modern and Ancient Sediments (Flemming, B.; Baetholomä, A.; editors), International Association of Sedimentologists, Special Publication 24: 301-311.

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