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Uppermost Lower Aptian transgressive records in Mexico and Spain: chronostratigraphic implications for the Tethyan sequences

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ABSTRACT

A widespread marine transgression, which began at the very end of the Early Aptian, is well recorded in Mexico and Spain. In Mexico, this transgression was the most important Aptian transgressive event and its record begins in the *Dufrenoyia justinae* Zone, whereas in Spain the corresponding transgression is registered in the uppermost part of the *Dufrenoyia furcata* Zone. The basal age of this Tethyan transgression does not correspond exactly to any of the Lower Aptian third-order sequences as reported in the literature. In Spain, the most important Aptian transgressive event was earlier, corresponding to the Tethyan sequence Ap3, which is well-defined below this transgression reported herein. Consequently, it is possible to correlate this later transgressive event with the third-order Ap4 sequence, which has commonly been attributed to the Upper Aptian. The available ammonoid data allow us to correct the basal age of the transgression, and to correlate the start of the ammonite record in Mexico with the Tethyan sequence Ap4.

Introduction

Mesozoic third-order sequences reflecting changes of relative sea-level have been recognized in basins of the western Tethys in Europe (Hardenbol *et al*., 1998). The calibration by means of biostratigraphic data of these third-order sequences makes it possible to establish correlations between different basins of Tethys (e.g., Pasquier and Strasser, 1997; Röhl and Ogg, 1998; Hillgärtner *et al*., 2003; Colombié and Strasser, 2005; Yose *et al*., 2006; Bover-Arnal *et al*., 2009, 2010a). For the Mesozoic Era, the age calibration of these sequences is essentially based on ammonite biostratigraphy, as this typically provides the highest biostratigraphic resolution. At the same time, this work is framed in a transgressive context in which the ammonoid provincialism diminishes or disappears (e.g., Kennedy and Cobban, 1976; Cecca *et al*., 2005; Latil, 2011).

At the start of modern sequence stratigraphy, Vail *et al*. (1977) proposed that the seismic-scale sequences that they recognized in seismic profiles were generated by worldwide changes in sea level. Thus, eustasy would have been an important factor in controlling accommodation on a long-term scale throughout geologic time. This imputes a global and synchronous character to the sequences. In effect, the sequences of Hardenbol *et al*. (1998) are thought to have been controlled in great part by eustasy, although at a local to regional scale tectonics would have also exerted control on the available depositional space. Major phases of tectonic control affect the volume of ocean basins, and can produce synchronous and global sequences similar to eustasy (e.g., Cloetingh, 1986, 1991). In addition, some studies have pointed out that these third-order sea-level events identifiable throughout Tethys were not always synchronous (e.g., Immenhauser and Scott, 1999). However, it is widely assumed that most of the Hardenbol's Mesozoic sequences had a Tethyan significance and can thus be recognized in different basins of Tethys (e.g., Röhl and Ogg, 1998; Gradstein *et al*., 2004). Therefore, when establishing trans-Tethyan correlations with

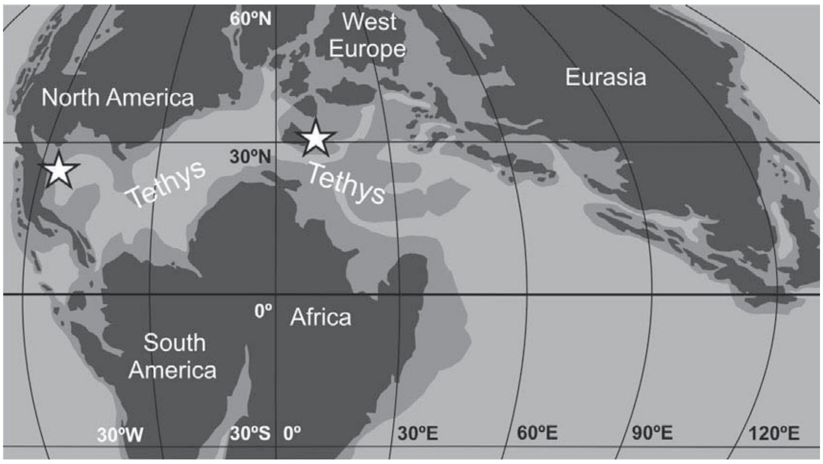

Fig. 1 Palaeogeographical reconstruction of the Tethyan realm during the late Early Cretaceous (120 Ma) (modified from http://www2.nau.edu/rcb7/mollglobe.html). The left star shows the location of the Durango area of north-east Mexico and the right star shows the Maestrat Basin of eastern Spain.

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these sequences a precise biostratigraphic control is needed.

In this paper we study the Aptian (Early Cretaceous) transgressive event corresponding to the Tethyan sequence Ap4 of Hardenbol *et al.* (1998), in Mexico and Spain (Fig. 1). These transgressive deposits contain an excellent ammonoid record characterized by the presence of the youngest species of the genus *Dufrenoyia*. This biostratigraphic control allows us to make a trans-Tethyan correlation. The comparison between the Mexican and Spanish transgressions permits the recognition of similarities and differences between both sedimentary records, as well as constraining the age of the boundary between the Aptian Tethyan sequences Ap3 and Ap4. In addition, we can contrast the correlation of the standard ammonite Mediterranean zonation of Reboulet *et al.* (2011), which was essentially established in western Tethys, with the Mexican Lower Aptian zonation, Atlantic extension of the Tethys.

The Mexican transgression

Several authors have documented the beginning of the ammonoid record in the lower part of the transgressive deposits, which are known as the La Peña or Otates formations. These transgressive strata usually overlie the platform carbonates of the Cupido Formation (Burckhardt, 1925; Humphrey, 1949; Cantu Chapa, 1963; Cantú Chapa, 1976; Barragan, 2001; Barragán and Maurrasse, 2008). In Mexico, the dominant taxon of these transgressive deposits is *Dufrenoyia justinae* (Hill, 1893) (Fig. 2). This ammonoid is recognized in several localities and sections, such as FZD: Francisco Zarco Dam Section (Fig. 3) in the state of Durango in north-east Mexico (Barragan, 2001 for location).

The same transgression is also well known in other parts of the Atlantic extension of Tethys, including the United States (e.g., Hill, 1893; Stoyanow, 1949), Colombia (e.g., Riedel, 1938; Etayo-Serna, 1979) and Venezuela (e.g., Renz, 1982; Arnaud *et al.*, 2000). In most of these countries, the Aptian ammonoid record seems to begin with *Dufrenoyia* beds. Accordingly, the magnitude of the transgression related to the *Dufrenoyia* beds is of widespread significance in the Atlantic extension of Tethys.

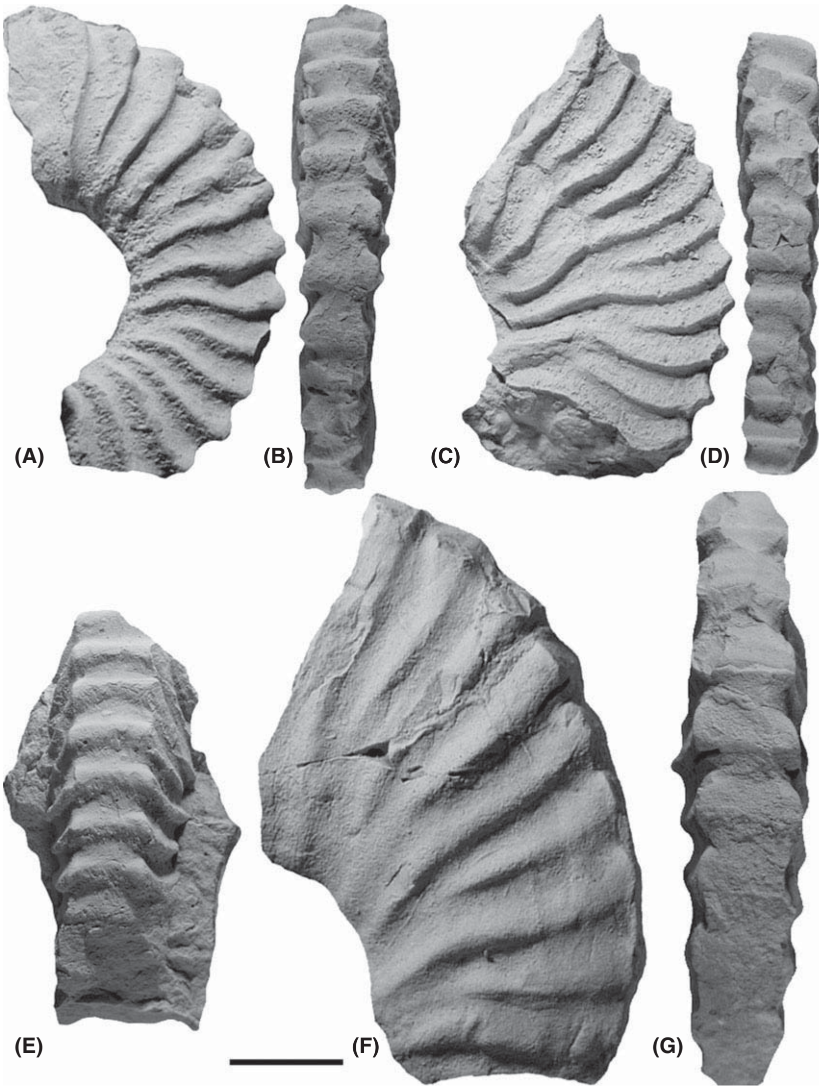

Fig. 2 *Dufrenoyia justinae* specimens collected in the Francisco Zarco Dam section (State of Durango; NE Mexico). A-B: *Dufrenoyia justinae* lateral and ventral views of the specimen IGM 6131 (Museo María del Carmen Perrilliat M., Colección Nacional de Paleontología, Instituto de Geología, Universidad Nacional Autónoma de México, México D.F., Mexico), bed 81. C–D: *Dufrenoyia justinae* lateral and ventral views of the specimen IGM 6132, bed 68. E: *Dufrenoyia justinae* ventral view of the specimen IGM 6133, bed 67. F–G: *Dufrenoyia justinae* lateral and ventral views of the specimen IGM 6134, bed 85. Scale bar = 1 cm.

The Spanish transgression

In the Maestrat Basin (eastern Spain), Salas (1987) identified the presence of a marine transgression at the base of the Benassal Formation. The base of this formation has been recently correlated in the western part of the basin with the upper part of the *Dufrenoyia dufrenoyi* Subzone (uppermost part of the *Dufrenoyia furcata* Zone; uppermost Lower Aptian) by Moreno-Bedmar (2010) (Fig. 3). The same transgressive event is being studied in the northern sector of the Maestrat Basin (Bover-Arnal *et al.*, 2010b), where several specimens of the index species *Dufrenoyia dufrenoyi* (d'Orbigny, 1841) have been collected (Figs 3 and 4). Therefore, the *Dufrenoyia dufrenoyi* Subzone is also recorded in this northern part of the basin. Presently, this age assignment is recognized

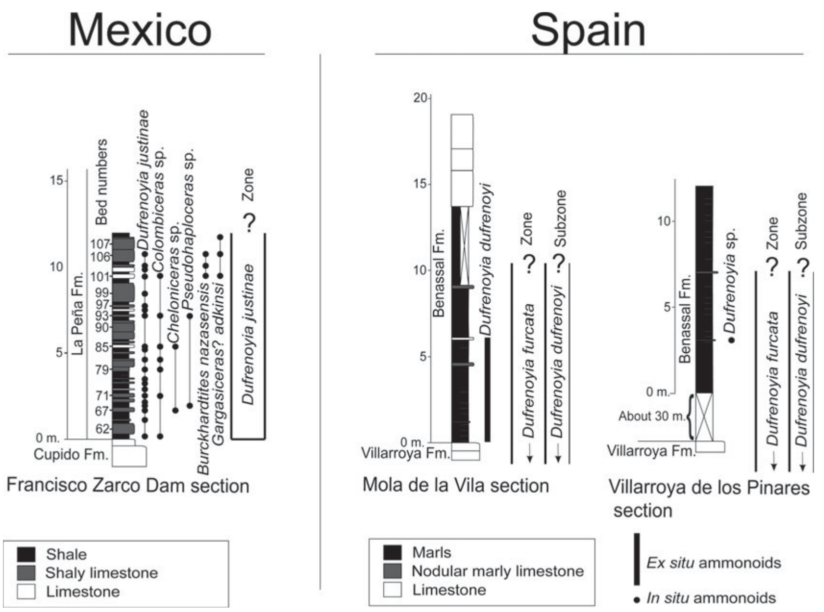

Fig. 3 Francisco Zarco Dam section, north-east Mexico (Barragan, 2001 for situation) and Mola de la Vila and Villarroya de los Pinares sections, eastern Spain (see Bover-Arnal *et al.*, 2010a, b).

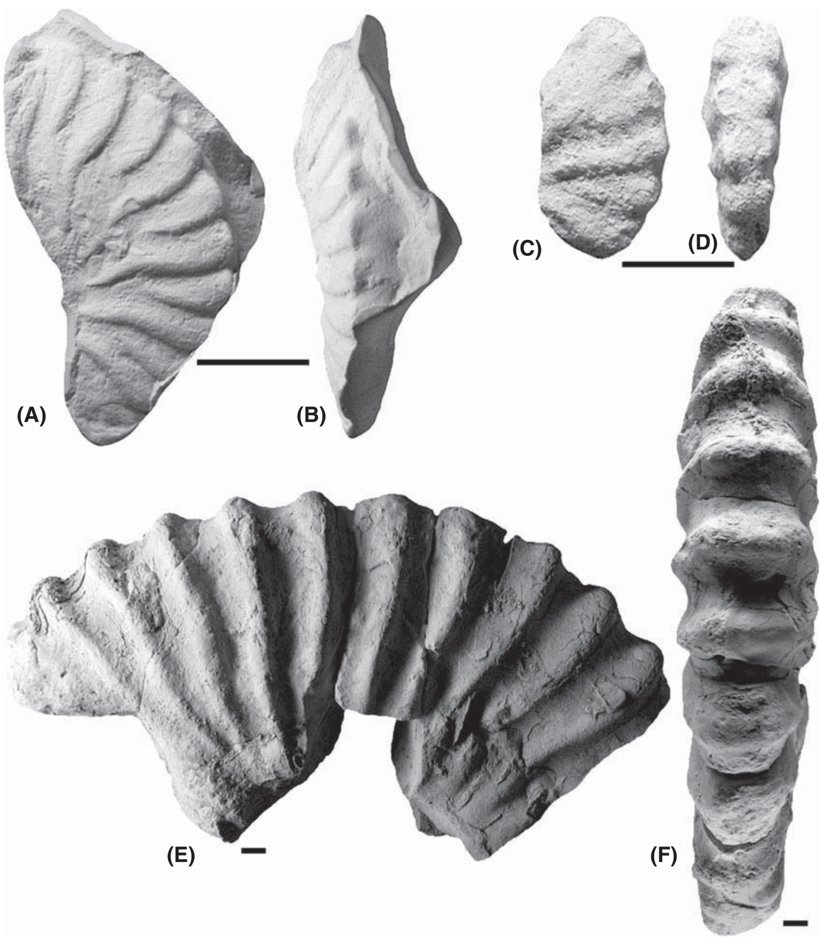

Fig. 4 *Dufrenoyia* specimens collected in the Maestrat Basin (E Spain). A–B: *Dufrenoyia dufrenoyi* lateral and ventral views of the specimen PUAB 88390 (Collections of Paleontology of the Universitat Autònoma de Barcelona, Barcelona, Spain), Mola de la Vila section. C–D: *Dufrenoyia dufrenoyi* lateral and ventral views of the specimen PUAB 88391, Mola de la Garumba section. E–F: *Dufrenoyia* sp. lateral and ventral views of the specimen VP-A6, Villarroya de los Pinares section. Scale bar = 1 cm.

in three sections of these two sectors of the Maestrat Basin: Villarroya de los Pinares (W Maestrat Basin), Mola de la Vila and Mola de la Garumba (N Maestrat Basin) (see Bover-Arnal *et al.*, 2010a,b for situation). The Villarroya de los Pinares and Mola de la Vila sections are shown in Fig. 3. The Tethyan sequence Ap3 is well recorded beneath this transgression in the Forcall and Villarroya de los Pinares formations (Bover-Arnal *et al.*, 2010a), and calibrated by means of ammonoids (Moreno-Bedmar *et al.*, 2010). Consequently, the later transgressive event can be assigned to the third-order sequence Ap4.

In the Basque-Cantabrian Basin (N Spain), the presence of transgressive strata containing *Dufrenoyia* specimens has recently been recognized in the lowermost part of Lareo Formation (Millán *et al.*, 2007; García-Mondéjar *et al.*, 2009). According to the ammonoid biostratigraphic analysis carried out by these authors, the Errenaga and Sarastarri formations, which are stratigraphically below the Lareo Formation, are coeval with the Tethyan Sequence Ap3 of Hardenbol *et al.* (1998). Thus, these transgressive deposits can be assigned to the Tethyan Sequence Ap4.

The succession of *Dufrenoyia* species in Spain

A clear succession of two species of *Dufrenoyia* is recorded in Spain. The first one is *Dufrenoyia furcata* (Sowerby, 1836) and the second one is *Dufrenoyia dufrenoyi* (d'Orbigny, 1841). This succession has been also recognized in the Vocontian Basin (France) by Dutour (2005). These two species give name to two subzones of the *Dufrenoyia furcata* Zone, which were recently proposed, accepted and published in Reboulet *et al.* (2011).

However, in the western margin of the Maestrat Basin (E Spain), a third species was recognized in the upper part of the *Dufrenoyia dufrenoyi* Subzone in the Barranco de las Calzadas section (see Bover-Arnal *et al.*, 2010a, 2011 for details). This third taxon, identified as *Dufrenoyia* sp. in Moreno-Bedmar *et al.* (2010), shows great similarities to the New World species *Dufrenoyia justinae*. Accordingly, it should be referred as *Dufrenoyia* cf. *justinae* (see Fig. 5). These independent data support the correlation of the uppermost Lower Aptian transgressive records identified in Mexico and Spain.

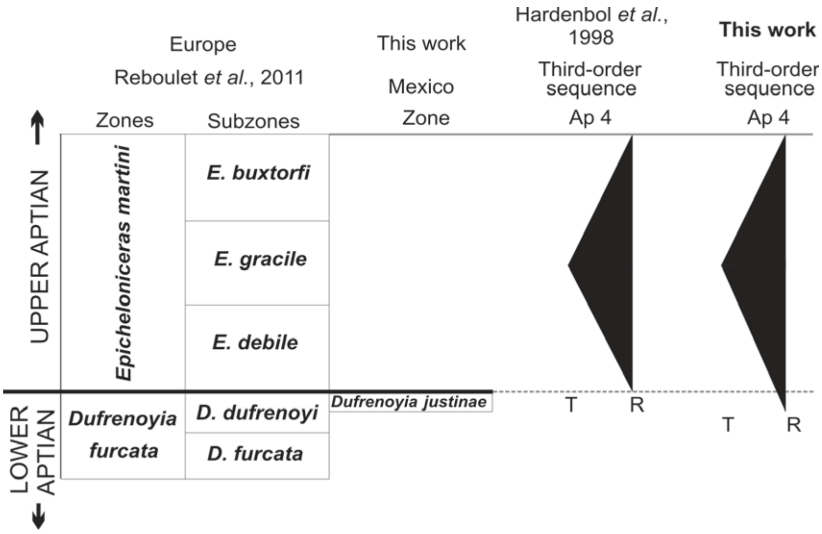

Fig. 6 The third-order sequence Ap4 with respect to the standard ammonite Mediterranean zonation of the uppermost Lower Aptian/lowermost Upper Aptian and the uppermost Lower Aptian ammonite Mexican zonation.

Age constraints of the limit between the Tethyan sequences Ap3 and Ap4

Neither the Mexican nor the Spanish transgressions reported can be correlated with any of the Lower Aptian Tethyan Sequences (Ap1–Ap3) of Hardenbol *et al.* (1998). In Spain, the most important Aptian transgression corresponds to the transgressive part of the Sequence Ap3. This transgression has been studied thoroughly, in particular its maximum flooding zone, which is coeval with the Oceanic Anoxic Event 1a (García-Mondéjar *et al.*, 2009; Moreno-Bedmar *et al.*, 2009, 2010, 2012; Bover-Arnal *et al.*, 2010a, 2011; Najarro *et al.*, 2011). The transgressive deposits above the Tethyan Sequence Ap3 contain the youngest *Dufrenoyia* species. Therefore, this latter transgression must be assigned to the sequence Ap4. According to Hardenbol *et al.* (1998), the Tethyan Sequence Ap4 commences with the Upper Aptian. However, our data in Spain show that this age must be corrected, if not globally, at least for the Cretaceous Iberian basins. In Iberia (Iberian plate), the start of the Ap4 should be placed in the uppermost part of the *Dufrenoyia furcata* Zone, more precisely in the upper part of the *Dufrenoyia dufrenoyi* Subzone (uppermost Lower Aptian) (Fig. 6).

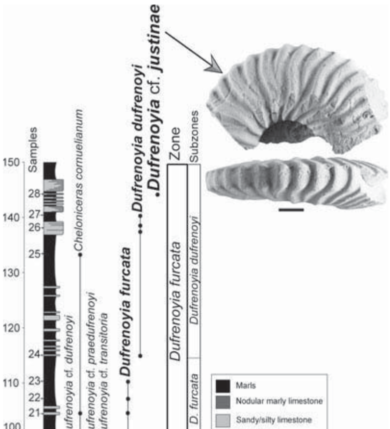

Fig. 5 Barranco de las Calzadas section, eastern Spain (modified of Moreno-Bedmar *et al.*, 2010). In the upper right of the figure *Dufrenoyia* cf. *justinae* lateral and ventral views of the specimen CPT-3728 (Collections of Conjunto Paleontológico de Teruel, Teruel, Spain). Scale bar = 1 cm.

In Mexico, the United States, Colombia and Venezuela, the strongest Aptian transgression recorded must be also assigned to the Ap4 sequence. This transgression consistently started with *Dufrenoyia* beds. Bralower *et al.* (1999) suggest that this transgression in Mexico was linked to the Oceanic Anoxic Event 1a (OAE 1a) that is related to the maximum flooding zone of the Ap3 sequence that occurred in the *Deshayesites forbesi* Zone, *Roloboceras hambrovi* Subzone (e.g. Moreno-Bedmar *et al.*, 2009, 2010, 2012; Bover-Arnal *et al.*, 2010a,b; Najarro *et al.*, 2011; Reboulet *et al.*, 2011). Our data show that the Mexican transgression is not associated with the OAE 1a because it clearly occurs later in the *Dufrenoyia justinae* Zone in agreement with Millán *et al.* (2009) and Skelton and Gili (2012).

The Mexican zone *Dufrenoyia justinae* was correlated with the entire *Dufrenoyia furcata* Zone of the Tethyan realm (Barragán-Manzo and Méndez-Franco, 2005). According to the new data concerning the age of the boundary between the Ap3 and Ap4 sequences, the *Dufrenoyia justinae* Zone would only be an equivalent to the upper part of *Dufrenoyia furcata* Zone (Fig. 5). This interpretation is consistent with the first appearance of *Dufrenoyia* cf. *justinae* in an equivalent stratigraphic position in Spain. Unfortunately, our data are restricted to Mexico and Spain. Nevertheless, this basal age of the Tethyan Sequence Ap4 can probably be expanded into several other basins of the Old and New worlds.

Conclusions

The widespread transgressive event that occurred in Mexico and in the New World (Atlantic extension of Tethys) during the latest-Early Aptian has also been identified in Spain (western Tethys), and are both correlatable with the transgressive part of the Tethyan sequence Ap4 of Hardenbol *et al.*

(1998). The ammonoid data permit us to calibrate the basal age of the Tethyan sequence Ap4 as follows: *Dufrenoyia justinae* Zone in Mexico and upper part of the *Dufrenoyia dufrenoyi* Subzone (uppermost part of the *Dufrenoyia furcata* Zone) in Spain. Accordingly, the boundary between the Tethyan sequences Ap3 and Ap4 is latest-Early Aptian in age, at least in the basins of these two countries. The transgressive event of the Tethyan sequence Ap4 is the most important Aptian transgression of the Atlantic extension of Tethys (New World), whereas in the western Tethys (Old World), the most important one is recorded in the Tethyan sequence Ap3. The correlation of the Tethyan sequence Ap4 between Mexico and Spain, and the succession of species of *Dufrenoyia* recognized in Spain, allow us to note that the Mexican ammonoid Zone *Dufrenoyia justinae* corresponds to the uppermost part of the *Dufrenoyia furcata* Zone of the western Tethys. Although differences exist in the sedimentary expression of the transgressions of sequences Ap3 and Ap4 in Mexico and Spain, the findings also highlight the Tethyan significance of these third-order sequences.

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