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High-Resolution Sequence Stratigraphy in the Middle Jurassic Cuyo Group, South Neuquén Basin, Argentina

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Abstract: A sequence-stratigraphic analysis, based on outcrop data, is presented for the Middle Jurassic Cuyo Group in the southern Neuquén Basin. The studied area is located 40 Km south of the city of Zapala, and comprises Middle Jurassic outcrops placed in the Lohan Mahuida - Picún Leufú - Cerro Lotena area. In these outcrops, the Cuyo Group comprises shallow marine to continental beds up to 1200 m of thickness. Twelve sedimentary sections were measured through the succession, in which facies and sequence stratigraphic analysis have been carried out. The study allowed to recognize eight depositional sequences, related to both third and fourth-order base level cycles. Third-order sequences, named JC4, JC5, JC6 and JC7, show an internal predictive succession of systems tracts, indicative of a mainly eustatically driven mechanics. Except for the last two sequences, which are continental deposits all over this area, ammonoid fossils remains indicate an Upper Aalenian-Upper Bajocian age. The JC4 depositional sequence is internally composed by a progradational fourth order sequence set. These minor sequences are named JC4.1, JC4.2, JC4.3, JC4.4, and JC4.5. Local to regional studies allow to recognize an extensive truncation - non deposition episode (up to 200 meters) between the JC4.1-JC4.2 and JC5 sequences, because three fourth order depositional sequences (JC4.3, JC4.4, and JC4.5) are missing in the central-east area. Tectonic evidences have also been found between the JC5-JC6 and JC6-JC7 sequences in the Puesto Bascuñán and Bosque Petrificado area. In this last position, the JC7 sequence rests over the JC6 sequence with a 50° angular uncorformity. The tectonic vs. eustatic controls of each sequence boundary is discussed. A detailed outcrop map of each recognized depositional sequences in the studied area is also included.

INTRODUCTION

Stratigraphical and sedimentological studies from outcrop analysis have experienced a great advance since the publication of the AAPG Memoir 26 [1]. This is mainly because sequence stratigraphic models and techniques have provided the conceptual framework and rules to model the scenario in which sedimentary processes take place. On the other hand, during the '70s and '80s sedimentology has got an improvement as the facies analysis methodology become better developed. This progress makes possible to analyze the stratigraphic record as a vertical succession of depositional environments, governed by both autocyclical and allocyclical processes. A detailed facies analysis also allows to determine the position of the mayor breaks in sedimentation, expressed by sharp facies changes, and to construct a chronostratigraphic framework in order to apply the sequence stratigraphic methods. This kind of approach has received much attention in the last years [2,3,4,5,6,7,8].

The aim of this paper is to introduce a detailed sequence stratigraphical framework for the Middle Jurassic Cuyo Group, in the south of the Neuquén Basin, Argentina. The study is based on outcrop data and all the conceptual information given in this synthesis derive from a regional study carried out during the last 7 years. Description and detailed discussion of the sedimentary facies are no treated here.

GEOLOGIC SETTING

The Neuquén basin is a back-arc basin located in western central Argentina. Basin onset took place during Late Triassic - Early Jurassic, and it was filled with up to 6,000 meters of marine to continental deposits, mainly during the Mesozoic and Early Cenozoic Eras. The Cuyo Group (Early - Middle Jurassic) (Fig. 1) represents the first major marine episode after the configuration of the basin. It comprises more than 2,500 m thick deposits, began with a transgressive event during Hettangian - Pliensbachian stages, followed by regressive deposition untill Middle Callovian. Marine claystones, known as the Los Molles Fm. [9], are diachronously overlaid by sand-rich shallow marine deposits assigned to the Lajas Fm. [9] (Fig. 1). The succession ends up with continental fine-grained red-beds which belong to the Challacó Fm. [10,11], and evaporites of the Tábanos Fm. [12]

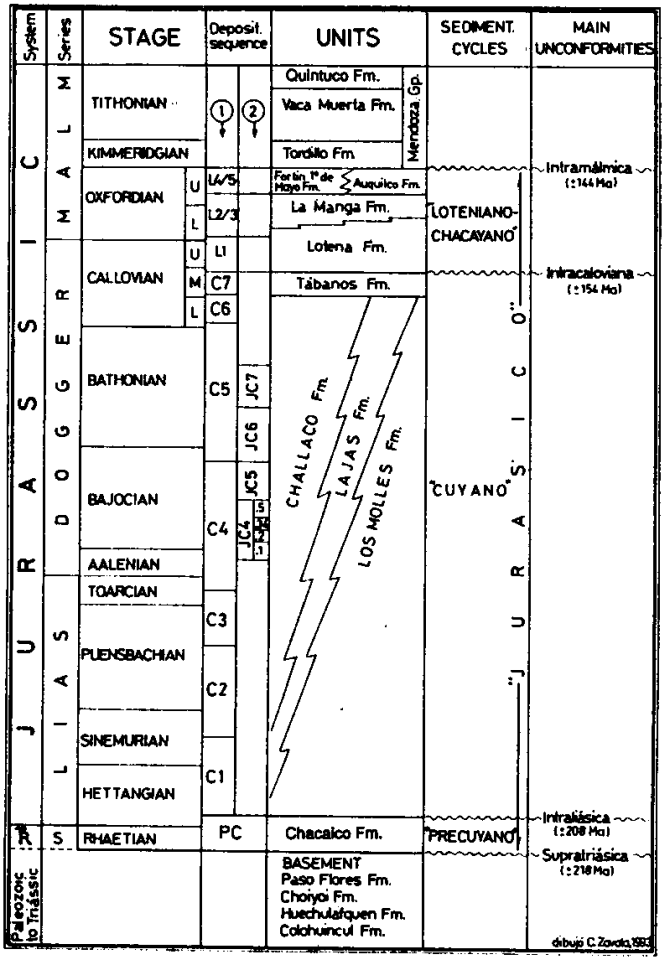

Figure 1: Stratigraphic chart for the Jurassic of the Neuquén Basin (From Gulisano et al., 1984).

developed mainly in the center of the basin (Fig. 1). Sequence stratigraphic studies carried out during the last ten years allow to recognize at least seven third-order depositional sequences [11,13], ranging from Hettangian to Middle Callovian ("1" in Fig. 1), in the Cuyo Group.

LOCATION AND METHODOLOGY

This sequence stratigraphic study of the Cuyo Group is based on the outcrops related to the Huíncul wrench fault system, in the southern part of the Neuquén Basin (Fig. 2). The study area comprises 2,800 Km^2, and is located almost 40 Km south of the city of Zapala. The general stratigraphy and sedimentology of this area have been partially described by several workers [14,15,16,17,18]. Although the lithostratigraphy of the area was well established, conventional and sequence stratigraphic techniques have been used to analyze in detail the stratigraphic evolution during the Middle Jurassic, and to resolve three main stratigraphical problems: (1) the local age of the Lajas Fm., (2) type and nature of the boundary between Lajas and Challacó fms., and (3) tectonic activity and sedimentation during the Middle Jurassic.

Twelve sedimentary sections were measured through the succession (Fig. 3), encompassing a total stratigraphic thickness in excess of 6.000 meters. These sections were described bed-to-bed. During the description, a special care was taken in the observation of beds primary characteristics, in order to allow a detailed facies analysis. The sections were first drawn in a 1:200 scale, aiming at to plot the sedimentary facies and facies associations, and at to analyze the presence of possible breaks in sedimentation. Each section was then drawn in a 1:5000 scale, with the scope of to schematize and to correlate the identified depositional sequences. Dating and correlation of marine depositional sequences between different sections was possible due to the determination of its ammonites content by Dr. A.C. Riccardi. When biostratigraphical control was unavailable, correlation was done using photointerpretation and lateral tracing techniques.

SEQUENCE STRATIGRAPHY

The sequence stratigraphy of the Middle Jurassic Cuyo Group is presented in the stratigraphic chart of figure 4. Four third-order depositional sequences, named JC4, JC5, JC6 and JC7, have been recognized. Both JC6 and JC7 sequences are represented by continental deposits all over the study region. On the other hand, the JC4 and JC5 sequences show shallow marine facies in the west, linked with coeval continental deposits located in the east of the area.

Depositional sequence JC4

This sequence was recognized in the lower levels of the studied sections, but its base is unknow. It is composed by offshore claystones followed by shallow marine sandstones and gravels, with a progradational trend. The thickness of this sequence is highly variable, from nearly 200 meters in the Sierra de Chacaico - Rincón del Aguila area, to more than 500 meters in the Lohan Mahuida section (Fig. 4). Internally, this 3rd order sequence is composed by a 4th order progradational sequence set. These minor sequences are named JC4.1, JC4.2, JC4.3, JC4.4 and JC4.5 (Fig. 4).

Sequence JC4.1: This sequence is recognized across the study area. In the eastern outcrops (Cerro Lotena, sections 7, 8 and 9) it includes off-shore claystones with thin beds with hummocky cross-stratification. The upper levels record progradation of deltaic mouth bars linked to braid-deltas. In the central outcrops (Sierra de Chacaico and Picún Leufú, sections 1, 2, 3, 4, and 11) JC4.1 consist of

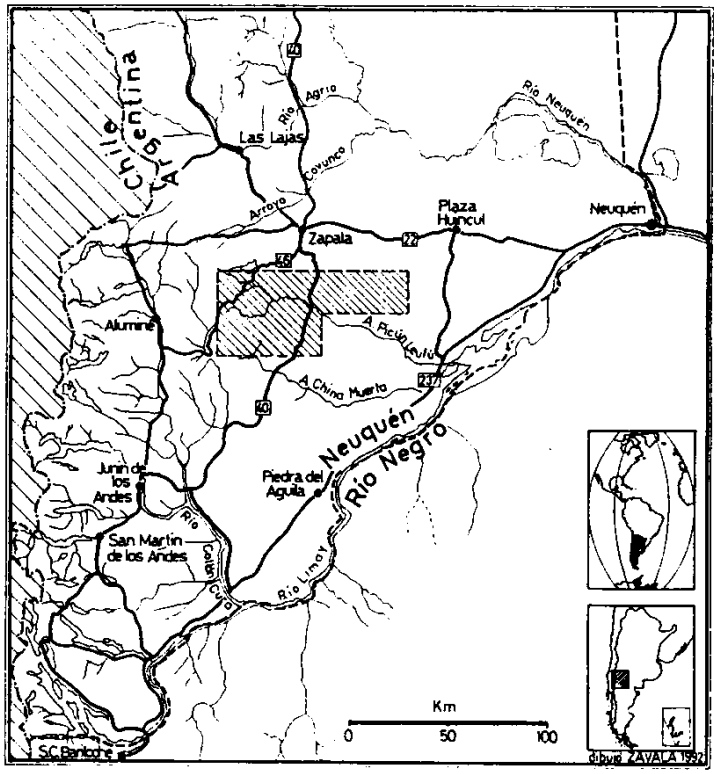

Figure 2: Location map, stippled areas show the location of Argentina, the Neuquén Basin and the study area.

off-shore claystones with minor sandstone layers with hummocky cross-stratification. Near to the top, the unit shows a progradation of input- to wave-dominated deltaic mouth bars. Over the western outcrops (Lohan Mahuida, section 5) the sequence is integrated by off-shore bars with tidal influence. All these deposits belong to the highstand systems tract (HST). The JC4.1 sequence contains ammonites from the *Puchenquia malarguensis* and *Pseudotoites singularis* Assemblage Zones. The upper levels carry ammonoids of the *Emileia giebeli submicrostoma* Assemblage Subzone. Its age in the studied section ranging from Late Aalenian to Early Lower Bajocian [19].

Sequence JC4.2: This sequence only has been recognized in the central and western part of the study area (sections 1, 2, 3, 4, 5 and 11) (Fig. 4). It is represented by some 100 meters of sandstones and claystones, with well defined transgressive systems tract (TST) and HST. The sequence boundary SB1 is indicated by a strong facies contrast, putting into contact estuarine channels or tidal sand waves over non-tidal facies of the JC4.1 sequence. Ammonites found in JC4.2 belong to the *Emileia giebeli* Assemblage Zone and its age is Early Bajocian [19].

Sequences JC4.3, JC4.4 and JC4.5: These sequences have only been recognized in the western outcrops (sections 5, 6, and 12) (Fig. 4). The first two ones are less than 50 meters thick and begin with thicker fluvial to estuarine channels, followed by a short transition to off-shore claystones. No HST deposits have been found in these sequences. Sequence JC4.5 shows a thickness of about 200 meters, and also begins with thicker fluvial channels, followed by littoral to shelf tidal facies with a retrogradational stacking pattern, interpreted as TST deposits. The HST begins with off-shore claystones followed by wave- to input-dominated deltaic systems. The last three lesser order sequences of the JC4 depositional sequence are mainly sandy units, and have scarce ammonites remains from the *Emileia giebeli* Assemblage Zone. Their ages are interpreted as Early Bajocian [19].

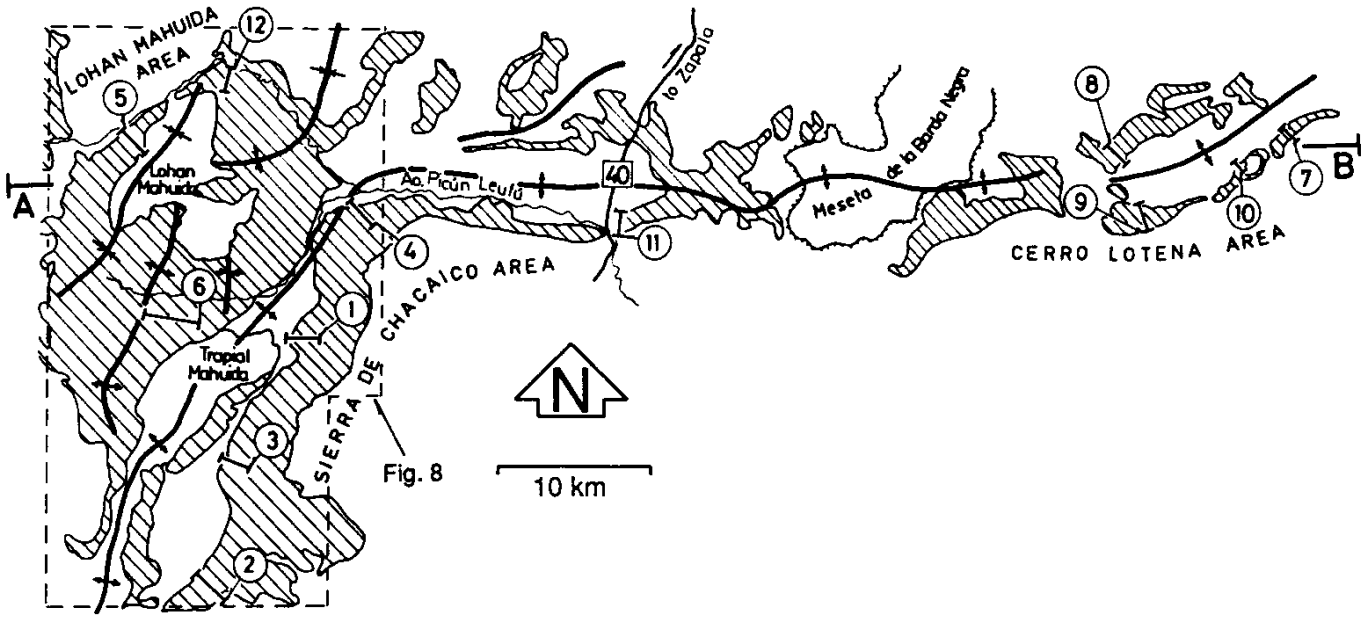

Figure 3: Lower to Middle Jurassic outcrops and main tectonic elements in the study area, showing the location of the measured sections and the chronostratigraphic chart of figure 4 (A-B). The area showed in the figure 8 is also indicated

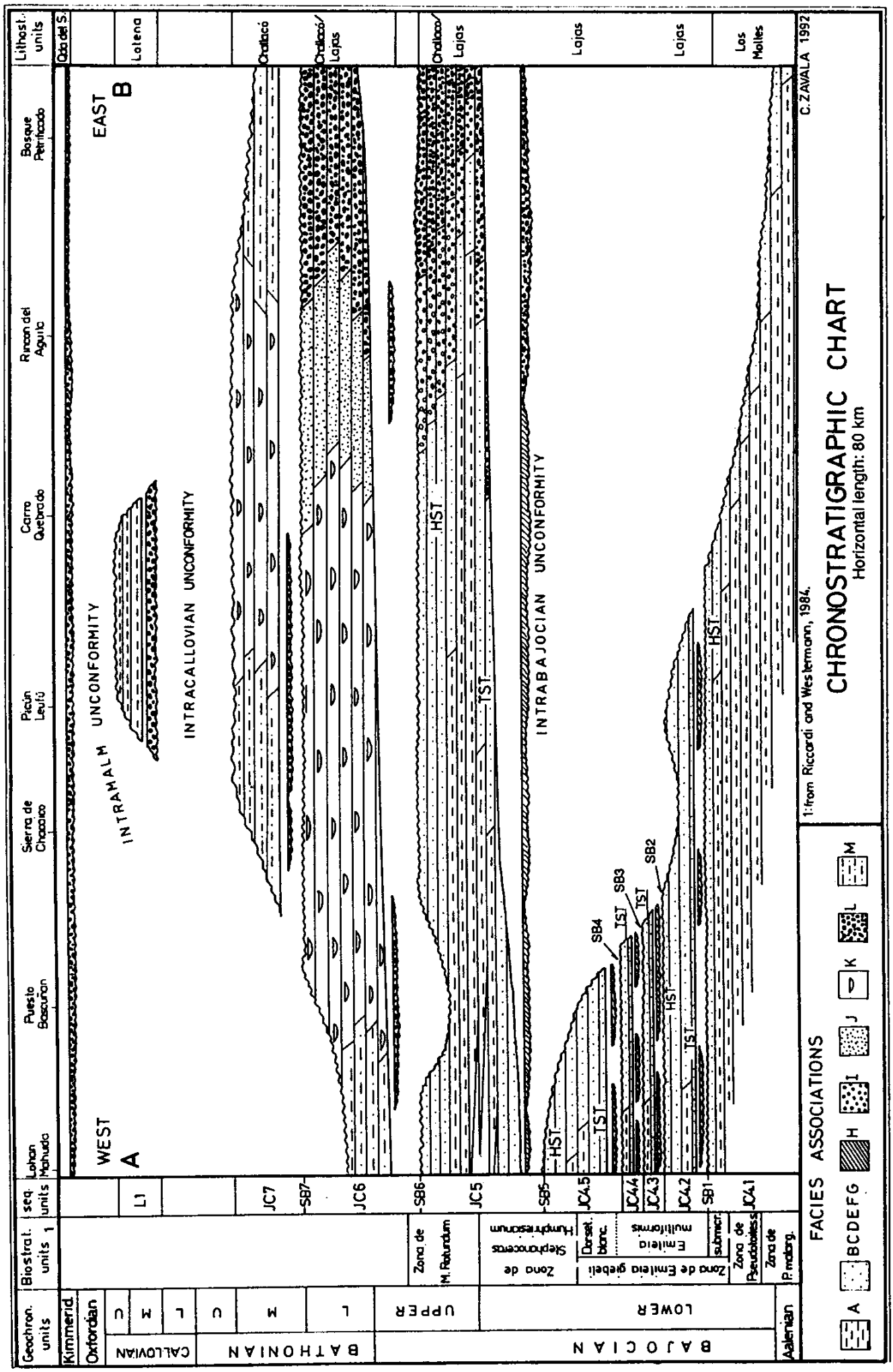

Figure 4: Chronostratigraphic chart for the Middle Jurassic in the study area. Facies associations: A: off-shore marine claystones; B,C,D,E,F and G: shallow marine sandstones; H: estuarine channel deposits; I: mixed load meandering rivers deposits; J: sandy braided fluvial deposits; K: anastomosed fluvial deposits; L: coarse grained braided rivers deposits; M: freshwater playa lake deposits. The location of this stratigraphic chart (A-B) is indicated in figure 3.

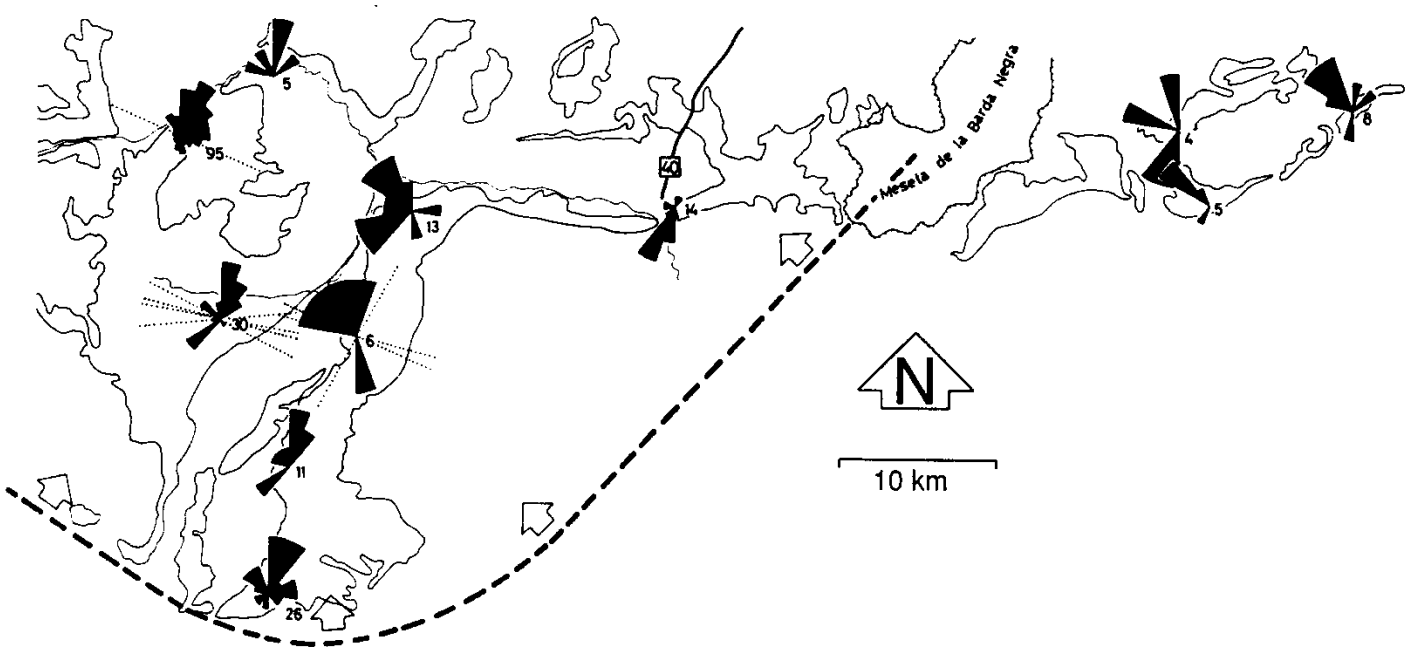

Figure 5: Paleocurrent measurements on the JC4 sequence (Lower Bajocian. The dashed line indicates the likely paleocoast orientation, and the arrows the main direction of progradation.

Paleocurrent measurements from the JC4 sequence at the different sections are shown in figure 5. The likely orientation of the paleocoast from strike of wave ripple crests [20] and regional data, is also indicated.

Depositional sequence JC5

This depositional sequence was recognized in all the described sections (Fig. 4). Its thickness is about 250 meters, and its basal boundary is a major unconformity (named SB5, or "Intrabajocian") for the study area. In the east part of the study area (section 8), the sequence JC5 begins with coarse grained braided river deposits resting unconformably over lower delta front claystones of the JC4.1 sequence. These fluvial deposits are followed by swamp sandstones, which in turn grade upward to off-shore marine claystones. These retrogradational deposits are interpreted as belonging to the TST. The off-shore marine claystones show a transition to input-dominated deltaic systems and mixed-load meandering rivers, showing a forestepping stacking pattern interpreted as representing the HST of the JC5 sequence. In easterly positions (sections 7 and 9) this sequence is totally represented by coarse grained braided river deposits (Fig. 4).

In the central area (sections 1, 2, 3, 4 and 11), sequence JC5 begins with thick sandy braided fluvial to estuarine channel deposits. These channels unconformably overlay delta front to delta plain deposits of the sequence JC4.2. They conform the classical rock ledge found in the eastern flank of Sierra de Chacaico (sections 1-4). Over the west area (sections 5, 6, and 12), the basal channels rest on HST deposits of sequence JC4.5. Over the channels, a tidal sandwave complex with a retrogradational stacking pattern, related to the TST, is found in west and central areas. The HST begins with off-shore claystones, followed by mainly input- to wave-dominated deltaic systems and delta plain deposits.

In the central and west area sequence JC5 carries ammonites from the *Humphriesianum* Zone and the *Megasphaeroceras rotundum* Assembage Zone. According to this [19], its age was established as Early to Late Bajocian (Fig. 4).

The paleocurrent measurements from the incised valleys fills of the sequence JC5 are showed in figure 6. Some areas with milder subsidence, and a possible tendency to emerge during sea level falls, are suggested. The paleocurrent measurements for both TST and HST of the JC5 sequence are presented in the figure 7.

The SB5 unconformity surface implies a substantial change in the depositional conditions below and above it. It strongly truncates the JC4 sequence, because four minor depositional sequences (JC4.2, JC4.3, JC4.4 and JC4.5) are missing (bevelled or not deposited) in the east area (Fig. 4). According to the normal distribution of systems tracts within the sequences below an above the unconformity surface [2], this sequence boundary is interpreted as mainly eustatic in origin, but enhanced by tectonic activity in the area during the Middle Jurassic.

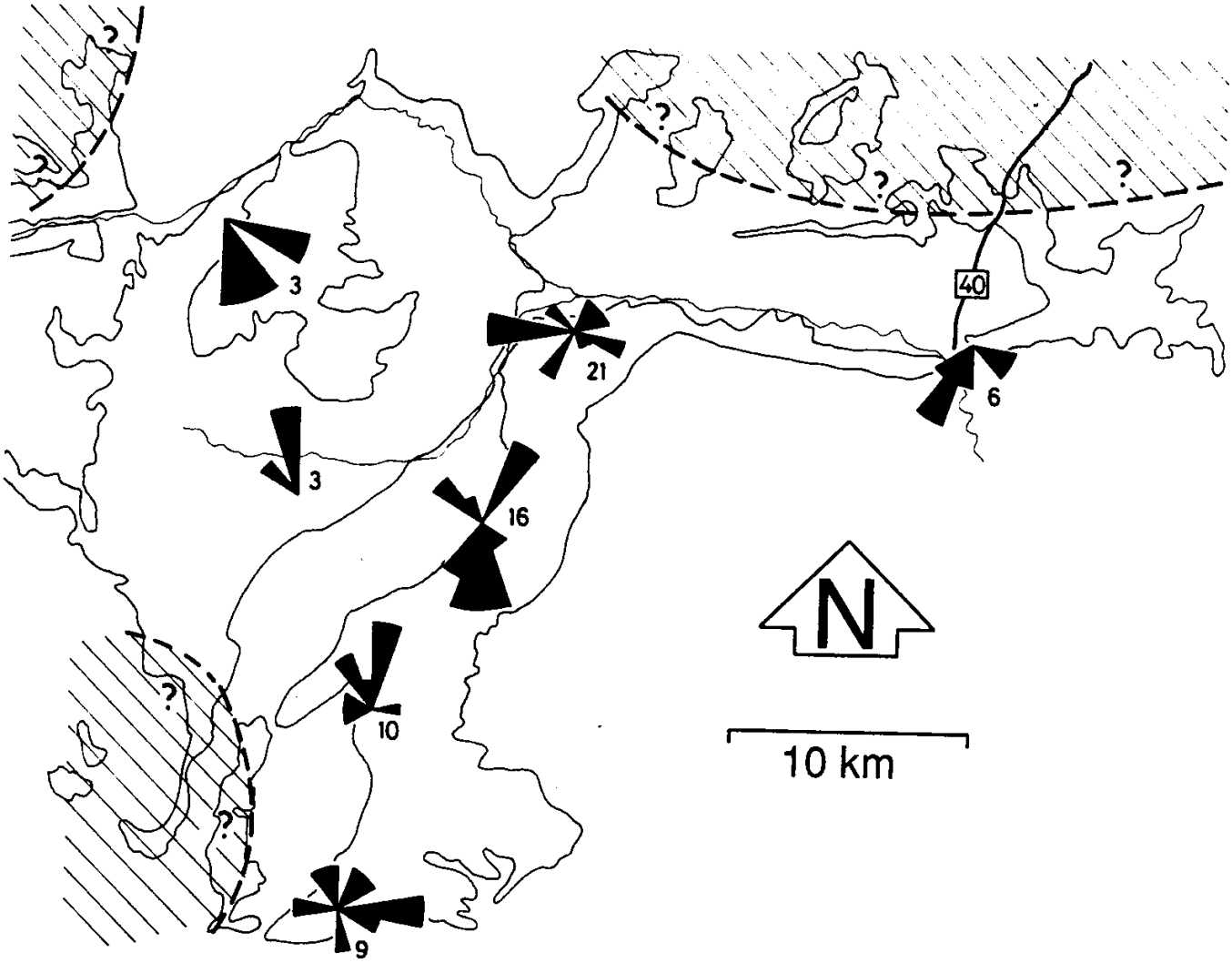

Figure 6: Paleocurrent measurements from incised valley fills in the JC5 sequence (Lower-Upper Bajocian). Foreset azimuths. The streacking areas indicate possible low subsidence zones.

Depositional sequence JC6

The depositional sequence JC6 is broadly distributed over the study area (Fig. 4), and shows an average thickness of 150 meters. In the east area (8), JC6 begins with coarse grained braided river deposits, and rests on sandy meandering-river deposits of sequence JC5. The basal coarse deposits are followed by sandy braided fluvial accumulations. In easterly positions (7;9) JC6 is mainly composed by coarse grained braided rivers deposits (Fig. 4).

In the central and west area, the JC6 sequence is integrated by mud-rich anastomosed fluvial deposits and related muddy freshwater playa lake deposits, resting with a dramatic facies change over shallow marine-coastal plain deposits of the JC5 sequence. Incised valley fills have been recognized only in section 6. They are composed of sandy-braided fluvial deposits resting over off-shore claystones of the HST from the JC5 sequence. All these deposits are referred to the Challacó Formation.

Depositional sequence JC7

The depositional sequence JC7 has only been recognized in sections 2, 3, 7 and 11. These strata belong to the Challacó Formation, and begins with thick coarse grained braided river deposits, followed by anastomosed fluvial, and mainly freshwater playa-lake muddy deposits. In the section 7, this sequence rest over an angular unconformity of about 50 degrees, that truncates beds of the JC5 sequence. This relationship suggest a tectonic component in the SB7 sequence boundary generation. The top of the JC7 sequence is marked by extensive truncation, related to the Intracallovian and the Intramalm regional unconformities (Fig. 4).

Both the JC6 and the JC7 sequences lack biostratigraphic control, and their ages were tentatively established as Late Bajocian-Early Bathonian and Middle Bathonian, by correlation with the Haq et al. [21] eustatic sea-level curve. Bathonian shallow marine deposits crop out in the Arroyo Covunco area (Gulisano, pers. com.) located about 60 Km far to the north. These marine deposits are

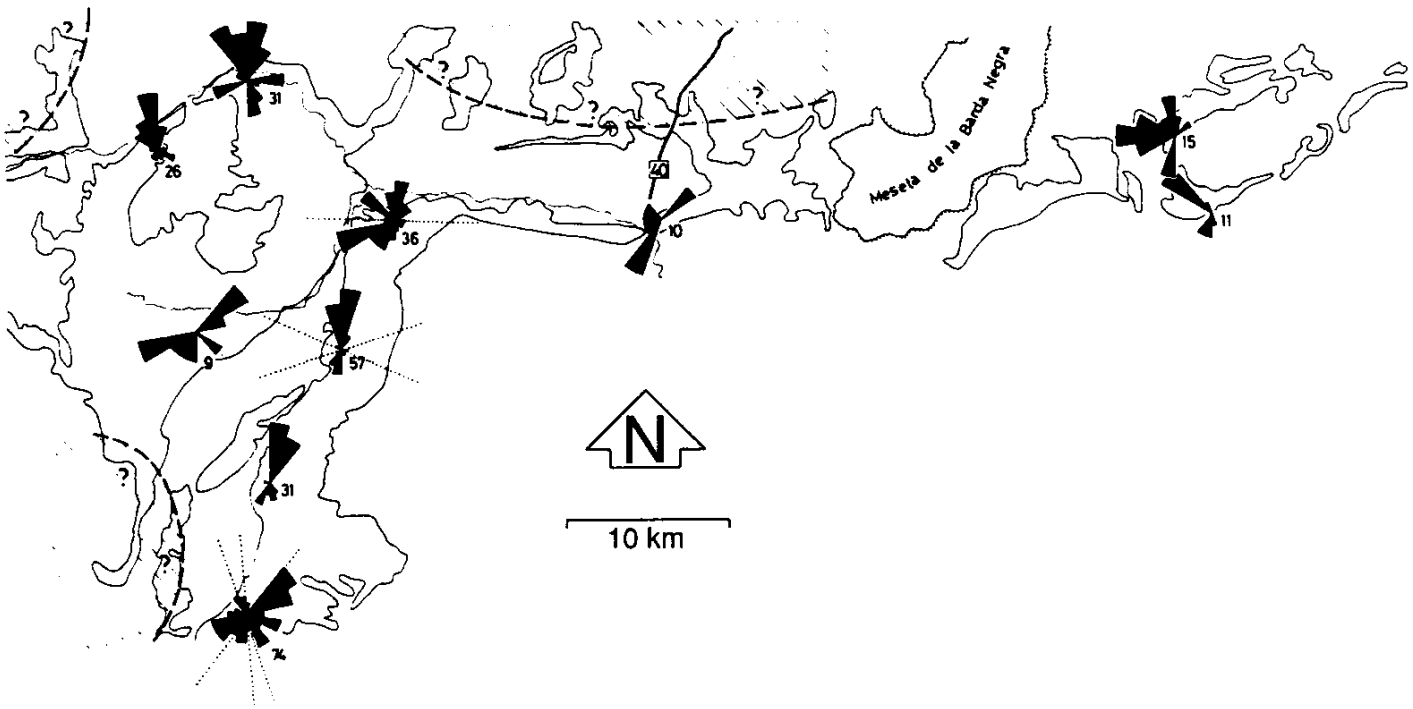

Figure 7: Paleocurent measurements from TST and HST of the JC5 sequence (Lower to Upper Bajocian). Foreset azimuths. The streaked areas indicate possible low subsidence zones.

interpreted as coeval with the continental deposits referred to the Challacó Formation in the study area [11].

CONCLUSIONS

1) Eight depositional sequences have been recognized in the Middle Jurassic Cuyo Group that crops out over southern half of the Neuquén Basin. An outcrop map of the main depositional sequences in the Sierra de Chacaico and Lohan Mahuida areas is presented in figure 8. Each genetic package is limited by sequence boundaries (Fig. 4). These sequence boundaries are regional surfaces with a chronostratigraphical significance, outlined by truncation and a basinward shift in facies. Sequence boundaries are also easily traceable along the outcrops.

2) Biostratigraphy and sequence stratigraphy allow to date the Lajas Formation in the south Neuquén, as deposited during the Early to Late Bajocian Span (Fig. 4). A similar age had been previously suggested by Gulisano et al. [11] but without biostratigraphic control. Other workers had interpreted the age of the Lajas Fm. as Early Callovian [17,18,22].

3) The boundary between the Lajas and the Challacó formations, in the analyzed region, is a sequence boundary (SB6). This unconformity is marked by an abrupt facies change and records a drastic paleogeographic modification (Fig. 4).

4) Evidences of tectonic activity have been recorded affecting the sequence boundaries SB5 (Early Bajocian), SB6 (Late Bajocian), and SB7 (Middle Bathonian). The last sequence boundary (SB7) also shows, in the section 7, angular relationships (40-50 degrees) within the sequences JC6 and JC7. During a fall in sea level, the interaction between tectonics and sequence boundary formation is enhanced. Attempting to reach a new equilibrium profile, fluvial systems incising and bevelling the shelf to reduce slight differences in elevation. Thus, uplifted strata tend to be "planed off" producing angular discordances beneath sequence boundaries if the timing between the sea-level fall and uplift is correct [23].

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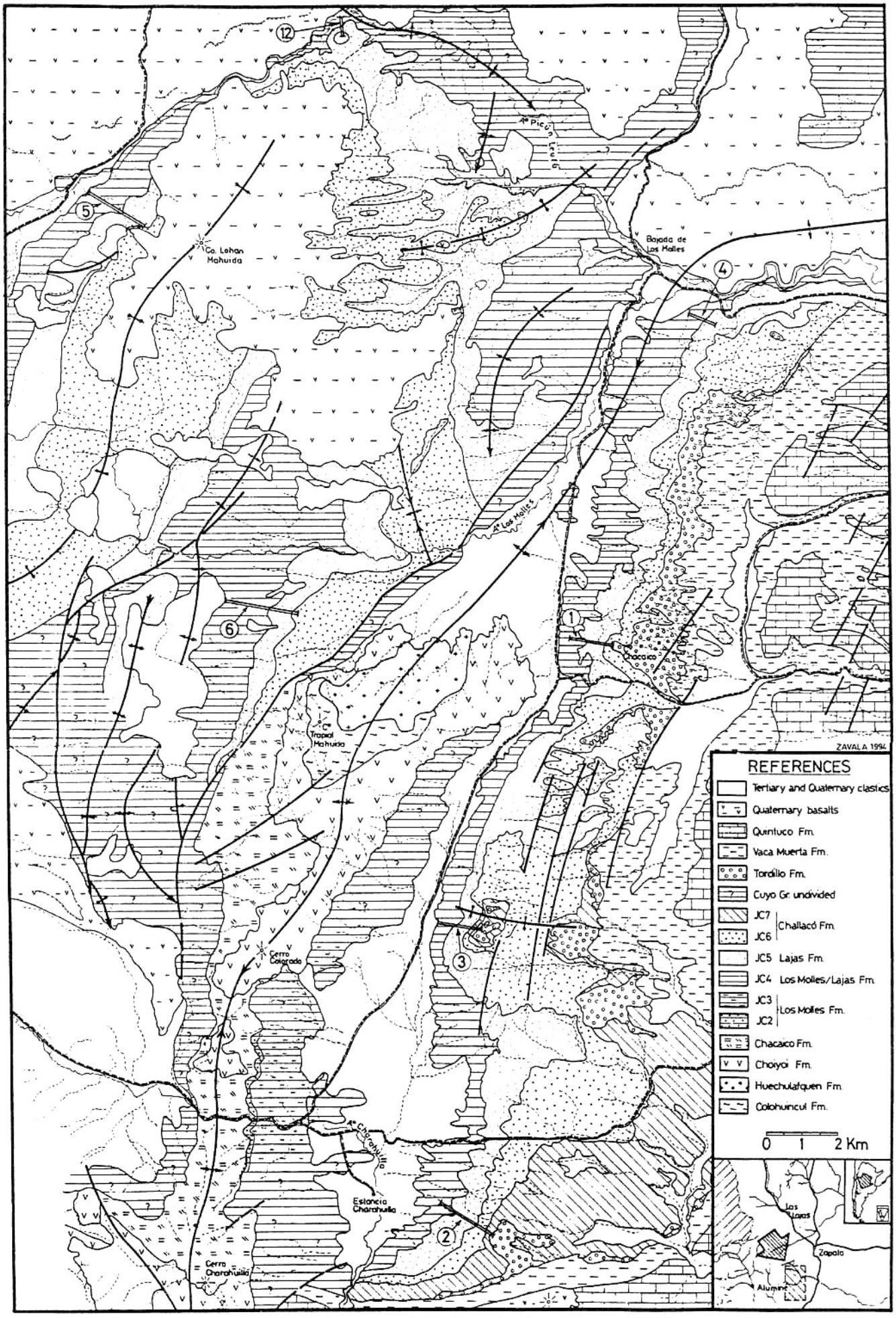

Figure 8: Geologic map showing the main lower-middle Jurassic depositional sequences and principal tectonic features in the Sierra de Chacaico and Lohan Mahuida area.

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REFERENCES CITED

[1] C.E. Payton, AAPG Memoir 26, v. 11, 516p (1977).
[2] E. Mutti, and M. Sgavetti, Ann. Univ. St. Ferrara. Sez. Sc. Terra. 1 (1): 1-22 (1987).
[3] J.C Van Wagoner, R.M. Mitchum, K.M. Campion and V.D. Rahmanian, AAPG Methods in Exploration Series N°7, 55p (1990).
[4] M. Rioult, O. Dugué, R. Jan Du Chene, C. Ponsot, G. Fily, J.-M. Moron, and P.R. Vail, Bull. Centres Rech. Explor.-Prod. Elf Aquitaine, 15 (1): 101-194 (1991)
[5] H.D. Sinclair, Sedimentology, 40: 955-978 (1993).
[6] T. Dreyer, T., and L.M. Fält, Sedimentology, 40: 667-697 (1993).
[7] W.J. Devlin, K.W. Rudolph, C.A. Shaw and K.D. Ehman, IAS Spec. Publ. 18: 501-520 (1993).
[8] E. Mutti, G. Davoli, S. Mora, and M. Sgavetti, 2nd high-resol. sequence stratigraphic conference, Spain, 20-26 june 1994. 83p (1994).
[9] C.E. Weaver, Memoir University of Washington, 1, (1931).
[10] C.I.C. De Ferrariis, Rev. Asoc.Geol. Argentina, II (3): 256-283 (1947).
[11] C.A. Gulisano, A.R. Gutierrez Pleimling and R.E. Digregorio, 9 Cong. Geol. Argentino,1: 236-259 (1984).
[12] P.N. Stipanicic, Rev. Asoc. Geol. Argentina, 20: 403-478 (1966).
[13] A.C. Riccardi, and C.A. Gulisano, Rev; Asoc; Geol; Argentina 45 (3-4): 346-364. 1990 (1992).
[14] T. Suero, Dir. Nac. Min., Bol. 76 (1951).
[15] D.A. Dellapé, G.A. Pando, M.A. Uliana and E.A. Musacchio, 7 Cong. Geol. Argentino, 2: 489-507 (1979).
[16] C.A. Gulisano, and G. Hinterwimmer, Bol. de Inform. Petrol., 8: 2-31 (1986).
[17] H.A. Leanza, Rev. Asoc. Geol. Argentina, 45 (3-4): 272-299, 1990 (1992).
[18] A. Del Valle, and D. Poire, 4ta. Reunión Argentina de Sediment., 1: 17-24 (1992).
[19] A.C. Riccardi, and G.A.G. Westermann, 9 Congr. Geol. Argentino, 4: 362-393 (1984)
[20] D.A. Leckie, and L.F. Krystinik, Journ. Sedim. Petrol., 59: 862-870 (1989).
[21] B.U. Haq, , J. Hardenbol and P.R. Vail, Science, 235: 1156-1167 (1987).
[22] W. Volkheimer, Ameghiniana, 10 (2): 105-131 (1973).
[23] J.C. Van Wagoner, AAPG Field Conf., September 21-28, 1991. Day one, accomp. overview paper 1-10 (1992).