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1 **Where humid and arid meet: Sedimentology of coastal siliciclastic successions deposited in**  
2 **apparently contrasting climates**

3

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21 **Running title:** Successions of apparently contrasting climates

22

**23 ABSTRACT**

24           Deciphering the palaeoenvironmental and palaeoclimatic setting of ancient successions  
25 that include deposits typical of different climates can be challenging. This is the case in the Late  
26 Jurassic succession cropping out in eastern Spain (South-Iberian and western Maestrazgo  
27 basins), where deposits characteristic of both arid to semiarid and humid to subhumid settings  
28 have been identified through a detailed analysis of eight stratigraphic sections. These sections  
29 comprise shallow marine carbonates changing upwards and laterally to a predominantly  
30 siliciclastic coastal and alluvial succession, including abundant dinosaur remains. Deposition of  
31 coastal and alluvial sediments occurred in flood plains, ephemeral and perennial fluvial  
32 channels, aeolian dunes, deltas, distributary mouth-bars and associated distributary channels,  
33 and shallow water bodies influenced by both fresh and marine waters. Some of these deposits,  
34 notably those of aeolian and ephemeral fluvial origin, are characteristic of arid to semiarid  
35 climates. However, there are also abundant deposits that can be demonstrably shown to have a  
36 coeval origin, which are indicative of permanent water courses: 1) sediments of seasonal  
37 discharge fluvial channels with perennial to semi-perennial flow, displaying subcritical and  
38 supercritical flow sedimentary structures; 2) deltaic sediments deposited in permanent  
39 freshwater bodies; and 3) abundant plant and dinosaur remains, especially of herbivorous  
40 dinosaurs, which required the presence of permanent water sources and abundant vegetation.  
41 These apparently contrasting sedimentary features indicate that deposition occurred under a  
42 seasonal climate controlled by monsoonal-type precipitation. These deposits are analogous to  
43 those observed nowadays in the Lençóis Maranhenses National Park (NE Brazil), where a  
44 subhumid tropical climate with a seasonal precipitation pattern prevails. Thus, this study shows  
45 that only through careful facies analysis and interpretation of depositional processes that can be  
46 shown to be occurring concurrently in neighbouring and related depositional systems can the  
47 detailed palaeoenvironmental and palaeoclimatic setting of complex coastal sedimentary  
48 successions be confidently reconstructed in detail.

**49 KEYWORDS**

50 Kimmeridgian-Tithonian, eastern Iberia, aeolian dunes, deltaic deposits, fluvial channels,  
51 supercritical flow bedforms.

## 52 INTRODUCTION

53 Sedimentological analyses of ancient successions, supported by comparison to analogous  
54 modern environments, provide a valuable technique with which to reconstruct ancient  
55 environmental and climatic settings. The sedimentary analysis of modern environments has  
56 allowed the recognition of certain deposits that predominate in different climate regimes (*i.e.*  
57 climatically significant rocks *sensu* Hallam, 1984, climate-indicative lithologies *sensu* Holz and  
58 Scherer, 2000, or climate-sensitive sediments *sensu* Gibbs *et al.*, 2002). The inferred  
59 significance of such deposits has been widely employed to interpret the palaeoclimatic setting of  
60 the fossil record. For example, the occurrence of evaporites, deposits of ephemeral channels (*i.e.*  
61 wadis), aeolian dunes and ephemeral lakes, among others, has been used to interpret arid to  
62 semiarid climates in the fossil record (*e.g.* Tucker and Benton, 1982; Stear, 1983; 1985; Hallam,  
63 1984; 1985; Zharkov *et al.*, 1998; Holz and Scherer, 2000; Rees *et al.*, 2004; Rodríguez-López  
64 *et al.*, 2010; Priddy and Clarke, 2020). Nevertheless, in the case of aeolian dunes, it is also  
65 important to remark that they are also widely reported from modern humid to subhumid settings  
66 (*e.g.* Mountney and Russell, 2009; Al-Masrahy and Mountney, 2015; dos Santos and dos  
67 Santos, 2015). In contrast, the presence of abundant coal, plant remains and permanent water  
68 courses has been used as the basis for interpreting humid to subhumid climates (*e.g.* Tucker and  
69 Benton, 1982; Hallam, 1984; Collinson, 1996; Zharkov *et al.*, 1998; Rees *et al.*, 2004).

70 A significant challenge arises when trying to reconstruct the palaeoenvironmental and  
71 palaeoclimatic setting of sedimentary successions that include features typical of both arid and  
72 humid settings. This is the case of the Late Jurassic Villar del Arzobispo Fm, which crops out in  
73 eastern Spain (western Maestrazgo and South-Iberian basins; Teruel and Valencia provinces;  
74 Fig. 1). This succession comprises mixed siliciclastic-carbonate sediments deposited in shallow  
75 marine, coastal and alluvial settings (*e.g.* Meléndez *et al.*, 1979; Mas and Alonso, 1981; Mas *et*

76 *al.*, 1984; Luque *et al.*, 2005; Campos-Soto *et al.*, 2016a, 2017a, 2019), and it is internationally  
77 renowned for its abundance of dinosaur remains of theropods, sauropods, thyreophoran and  
78 ornithopods (*e.g.* Suñer *et al.*, 2008; Alcalá *et al.*, 2009; 2018; Campos-Soto *et al.*, 2017a and  
79 references therein; Cobos *et al.*, 2020; Royo-Torres *et al.*, 2020), including the fossils of the  
80 largest dinosaur found in Europe, *Turiasaurus riodevensis* Royo-Torres, Cobos and Alcalá,  
81 2006. The stratal arrangement of siliciclastic coastal and alluvial deposits of this unit indicates  
82 the apparently contemporaneous development of a variety of subaqueous and subaerial  
83 depositional settings (Campos-Soto *et al.*, 2016a, 2017a, 2019). They include aeolian dune and  
84 ephemeral channel deposits, which are apparently indicative of arid to semiarid climates.  
85 However, the succession additionally comprises other coeval deposits that are apparently  
86 indicative of a humid to subhumid climate, such as those of deltas with abundant plant remains,  
87 as well as diverse and abundant large dinosaur faunas, which would require the availability of  
88 permanent water sources and abundant vegetation. Moreover, this succession includes deposits  
89 of perennial to semi-perennial fluvial channels with evidence of seasonal discharge, which  
90 commonly develop nowadays in monsoonal domains, but which could also conceivably occur in  
91 arid to semiarid settings if their catchment area is located in the monsoonal domain (Plink-  
92 Björklund, 2015). Thus, sedimentological features characteristic of both arid and humid climatic  
93 end-members are present in deposits of sub-environments that were apparently active  
94 contemporaneously; the palaeoenvironmental and palaeoclimatic interpretation of this  
95 succession is therefore challenging.

96         The aim of this study is to show how a detailed lithofacies analysis of a dominantly  
97 siliciclastic coastal and alluvial-plain succession can be applied to demonstrate the co-existence  
98 of a range of sub-environments that are variably indicative of both arid and humid climatic  
99 settings. Specific research objectives are to: i) analyse the subaqueous and subaerial  
100 depositional settings and document their interactions; ii) compare these deposits with modern  
101 analogues; iii) reconstruct the palaeoenvironments, palaeogeography and palaeoclimate of

102 eastern Iberia during deposition; and iv) demonstrate how the deposits of coeval sub-  
103 environments with evidence for apparently contrasting climates can co-exist.

#### 104 **GEOLOGICAL SETTING**

105         The South-Iberian and Maestrazgo basins are two of the extensional basins in the  
106 Mesozoic Iberian Extensional System (also referred to as the Iberian Basin) developed in  
107 eastern Iberia during the Late Oxfordian-Middle Albian (Fig. 1A-C), and inverted during the  
108 Cenozoic Alpine Orogeny (*e.g.* Salas *et al.*, 2001; Mas *et al.*, 2004; Martín-Chivelet *et al.*,  
109 2019). During their extensional development, these basins were surrounded to the W and NE by  
110 the Iberian and Ebro massifs, respectively, while marine areas were located to the E-SE and N  
111 of Iberia (Tethys and Boreal realms, respectively; Fig. 1D; *e.g.* Salas *et al.*, 2001; Mas *et al.*,  
112 2004). These basins were separated by the Valencian Massif, a NW-SE emergent area  
113 developed in the position where the Javalambre Range is now located (Fig. 1B, D; *e.g.* Mas and  
114 Alonso, 1981; Mas *et al.*, 2004; Campos-Soto *et al.*, 2019). The Maestrazgo Basin comprises  
115 several sub-basins separated by tectonic structures (*e.g.* Salas and Guimerà, 1996, 1997; Salas *et*  
116 *al.*, 2001; Martín-Chivelet *et al.*, 2019). The sedimentary record analysed in this paper crops out  
117 in the western Peñagolosa sub-basin, located to the SW of the Maestrazgo basin (Fig. 1B).

118         The deposits documented herein belong to the Villar del Arzobispo Fm (*sensu* Campos-  
119 Soto *et al.*, 2019; Figs. 1C, 2, 3), a mixed siliciclastic-carbonate succession dated as  
120 Kimmeridgian-Tithonian (Campos-Soto *et al.*, 2016a; 2016b; 2017a, 2019). This succession  
121 was deposited in a shallow marine carbonate platform setting that evolved into essentially  
122 siliciclastic coastal and alluvial environments, expressed as an overall regressive trend (Figs. 2,  
123 3; *e.g.* Meléndez *et al.*, 1979; Mas and Alonso, 1981; Mas *et al.*, 1984, 2004; Hernández *et al.*,  
124 1985; Luque *et al.*, 2005; Campos-Soto *et al.*, 2016a, 2017a, 2019; Pacios *et al.*, 2018).  
125 However, Campos-Soto *et al.* (2016b, 2017a, 2019) documented evidence for a marine  
126 transgression in the Tithonian, during the deposition of the uppermost part of the unit (Figs. 2,  
127 3). Additionally, marked thickness variations of the studied succession were largely controlled

128 by the development of syn-sedimentary extensional faults (Figs. 2 and 3 and Fig. S1 of  
129 Supplementary Material; see Campos-Soto *et al.*, 2017a, 2019).

130 The Villar del Arzobispo Fm conformably overlies the Higuieruelas Fm (Figs. 1C, 2, 3),  
131 an oncolitic limestone unit dated as Kimmeridgian (Campos-Soto *et al.*, 2015a, 2016a, 2017a;  
132 Pacios *et al.*, 2018) and deposited in a mid to inner carbonate platform setting (*e.g.* Gómez,  
133 1979; Gómez and Goy, 1979; Aurell *et al.*, 1994; Campos-Soto *et al.*, 2015a, 2016a). The Villar  
134 del Arzobispo Fm is unconformably overlain by Lower Cretaceous siliciclastic and/or carbonate  
135 units (Figs. 1C, 2, 3), deposited in shallow marine to coastal and alluvial environments (*e.g.*  
136 Vilas *et al.*, 1982; Canerot *et al.*, 1982; Salas, 1987; Mas *et al.*, 2004; Fernandez-Labrador,  
137 2016).

138 The Villar del Arzobispo Fm has been studied in different areas of the South-Iberian  
139 and western Maestrazgo basins (Figs. 1C, 2, 3). In all areas, its sedimentary record is equivalent  
140 and comprises two informal parts (Fig. 2; Campos-Soto *et al.*, 2016b, 2017a, 2019): 1) a  
141 Kimmeridgian, essentially carbonate lower part (CLP); and 2) a Kimmeridgian-Tithonian,  
142 essentially siliciclastic upper part (SUP). The thickness and facies distribution differ in sections  
143 located to the E-SE and sections located to the N and W (Campos-Soto *et al.*, 2017a, 2019; Figs.  
144 1C, 2, 3). The eastern and south-eastern sections, located closer to the Tethys Ocean, occupied a  
145 part of the basin subject to relatively high subsidence rates during sedimentation; here, the  
146 accumulated succession is thicker and deposits display greater marine influence than in the  
147 northern and western sections, which themselves occupied more landward and slowly subsiding  
148 areas (Figs. 1D, 2, 3; Campos-Soto *et al.*, 2017a, 2019).

149 In all areas, the CLP comprises bioclastic and/or oolitic limestone with abundant marine  
150 fossils alternating with non-channelized sandstone, siliciclastic mudstone, marl and minor  
151 channelized sandstone and conglomerate (Figs. 2 and 3); this part of the succession,  
152 Kimmeridgian in age, has been interpreted as deposited in a shallow marine carbonate platform  
153 that received siliciclastic sediments from nearby emergent areas (Campos-Soto *et al.*, 2016a,

154 2017a, 2019). Shallow marine deposits of the CLP change upwards to deposits of the SUP,  
155 which mainly comprises reddish siliciclastic mudstone interbedded with non-channelized  
156 sandstone and channelized sandstone and conglomerate, interpreted as deposited in a coastal  
157 and alluvial plain during a regressive stage during the Kimmeridgian-Tithonian (Figs. 1D, 2, 3,  
158 4; Campos-Soto *et al.*, 2015b, 2016a, 2017a, 2017b, 2019). Siliciclastic deposits are interbedded  
159 and laterally related with limestone and marl, mainly towards the upper part of the SUP, during  
160 which a marine transgression took place during the Tithonian (Figs. 2, 3, 5 and Fig. S1 of  
161 Supplementary Material; Campos-Soto *et al.*, 2016b, 2017a, 2019). Some limestone beds are  
162 peloidal and/or micritic, include very scattered marine fossils, and display tidal structures and  
163 abundant subaerial exposure features (including abundant dinosaur tracks). Collectively, these  
164 features indicate sedimentation in inter- to supratidal carbonate flats (Campos-Soto *et al.* 2017a,  
165 2019). Other limestone beds are bioclastic and/or oolitic and include abundant marine fossils  
166 (Fig. 2). These limestone beds are progressively more abundant and include a higher proportion  
167 of fossils characteristic of normal marine salinities (such as echinoderms, dasyclads, red algae  
168 and corals) towards the east and south-eastern sections (Figs. 2, 5 and Fig. S1 of Supplementary  
169 Material), indicating that the coastal setting was laterally connected to the E-SE to a shallow  
170 marine carbonate platform (Campos-Soto *et al.*, 2017a, 2019).

## 171 MATERIALS AND METHODS

172 This paper is based on the detailed stratigraphic and sedimentological study, and  
173 geological mapping, of the Villar del Arzobispo Fm (Figs. 1C, 2). Geological mapping was  
174 performed by field observations, supported by analysis of aerial photographs and data  
175 (stratigraphic units and tectonic structures) provided by the Spanish Geological Survey  
176 (GEODE, scale 1:50.000; López-Olmedo *et al.*, 2018). The map shown in Figure 1C was  
177 generated with the ArcGIS software.

178 Eight stratigraphic sections were measured and logged at cm- to m-scale in the areas  
179 with best outcrop exposures: the total cumulative length of measured sections is 5072 m of (Fig.

180 2). Four sections were logged in the western Maestrazgo Basin (Cedrillas, El Castellar,  
181 Formiche Alto and Mora de Rubielos); the other four in the South-Iberian Basin (Riodeva,  
182 Losilla-Alpuente, Benagéber and Villar del Arzobispo). One-hundred-and-forty-six additional  
183 outcrops of the studied succession were also analysed to study the composition, texture,  
184 sedimentary structures, fossil content, facies relationships, geometry and lateral continuity of  
185 beds that make up larger-scale architectural elements (see details of the additional studied  
186 outcrops in Campos Soto, 2020). Three-hundred-and-forty-eight palaeocurrent measurements  
187 were obtained from the studied siliciclastic deposits, mainly from the dip azimuth of large-scale  
188 cross strata and clinofolds, and also from small-scale ripple structures. Palaeocurrents obtained  
189 from supercritical flow sedimentary structures have not been taken into consideration for  
190 palaeocurrent analysis, as these bedforms could migrate downstream and upstream (*e.g.*  
191 Alexander *et al.*, 2001; Cartigny *et al.*, 2014; Ono *et al.*, 2020). Paleocurrent data were plotted  
192 as rose diagrams using the PAST software (Hammer *et al.*, 2001). Rose diagrams were  
193 constructed for architectural elements to show mean palaeocurrent directions and their  
194 variability, grouped in classes of 24°, in which the length of each sector represents the relative  
195 abundance of measurements. The number of readings has been indicated with the letter “n”.

196 Four-hundred-and-fifty-five rock samples were systematically collected throughout the  
197 stratigraphic sections and from the additional studied outcrops. A 30 µm-thick, polished and  
198 uncovered thin section was prepared for each sample to perform petrographic analysis under  
199 transmitted light microscopy. The terminology used for siliciclastic rocks follows the Udden-  
200 Wentworth grain-size scale classification (Udden, 1914; Wentworth, 1922) modified by Blair  
201 and McPherson (1999) and the classifications of Folk (1968) and Powers (1953) for sorting and  
202 roundness, respectively. Carbonate rocks were classified following the classification of Dunham  
203 (1962).

204 This research also includes the analysis of Google Earth’s satellite images of modern  
205 coastal settings deemed to be analogous to the studied ancient succession, principally that  
206 located at the Lençóis Maranhenses National Park (NE Brazil), in which the different

207 subenvironments (aeolian dunes, interdunes, fluvial and tidal channels, shallow water bodies,  
208 deltas, flood plains) and the interactions observed between them have been analysed in detail in  
209 this study.

## 210 **RESULTS**

211 This research focuses on the sedimentological analysis of the siliciclastic deposits of the  
212 Villar del Arzobispo Fm, which form 65-85% of the succession, depending on the location  
213 (Figs. 2, 3). The other 15-35% are the shallow marine and tide-influenced limestone deposits  
214 (Figs. 2, 3). The siliciclastic deposits are more abundant in the SUP and towards the landward  
215 sections located to the N and W (Riodeva and Benagéber sections in the South-Iberian Basin;  
216 Cedrillas and El Castellar sections in the western Maestrazgo Basin) (Figs. 2, 3, 4). They are  
217 less abundant towards the seaward sections located to the E-SE (Losilla-Alpuente and Villar del  
218 Arzobispo sections in the South-Iberian Basin; Formiche Alto and Mora de Rubielos sections in  
219 the western Maestrazgo Basin) (Figs. 2, 3, 5). Through sedimentological analysis, eleven  
220 siliciclastic architectural elements have been identified, each of them comprising a distinctive  
221 facies assemblage and geometric arrangement; these correspond to elements deposited in four  
222 primary depositional settings: (i) fluvial, (ii) deltaic, (iii) coastal to shallow marine and (iv)  
223 aeolian (Table 1).

### 224 **Fluvial depositional setting**

225 Fluvial deposits are observed along the SUP and rarely in the CLP (Fig. 2). They are  
226 interbedded and laterally related with the aeolian and deltaic elements (Figs. 2, 4) and with the  
227 coastal to shallow marine elements (Fig. 2). Three fluvial architectural elements have been  
228 distinguished.

#### 229 *Ephemeral fluvial channel architectural element*

230 *Description.* This element typically forms less than 1% of the studied unit, although in  
231 the landward areas of the South-Iberian Basin it forms up to 3% of the succession (Fig. 2). It is

232 interbedded with the flood plain, aeolian dune and deltaic elements (Figs. 2, 6A-C). It comprises  
233 decimetre to metre-thick conglomerate lenses (up to 3 m-thick) displaying erosive bases, sharp  
234 flat tops and short lateral extent (commonly <10 m; Fig. 6A-C). Erosive bases are commonly  
235 symmetrical and slightly incisive (1:7 height/width ratios; Fig. 6B) or, locally, they are  
236 asymmetrical, displaying one very steep margin and another less steep one, and incising up to 3  
237 m into the underlying deposits (1:3 height/width ratios; Fig. 6C). Conglomerate lenses may be  
238 massive or may display a large-scale (up to 3 m-thick) cross strata set (Fig. 6B-C). In the case of  
239 the asymmetrical lenses, strata are conformable to the less steep margin of the erosive surface  
240 (Fig. 6C). Conglomerate is very poorly sorted and mostly clast-supported, though locally  
241 matrix-supported, and comprises subangular to subrounded pebbles and cobbles within a  
242 medium- to coarse-grained sandy matrix (Fig. 6D-F). Conglomerate clasts mainly consist of  
243 siliciclastic mudstone, carbonate and sandstone (Fig. 6E-F), ranging from 0.4 to 10 cm in  
244 diameter, although larger clasts up to 20 cm in diameter locally occur. Rounded quartzite  
245 pebbles, up to 6 cm in diameter, are rarely observed (Fig. 6D), although they become relatively  
246 abundant upwards in the SUP in the South-Iberian Basin. In places, conglomerate includes  
247 fragments of tree trunks (up to 12 cm in length) and some incomplete dinosaur teeth and bones  
248 (up to 20 cm in length; Fig. 6G).

249 Palaeocurrents in the South-Iberian Basin indicate transport directions towards the SW-  
250 NW and the NE-SE, whereas the scarce palaeocurrents obtained in the western Maestrazgo  
251 Basin indicate a main transport towards the S-SW and the SE (Figs. 2, 6A).

252 *Interpretation.* Clast- or locally matrix-supported fabrics, sandy matrix and the very  
253 poor sorting of conglomerates, suggest deposition by flash flows, which transported high  
254 concentrations of sediment (sand and gravels) in suspension (Costa, 1988; DeCelles *et al.*, 1991;  
255 Pierson, 2005). The erosive bases and the short lateral extent of the conglomerates, and their  
256 relation to flood plain and aeolian deposits indicates their likely deposition in ephemeral  
257 channels under episodic and high velocity currents, similar to those observed in other ancient  
258 (*e.g.* Cain and Mountney, 2009; Banham and Mountney, 2014) and modern settings (*e.g.*

259 Glennie, 1970; Picard and High, 1973). In present-day settings, ephemeral channels develop  
260 during seasonal rainfalls and are characterized by short periods of flow (Picard and High, 1973).  
261 The fact that these deposits are commonly characterised by a single set of cross strata indicates  
262 that channel development may have occurred in a single scour and fill event. This is also  
263 interpreted for conglomerates displaying massive fabrics, as they do not show internal erosive  
264 surfaces, grain size variations or other evidence of flow fluctuation or interruption. The  
265 asymmetrical erosive bases with strata that are conformable to their less steep margin, and the  
266 upstream-dipping cross strata are similar to experimentally produced hydraulic jump deposits in  
267 Froude supercritical flow conditions, where upstream dipping backset strata formed during  
268 upstream migration of hydraulic jumps, and the infilling of hydraulic jump scours resulted in  
269 conformable strata (Ono *et al.*, 2020). Similar strata have been documented in ancient fluvial  
270 deposits and interpreted as chute and pool and cyclic step deposits (*e.g.* Fielding, 2006; Plink-  
271 Björklund, 2015; Wang and Plink-Björklund, 2020).

272           Paleocurrents directed to the NE-SE in the South-Iberian Basin and to the S-SW and SE  
273 in the western Maestrazgo Basin suggest that these deposits were derived from erosion of the  
274 Iberian and Ebro massifs, located to the NW-SW and to the N-NE, respectively (Fig. 1D),  
275 which were the main emergent areas in Iberia during the Late Jurassic (*e.g.* Salas *et al.*, 2001;  
276 Mas *et al.*, 2004). Nevertheless, palaeocurrents of the South-Iberian Basin also indicate  
277 transport directions to the SW-NW, which are more difficult to interpret. They could indicate  
278 that these deposits were also derived from the Valencian Massif, located to the NE-SE (Fig.  
279 1D). Alternatively, they could correspond to palaeocurrents measured in the backsets produced  
280 by hydraulic jump migration (*e.g.* Alexander *et al.*, 2001; Cartigny *et al.*, 2014; Ono *et al.*,  
281 2020).

282           The very poorly sorted siliciclastic mudstone, carbonate and sandstone pebbles and  
283 cobbles are interpreted as intraformational clasts derived from the erosion and reworking of  
284 compacted sediments located in nearby flood plain areas, as similarly interpreted in other  
285 ancient fluvial deposits (*e.g.* North and Taylor, 1996; Deluca and Eriksson, 1989; Hinds *et al.*,

286 2004; Cain and Mountney, 2006; Banham and Mountney, 2014). The fact that conglomerates  
287 contain a greater abundance of quartzite pebbles upwards in the SUP in the South-Iberian Basin  
288 suggests that older rocks were successively eroded, i.e. Jurassic carbonate rocks in the earlier  
289 stages of erosion and Paleozoic to Triassic rocks in the later stages. Nevertheless, further  
290 provenance studies are necessary to determine the specific source area of these clasts.

### 291 *Multistorey fluvial channel architectural element*

292 *Description.* This element forms 10 to 25% of the studied succession in the South-  
293 Iberian Basin (Fig. 2) and 5 to 10% in the western Maestrazgo Basin (Fig. 2). It is more  
294 abundant in the landwards sections of both basins. In all areas, this element is more abundant in  
295 the SUP, although rare examples are observed in the CLP (Fig. 2). It is interbedded with the  
296 flood plain element (Figs. 4, 7A-E) and with the aeolian dune elements (Fig. 4). It comprises  
297 sandstone or sandstone and conglomerate arranged in metre-thick multistorey bodies (in some  
298 cases up to 15 m thick, Figs. 4, 7A-E) displaying erosive bases and a large lateral extent, in  
299 some exposures in excess of 250 m.

300 Sandstone is moderately to poorly sorted and displays medium to coarse grain sizes,  
301 although fine grain sizes are also observed in some bodies. Sandstone shows large-scale sets of  
302 cross strata (rarely trough cross strata) up to 1.5 m-thick (Fig. 7B-C, E). Set thickness decreases  
303 upwards in some bodies (Fig. 7B-C). Locally, mm- to cm-thick layers of siliciclastic mudstone,  
304 which may contain abundant carbonaceous detritus, occur between cross sets (Fig. 7E-F) and/or  
305 at the lower part of the foresets and bottomsets.

306 A distinctive feature of this element is the common occurrence of large internal erosive  
307 surfaces that locally incise downwards up to 2.4 m (Fig. 7B-F). Another distinctive feature is  
308 the occurrence of sandstone displaying convex-up low-angle cross strata (Fig. 8A-B) and scour-  
309 and-fill structures, which are filled by backset or foreset strata that, in places, gradually flatten  
310 upwards (Figs. 7B-C, 8C-D). Locally, flattening-upwards strata show wavelengths of several

311 metres (Fig. 7B-C). In addition, sandstone locally includes fragments of fossilized wood and  
312 tree trunks up to a few metres long.

313 Conglomerate, where present, overlies the erosive base of bodies and/or the internal  
314 erosive surfaces (Fig. 7B-D) and may be up to 2 m thick. Conglomerate is very poorly sorted  
315 and comprises subangular to subrounded pebbles and cobbles (up to 8 cm in diameter), and  
316 fragments of fossilised wood up to 10 cm long in places. Composition of conglomerate is  
317 identical to that reported in the ephemeral channel element. Conglomerate is structureless or  
318 displays large-scale cross strata with sets up to 1.5 m thick. In some bodies, conglomerate  
319 displays scour-and-fill structures comprising asymmetrical scours, with a steeper upstream  
320 margin, and are filled by backset strata that gradually flatten upwards and fine upwards to  
321 medium- to coarse-grained sandstone (Fig. 7B-C).

322 Palaeocurrents measured in the South-Iberian Basin indicate main transport directions to  
323 the NE-S and, less commonly, to the SW-N, whereas in the western Maestrazgo Basin, data  
324 indicate main transport directions to the NE and, less commonly, to the N and E-S (Fig. 7A).

325 *Interpretation.* The erosive bases and large lateral extent of these deposits and their  
326 interbedding with flood plain deposits, are features typical of fluvial channels that migrated  
327 across a flood plain. The internal erosive surfaces filled by very poorly-sorted conglomerate or  
328 sandstone, are interpreted to develop during episodes of intense precipitation that produced a  
329 rapid rise in flow discharge and velocity within the channels, causing the partial erosion of  
330 earlier deposits of the channels and the subsequent deposition of intraformational clasts  
331 (siliciclastic mudstone, carbonate and sandstone clasts) and fragments of tree trunks and other  
332 plant remains, which were eroded and transported from nearby flood plain areas. Similar  
333 sedimentary features have been reported in other ancient and modern fluvial channels  
334 characterized by a seasonally highly variable discharge (Abdullatif, 1989; Deluca and Eriksson,  
335 1989; Browne and Plint, 1994; North and Taylor, 1996; McKie, 2011; Fielding *et al.*, 2009,  
336 2011, 2018; Plink-Björklund, 2015). In these seasonal rivers, intraformational conglomerates

337 are locally derived (*i.e.* from flood plains) and their deposits are associated with a rapid decrease  
338 of water level occurring during early phases of the waning stage of floods, when upper flow  
339 regime conditions occur (*e.g.* Singh *et al.*, 1993; North and Taylor, 1996; Gibling and Tandom,  
340 1997; Plink-Björklund, 2015). Fragments of tree trunks and plant remains similar to those of the  
341 studied deposits have been described in other ancient and modern seasonal rivers, especially in  
342 those developed in subhumid subtropics (*e.g.* Fielding and Alexander, 1996; Alexander *et al.*,  
343 1999; Fielding *et al.*, 1997, 2009, 2011; Allen *et al.*, 2014; Plink-Björklund, 2015 and  
344 references therein), and are derived from the destruction of trees or other plants, during floods,  
345 that grow in the channel margins or in areas of channel bed that get exposed during periods of  
346 non-flood discharges (Fielding *et al.*, 1997; Alexander *et al.*, 1999).

347         The convex-up low-angle cross strata resemble antidune structures formed under  
348 supercritical flow in flume experiments (*e.g.* Alexander *et al.*, 2001; Cartigny *et al.*, 2014), and  
349 in other ancient fluvial deposits (*e.g.* Fielding, 2006; Fielding *et al.*, 2009; Plink-Björklund,  
350 2015; Wang and Plink-Björklund, 2020). The asymmetrical scour-and-fill structures with  
351 backset or foreset strata that in places flatten and fine upwards are similar to the structures  
352 produced during the infilling of hydraulic jump scours under supercritical flow conditions in  
353 chutes and pools and cyclic steps in flume experiments (*e.g.* Alexander *et al.*, 2001; Cartigny *et*  
354 *al.*, 2014; Ono *et al.*, 2020), in numerical simulations (Vellinga *et al.*, 2018), and in other  
355 ancient seasonal fluvial channels (*e.g.* Fielding, 2006; Fielding *et al.*, 2009; Plink-Björklund,  
356 2015; Wang and Plink-Björklund, 2020). Backset strata have also been reported in bar head  
357 deposits of some Pliocene alluvial sediments in SE Spain (Viseras and Fernández, 1994, 1995).  
358 However, bar deposits have not been identified in the studied fluvial channel deposits. In fact,  
359 the occurrence of poorly developed barforms, or even their absence, is a common characteristic  
360 that has been reported in many ancient and modern examples of seasonal discharge rivers (*e.g.*,  
361 Fielding *et al.*, 2009; Plink-Björklund, 2015 and references therein).

362         Regarding the recent experimental work performed on the study of supercritical flow  
363 bedforms, it has been observed that antidunes develop downstream of chutes and pools

364 (Cartigny *et al.*, 2014), and convex-up low-angle strata and scour-and-fill structures have been  
365 observed developing coevally by the upstream migration of cyclic steps (Ono *et al.*, 2020).  
366 Thus, these authors highlight that, although these structures are produced under supercritical  
367 flows, caution must be used when trying to assign specific structures observed at the outcrop to  
368 specific supercritical flow bedforms.

369         During periods of non-flood discharges, sand would have been deposited through the  
370 migration of subaqueous dunes, as indicated by the occurrence of sandstone displaying large-  
371 scale cross strata (occasionally trough cross strata). This is similarly observed in some channels  
372 developed in settings with seasonal rainfall, such as in the Gash River in Sudan (Abdullatif,  
373 1989), in which subaqueous dunes and ripples migrate during periods of non-flood discharges  
374 or during less intense flood phases (Plink-Björklund, 2015).

375         In addition, the local occurrence of thin layers of siliciclastic mudstone containing  
376 abundant carbonaceous detritus between sandstone cross sets and/or at the lower part of the  
377 foresets and at the bottomsets has been similarly identified in other modern and ancient seasonal  
378 fluvial channels, where they are deposited during the rapid waning stage that occur after high  
379 magnitude floods (e.g. Williams, 1971; Abdullatif, 1989; Singh *et al.*, 1993; Shukla *et al.*, 2001;  
380 Allen *et al.*, 2011; Plink-Björklund, 2015 and references therein).

381         Thus, this element is interpreted as deposited in fluvial channels occupied by perennial  
382 or semi-perennial flow and characterized by episodic and seasonal discharge. Palaeocurrents  
383 measured in the South-Iberian Basin indicate that these deposits were mainly derived from the  
384 Iberian Massif and, in minor proportion, from the Valencian Massif, located to the SW-N and  
385 NE-S, respectively (Fig. 1D). By contrast, in the western Maestrazgo Basin, these deposits were  
386 derived from the Valencian Massif and, in minor proportion, from the Iberian and Ebro massifs  
387 (Fig. 1D).

388 *Flood plain architectural element*

389           *Description.* This is the most abundant element of the succession, especially in the SUP  
390 (Fig. 2). Depending on the section, it forms 40 to 70% of the studied succession in both basins,  
391 although in the most seaward section of the western Maestrazgo Basin (Mora de Rubielos  
392 section) it only forms around 15% of the studied succession. It is interbedded with the  
393 ephemeral and multistorey fluvial channel, deltaic, aeolian and coastal to shallow marine  
394 elements (Figs. 2, 4). Towards the seaward sections it is also interbedded with limestone of tidal  
395 and shallow marine origin (Fig. 2). It is composed of siliciclastic mudstone alternating with  
396 non-channelized sandstone and locally oncolitic and stromatolitic limestone (Fig. 9A).  
397 Siliciclastic mudstone is typically reddish in colour and displays greenish or greyish mottling,  
398 carbonate nodules and root traces (Fig. 9B). In places, it includes dinosaur bones, which are  
399 commonly associated, disarticulated and/or articulated (Royo-Torres *et al.*, 2009; Cobos *et al.*,  
400 2010; Campos-Soto *et al.*, 2017a and references therein).

401           Non-channelized sandstones comprise very fine- to medium-grained sandstone,  
402 arranged in dm-thick strata (up to 60 cm-thick), displaying tabular geometries (Fig. 9C-D) or,  
403 locally, flat bases and convex-up tops (Fig. 9E), and short lateral extent (up to 40 m). Tabular  
404 sandstone may be massive or display large-scale cross strata or parallel lamination, followed  
405 upwards by current ripple strata (commonly climbing ripple strata), which are rarely overlain by  
406 wave ripple strata (Fig. 9D). Tabular sandstone in places is arranged in thickening- and  
407 coarsening- upwards bodies up to 1.5 m-thick (Fig. 9C). Sigmoidal cross strata have been also  
408 observed in sandstone (Fig. 9E).

409           Palaeocurrents indicate the main transport direction to the E-NE in the western  
410 Maestrazgo Basin and in the South-Iberian Basin to the W-SW, and less commonly to the NE  
411 (Fig. 9A).

412           Sandstone locally includes plant remains and large fragments of dinosaur bones, which  
413 are associated and/or articulated in places (see Royo-Torres *et al.*, 2009, 2020; Cobos *et al.*,  
414 2010). Dinosaur tracks have locally been observed at the base of some sandstone bodies,

415 preserved as convex hyporeliefs or natural track casts (Fig. 9F), and locally at the top, preserved  
416 as concave epirreliefs (see Campos-Soto *et al.*, 2017a). In places, sandstone shows vertical and  
417 horizontal burrowing traces at the top. Some of the vertical traces are observed as paired circular  
418 openings at the top of sandstone (Fig. 9G). Sandstone of this element may also display edaphic  
419 features at the top, such as reddish, orange, yellowish and/or greenish mottling and root traces.

420         Locally, limestone up to 30 cm-thick and displaying very limited lateral extension (less  
421 than 100 m) is sparsely interbedded with deposits of this element (Fig. 9A, H). Limestone  
422 includes oncoids (Fig. 9I), stromatolites, variable amounts of quartz grains and may be  
423 associated with poorly sorted fragments of bivalves, including ostreids, up to 4 cm (Fig. 9J).  
424 Very rarely limestone includes benthic foraminifera, echinoid spines, gastropods, ostracods,  
425 charophytes and very scarce fragments of corals and ooids (Fig. 9K). Locally, limestone made  
426 up of oncoids is arranged in bodies with erosive bases and short lateral extent (up to 3 metres).

427         *Interpretation.* This element is interpreted as deposited in a flood plain located in  
428 alluvial to coastal areas. Specifically, reddish siliciclastic mudstone displaying carbonate  
429 nodules, green mottling and root traces is interpreted as deposited on a flood plain (*e.g.* Miall,  
430 1996; Selley, 2000; Viseras *et al.*, 2006) subject to subaerial exposure periods and palaeosol  
431 development (Freytet and Plaziat, 1982; Alonso-Zarza and Wright, 2010; Soares *et al.*, 2020;  
432 Yeste *et al.*, 2020). Non-channelized sandstone displaying parallel lamination at the base and  
433 current or, commonly, climbing ripple strata at the top is interpreted as splay lobe deposits  
434 (Burns *et al.*, 2017, 2019; Yeste *et al.*, 2020), which developed due to the spreading out of an  
435 unconfined flow as a result of the breaking of a levee of a fluvial channel during flood events  
436 (Coleman, 1969; Miall, 2010). During these flood events, ephemeral currents transported large  
437 dinosaur bone remains, as similarly reported in other ancient settings (*e.g.* González Riga and  
438 Astini, 2007; Vogt *et al.*, 2016; Coram *et al.*, 2017). Repeated flooding episodes produced the  
439 progradation of the splay deposits, giving rise to the coarsening- and thickening-upwards  
440 bodies, which are common in this type of deposits (*e.g.* Farrell, 1987; Bridge, 2006; Yeste *et al.*,  
441 2020). Moreover, the sigmoidal cross strata observed in some bodies is interpreted as the result

442 of progradation of splay lobes into standing water bodies (*cf.* Mutti, 1996; Turner and Tester,  
443 2006).

444           Following deposition, the upper parts of splay lobes were reworked by waves and  
445 colonized by burrowers, as evidenced by the occurrence of wave ripple strata and burrows at the  
446 top of sandstone. Bioturbation observed as paired circular openings at the top of sandstone may  
447 correspond to U- or Y-shaped burrows, which are common in marginal-marine environments  
448 (Buatois and Mangano, 2011), as similarly occurs in the deposits of the fluvial-tidal transition in  
449 the Upper Cretaceous Tresp Fm, in the Pyrenees (Díez-Canseco *et al.*, 2014; 2016), for  
450 example. Splay lobes underwent subaerial exposure as indicated by the occurrence of edaphic  
451 features, as similarly reported in other ancient deposits (Yeste *et al.*, 2020), as well as by the  
452 local occurrence of dinosaur tracks at the top of sandstone. The occurrence of natural track casts  
453 at the base of sandstone indicates that dinosaurs passed across the flood plain, producing tracks  
454 in the underlying muddy sediment, as interpreted by Campos-Soto *et al.* (2017a) for the natural  
455 track casts present in sandstone in the western Maestrazgo Basin.

456           Limestone including oncoids and stromatolites and interbedded with siliciclastic  
457 deposits, is interpreted as deposited in shallow water bodies where benthic microbial  
458 communities interacted with detrital sediments and/or produced calcium carbonate precipitation  
459 (Burne and Moore, 1987; Riding, 1999; 2000). These shallow water bodies received siliciclastic  
460 and freshwater inputs, as limestone includes quartz grains, which may be abundant, and locally  
461 charophytes, and were also influenced by brackish and marine waters, as limestone locally  
462 includes poorly sorted brackish and marine bioclasts that were transported by storms and/or  
463 spring tides (Campos-Soto *et al.*, 2016a, 2019). Oncolitic limestone bodies displaying erosive  
464 bases and short lateral extent are interpreted as oncolite channels, similar to those reported in  
465 other ancient coastal (Suarez-Gonzalez *et al.*, 2015) and fluvio-lacustrine settings (Arenas-Abad  
466 *et al.*, 2010).

467 **Deltaic depositional setting**

468            *Description.* Deltaic deposits are mainly observed in the SUP of the South-Iberian  
469 Basin, where they form 2 to 6% of the studied succession. In the western Maestrazgo Basin,  
470 these deposits form less than 1% of the studied succession (Fig. 2). They are interbedded and  
471 laterally related with the fluvial and aeolian elements (Figs. 2, 4). Deltaic deposits comprise  
472 sandstone with minor proportions of carbonaceous detritus and carbonaceous-rich, dark grey  
473 siliciclastic mudstone, displaying a coarsening- and thickening-upwards succession. Each  
474 succession displays dm to m thicknesses (up to 2 m), an exposed lateral extent of up to 100 m  
475 (Figs. 10, 11) and includes, from base to top, three architectural elements that are intimately  
476 related: the *delta-toe*, *delta-front* and *delta distributary channel elements*. Several deltaic  
477 successions may be vertically stacked giving rise to composite bodies up to 10 m thick, with an  
478 exposed lateral extension of up to 200m (Fig. 10A-C).

479            The *delta-toe element* comprises carbonaceous-rich, dark grey siliciclastic mudstone,  
480 interbedded upwards with mm- to cm-thick layers of very fine-grained and rippled sandstone,  
481 which display a very low angle-inclination and a great lateral extent (Fig. 10A-D).

482            Deposits of the *delta-toe element* change laterally and upwards to the *delta-front*  
483 *element*, comprising sandstone displaying clinofolds, which have a sigmoidal outline in a flow-  
484 parallel direction (Fig. 11A-B). The lower part of the *delta-front element* comprises the lower  
485 part of foresets of clinofolds, which display a very low angle-inclination and pass laterally and  
486 downwards, along the bottomsets, to the delta-toe deposits (Fig.10B-C). The lower part of  
487 foresets comprise cm-thick, very fine- to fine-grained, well-sorted sandstone layers that  
488 alternate with mm- to cm-thick layers of carbonaceous detritus (Figs. 10B-C, E, 11B). Locally,  
489 sandstone layers at the lowermost part of the delta-front element, along the bottomsets, display  
490 poorly preserved dinosaur tracks, recorded as convex hyporeliefs or natural track casts, which  
491 show elongated shapes with irregular and deformed outlines and penetrate downwards into the  
492 underlying delta-toe deposits (Fig. 10F). The upper part of the *delta-front element* comprises the  
493 upper part of foresets and the topsets of clinofolds, which are made up of fine- to medium-

494 grained, well-sorted sandstone that locally display bioturbation. Locally, drapes of carbonaceous  
495 detritus may extend up to the topsets (Figs. 10A, 11B).

496 The upper part of the *delta-front element* deposits may be truncated by erosive surfaces  
497 (Figs. 10B-C, 11C-E), which become progressively more abundant and more incisive upwards  
498 and eventually are overlain by deposits of the *delta terminal distributary channel element* (Fig.  
499 11C-E). The *delta terminal distributary channel element* comprises dm- to m-thick sandstone  
500 bodies (up to 1.5 m) displaying erosive bases and a lateral extent of up to 10 m (Figs. 10A-C,  
501 11C-E). Sandstone is well-sorted and displays fine to medium grain sizes (Fig. 11F). Sandstone  
502 displays large-scale cross-strata with sets up to 1 m-thick (Figs. 11C-E). In places, sandstone  
503 displays backset strata or upwards flattening strata (Fig. 10B-C).

504 Palaeocurrents measured in the South-Iberian Basin, mainly in the clinofolds of delta-  
505 front element and, in less proportion, in the cross-bedded sets of the delta terminal distributary  
506 channel element, indicate main transport directions to the S, to the W-NW and to the NE (Fig.  
507 10A).

508 *Interpretation.* The coarsening- and thickening- upwards trend and the clinofolds  
509 observed in these deposits likely record the progradation of deltaic sediments into standing  
510 water bodies (*e.g.* Bhattacharya, 2006, 2010; Enge *et al.*, 2010a; Legler *et al.*, 2013; Gugliotta *et*  
511 *al.*, 2015, 2016; Kurcinka *et al.*, 2018).

512 Carbonaceous-rich, dark grey siliciclastic mudstone located in the lower part of the  
513 element, along the *delta-toe* (Fig. 10A-D), is interpreted to have been deposited by settling of  
514 suspension load during periods of low flow (Bhattacharya, 2010; Legler *et al.*, 2013; Enge *et*  
515 *al.*, 2010a). The thin layers of very fine-grained rippled sandstone interbedded with  
516 carbonaceous-rich, dark grey siliciclastic mudstone at the delta-toe indicate the episodic influx  
517 of siliciclastic discharges into the delta toes.

518 *Delta-toe* deposits change laterally and upwards to *delta-front* sandstone displaying  
519 clinofolds characterized by low-angle and laterally-continuous foresets with drapes of

520 carbonaceous detritus that may extend up to the lower part of foresets, as similarly reported in  
521 other ancient and modern deltaic deposits (*e.g.* Bhattacharya, 2006, 2010; Enge *et al.*, 2010a,  
522 2010b; Schomacker *et al.*, 2010; Bayet-Goll and de Carvalho, 2013; Legler *et al.*, 2013; Ahmed  
523 *et al.*, 2014; Kurcinka *et al.*, 2018). Sandstone is interpreted to be deposited by unconfined  
524 flows during flood episodes and carbonaceous detritus by settling down from suspension during  
525 periods of low flow (interflood periods *sensu* Gugliotta *et al.*, 2015, 2016). During periods of  
526 low flow delta-front deposits were occasionally burrowed, as suggested by bioturbation present  
527 locally at the top of sandstone.

528         The large-scale cross-strata sandstone infilling the erosive surfaces that incise  
529 downwards into the upper part of the *delta-front* sediments are interpreted as the infill of *deltaic*  
530 *terminal distributary channels* that migrated in a deltaic plain, as similarly observed in other  
531 ancient deltaic deposits (Olariu and Bhattacharya, 2006; Bhattacharya, 2010). In places,  
532 sandstone displays backset or flattening upwards strata (Fig. 10B-C). Similar structures have  
533 been observed in experimentally produced deltaic deposits (Muto *et al.*, 2012) due to the  
534 development of hydraulic jumps at the channel mouth, and have also been identified in other  
535 ancient deltaic successions (*e.g.* Massari, 1996, Lang *et al.*, 2017). Thus, it is possible that,  
536 during episodes of intense rainfall, supercritical flow conditions were achieved in the *delta*  
537 *terminal distributary channels*, leading to the formation of hydraulic jumps and the infilling of  
538 associated scours.

539         Palaeocurrents obtained in the South-Iberian Basin indicate that deltaic deposits were  
540 mainly associated with fluvial channels flowing to the W-NW, to the S and to the NE, which  
541 coincides with some of the transport directions of the multistorey fluvial channel deposits of this  
542 basin (see Figs. 7A, 10A). The standing water bodies where deltaic sediments were deposited  
543 occupied positions on a flood plain, as the deltaic deposits are commonly interbedded with the  
544 flood plain element. These water bodies were shallow, as evidenced by the height of clinofolds  
545 (from dm to up to 2 m) and by the occurrence of dinosaur tracks at the base of thinly bedded  
546 sandstone layers overlying delta toe deposits (Fig. 10F). The poor preservation of dinosaur

547 tracks, showing irregular and deformed outlines, suggests that the delta-toe sediments had a  
548 high-water content and a low yield strength at the moment when the tracks were made (Allen,  
549 1997; Marty *et al.*, 2009). The scarcity of evidence for subaerial exposure and edaphic features,  
550 which are common in the flood plain and splay lobe deposits, but have been only observed  
551 locally at the top of the *delta-toe to delta-front element* (see flood plain architectural element),  
552 suggests that the water bodies were also relatively permanent.

553         The salinity of the water bodies is difficult to determine as no fossils or sedimentary  
554 structures indicative of salinity have been observed within the deltaic deposits. If these water  
555 bodies received some marine influence during their deposition, it would be expected to observe  
556 brackish or marine fossils, as they occur in the sediments deposited in the shallow marine- to  
557 brackish-influenced water bodies located in the flood plain (see limestone of flood plain  
558 element). It would be also expected to observe tidal structures, such as the occurrence of a  
559 cyclical pattern in the distribution of carbonaceous detritus within the delta-front deposits, for  
560 instance. However, none of these sedimentary structures or fossils have been observed within  
561 the deltaic elements. It cannot be discarded that the studied deltaic sediments were deposited in  
562 freshwater bodies, as dinosaurs would require the presence of permanent water sources and  
563 abundant vegetation; in fact, freshwater fossils of turtles (Pérez-García *et al.*, 2014) and bivalves  
564 (Delvene *et al.*, 2013) have been reported in the fluvial deposits of the studied succession in the  
565 South-Iberian Basin. Nevertheless, given the coastal setting of the studied succession, mixing of  
566 fresh and marine waters or local tidal influence is conceivable for some water bodies.

567         In addition, the occurrence of vertically stacked coarsening and thickening upwards  
568 deltaic successions, of up to 2m-thick, leading to composite bodies of up to 10m-thick, is  
569 interpreted as a result of the combination of subsidence and high sedimentation rates, which  
570 would have produced the vertical superposition of the deltaic deposits.

571         **Coastal to shallow marine depositional setting**

572 Coastal to shallow marine siliciclastic deposits are observed both in the CLP and SUP  
573 interbedded and laterally related with tidal or shallow marine limestone and with marl, which  
574 includes brackish to marine bioclasts (ostreids, trigonioids and other bivalves, and large benthic  
575 foraminifera) and charophytes and was deposited in shallow marine to brackish areas that  
576 received freshwater inputs (Figs. 2, 5; Campos-Soto *et al.*, 2016a, 2019). Coastal to shallow  
577 marine deposits form less than 3% to 6 % of the studied succession in the landward sections of  
578 the South-Iberian and western Maestrazgo basins, respectively (Fig. 2). In the seaward sections,  
579 they form up to 15 and 20% of the studied succession in the South-Iberian and western  
580 Maestrazgo basins respectively (Figs. 2, 5). Two elements have been distinguished:

581 *Coastal terminal distributary channel architectural element*

582 *Description.* This element occurs interbedded with the distributary mouth-bar element  
583 and with marl (Figs. 5, 12A-B). It comprises fine- to medium-grained sandstone arranged in  
584 meter-thick bodies (up to 3 m thick), with erosive bases and an exposed lateral extent of 50 m  
585 (Figs. 5, 12A-C). Sandstone displays large-scale cross strata (Fig. 12D-E) and rarely includes  
586 mm- to cm-thick layers of carbonaceous-rich marl between cross sets (Fig. 12D-F). These thin  
587 layers of carbonaceous-rich marl may be also present at the bottomsets and the lower part of the  
588 foresets of large-scale cross strata (Fig. 12E). In addition, some sandstone bodies may show  
589 internal erosive surfaces (Fig. 12C, F), similar to those described in the multistorey fluvial  
590 channel element.

591 Locally, poorly sorted conglomerate is observed overlying the basal erosive surface of  
592 sandstone bodies or the internal erosive surfaces (Fig. 12F-G). It is made up by subangular to  
593 subrounded mudstone pebbles (up to 2.5 cm in diameter), within a coarse-grained sandy matrix,  
594 similar to those described in the multistorey fluvial channel element, although in this case, it  
595 also includes scarce fragments of bivalves (Fig. 12G).

596 The scarce palaeocurrent data obtained in the W Maestrazgo Basin indicate main  
597 transport directions to the E-SE (Fig. 12B).

598           *Interpretation.* Channelized sandstone of this element, interbedded with distributary  
599 mouth-bar element and marl, represents the infill of terminal distributary channels flowing into  
600 coastal and shallow marine areas and feeding distributary mouth-bar deposits, as similarly  
601 reported in other ancient examples (*e.g.* Olariu and Bhattacharya, 2006; Bhattacharya, 2010).  
602 The palaeocurrent data obtained in the W Maestrazgo Basin also support this interpretation, as  
603 they indicate that these distributary channels were flowing to the E-SE, which coincides with  
604 the location of the Tethys Ocean during the Late Jurassic (Fig. 1D), as well as with the transport  
605 directions obtained in some of the distributary mouth-bar deposits of this basin (Figs. 12B and  
606 13A). The thin layers of carbonaceous-rich marl occurring between large-scale cross sets and at  
607 the lower part of foresets and bottomsets are interpreted to be deposited by settling down from  
608 suspension during periods of low river discharge. Nevertheless, tidal influence could not be  
609 discarded, as these deposits were debouching into shallow marine areas. Moreover, the internal  
610 erosion surfaces observed within sandstone are interpreted to develop during periods of intense  
611 precipitation, which led to an increase of flow velocity and the erosion of the sediments of the  
612 channels, as similarly occurs in the multistorey fluvial channel architectural element. This  
613 process was followed by deposition of poorly sorted mudstone conglomerates eroded and  
614 transported from upstream flood plain areas, as well as of fragments of bivalves, which were  
615 transported from nearby shallow marine areas.

#### 616 *Distributary mouth-bar architectural element*

617           *Description.* This element occurs commonly interbedded with the coastal terminal  
618 distributary channel element and marl or with tidal limestone, including tidal sedimentary  
619 structures or with shallow marine limestone, which contains marine fossils, including locally  
620 corals in life position (Figs. 12A, 13A-F). It is made up of fine- to medium-grained sandstone  
621 commonly arranged in decimetre- to metre-thick bodies (from 10 cm to 2.50 m), which display  
622 flat bases and flat or convex-up tops, commonly show short lateral extent (<20 m; Figs. 12A,  
623 13A-D) and rare thickening- and coarsening-upwards trend (Fig. 13B). Sandstone may be  
624 massive or display large-scale cross strata, which may be sigmoidal (Fig. 13C-D), and rare

625 current and/or wave ripple strata at the top. Cross-bedded sandstone bodies pass seawards to  
626 centimetre-thick bodies displaying current and/or wave ripple strata at the top, which alternate  
627 with marl, giving rise to wavy bedding (Fig. 13G). Sandstone may include carbonate intraclasts,  
628 ooids, brackish and marine bioclasts (Fig. 13H, Table 1) and plant remains. In places, sandstone  
629 displays bioturbation at the top (Fig. 13I).

630 Palaeocurrents measured in the South-Iberian Basin indicate main transport directions to  
631 the E, and less commonly to the N and SE, and palaeocurrents measured in the western  
632 Maestrazgo Basin indicate main transport directions to the NE and E and less commonly to the  
633 N and S (Fig. 13A).

634 *Interpretation.* These sandstone bodies are interpreted as distributary mouth-bars (*sensu*  
635 Wright, 1977; Bhattacharya, 2010) that were formed by the dispersal of unconfined flows at the  
636 mouth of terminal distributary channels debouching into coastal to shallow marine areas (*e.g.*  
637 Roberts, 1998; DuMars, 2002; Bhattacharya, 2010; Li *et al.*, 2013; Allgöwer and Lignum,  
638 2019). This interpretation is supported by palaeocurrent data, indicating that sediment was  
639 mainly transported to the NE-SE (Fig. 13A), where the Tethys Ocean was located at the time  
640 (Fig. 1D). These sediments were deposited in shallow marine areas where even coral reefs  
641 developed (Fig. 13C-F). This has been similarly observed in some Upper Miocene deposits of  
642 SE Spain, interpreted as the result of distributary mouth-bars flowing into an interdistributary  
643 bay where coral reef patches developed (García-García *et al.*, 2006). Another example of this  
644 relationship is observed in the Indonesian Mahakam River Delta, although at a much larger  
645 scale, where large siliciclastic lobes of sediment are debouching into shallow marine areas  
646 where Halimeda bioherms are present (Storms *et al.*, 2005; Roberts and Sydow, 2010).

647 At the mouth of terminal distributary channels, sediment was deposited through the  
648 migration of subaqueous dunes and, progressively seawards, through the migration of ripples, as  
649 a consequence of the decrease of flow velocity. This is indicated by the occurrence of dm- to m-  
650 thick sandstone bodies displaying large-scale cross strata, which passes seawards to cm-thick

651 rippled sandstone bodies. The repeated arrival of sand at the distributary mouth would have  
652 produced the progradation of these unconfined sediment bodies, giving rise to the coarsening-  
653 and thickening upwards trend observed in this element. After deposition, these sediment bodies  
654 were prone to reworking by waves, as indicated by the occurrence of wave ripple strata at the  
655 top of sandstone and by tidal currents, as indicated by the occurrence of wavy bedding and the  
656 fact that these deposits occur interbedded with inter- to supratidal limestone including tidal  
657 sedimentary structures also indicates that they were deposited in a setting influenced by tides.  
658 Locally, these deposits were also reworked by storms, as interpreted by Campos-Soto *et al.*  
659 (2016a) in the Benagéber area (Fig. 1C).

### 660 **Aeolian depositional setting**

661 Aeolian deposits are observed in the SUP of the South-Iberian Basin, being more  
662 abundant in the landward sections (Figs. 2, 4), where they form up to 5% of the studied  
663 succession. They occur interbedded and laterally related with the fluvial and deltaic elements  
664 (Figs. 2, 4). Three types of architectural elements have been distinguished:

#### 665 *Simple aeolian dune architectural element*

666 *Description.* This element occurs interbedded with the flood plain element or locally  
667 overlies the ephemeral fluvial channel or deltaic elements (Figs. 2, 14). This element is  
668 composed of fine- to medium-grained, sub-angular to rounded and well-sorted sandstone, which  
669 is arranged in bodies up to 6 m thick (Fig. 14A-E, G-H), with flat bases and tops, and exposed  
670 lateral extents up to 100 m. Sandstone bodies characteristically comprise a single large-scale  
671 cross-stratified set up to 6 m-thick, whose foresets are inclined up to 36° (Fig. 14A-E). A  
672 distinctive feature of this element is that, in some sandstone bodies, foresets display a convex-  
673 up outline and pass upwards to low-angle inclined topsets (Fig. 14B-C). In detail, foreset  
674 deposits are made up of successive mm- to cm-thick stratal packages (Fig. 14F). Each stratum  
675 may show inverse grain size grading (from very fine to fine grain sizes at the bottom to medium  
676 grain sizes at the top, Fig. 14H). The contact between each stratum is sharp. Very rarely,

677 scattered rounded to subrounded muddy-soft pebbles and rounded quartzite pebbles (up to 1.4  
678 cm in diameter) have been observed but are confined exclusively to the lower part of foresets (in  
679 the lowermost 70 cm of sets). Palaeocurrents indicate transport directions towards the SE, W-  
680 SW, or the NW, depending on the sandstone body measured (Fig. 14A).

681 *Interpretation.* Features of this element, notably the well-sorted nature of the sandstone,  
682 the characteristic occurrence of very large-scale cross-stratified sets up to 6 m-thick with  
683 foresets inclined at angles up to 36°, its geometry (flat bases and tops) and exposed lateral extent  
684 of up to 100 m, lead most logically to the interpretation of migratory aeolian dunes (Ahlbrandt  
685 and Fryberger, 1982; McKee, 1966; Mountney, 2006).

686 The internal structure of foresets, made up of mm- to cm-thick strata displaying inverse  
687 grain size grading, is interpreted as the result of accumulation of grainflow deposits, as similarly  
688 reported from other ancient and modern aeolian dunes (McKee *et al.*, 1971; Hunter, 1977;  
689 Kocurek and Dott, 1981; Fryberger and Schenk, 1988), in which they are explained as the result  
690 of the repeated avalanching of sand in the lee side of dunes exceeding the angle of repose  
691 (Hunter, 1977; Ahlbrandt and Fryberger, 1982; Kocurek, 1991; Mountney, 2006).

692 Palaeocurrents indicate transport of sand towards the W-SW, the NW or the SE, depending on  
693 the sandstone body measured (Fig. 14A; see interpretation of wind palaeocurrents in  
694 Discussion). This suggests that aeolian dunes migrated under the influence of prevailing  
695 unidirectional winds, which is characteristic of transverse aeolian dunes (*sensu* Fryberger and  
696 Dean, 1979; Mountney 2006). The style of the cross strata observed in some bodies,  
697 characterized by convex-up foresets with preserved topsets, together with their vertical scale  
698 (Fig. 14B-C), is very similar to the features described in recent dome-shaped aeolian dunes by  
699 McKee (1966, 1979) in the White Sand National Monument (USA). According to this author,  
700 dome-shaped aeolian dunes initially begin as transverse or other type of dunes that are  
701 controlled by one dominant wind direction and are subsequently affected by episodes of strong  
702 winds. Therefore, the studied aeolian sandstone likely represents one of the few examples of  
703 well-preserved dome-shaped aeolian dunes in the pre-Quaternary fossil record; the few other

704 examples are those of the Proterozoic of Greenland (Clemmensen, 1988) and India  
705 (Chakraborty, 1991), the Devonian of Australia (Jones, 1972) and the Triassic of the Cheshire  
706 Basin, UK (Thompson, 1969). In addition, the fact that aeolian dune deposits of this element are  
707 formed by one single set of large-scale cross strata, suggests that they were formed under  
708 relatively low rates of sediment supply that merely allowed the migration, but not the climb, of  
709 one single transverse or dome-shaped aeolian dunes (Kocurek and Havholm, 1993; Mountney,  
710 2006).

711 Sandstone of this element is well sorted and made up of sub-angular to rounded grains.  
712 The occurrence of sub-angular (rarely even angular) grains has been identified in modern and  
713 ancient aeolian dune deposits (*e.g.* Kiersch, 1950; Thompson, 1969; Glennie, 1970; McKee,  
714 1979; Rodríguez-López *et al.*, 2008; Galán-Abellán *et al.*, 2013), and some authors have even  
715 reported aeolian dune deposits displaying moderate (Mountney *et al.*, 1998) to poor sorting  
716 (McKee, 1966; Ahlbrandt, 1979), due to the short time of reworking and the close proximity to  
717 the source of sand.

718 The occurrence of pebbles in the lower parts of aeolian dune sets has been described in  
719 ancient and modern aeolian deposits. Mader (1981) and Turner and Makhlof (2005) identified  
720 pebbles up to 1 cm long and chert pebbles up to 5 cm long along the foresets of Triassic and  
721 Quaternary aeolian dune deposits of Germany and Jordan, respectively. Kiersch (1950) reported  
722 small pebbles and coarse grains of quartz and chalcedony along several cross strata planes in the  
723 Jurassic Navajo Sandstone (Utah, USA). Rodríguez-López *et al.* (2010) identified scattered  
724 quartzite pebbles in the toesets of mid-Cretaceous aeolian dune deposits of Spain and  
725 interpreted them as derived from adjacent deflated wadis. These authors cite the work Glennie  
726 (1970), who reported pebbles in the foresets of small recent aeolian dune deposits and  
727 interpreted them as derived from an adjacent wadi bank by rolling or sliding. Additionally,  
728 pebbles of up to 1.5 cm and 2.3 cm in diameter have been recorded lodged in telephone poles at  
729 1.6 m and 0.8 m heights, respectively; these were interpreted as having been transported by  
730 saltation during an intense windstorm in California, USA (Sakamoto-Arnold, 1981).

731 *Massive and indistinctly stratified aeolian dune architectural element*

732 *Description.* This element overlies the flood plain element and is overlain by the  
733 multistorey fluvial channel element (Fig. 15A-C). This element may occur interbedded with  
734 ephemeral fluvial channelized conglomerate bodies, which display 90 cm- to 3 m of thickness  
735 and up to 20 m of lateral extent (Fig. 15C-D; see ephemeral fluvial channel architectural  
736 element).

737 This element is made up of fine- to medium-grained, sub-angular to rounded, well-  
738 sorted sandstone arranged in up to 25 m-thick bodies, displaying flat bases and tops and an  
739 exposed lateral extent of up to 80 m (Fig. 15B-E). Sandstone mostly shows a massive  
740 appearance, although locally displays poorly preserved large-scale cross strata with sets of up to  
741 7 m-thick (Fig. 15C-D), and with foresets inclined up to 30° (Fig. 15D, G-H). In some cross  
742 stratified sets, foresets pass downwards to laterally continuous bottomsets (Fig. 15B, E, G-H).  
743 Locally, the bottomsets and, less commonly, the lowermost part of foresets are draped by mm-  
744 to cm-thick layers of carbonaceous detritus and mica flakes (Fig. 15G-H). Palaeocurrents  
745 indicate main transport directions to the W-NW and, in minor proportion, to the SW (Fig. 15A).

746 *Interpretation.* The homogeneous and well-sorted sandstone of this element, together  
747 with its massive appearance, its large thickness (up to 25 m-thick), its flat base and great  
748 exposed lateral extent (up to 80 m), suggest an aeolian origin. The homogeneity of grain size  
749 and the good sorting are features typically described in aeolian deposits, such as in the Lower  
750 Jurassic Navajo Sandstone (*e.g.* Kiersch, 1950; Prothero and Schab, 1996; McKee, 1979),  
751 which, in places, characteristically exhibits a massive appearance (*e.g.* Ekdale *et al.*, 2007).  
752 Moreover, the occurrence of poorly preserved, large-scale cross strata with sets of up to 7 m  
753 thick, displaying foresets inclined up to 30°, further supports an aeolian dune origin.  
754 Palaeocurrents indicate aeolian dune migration to the NW-SW (Fig. 15A; see more details of  
755 wind palaeocurrents in Discussion).

756           The drapes of carbonaceous detritus and mica flakes locally observed in the bottomsets  
757 and in the lowermost part of foresets are interpreted to have settled from suspension in wet  
758 interdunes subject to episodic floods (Ahlbrandt and Fryberger, 1981; 1982; Mountney, 2006).  
759 The occurrence of drapes in the lower part of the foresets indicates that the water level reached  
760 the lower part of aeolian dune flanks, and likely fluctuated. A similar process has been reported  
761 in the Great Sand Dunes (USA) and in the Namib Desert (Skeleton Coast), where episodic  
762 fluvial floods cause the inundation of interdune areas, where clays and/or wood detritus settle  
763 down and drape the interdune floor and the lower part of dune flanks (Langford, 1989 and  
764 Stanistreet and Stollhofen, 2002, respectively). Repeated interdune flooding and aeolian dune  
765 migration produced the successive interfingering of drapes and grainflows within the same cross  
766 strata set (Langford and Chan, 1989; Langford, 1989; Cain and Mountney, 2011). This type of  
767 draping (*i.e.* mud layers, carbonaceous/wood detritus and mica flakes) has been reported in  
768 other ancient (*e.g.* Thompson, 1969; Gradziński *et al.*, 1979; Pulvertaft, 1985; Langford and  
769 Chan, 1988; Veiga and Spalletti, 2007; Rodríguez-López *et al.*, 2008, 2012) and modern aeolian  
770 dune deposits (*e.g.* Ahlbrandt and Fryberger, 1981; Fryberger *et al.*, 1990; García-Hidalgo *et*  
771 *al.*, 2002; Mountney and Russell, 2006; 2009; Kocurek *et al.*, 2020).

772           The occurrence of ephemeral fluvial deposits interbedded with massive and indistinctly  
773 stratified aeolian dune deposits (Fig. 15C-D) is interpreted as the result of development of  
774 ephemeral channels between aeolian dunes during periods of intense precipitation, which would  
775 have led to the erosion of aeolian dune deposits. This type of fluvial-aeolian interaction has  
776 similarly been documented in other arid to semiarid modern (*e.g.* Glennie, 1970; Al-Masrahy  
777 and Mountney, 2015) and ancient settings (*e.g.* Herries, 1992; de Witt, 1999; Mountney *et al.*,  
778 1998; Veiga *et al.*, 2002; Mountney and Jagger, 2004; Jordan and Mountney, 2010, 2012;  
779 Rodríguez-López *et al.*, 2010; 2014 and references therein; Soria *et al.*, 2011; Tripaldi *et al.*,  
780 2011), as a result of development of wadis between aeolian dunes during flash-flood events. In  
781 the studied succession, aeolian dune deposits overlie those of ephemeral fluvial channels,  
782 indicating that, once the flood episode had finished, aeolian dunes would have migrated over the

783 deposits of the once-again dry ephemeral channels, a process that similarly occurs in modern  
784 desert settings (Al-Masrahy and Mountney, 2015; Liu and Coulthard, 2015).

785 *Climbing aeolian dune architectural element*

786 *Description.* This element is interbedded with the deltaic and fluvial channel elements,  
787 and is overlain by the flood plain element (Figs. 4, 16). It comprises sub-angular to rounded,  
788 fine- to medium-grained, well-sorted sandstone, which is arranged in metre-thick bodies (up to  
789 5 m-thick) with an exposed lateral extent of around 100 m (Fig. 16A-D). Sandstone displays  
790 large-scale cross strata with sets up to 2 m-thick (Fig. 16B), which are stacked in cosets (Fig.  
791 16C-D). A characteristic feature of this element is the occurrence of bounding surfaces  
792 delimiting individual sets of cross strata, which are inclined at low angles ( $<10^\circ$ ) relative to the  
793 master coset bedding surface and dip in the opposite direction to the foreset dip (Fig. 16C-D). In  
794 some outcrops parallel to transport direction, these surfaces can be laterally traced at least for 50  
795 m. Large-scale cross strata comprises tangential foresets inclined at angles up to  $32^\circ$  (Fig. 16B-  
796 E), which occasionally are slightly deformed (Fig. 16E). In detail, foreset deposits comprise  
797 mm- to cm-thick strata, made up of fine- to medium-grained well-sorted sandstone, which pinch  
798 out towards the bottomsets (Fig. 16F-H). Towards the bottomsets, these strata are interbedded  
799 with other mm- to cm-thick strata comprised of very fine- to fine-grained and well-sorted  
800 sandstone, which pinch out upwards (Fig. 16G-H).

801 Pseudomorphs after gypsum crystals, forming desert roses (Fig. 16I), have been locally  
802 observed within the sandstone. Additionally, very scattered subrounded muddy pebbles and  
803 rounded quartzite pebbles (up to 1.5 cm in diameter) are locally observed towards the lower part  
804 of sandstone bodies that overlie fluvial channelized elements, similarly to those described in the  
805 simple aeolian dune architectural element. These pebbles mostly occur along the tangential  
806 foresets, preferentially towards the bottomsets.

807 Palaeocurrents measured in the tangential cross strata sets indicate main transport  
808 directions towards the SE in some sandstone bodies and towards the NW in other sandstone  
809 bodies located in different stratigraphic positions (Fig. 16A).

810 *Interpretation.* Features of these deposits, such as the well-sorted grain texture, the  
811 occurrence of large-scale cross strata sets comprising tangential foresets, which might be locally  
812 slightly deformed, and the occurrence of low-angle inclined bounding surfaces delimiting sets  
813 of cross strata, indicate that this element records the downwind migration and accumulation of  
814 aeolian dunes, as has been similarly described in other ancient aeolian dune deposits (*e.g.*  
815 Kocurek, 1981; Ahlbrant and Fryberger, 1982; Spalletti and Colombo Piñol, 2005; Scherer and  
816 Lavina, 2005; Mountney, 2006; Spalletti *et al.*, 2010).

817 The internal structure of tangential cross strata sandstone, comprising mm- to cm-thick  
818 strata pinching out downwards, is very similar to the sandflow cross strata described by Hunter  
819 (1977) in modern aeolian dunes (here referred to as grainflow cross strata *sensu* Kocurek and  
820 Dott, 1981, and Kocurek, 1991, 1996), which develop due to the successive avalanching of sand  
821 in aeolian dune slipfaces. The very fine- to fine-grained sandstone strata located at the  
822 bottomsets pinching out upwards are interpreted as wind ripples that migrated over the plinth of  
823 aeolian dunes and dry interdunes (Hunter, 1977; Ahlbrant and Fryberger, 1982; Kocurek, 1991).  
824 The occurrence of slightly deformed foresets is interpreted as the result of slumping of cohesive,  
825 semi-consolidated sand in the lee side of dunes wetted by rains or dews (*e.g.* McKee *et al.*,  
826 1971; Due and Dott, 1980; Loope *et al.*, 2001). Similarly to what occurs in the simple aeolian  
827 dune architectural element, palaeocurrents show a unidirectional transport pattern for each  
828 sandstone body measured in different stratigraphic positions, indicating aeolian dune migration  
829 to the SE for some bodies or the NW for others (Fig. 16A; see interpretation of wind  
830 palaeocurrents in Discussion) and suggesting that deposition occurred in transverse aeolian  
831 dunes (*sensu* Fryberger and Dean, 1979; Mountney 2006).

832           The low-angle-inclined bounding surfaces that delimit individual sets of cross strata are  
833 very similar to the interdune surfaces defined by Kocurek (1981, 1996) and described in many  
834 ancient aeolian deposits (*e.g.* Mountney and Thompson, 2002; Scherer and Lavina, 2005;  
835 Mountney and Jagger, 2004; Rodríguez-López *et al.*, 2008; Bállico *et al.*, 2017). Interdune  
836 surfaces result from the downwind migration of an interdune trough over the stoss side of the  
837 preceding aeolian dune, producing the partial erosion and truncation of its upper part (Rubin and  
838 Hunter, 1982; Kocurek, 1981; 1991; 1996; Mountney, 2006). Climbing transverse aeolian dune  
839 bedforms migrated over these surfaces, as they are overlain by tangential cross strata sandstone.  
840 The fact that these deposits were formed by the accumulation of climbing aeolian bedforms  
841 indicates that the sediment supply during their deposition was high (Kocurek and Havholm,  
842 1993; Mountney, 2006).

843           The occurrence of pseudomorphs after gypsum crystals, forming desert roses, similar to  
844 those locally observed within this element, have been reported in other aeolian deposits (*e.g.*  
845 Loope, 1988; Simpson and Erikson, 1993; Tripaldi *et al.*, 2011; Rodríguez-López *et al.*, 2013)  
846 and are interpreted as intrasediment gypsum crystals that grew in the pore spaces of aeolian  
847 sand located close to the water table (Warren, 2016).

## 848 **DISCUSSION**

### 849 **Palaeoenvironmental setting of eastern Iberia during the Late Jurassic**

850           Siliciclastic sediments of the Villar del Arzobispo Fm were deposited in fluvial, deltaic,  
851 aeolian and coastal to shallow marine depositional environments that developed in eastern Iberia  
852 during the Late Jurassic (Figs. 1D, 17). These deposits are interbedded and laterally related with  
853 each other and possess stratal relationships to indicate that they developed coevally (Figs. 2, 3,  
854 4, 5, 17 and Fig. S1 of Supplementary Material). During the first steps of evolution of the  
855 studied succession (during sedimentation of the CLP), deposition of siliciclastic sediments was  
856 scarce and mainly occurred in coastal to shallow marine marly and carbonate areas (Figs. 2, 3;  
857 Campos-Soto *et al.*, 2016a, 2017a, 2019). Upwards, during sedimentation of the SUP, a large

858 abundance of siliciclastic sediments was deposited in a coastal and alluvial plain (Figs. 2, 3, 17;  
859 Campos-Soto *et al.*, 2016a, 2017a, 2019 Campos-Soto *et al.*, 2016a, 2017a, 2019). Landwards,  
860 deposition mainly took place in fluvial, deltaic and aeolian environments that were laterally and  
861 vertically related (Figs. 3, 4, 17), while seawards, it progressively occurred in coastal to shallow  
862 marine environments located in areas with high subsidence rates, where siliciclastics are  
863 interbedded to the E-SE with shallow water marl, with inter- to supratidal peloidal and/or  
864 micritic limestone and with shallow marine bioclastic and oolitic limestone (Figs. 2, 3, 5, 17 and  
865 Fig. S1 of Supplementary Material; Campos-Soto *et al.*, 2016a, 2017a, 2019).

866         The coastal and alluvial plain was formed by broad and vegetated flood plains (see  
867 Flood plain architectural element), which were crossed by ephemeral and perennial to semi-  
868 perennial fluvial channels that had a highly seasonal discharge (see Ephemeral and Multi-storey  
869 fluvial channel architectural elements, respectively; Fig. 17). During flood events, flood plain  
870 areas underwent deposition of splay lobes as a result of the breaking of channel levees (see  
871 Flood plain architectural element). Fluvial channels flowed into shallow water bodies located in  
872 the flood plain that were probably freshwater, leading to deposition of small deltas (see Deltaic  
873 architectural elements). Some fluvial channels ultimately flowed into coastal to shallow marine  
874 areas (see Coastal terminal distributary channel architectural element), resulting in the  
875 deposition of distributary mouth-bars (see Distributary mouth-bar architectural element; Figs. 5,  
876 17). Some of the shallow water bodies located in the flood plain underwent carbonate  
877 precipitation and development of oncoids and stromatolites (see Flood plain architectural  
878 element). Some of these water bodies were influenced by freshwater and received siliciclastic  
879 input, as limestone includes abundant quartz grains and locally charophytes. Other water bodies  
880 were also influenced by brackish and marine waters, as limestone locally includes brackish and  
881 marine fossils that were probably transported from shallow marine areas by storms and/or  
882 spring tides (see Flood plain architectural element; Fig. 17).

883         During periods of non-flood discharges, subaqueous siliciclastic deposits likely  
884 underwent periods of subaerial exposure. Subsequently, sand of these deposits was reworked by

885 wind and deposited in aeolian dunes that migrated over the coastal and alluvial plain, as  
886 reported in modern (*e.g.* Glennie, 1970; Langford, 1989; Singh *et al.*, 1993; Collinson, 1996)  
887 and ancient settings (*e.g.* Thompson, 1969; Mountney *et al.*, 1998). Aeolian dunes developed  
888 next to deltas and eventually migrated over their deltaic plain, as evidenced by the occurrence of  
889 aeolian deposits overlying the deltaic elements (Figs. 2, 4, 10A, 16C-D, 17). Aeolian dunes  
890 could also migrate over deposits of fluvial channels that became subaerially exposed during  
891 periods of non-flood discharges, as indicated by the occurrence of aeolian dune deposits  
892 overlying fluvial channel sediments (Figs. 4, 15C-D). Aeolian deposits are only preserved in the  
893 landward sections of the South-Iberian Basin (Riodeva and Benagéber sections; Figs. 1C-D, 2,  
894 4), which contain a greater proportion of subaqueous siliciclastic deposits than sections of the  
895 western Maestrazgo Basin. The South-Iberian Basin was largely surrounded by emergent areas  
896 (Iberian and Valencian massifs), whereas the western Maestrazgo Basin only had emergent  
897 areas towards the SW (Fig. 1D). In this way, the South-Iberian Basin received greater input of  
898 siliciclastic detritus. Subaerial exposure was common, and deposits were repeatedly reworked  
899 by the wind. In contrast, broader coastal plains developed in the western Maestrazgo Basin and  
900 received relatively less siliciclastic input.

901 Palaeocurrents of the aeolian dune deposits indicate predominant wind transport  
902 directions to the W (ranging between NW-SW) and rarely to the SE (Figs. 14A, 15A, 16A).  
903 This is based on the interpretation of perfectly transverse dune types migrating under the  
904 influence of a unidirectional wind (*cf.* Rubin, 1987). Palaeocurrents pointing to the W (NW-  
905 SW) are in agreement with palaeowind directions shown in the palaeogeographic models of  
906 eastern Iberia during the Late Jurassic (Fig. 1D), which interpret winds approaching eastern  
907 Iberia from the E and S (from the Tethys Ocean; Fig. 1D) during the winter and summer,  
908 respectively (Sellwood and Valdes, 2008), as well as hurricanes and storms also coming from  
909 the Tethys Ocean (Marsaglia and Klein, 1983). Winds approaching the South-Iberian Basin  
910 from the Tethys Ocean might have been deflected by the surrounding Iberian and Valencian  
911 massifs, resulting in them blowing parallel to the NW-SE oriented Valencian Massif, thereby

912 producing winds blowing to the SE in the basin and, thus, leading to the migration of aeolian  
913 dunes to the SE. This similarly occurs in some present-day mountain ranges, which act as  
914 barriers to prevailing wind currents, causing their deflection, so they blow parallel to the trend  
915 of the mountain ranges (*e.g.* O'Connor *et al.*, 1994; McCauley and Sturman, 1999; Neiman *et*  
916 *al.*, 2010). Moreover, other investigations interpret that winds also approached Iberia from the N  
917 (from the Boreal realm; Fig. 1D) during the Kimmeridgian (Benito *et al.*, 2005). These  
918 northerly winds could have penetrated along the Iberian Basin and increased their velocity, as a  
919 consequence of its southwards narrowing (Fig. 1D), leading to the occurrence of south-  
920 eastwards winds in the SE Iberian Basin.

### 921 **Deciphering the palaeoclimate of eastern Iberia during the Late Jurassic**

922 Palaeoclimatic and palaeogeographic reconstructions for the Late Jurassic show that  
923 Iberia was located in the subtropics (Fig. 1D) and that its climate was warm (Valdes, 1993;  
924 Valdes and Sellwood, 1992), seasonal (Rees *et al.*, 2000; Diéguez *et al.*, 2010) and subject to  
925 seasonal rainfalls (Valdes and Sellwood, 1992) and hurricanes coming from the Tethys Ocean  
926 (Marsaglia and Klein, 1983). Models also show a trend of increasing aridity during the Late  
927 Jurassic (Hallam, 1984, 1985; Hallam *et al.*, 1993). However, recent studies place the limit  
928 between the arid and the tropical-subtropical belts at the eastern margin of Iberia, from where  
929 more humid conditions prevailed (Sellwood and Valdes, 2008; Boucot *et al.*, 2013). In this  
930 context, the fact that the siliciclastic sediments of the studied succession include coeval deposits  
931 that are common of both arid to semiarid and humid to subhumid settings makes it difficult to  
932 discern the specific palaeoclimatic setting that prevailed during deposition.

933 The studied succession includes ephemeral fluvial channels and aeolian dune deposits,  
934 locally containing desert roses, which are features commonly linked to arid to semiarid settings  
935 (*e.g.* Tucker and Benton, 1982; Holz and Scherer, 2000; Spalletti and Colombo Piñol, 2005;  
936 Boucot *et al.*, 2013; Priddy and Clarke, 2020). In fact, the fluvial-aeolian interactions recorded  
937 in the studied deposits, such as the development of ephemeral fluvial channels between aeolian

938 dunes and the presence of standing water bodies in interdunes during periods of rainfalls, are  
939 similar to those reported in many present-day and ancient arid to semiarid environments (*e.g.*  
940 Glennie, 1970; Langford, 1989; Stanistreet and Stollhofen, 2002; Veiga *et al.*, 2002; Veiga and  
941 Spalletti, 2007; Rodríguez-López *et al.*, 2014 and references therein; Al-Masrahy and  
942 Mountney, 2015; Liu and Coulthard, 2015; Kocurek *et al.*, 2020; see Massive and indistinctly  
943 stratified aeolian dune architectural element; Fig. 15). Nevertheless, similar fluvial-aeolian  
944 interactions can also occur in humid to subhumid climates in present-day settings (*e.g.*  
945 Mountney and Russell, 2009; Al-Masrahy and Mountney, 2015; dos Santos and dos Santos,  
946 2015). Aeolian dunes, accumulated through the process of bedform climbing, have been widely  
947 documented in many ancient examples developed in arid to semiarid settings (*e.g.* Kocurek,  
948 1981; Clemmensen, 1989; Mountney *et al.*, 1999; Mountney and Thompson, 2002), but they  
949 also occur nowadays in modern humid to subhumid climates, such as in the coastal plains of  
950 Oregon (USA; Cooper, 1958; Hunter *et al.*, 1983; Peterson *et al.*, 2007). In these coastal plains  
951 of Oregon, aeolian dune fields of relatively modest size (from 7 to 15 km<sup>2</sup> approximately)  
952 develop next to coastal lakes and vegetated areas, which are crossed by rivers (Cooper, 1958;  
953 Hunter *et al.*, 1983; Peterson *et al.*, 2007). These aeolian dunes develop in areas with high  
954 sediment supply, where aeolian sand comes from wind reworking of a local source of subaerial  
955 exposed sand; this is similar to the interpreted setting for the climbing aeolian dune deposits of  
956 the studied succession. In the case of the coastal aeolian dunes of Oregon, aeolian sand comes  
957 predominantly from the reworking of sandy beach sediments (Peterson *et al.*, 2007), whereas in  
958 the case of the Late Jurassic succession it was predominantly derived from the sandy fluvial and  
959 deltaic sediments that underwent subaerial exposure after periods seasonal rainfalls (see  
960 Palaeoenvironmental setting of eastern Iberia during the Late Jurassic).

961         The studied unit also includes abundant deposits indicative of permanent water courses  
962 that occur laterally and vertically related with those of the aeolian and ephemeral fluvial  
963 channels (Figs. 2, 4). Some of them correspond to those deposited in perennial to semi-perennial  
964 fluvial channels that had a seasonal discharge. Variable discharge rivers nowadays occur in

965 areas controlled by monsoonal-type precipitation (*e.g.* Fielding *et al.*, 2011; Plink-Björklund,  
966 2015), which is coherent with the interpretation of common development of seasonal storms and  
967 hurricanes in Iberia during the Late Jurassic (Marsaglia and Klein, 1983; Valdes and Sellwood,  
968 1992). In present-day settings, seasonal rivers transmit a perennial discharge in monsoonal  
969 domains, whereas in subtropical arid to semiarid settings they typically only transmit flow  
970 during the monsoonal season and could even be dry the rest of time, unless their catchment area  
971 is located in the monsoonal domain (*e.g.* Nile River; Plink-Björklund, 2015). Other deposits  
972 indicative of permanent water courses correspond to the deltaic sediments, which were  
973 deposited in permanent to semi-permanent water bodies, as well as the abundant vegetation.  
974 Although vegetation can locally develop in arid to semiarid settings in low-lying areas with a  
975 high water table, the occurrence of plant remains (carbonaceous detritus, fragments of fossil  
976 trunks and other remains) and/or edaphic features occurs widespread in all the studied deposits  
977 (fluvial channels, distributary mouth-bars, deltaic, flood plain, splay lobes, wet interdunes of the  
978 Massive and indistinctly stratified aeolian element) in both basins (Fig. 2; Table 1).  
979 Furthermore, the studied deposits include a great abundance of dinosaur remains and,  
980 especially, of herbivorous dinosaurs (sauropods, stegosaurs and scarce ornithopods; *e.g.*  
981 Casanovas-Cladellas *et al.*, 1999, 2001; Cobos *et al.*, 2010, 2020; Royo-Torres *et al.*, 2006,  
982 2009, 2020; Alcalá *et al.*, 2009, 2018; Company *et al.*, 2010; Suñer *et al.*, 2014). These  
983 observations reinforce the interpretation of a setting with availability of abundant vegetation and  
984 permanent freshwater sources. Therefore, collectively these features indicate a more humid and  
985 seasonal setting that was controlled by monsoonal-type precipitation during deposition of the  
986 studied succession. This interpretation is coherent with that recently made for the coeval Late  
987 Jurassic Lourinhã Fm in Portugal, which points to a warm subhumid climate with a strongly  
988 seasonal precipitation pattern (Myers *et al.*, 2012).

#### 989 **Comparison with modern analogous systems**

990 A modern coastal setting that includes a wide variety of depositional subenvironments  
991 characteristic of arid to semiarid and humid to subhumid settings, similarly to what occurs in the

992 Villar del Arzobispo Fm, is developed in the Lençóis Maranhenses National Park in NE Brazil  
993 (Fig. 18). It comprises an aeolian dune field located next to an estuary (Fig. 18A), where flood  
994 plains, intermittent interdune ponds, perennial and ephemeral rivers, tidal plains (*e.g.* Gonçalves  
995 *et al.*, 2003; Parteli *et al.*, 2006; dos Santos and dos Santos, 2015; Ielpi, 2017) and deltas  
996 develop. This system forms in a tropical subhumid climate in which 90% of annual rainfall  
997 occurs during the wet season (Parteli *et al.*, 2006; dos Santos and dos Santos, 2015). During  
998 seasonal rainfalls, interdune ponds are flooded by rainwater or by the upwelling of groundwater  
999 (dos Santos and dos Santos, 2015), giving rise to standing water bodies in the interdunes areas  
1000 (Fig. 18B), as similarly interpreted for the studied aeolian deposits (see Massive and indistinctly  
1001 stratified aeolian dune architectural element). In Lençóis Maranhenses, sand of aeolian dunes  
1002 developing next to tidal channels is reworked by tides (Fig. 18C). This process cannot be  
1003 discarded in the studied deposits, as aeolian interdunes might have been flooded by storms  
1004 and/or spring tides, since they developed in a coastal setting.

1005 In Lençóis Maranhenses, semi-perennial rivers cross the flood plain areas and flow into  
1006 shallow water bodies where deltaic sediments are deposited (Fig. 18D), as similarly interpreted  
1007 for the studied deposits (see Deltaic architectural elements). In this system, rivers also transect  
1008 the aeolian dune field (Fig. 18E-G; Ielpi, 2017). In some cases, rivers erode aeolian dune flanks  
1009 (Fig. 18F) and, in other cases, aeolian dunes migrate over fluvial channels that are dried out or  
1010 transmit a very low discharge (Fig. 18G), as similarly interpreted for the studied succession (see  
1011 Massive and indistinctly stratified aeolian dune architectural element). Furthermore, in Lençóis  
1012 Maranhenses, aeolian dunes migrate over small shallow deltas (Fig. 18E, H-I). Similarly, the  
1013 studied fossil aeolian dunes locally overlie deltaic deposits (Figs. 4, 10A, 16C-D), indicating  
1014 that aeolian dunes developed next to a delta and migrated over the deltaic plain. In Lençóis  
1015 Maranhenses, aeolian dunes are reworked by distributary channels (Fig. 18I). A similar process  
1016 would explain the generally well-sorted texture of sandstone deposited in the delta terminal  
1017 distributary channels and the delta fronts of the studied deposits (Fig. 11F).

1018           Nevertheless, although the Late Jurassic and the Brazilian systems have numerous  
1019 similarities, they also show differences regarding their geotectonic setting, which influence the  
1020 sedimentary features of their fluvial deposits. The presently active Brazilian system is  
1021 developed in a stable tectonic setting. By contrast, the Late Jurassic succession was deposited in  
1022 a tectonically-active extensional basin, which would have led to the development of steeper  
1023 topographic gradients. This would have favoured the incision of streams, as occurs in nowadays  
1024 tectonically-active settings (*e.g.* Bull, 2007; Allen and Allen, 2013), which could transport very  
1025 poorly sorted conglomerates displaying clasts of large sizes and subangular shapes and deposit  
1026 them in the ephemeral and perennial to semi-perennial fluvial channels during periods of intense  
1027 rainfalls (Figs. 1D, 2, 17), as those observed in the studied succession. Another difference is  
1028 that, in the Late Jurassic system, aeolian dunes did not form an extensive dune field like in  
1029 Lençóis Maranhenses. The ancient system was likely similar to the transition zone located  
1030 between the tidal flats of the estuary and the aeolian field of the Brazilian analogue (Fig. 18A).  
1031 Aeolian dunes were apparently more abundant towards the landward areas of the South-Iberian  
1032 Basin (Fig. 1D).

1033           Moreover, the studied succession locally includes desert roses in the aeolian deposits  
1034 (see Climbing aeolian dune architectural element), which, to our knowledge, have not been  
1035 reported in the Brazilian aeolian dunes. Nevertheless, although the occurrence of evaporites has  
1036 traditionally been linked to arid or semiarid settings (*e.g.* Hallam, 1984; Warren, 2016), they  
1037 have also been locally identified in humid (see Argentinean Rio de la Plata estuary in Carol *et*  
1038 *al.*, 2016) and subhumid settings (see Australian Burdekin River Delta in Fielding *et al.*, 2006).

1039           Thus, the comparison made between deposits of the Villar del Arzobispo Fm and those  
1040 of present-day settings highlights that deposits that characteristically develop under the  
1041 influence of contrasting climate regimes (arid and humid) could appear laterally and vertically  
1042 interbedded in the fossil record as a result of deposition in intermediate climates. This study  
1043 highlights the importance of carrying out a careful and thorough sedimentological analysis  
1044 when interpreting the palaeoclimatic significance of ancient successions, taking into account all

1045 available evidence from deposits that represent multiple coeval sub-environments in the rock  
1046 record.

## 1047 **CONCLUSIONS**

1048 This work presents the sedimentological analysis of the siliciclastic deposits of the Late  
1049 Jurassic Villar del Arzobispo Fm cropping out in the South-Iberian and western Maestrazgo  
1050 basins. Detailed lithofacies analysis has enabled establishment of the palaeoenvironmental,  
1051 palaeogeographical and palaeoclimatic setting of eastern Iberia during the Late Jurassic.

1052 The siliciclastic studied succession was deposited in a coastal and alluvial plain crossed  
1053 by ephemeral and perennial to semi-perennial fluvial channels that had a seasonal discharge and  
1054 underwent deposition of splay lobes during flood events. Fluvial channels flowed into shallow  
1055 freshwater bodies located in the flood plain, leading to the accumulation of small deltas.  
1056 Seawards, fluvial channels bifurcated in distributary channels, which flowed into coastal and  
1057 shallow marine areas, leading to the development of distributary mouth-bars. Some water  
1058 bodies located in the flood plain were connected to the sea, allowing transport of brackish and  
1059 marine bioclasts from shallow marine areas during storms and/or spring tides. Siliciclastic  
1060 sediments underwent periods of subaerial exposure, causing the wind-reworking of sand to form  
1061 aeolian dunes; this led to the preservation of one of the few known examples of dome-shaped  
1062 aeolian dunes in the fossil record. The coastal and alluvial plain was laterally connected to the  
1063 E-SE to tidal flats and shallow marine areas, which underwent deposition of peloidal and/or  
1064 micritic limestone and bioclastic and/or oolitic limestone, respectively.

1065 The studied coastal and alluvial succession includes deposits that are typical of arid to  
1066 semiarid settings, such as aeolian dunes and ephemeral channel deposits. However, the coeval  
1067 occurrence of deposits indicative of permanent water courses, such as perennial to semi-  
1068 perennial fluvial channel deposits and deltaic sediments deposited in permanent water bodies, as  
1069 well as abundant plant remains and large dinosaur faunas, suggests a more humid and seasonal  
1070 setting controlled by monsoonal-type precipitation.

1071 A comparison performed between these Late Jurassic deposits and those developing  
1072 nowadays in the Lençóis Maranhenses National Park (NE Brazil) – a coastal system located in a  
1073 subhumid tropical setting with a seasonal precipitation pattern that includes very similar aeolian,  
1074 fluvial and deltaic environments to those interpreted in the studied succession – has revealed  
1075 that deposits characteristic of contrasting climate regimes (arid and humid) could be laterally  
1076 and vertically related in ancient successions as a result of deposition in complex coevally active  
1077 coastal environments present in intermediate climates.

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#### 1091 **DATA AVAILABILITY STATEMENT**

1092 The data that support the findings of this study are available from the corresponding  
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#### 1786 **FIGURE CAPTIONS**

1787 **Fig. 1.** A) Simplified geological map of the Iberian Peninsula indicating the location of the  
1788 South-Iberian and Maestrazgo basins within the Mesozoic Iberian Extensional System  
1789 (modified from Mas *et al.*, 2004). The red square indicates the location of the map shown in Fig.  
1790 1B. B) Geological map of eastern Spain showing the limits of the deposits of the Maestrazgo  
1791 Basin and its sub-basins -sb- (modified from Salas and Guimerà, 1996, 1997, Salas *et al.*, 2001;  
1792 Bover-Arnal and Salas, 2019) and the South-Iberian Basin. The geological information of this  
1793 map was obtained and modified from the geological map of the Iberian Peninsula and the  
1794 Balearic and Canary Islands (1995 edition, scale 1:1.000.000, Caride de Liñan, 1995). C)  
1795 Geological map of the study area of the South-Iberian and the western Maestrazgo basins  
1796 (modified from Campos-Soto *et al.*, 2019), showing the location of the stratigraphic sections,  
1797 the main areas where additional outcrops have been studied for this work (for more details on  
1798 the additional studied outcrops see Campos Soto, 2020) and the panels shown in Figs. 4 and 5.  
1799 The geological data were obtained and modified from the geological map Z1700 of the  
1800 Geological Spanish Survey (GEODE, scale 1:50.000; López-Olmedo *et al.*, 2018). D)  
1801 Palaeogeographic reconstruction of eastern and northern Iberia during the Tithonian, to the left  
1802 (palaeogeography and palaeocurrents obtained and modified from Thierry *et al.*, 2000 and  
1803 Campos-Soto *et al.*, 2019 and references therein). To the right detailed palaeogeography of the  
1804 South-Iberian and western Maestrazgo basins (data obtained and modified from Campos-Soto *et*  
1805 *al.*, 2019). The line that represents the 30°N latitude in the palaeogeographic reconstruction of

1806 eastern and northern Iberia has been modified according to data published by Sellwood and  
1807 Valdes (2008) and Boucot *et al.* (2013). Tracks of hurricanes and storms for the Late Jurassic  
1808 are based on Marsaglia and Klein (1983) and wind tracks blowing from the Tethys and the  
1809 Boreal realms are based on Sellwood and Valdes (2008) and Benito *et al.* (2005), respectively.  
1810 Palaeocurrents obtained in this work from the subaquatic and aeolian deposits in the different  
1811 studied areas of both basins have been represented in the palaeogeographic map with blue and  
1812 orange arrows, respectively. The length of the arrows corresponds to the abundance of  
1813 measurements. The palaeogeographic reconstruction of the South-Iberian and the western  
1814 Maestrazgo Basin, to the right, shows the location of the specific areas studied here: CE  
1815 (Cedrillas), CAS (El Castellar), FA (Formiche Alto) and MO (Mora de Rubielos) in the western  
1816 Maestrazgo Basin, and RI (Riodeva), LO-AL (Losilla-Alpuente), BE (Benagéber) and VI  
1817 (Villar del Arzobispo) in the South-Iberian Basin.

1818 **Fig. 2.** Stratigraphic sections of the Villar del Arzobispo Fm logged in the western Maestrazgo  
1819 (Cedrillas, El Castellar, Formiche Alto and Mora de Rubielos) and in the South-Iberian basins  
1820 (Riodeva, Losilla-Alpuente, Benagéber and Villar del Arzobispo). Modified from Campos-Soto  
1821 *et al.* (2019). This figure also includes a simplified map showing the location of the sections at  
1822 the studied areas (see also Fig. 1C). All the sections show, at their right part, the main  
1823 sedimentary structures and paleontological data, including the dinosaur remains (for more  
1824 information on dinosaur fossil sites see Figs. 2 and 3 of Campos-Soto *et al.*, 2017a and Fig. 3A  
1825 of Campos-Soto *et al.*, 2019). The Losilla-Alpuente section also shows, at its right part, some  
1826 partial stratigraphic sections logged in laterally related outcrops.

1827 **Fig. 3.** A) Diagrams showing the different stages of system evolution during sedimentation of  
1828 the Villar del Arzobispo Fm. These stages comprise: i) the deposition of shallow marine  
1829 deposits of the CLP during the Kimmeridgian; ii) deposition of the essentially siliciclastic  
1830 deposits of the SUP during a regressive stage during the Kimmeridgian-Tithonian; during this  
1831 stage, fluvial, aeolian and deltaic depositional settings mainly developed landwards; these  
1832 settings passed gradually seawards to coastal to shallow marine settings; iii) deposition of the

1833 upper part of the SUP during the Tithonian marine transgression. The reconstruction of the  
1834 different stages of evolution is based on the data obtained from the stratigraphic sections (Fig.  
1835 2), the geological mapping (see Fig. 1C and Fig. S1 of Supplementary Material), and the ages  
1836 obtained through the analysis of the larger benthic foraminifera (see Campos-Soto *et al.* (2016a;  
1837 2016b; 2017a; 2019). Deposits of each studied area are delimited by syn-sedimentary faults,  
1838 which have been represented with vertical lines. In the Formiche Alto area, sedimentation took  
1839 place in two different blocks delimited by syn-sedimentary faults (F1 and F2; see location on  
1840 geological maps of Figs. 3C and Fig. S1 of Supplementary Material). Note that the block  
1841 located to the southeast of F2 corresponds to the stratigraphic section shown in Fig. 2 for the  
1842 Formiche Alto area. Areas with no outcrop control correspond to the areas where no Upper  
1843 Jurassic deposits have been identified (see details in geological map of Fig. 1B). B) Simplified  
1844 palaeogeographic reconstruction of eastern Iberia during the Late Jurassic (see Fig. 1D for  
1845 details), showing the location of the studied areas and the correlation line displayed in diagrams  
1846 of Fig. 3A. The blue dashed line shows the position of the geological map of the Peñagolosa  
1847 sub-basin shown in Fig. 3C. C) Simplified geological map of the Peñagolosa sub-basin (western  
1848 Maestrazgo basin) showing the location of the stratigraphic sections and the faults F1 and F2,  
1849 which bound the two sedimentation blocks of the Formiche Alto area represented in Fig. 3A  
1850 (modified from Campos-Soto *et al.*, 2017a). For more details of this geological map, see Fig. S1  
1851 of Supplementary Material.

1852 **Fig. 4.** A-B) Panoramic field photograph (A) and line drawing (B) of deposits of the SUP of the  
1853 Villar del Arzobispo Fm at the most landward area of the South-Iberian Basin (see Fig. 1C for  
1854 location). The SUP comprises flood plain, fluvial channel, aeolian dune and deltaic deposits that  
1855 are interbedded and laterally related.

1856 **Fig. 5.** A-B) Panoramic field photograph (A) and line drawing (B) of deposits of the uppermost  
1857 part of the SUP of the Villar del Arzobispo Fm at the most seawards area of the W Maestrazgo  
1858 Basin (Mora de Rubielos area; see Fig. 1C and Fig. S1 of Supplementary Material for location).  
1859 Note that siliciclastic deposits (coastal terminal distributary channel and distributary-mouth bar

1860 deposits) and marl are interbedded and pass laterally to the S to shallow marine bioclastic and  
1861 oolitic limestone, which, in turn, gets progressively thicker and more abundant southwards.

1862 **Fig. 6.** Ephemeral fluvial channel architectural element. A) Schematic diagram and log of the  
1863 ephemeral fluvial channel architectural element (bracket in the diagram shows the location of  
1864 the log; see Fig. 2 for legend) and palaeocurrents. B) Field photograph (Riodeva area) of  
1865 channelized conglomerate displaying large-scale cross strata and a slightly incisive erosive base.  
1866 Hammer for scale (white circle). C) Field photograph (Riodeva area) of a conglomerate lens  
1867 displaying an asymmetric and incisive erosive base, with a very steep margin, to the right, and a  
1868 less steep one, to the left. Conglomerate displays a unique set of cross strata that is conformable  
1869 to the less steep margin of the erosive base. D) Field photograph (Riodeva area) of a very  
1870 poorly-sorted and clast-supported conglomerate made by rounded quartzite (white arrows) and  
1871 sandstone clasts (red arrow). E-F) Field photographs (Cedrillas and Riodeva areas, respectively)  
1872 of poorly-sorted and clast-supported conglomerates made up of subangular to subrounded,  
1873 muddy and carbonate soft clasts. G) Dinosaur bone (red arrow) observed within conglomerate in  
1874 the Riodeva area.

1875 **Fig. 7.** Multistorey fluvial channel architectural element. A) Schematic diagram and log of the  
1876 multistorey fluvial channel architectural element (bracket in the diagram shows the location of  
1877 the log; see Fig. 2 for legend) and palaeocurrents. B-C) Field photograph (B) and line drawing  
1878 (C) of channelized sandstone and conglomerate element at the Riodeva area. Sandstone displays  
1879 large internal erosive surfaces filled by conglomerate or sandstone (red arrows). Sandstone  
1880 displays scour and fill structures (blue arrows) filled by foresets and backsets (green arrows)  
1881 strata that flatten upwards in places. In the lower part of the body, sandstone displays upwards  
1882 flattening strata with long wavelength (blue bracket). Sandstone also displays sets of large-scale  
1883 cross strata at the upper part of the body (pink arrows), whose thickness decreases upwards (red  
1884 bracket). Conglomerate displays scour and fill structures filled by backset strata (white arrows).  
1885 Note the asymmetrical scour filled by conglomerate in the lower part of the body, displaying  
1886 backset strata that flatten upwards and fine upwards to sandstone (green bracket). D) Field

1887 photograph (Riodeva area) of a multistorey fluvial channel element composed of sandstone and  
1888 conglomerate. Note that sandstone displays internal erosive surfaces (red dotted lines), which  
1889 are filled by sandstone or conglomerate (white arrow and orange-shaded area). E) Channelized  
1890 sandstone (El Castellar area) displaying a basal and internal erosive surfaces (red-dotted lines),  
1891 which are filled by large-scale cross strata sandstone. Locally there is a thin layer of siliciclastic  
1892 mudstone containing abundant carbonaceous detritus interbedded with sandstone (yellow  
1893 arrows). F) Detail of the thin layers of siliciclastic mudstone containing carbonaceous detritus  
1894 (yellow arrows) observed in Fig. 7E.

1895 **Fig. 8.** Upper flow regime sedimentary structures observed within the multistorey fluvial  
1896 channel architectural element (El Castellar area). A-B) Field photograph (A) and line drawing  
1897 (B) of a sandstone body displaying convex-up low-angle cross strata (red bracket; blue arrows).  
1898 C-D) Field photograph (C) and line drawing (D) of sandstone displaying scour and fill  
1899 structures, which is directly overlying the convex-up low-angle cross strata sandstone of Fig. 8A  
1900 (red asterisk marks the same point in both pictures). Note that scours are filled by foreset and  
1901 backset strata (yellow and red arrows, respectively) that flatten upwards in places (blue bracket).  
1902 In the upper part of the body, a large-scale cross strata set is observed (white arrow), in which  
1903 the inclination of foresets indicates the flow direction.

1904 **Fig. 9.** Flood plain architectural element. A) Schematic diagram and log of the flood plain  
1905 architectural element (bracket in the diagram shows the location of the log; see Fig. 2 for  
1906 legend) and palaeocurrents measured in the non-channelized sandstone deposits included in this  
1907 element. B) Field photograph (Formiche Alto area) of reddish siliciclastic mudstone displaying  
1908 green mottling (red arrows). C) Non-channelized sandstone body (El Castellar area) displaying  
1909 a coarsening- and thickening-upwards trend (yellow bracket). The lower part is made up of  
1910 decimetre-thick sandstone beds, which include a fragment of a dinosaur bone (white arrow) and  
1911 which are interbedded with greyish-greenish siliciclastic mudstone. D) Non-channelized  
1912 sandstone (Riodeva area) displaying parallel lamination followed upwards by small-scale cross  
1913 strata. Wave ripple cross strata are observed at the top. E) Non-channelized sandstone

1914 displaying large-scale sigmoidal cross strata (Benagéber area). F) Dinosaur track observed at the  
1915 base of a non-channelized sandstone bed (dotted yellow line) at the Riodeva area. The dinosaur  
1916 track is preserved as a convex hyporelief (natural track cast) and shows slide marks (parallel  
1917 striations, white arrow) made by skin scales. G) Bioturbation observed as paired circular  
1918 openings at the top of a non-channelized sandstone bed at the Riodeva area. H) Field  
1919 photograph of limestone (red arrow) interbedded with reddish siliciclastic mudstone (Riodeva  
1920 area). I) Limestone made up of oncoids (white arrows) that are up to 6-7 cm large at the  
1921 Riodeva area. J) Field photograph of bioclastic limestone containing poorly-sorted bivalve  
1922 fragments (Losilla-Alpuente area). K) Photomicrograph of poorly-sorted bioclastic limestone,  
1923 which includes quartz grains, fragments of bivalves (green arrow), gastropods (yellow arrow),  
1924 echinoderms (blue arrow), ostracods (white arrow), miliolids (red arrow) and ooids (orange  
1925 arrows).

1926 **Fig. 10.** Deltaic architectural elements. A) Schematic diagram and log of the deltaic elements  
1927 (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents  
1928 obtained in clinofolds of the delta-front element and in cross-bedded sets of the delta terminal  
1929 distributary channel element. B-C) Field photograph (B) and line drawing (C) of four  
1930 coarsening- and thickening-upwards deltaic successions (marked with blue brackets). Note that  
1931 the lower and uppermost deltaic successions do not crop out completely. The first three deltaic  
1932 successions, starting from the base, are made up of laterally-extensive cm-thick, very fine-to  
1933 fine-grained sandstone layers showing a very low angle inclination and alternating with mm-  
1934 thick carbonaceous detritus layers, which are interpreted as deposits of the delta front element  
1935 (see text for details). In the two lowermost deltaic successions, the delta-front deposits are  
1936 truncated at their uppermost part by the delta terminal distributary channel element (orange  
1937 arrows). The delta terminal distributary channel element displays erosive surfaces and is filled  
1938 by sandstone displaying upwards flattening strata or backset strata (purple and green arrows,  
1939 respectively). The uppermost deltaic succession is made up of carbonaceous-rich, dark-grey  
1940 siliciclastic mudstone (delta-toe element, blue colour), which changes upwards to alternating

1941 sandstone and carbonaceous detritus layers (delta front element). D) Field photograph of the  
1942 delta-toe element comprising carbonaceous-rich, dark-grey siliciclastic mudstone interbedded  
1943 with very fine-grained rippled sandstone. E) Field photograph of cm-thick sandstone layers  
1944 alternating with mm to cm-thick carbonaceous detritus layers at the lower part of foresets of the  
1945 delta-front element. F) Field photograph of a sandstone layer at the lowermost part of the delta-  
1946 front element displaying poorly-preserved dinosaur tracks at the base, which are preserved as  
1947 convex hyporeliefs or natural casts (white arrows and black dotted line). The dinosaur tracks  
1948 display elongated shapes, with irregular and deformed outlines and their infill is massive. They  
1949 penetrate up to 70 cm into the underlying deposit, made up of alternating carbonaceous-rich,  
1950 dark-grey siliciclastic mudstone and rippled sandstone layers, interpreted as delta toe deposits  
1951 (see text for details). All photographs were taken at the Riodeva area.

1952 **Fig. 11.** Deltaic architectural elements. A) Field photograph of sandstone displaying clinoforms.  
1953 B) Detail of three coarsening- and thickening-upwards deltaic successions (marked with blue  
1954 brackets) displaying clinoforms. Note that the lower part of foresets are draped by carbonaceous  
1955 detritus (red arrow) and, locally, these drapes extend upwards to the topsets (white arrow). C-D)  
1956 Field photograph (C) and line-drawing (D) of three coarsening- and thickening-upwards deltaic  
1957 successions (marked with blue brackets). Note that deposits of the lowermost succession are  
1958 truncated by an erosive surface, which incises 1.30 m downwards into the underlying sediments,  
1959 made up of thinly-bedded sandstone and carbonaceous detritus layers (delta-front element), and  
1960 it is filled by sandstone displaying large-scale cross strata (delta terminal distributary channel  
1961 element). The yellow star indicates the position of the sample shown in Fig. 11F. E) Detail of  
1962 deposits of the delta terminal distributary channel element observed in Fig.11C-D, displaying an  
1963 erosive base and formed by large-scale cross strata sandstone. F) Transmitted light  
1964 photomicrograph of a well-sorted sandstone. The location of the sample is indicated in Fig.  
1965 11C-D with a yellow star. All photographs were taken at the Riodeva area.

1966 **Fig. 12.** Coastal to shallow marine architectural elements. A) Schematic diagram of the coastal  
1967 to shallow marine architectural elements indicating the position of the logs shown in Fig. 12B

1968 and 13A. B) Log of the coastal terminal distributary channel architectural element (bracket in  
1969 the diagram shows the location of the log in Fig. 12A; see Fig. 2 for legend) and palaeocurrents  
1970 obtained in the W Maestrazgo Basin. C-D) Channelized sandstone (Formiche Alto area)  
1971 displaying a basal erosive base (red dotted line) and large-scale cross strata. This body is  
1972 interbedded with marl (white arrows), which, in turn, is interbedded with shallow marine  
1973 limestone (blue arrow) and distributary mouth-bar sandstone (orange arrows). Note that  
1974 sandstone displays an internal erosive surface (pink dotted line) filled by poorly-sorted  
1975 conglomerate and also includes thin layers of carbonaceous-rich marl between the large-scale  
1976 cross strata sets (yellow arrows). E) Detail of the thin layers of carbonaceous-rich marl located  
1977 between large-scale cross-strata sets (yellow arrow) and draping the bottomsets and the lower  
1978 part of foresets (white arrows). See location in Fig. 12D. F) Detail of the internal erosive surface  
1979 (pink dotted line) filled by poorly-sorted conglomerate (see location in Fig. 12C). G) Field  
1980 photograph of poorly-sorted mudstone pebbles including fragments of bivalves overlaying the  
1981 internal erosive surface (pink dotted line). See location in Fig. 12F.

1982 **Fig. 13.** Coastal to shallow marine architectural elements. A) Log of the distributary mouth-bar  
1983 element (bracket in the diagram shows the location of the log in Fig. 12A; see Fig. 2 for legend)  
1984 and palaeocurrents. B) Field photograph (Benagéber area) of a sandstone body displaying a  
1985 coarsening- and thickening-upwards trend (yellow bracket) and interbedded with shallow  
1986 marine limestone (greyish strata below and above yellow bracket). C-D) Field photograph (C)  
1987 and line drawing (D) of the distributary mouth-bar element (Mora de Rubielos area) comprising  
1988 a non-channelized sandstone body interbedded with marl that includes corals in life position  
1989 (black arrow indicates location of corals). Note that sandstone displays large-scale and  
1990 sigmoidal cross strata (white arrows). Hammer for scale. E) Field photograph of colonial corals  
1991 observed in life position at the Mora de Rubielos area. Note that the white arrows point to its  
1992 growth lines. See location of the coral at Fig. 13C-D. F) Detail of the septa of the coral shown in  
1993 Fig. 13E. G) Field photograph (Mora de Rubielos area) of cm-thick sandstone displaying wave  
1994 ripple strata at the top (white arrows) and interbedded with marl, giving rise to wavy bedding.

1995 H) Trigonioids and ostreids observed within a sandstone body (white and blue arrows,  
1996 respectively) at the Mora de Rubielos area. I) Burrowing traces observed at the top of a  
1997 sandstone body in the Formiche Alto area.

1998 **Fig. 14.** Simple aeolian dune architectural element. A) Schematic diagram and log of the simple  
1999 aeolian dune architectural element (bracket in the diagram shows the location of the log, see  
2000 Fig. 2 for legend) and palaeocurrents. B-C) Field photograph (B) and line drawing (C) of a  
2001 sandstone body displaying a 6 m-thick large-scale cross strata set. Large-scale cross strata set is  
2002 made up of convex-up foresets passing upwards to low-angle inclined topsets. D) Field  
2003 photograph of a metre-thick sandstone body displaying a single set of large-scale cross strata. E)  
2004 Metre-thick sandstone body comprising a 4 m-thick large-scale cross strata set. Hammer for  
2005 scale (black circle). F) Detail of large-scale cross strata set observed in Fig. 14E. Large-scale  
2006 cross strata set is made up of successive cm-thick inversely graded strata. Note that the contact  
2007 between each stratum is sharp (red arrows). Hammer for scale. G) Transmitted light  
2008 photomicrograph of simple dune aeolian sandstone displaying well-sorted subrounded to  
2009 subangular grains. H) Transmitted light photomicrograph of sandstone strata displaying inverse  
2010 grain size grading. All photographs were taken at the Riodeva area.

2011 **Fig. 15.** Massive and indistinctly stratified aeolian dune architectural element. A) Schematic  
2012 diagram and log of the massive and indistinctly stratified aeolian dune architectural element  
2013 (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents.  
2014 B) Field photograph of massive and indistinctly stratified aeolian dune sandstone overlain by  
2015 the multistorey fluvial channel architectural element (its base is indicated with a yellow line).  
2016 Black lines represent faults. C) Field photograph of massive and indistinctly stratified aeolian  
2017 dune sandstone, which is laterally interbedded with conglomerate bodies of the ephemeral  
2018 fluvial channel architectural element (delimited by red lines). D) Field photograph of massive  
2019 and indistinctly stratified sandstone interbedded with conglomerate bodies (delimited by red  
2020 lines). Sandstone displays poorly preserved large-scale cross strata (foresets are outlined with  
2021 black lines). Note that the blue circle shows a 2 m large pocket rule (white line). E) Field

2022 photograph of massive and indistinctly stratified aeolian dune sandstone overlain by the  
2023 multistorey fluvial channel architectural element (its base is indicated with a yellow line). F)  
2024 Transmitted light photomicrograph of sandstone displaying subangular to subrounded and well-  
2025 sorted grains. G-H) Field photograph (G) and line drawing (H) of sandstone displaying large-  
2026 scale cross strata in which foresets pass downwards to laterally continuous bottomsets.  
2027 Carbonaceous detritus and mica flakes drape some bottomsets and the lowermost part of some  
2028 foresets. Note the high-angle foresets displayed by the cross strata set to the right of the  
2029 photograph (blue arrow). All photographs were taken at the Riodeva area.

2030 **Fig. 16.** Climbing aeolian dune architectural element. A) Schematic diagram and log of the  
2031 climbing aeolian dune architectural element (bracket in the diagram shows the location of the  
2032 log; see Fig. 2 for legend) and palaeocurrents. B) Field photograph of sandstone displaying a  
2033 large-scale cross stratified set, at least 2 m thick (note that the person in the photograph is 1.65  
2034 m tall). C-D) Field photograph (C) and line drawing (D) of sandstone displaying large-scale  
2035 tangential cross strata sets. Individual sets are delimited by low-angle inclined bounding  
2036 surfaces, which dip in the opposite direction to the foresets dip. E) Field photograph of large-  
2037 scale and high-angle cross strata sandstone whose foresets are slightly deformed (yellow  
2038 arrows). F) Field photograph of tangential cross strata sandstone. G) Detail of the lower part of  
2039 foresets and bottomsets of large-scale cross strata sandstone. Foresets comprise cm-thick strata  
2040 pinching out downwards, which correspond to grainflow strata (gf). Grainflow strata are  
2041 interbedded with cm-thick strata pinching out upwards, corresponding to wind ripple strata (wr).  
2042 H) Detail of grainflow strata made up of fine- to medium-grained sandstone (blue bracket) and  
2043 wind ripple strata made up of very fine- to fine-grained sandstone (red brackets). I) Sandstone  
2044 pseudomorph after gypsum (desert rose formed by a rosette-like crystal aggregate). All  
2045 photographs were taken at the Riodeva area.

2046 **Fig. 17.** Reconstruction of the different palaeoenvironments inhabited by dinosaurs of the Villar  
2047 del Arzobispo Fm and of the lateral relationships between them (not at scale).

2048 **Fig. 18.** Interactions between fluvial, tidal, deltaic, and aeolian environments observed in the  
2049 Lençóis Maranhenses National Park (NE Brazil). Satellite images were taken from Google  
2050 Earth in 2019. A) The coastal dune field of the Lençóis Maranhenses National Park (to the  
2051 right) is located next to the estuary of the Mearim River (to the left). B) Aeolian dunes  
2052 developing in a flooded area, at the end of the dune field. Note that stagnant water bodies  
2053 develop in the interdune areas (blue arrows). C) Aeolian dunes approaching a tidal channel  
2054 (blue arrows). Note how the aeolian interdunes may get flooded (red arrows). D) The coastal  
2055 flood plain is crossed by the Grande River, which flows into a shallow water body in which  
2056 deltaic sediments are deposited (red arrow). E) The coastal dune field is penetrated by the Negro  
2057 River (blue arrows) and in its margin small deltas develop in stagnant water bodies (red  
2058 squares). F-G) Interdune areas crossed by the Negro River. Note that the fluvial channel erodes  
2059 the aeolian dune sediments in F (pink arrow) and that aeolian dunes migrate over the fluvial  
2060 channel in G (blue arrow). Note that small deltas develop in the interdune areas (red arrows). H-  
2061 I) Deltas developing in the margins of the dune field. Note that the aeolian dunes migrate over  
2062 the delta plain in H (blue arrows) and that the distributary channels rework the aeolian dune  
2063 sediments in I (red arrow).

2064 **Table 1.** Summary of the essentially siliciclastic coastal and alluvial architectural elements of  
2065 the Villar del Arzobispo Fm in the South-Iberian and western Maestrazgo basins. See Fig. 2 for  
2066 location of the architectural elements. The references are cited in the main text.

### 2067 **Supplementary Material**

2068 **S1.** A) Geological map of western Maestrazgo and South-Iberian Basins (modified from  
2069 Campos-Soto *et al.*, 2019). The blue dotted rectangle indicates the location of the map shown in  
2070 Fig. S1B. B) Geological map of western Maestrazgo Basin (modified from Campos-Soto *et al.*,  
2071 2017a), showing the location of the stratigraphic sections of the Villar del Arzobispo Fm  
2072 included in Fig. 2 and the position of the panel shown in Fig. 5. The map includes the detailed  
2073 mapping of the shallow marine bioclastic and oolitic limestone (dark blue lines) and the inter-

2074 supratidal peloidal and micritic limestone (light blue lines) of the studied succession, as well as  
2075 the mapping of the syn-extensional faults that controlled its thickness variations. Note how  
2076 shallow marine bioclastic and oolitic limestone gets progressively thinner and less abundant  
2077 towards the north and gets thicker and more abundant towards the SE of the study area, where  
2078 the thickness of the studied succession significantly increases.

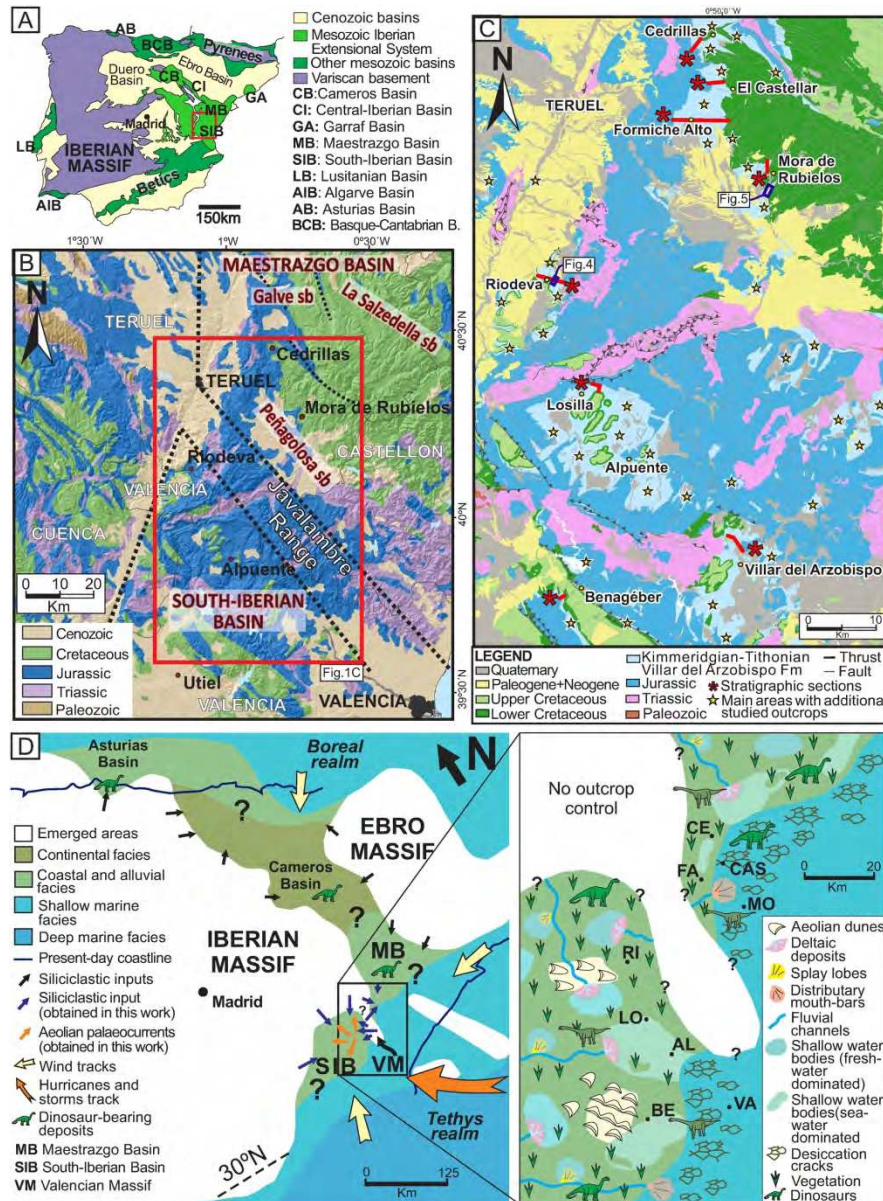


Fig. 1. A) Simplified geological map of the Iberian Peninsula indicating the location of the South-Iberian and Maestrazgo basins within the Mesozoic Iberian Extensional System (modified from Mas et al., 2004). The red square indicates the location of the map shown in Fig. 1B. B) Geological map of eastern Spain showing the limits of the deposits of the Maestrazgo Basin and its sub-basins -sb- (modified from Salas and Guimerà, 1996, 1997, Salas et al., 2001; Bover-Arnal and Salas, 2019) and the South-Iberian Basin. The geological information of this map was obtained and modified from the geological map of the Iberian Peninsula and the Balearic and Canary Islands (1995 edition, scale 1:1.000.000, Caride de Liñan, 1995). C) Geological map of the study area of the South-Iberian and the western Maestrazgo basins (modified from Campos-Soto et al., 2019), showing the location of the stratigraphic sections, the main areas where additional outcrops have been studied for this work (for more details on the additional studied outcrops see Campos Soto, 2020) and the panels shown in Figs. 4 and 5. The geological data were obtained and modified from the geological map Z1700 of the Geological Spanish Survey (GEODE, scale 1:50.000; López-Olmedo et al., 2018). D) Palaeogeographic reconstruction of eastern and northern Iberia during the Tithonian, to the left (palaeogeography and palaeocurrents obtained and modified from Thierry et al., 2000 and Campos-Soto et

al., 2019 and references therein). To the right detailed palaeogeography of the South-Iberian and western Maestrazgo basins (data obtained and modified from Campos-Soto et al., 2019). The line that represents the 30°N latitude in the palaeogeographic reconstruction of eastern and northern Iberia has been modified according to data published by Sellwood and Valdes (2008) and Boucot et al. (2013). Tracks of hurricanes and storms for the Late Jurassic are based on Marsaglia and Klein (1983) and wind tracks blowing from the

Tethys and the Boreal realms are based on Sellwood and Valdes (2008) and Benito et al. (2005), respectively. Palaeocurrents obtained in this work from the subaquatic and aeolian deposits in the different studied areas of both basins have been represented in the palaeogeographic map with blue and orange arrows, respectively. The length of the arrows corresponds to the abundance of measurements. The palaeogeographic reconstruction of the South-Iberian and the western Maestrazgo Basin, to the right, shows the location of the specific areas studied here: CE (Cedrillas), CAS (El Castellar), FA (Formiche Alto) and MO (Mora de Rubielos) in the western Maestrazgo Basin, and RI (Riodeva), LO-AL (Losilla-Alpuente), BE (Benagéber) and VI (Villar del Arzobispo) in the South-Iberian Basin.

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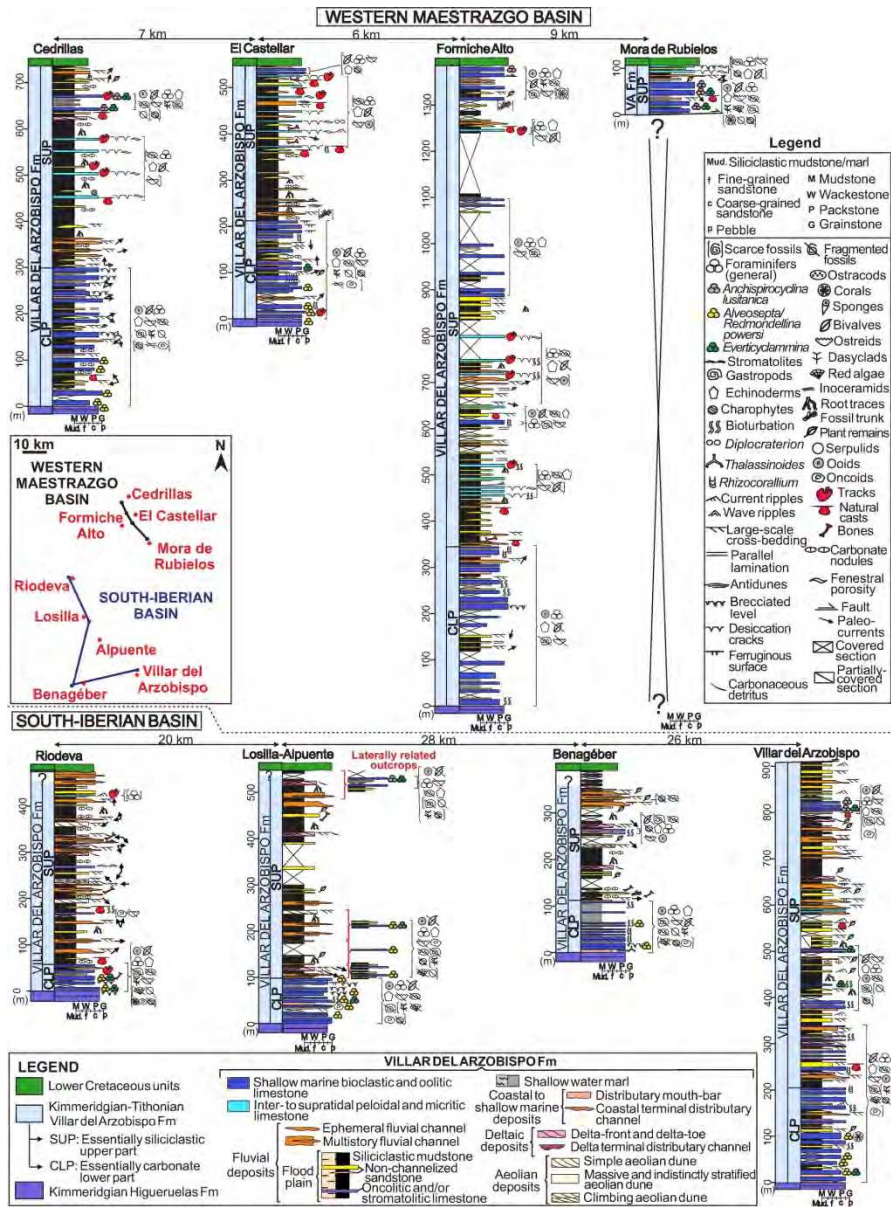


Fig. 2. Stratigraphic sections of the Villar del Arzobispo Fm logged in the western Maestrazgo (Cedrillas, El Castellar, Formiche Alto and Mora de Rubielos) and in the South-Iberian basins (Riodeva, Losilla-Alpuente, Benagéber and Villar del Arzobispo). Modified from Campos-Soto et al. (2019). This figure also includes a simplified map showing the location of the sections at the studied areas (see also Fig. 1C). All the sections show, at their right part, the main sedimentary structures and paleontological data, including the dinosaur remains (for more information on dinosaur fossil sites see Figs. 2 and 3 of Campos-Soto et al., 2017a and Fig. 3A of Campos-Soto et al., 2019). The Losilla-Alpuente section also shows, at its right part, some partial stratigraphic sections logged in laterally related outcrops.

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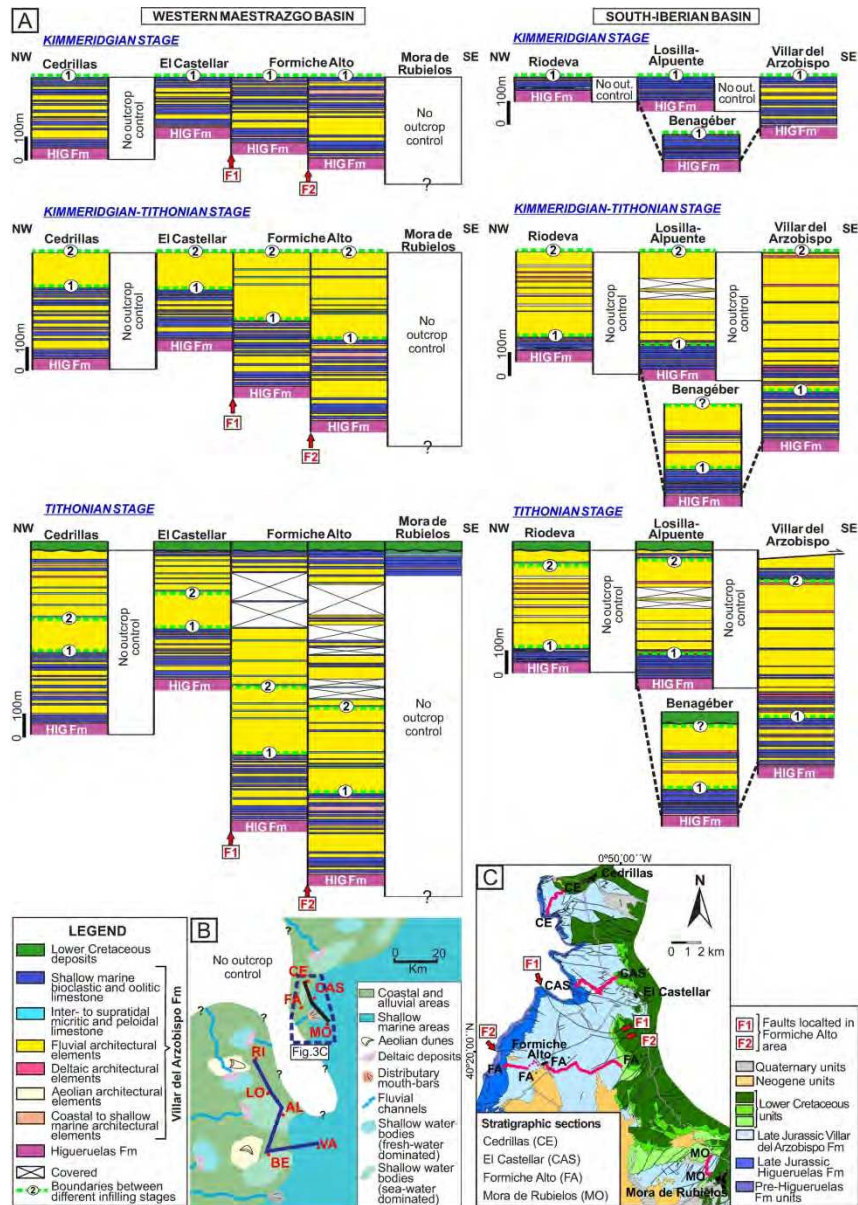


Fig. 3. A) Diagrams showing the different stages of system evolution during sedimentation of the Villar del Arzobispo Fm. These stages comprise: i) the deposition of shallow marine deposits of the CLP during the Kimmeridgian; ii) deposition of the essentially siliciclastic deposits of the SUP during a regressive stage during the Kimmeridgian-Tithonian; during this stage, fluvial, aeolian and deltaic depositional settings mainly developed landwards; these settings passed gradually seawards to coastal to shallow marine settings; iii) deposition of the upper part of the SUP during the Tithonian marine transgression. The reconstruction of the different stages of evolution is based on the data obtained from the stratigraphic sections (Fig. 2), the geological mapping (see Fig. 1C and Fig. S1 of Supplementary Material), and the ages obtained through the analysis of the larger benthic foraminifera (see Campos-Soto et al. (2016a; 2016b; 2017a; 2019). Deposits of each studied area are delimited by syn-sedimentary faults, which have been represented with vertical lines. In the Formiche Alto area, sedimentation took place in two different blocks delimited by syn-sedimentary faults (F1 and F2; see location on geological maps of Figs. 3C and Fig. S1 of Supplementary Material). Note that the block located to the southeast of F2 corresponds to the stratigraphic section shown in Fig. 2 for the Formiche Alto area. Areas with no outcrop control correspond to the areas where no Upper

Jurassic deposits have been identified (see details in geological map of Fig. 1B). B) Simplified palaeogeographic reconstruction of eastern Iberia during the Late Jurassic (see Fig. 1D for details), showing the location of the studied areas and the correlation line displayed in diagrams of Fig. 3A. The blue dashed line shows the position of the geological map of the Peñagolosa sub-basin shown in Fig. 3C. C) Simplified geological map of the Peñagolosa sub-basin (western Maestrazgo basin) showing the location of the stratigraphic sections and the faults F1 and F2, which bound the two sedimentation blocks of the Formiche Alto area represented in Fig. 3A (modified from Campos-Soto et al., 2017a). For more details of this geological map, see Fig. S1 of Supplementary Material.

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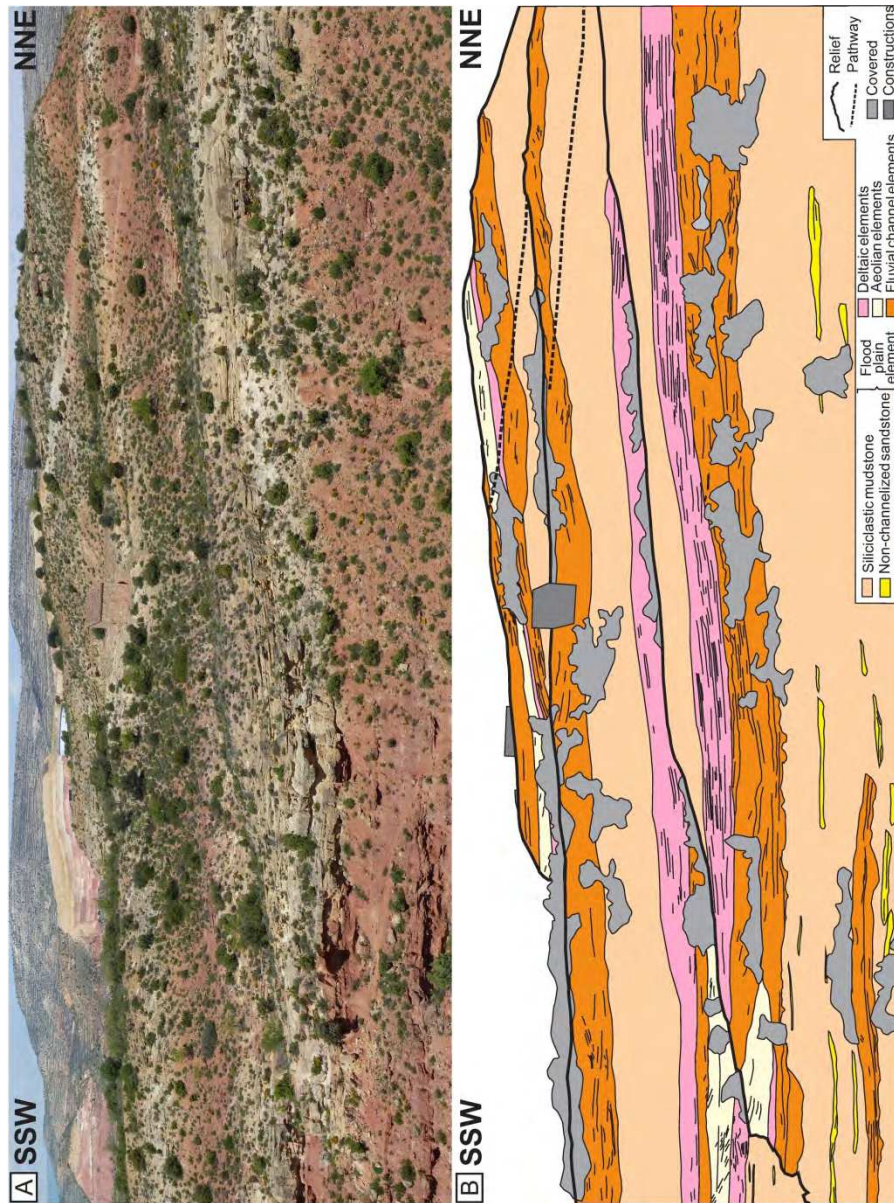


Fig. 4. A-B) Panoramic field photograph (A) and line drawing (B) of deposits of the SUP of the Villar del Arzobispo Fm at the most landward area of the South-Iberian Basin (see Fig. 1C for location). The SUP comprises flood plain, fluvial channel, aeolian dune and deltaic deposits that are interbedded and laterally related.

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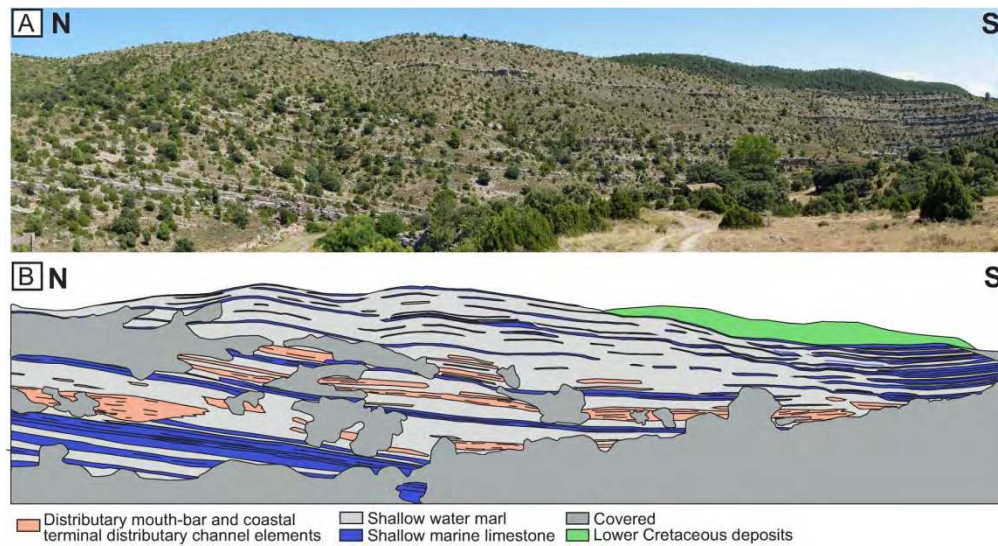


Fig. 5. A-B) Panoramic field photograph (A) and line drawing (B) of deposits of the uppermost part of the SUP of the Villar del Arzobispo Fm at the most seawards area of the W Maestrazgo Basin (Mora de Rubielos area; see Fig. 1C and Fig. S1 of Supplementary Material for location). Note that siliciclastic deposits (coastal terminal distributary channel and distributary-mouth bar deposits) and marl are interbedded and pass laterally to the S to shallow marine bioclastic and oolitic limestone, which, in turn, gets progressively thicker and more abundant southwards.

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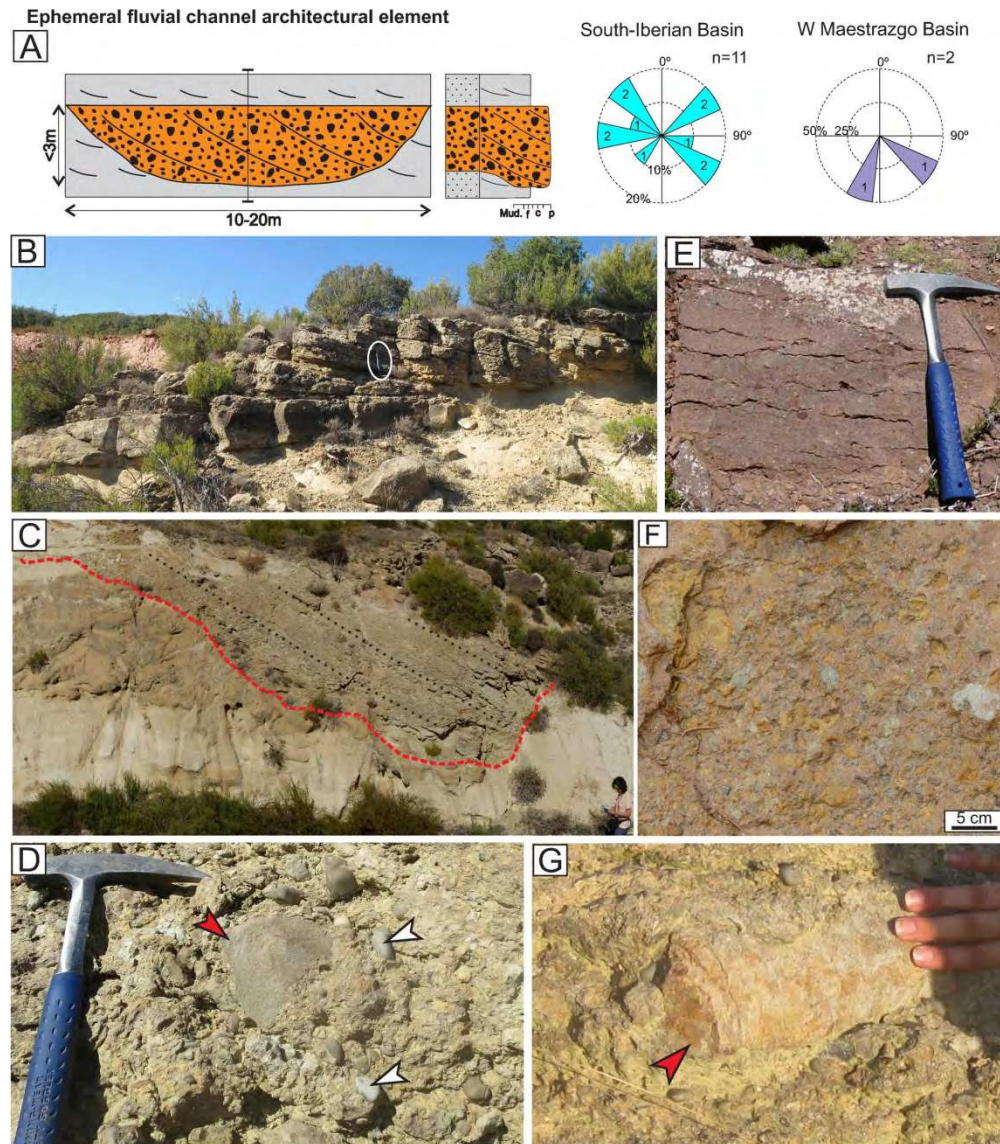


Fig. 6. Ephemeral fluvial channel architectural element. A) Schematic diagram and log of the ephemeral fluvial channel architectural element (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents. B) Field photograph (Riodeva area) of channelized conglomerate displaying large-scale cross strata and a slightly incisive erosive base. Hammer for scale (white circle). C) Field photograph (Riodeva area) of a conglomerate lens displaying an asymmetric and incisive erosive base, with a very steep margin, to the right, and a less steep one, to the left. Conglomerate displays a unique set of cross strata that is conformable to the less steep margin of the erosive base. D) Field photograph (Riodeva area) of a very poorly-sorted and clast-supported conglomerate made by rounded quartzite (white arrows) and sandstone clasts (red arrow). E-F) Field photographs (Cedrillas and Riodeva areas, respectively) of poorly-sorted and clast-supported conglomerates made up of subangular to subrounded, muddy and carbonate soft clasts. G) Dinosaur bone (red arrow) observed within conglomerate in the Riodeva area.

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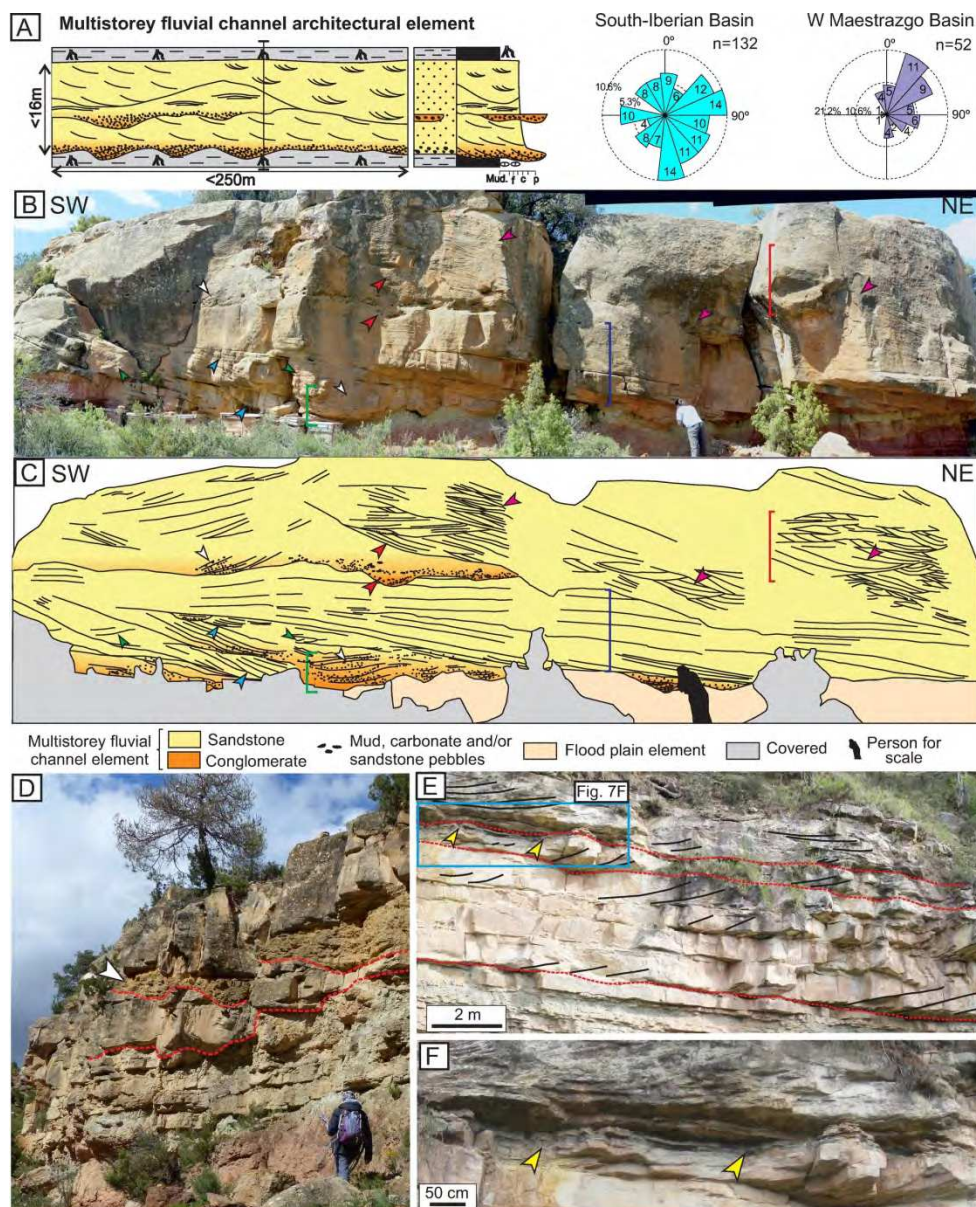


Fig. 7. Multistorey fluvial channel architectural element. A) Schematic diagram and log of the multistorey fluvial channel architectural element (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents. B-C) Field photograph (B) and line drawing (C) of channelized sandstone and conglomerate element at the Riodeva area. Sandstone displays large internal erosive surfaces filled by conglomerate or sandstone (red arrows). Sandstone displays scour and fill structures (blue arrows) filled by foresets and backsets (green arrows) strata that flatten upwards in places. In the lower part of the body, sandstone displays upwards flattening strata with long wavelength (blue bracket). Sandstone also displays sets of large-scale cross strata at the upper part of the body (pink arrows), whose thickness decreases upwards (red bracket). Conglomerate displays scour and fill structures filled by backset strata (white arrows). Note the asymmetrical scour filled by conglomerate in the lower part of the body, displaying backset strata that flatten upwards and fine upwards to sandstone (green bracket). D) Field photograph (Riodeva area) of a multistorey fluvial channel element composed of sandstone and conglomerate. Note that sandstone displays internal erosive surfaces (red dotted lines), which are filled by sandstone or conglomerate (white arrow and orange-shaded area). E) Channelized sandstone (El Castellar area)

displaying a basal and internal erosive surfaces (red-dotted lines), which are filled by large-scale cross strata sandstone. Locally there is a thin layer of siliciclastic mudstone containing abundant carbonaceous detritus interbedded with sandstone (yellow arrows). F) Detail of the thin layers of siliciclastic mudstone containing carbonaceous detritus (yellow arrows) observed in Fig. 7E.

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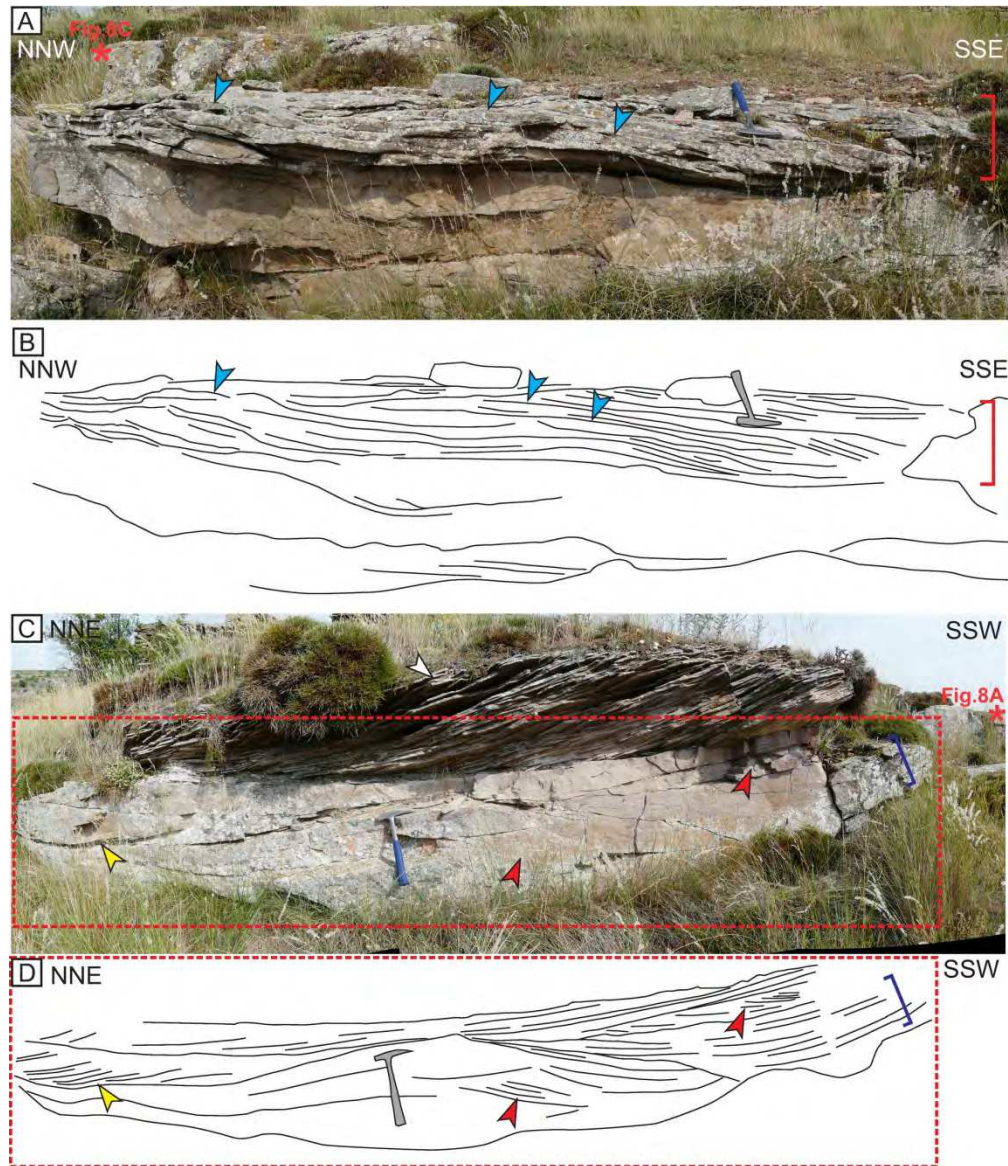


Fig. 8. Upper flow regime sedimentary structures observed within the multistorey fluvial channel architectural element (El Castellar area). A-B) Field photograph (A) and line drawing (B) of a sandstone body displaying convex-up low-angle cross strata (red bracket; blue arrows). C-D) Field photograph (C) and line drawing (D) of sandstone displaying scour and fill structures, which is directly overlying the convex-up low-angle cross strata sandstone of Fig. 8A (red asterisk marks the same point in both pictures). Note that scours are filled by foreset and backset strata (yellow and red arrows, respectively) that flatten upwards in places (blue bracket). In the upper part of the body, a large-scale cross strata set is observed (white arrow), in which the inclination of foresets indicates the flow direction.

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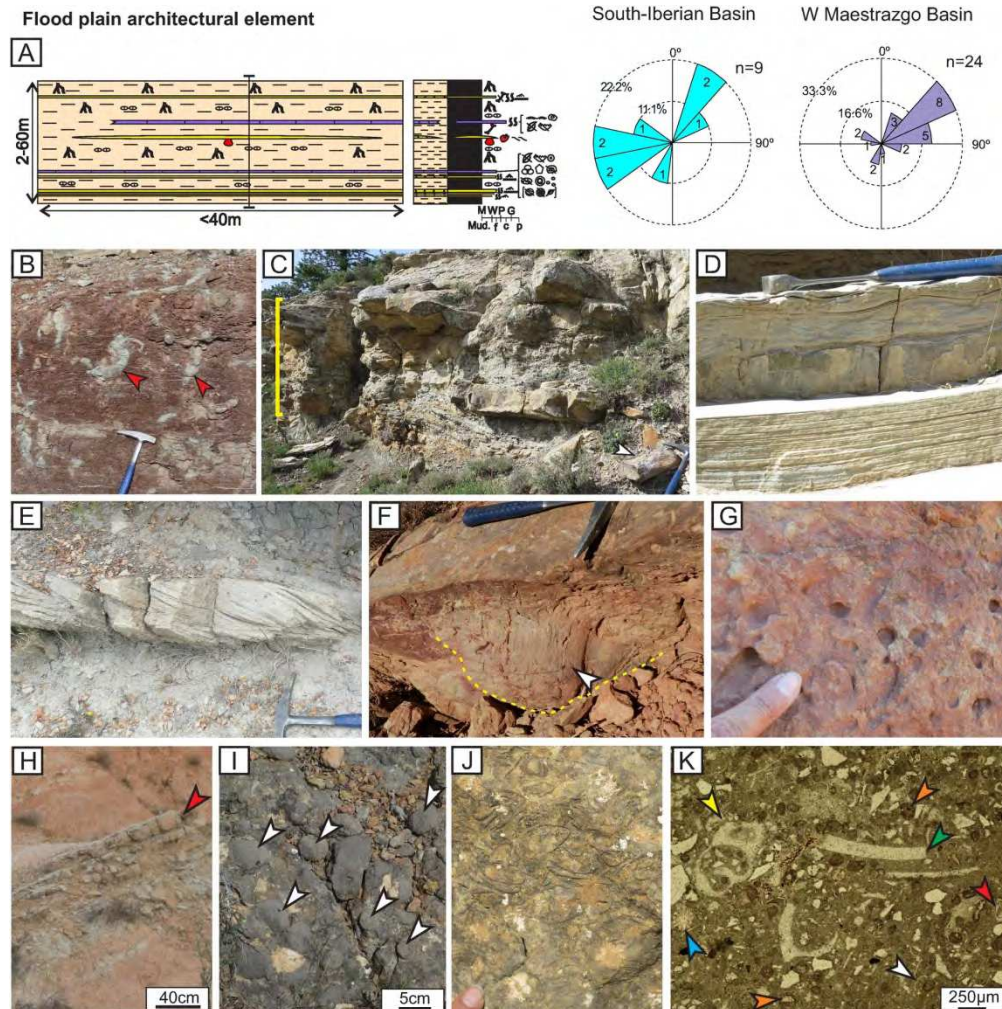


Fig. 9. Flood plain architectural element. A) Schematic diagram and log of the flood plain architectural element (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents measured in the non-channelized sandstone deposits included in this element. B) Field photograph (Formiche Alto area) of reddish siliciclastic mudstone displaying green mottling (red arrows). C) Non-channelized sandstone body (El Castellar area) displaying a coarsening- and thickening-upwards trend (yellow bracket). The lower part is made up of decimetre-thick sandstone beds, which include a fragment of a dinosaur bone (white arrow) and which are interbedded with greyish-greenish siliciclastic mudstone. D) Non-channelized sandstone (Riodeva area) displaying parallel lamination followed upwards by small-scale cross strata. Wave ripple cross strata are observed at the top. E) Non-channelized sandstone displaying large-scale sigmoidal cross strata (Benagéber area). F) Dinosaur track observed at the base of a non-channelized sandstone bed (dotted yellow line) at the Riodeva area. The dinosaur track is preserved as a convex hyporelief (natural track cast) and shows slide marks (parallel striations, white arrow) made by skin scales. G) Bioturbation observed as paired circular openings at the top of a non-channelized sandstone bed at the Riodeva area. H) Field photograph of limestone (red arrow) interbedded with reddish siliciclastic mudstone (Riodeva area). I) Limestone made up of oncoids (white arrows) that are up to 6-7 cm large at the Riodeva area. J) Field photograph of bioclastic limestone containing poorly-sorted bivalve fragments (Losilla-Alpuente area). K) Photomicrograph of poorly-sorted bioclastic limestone, which includes quartz grains, fragments of bivalves (green arrow), gastropods (yellow arrow), echinoderms (blue arrow), ostracods (white arrow), miliolids (red arrow) and ooids (orange arrows).

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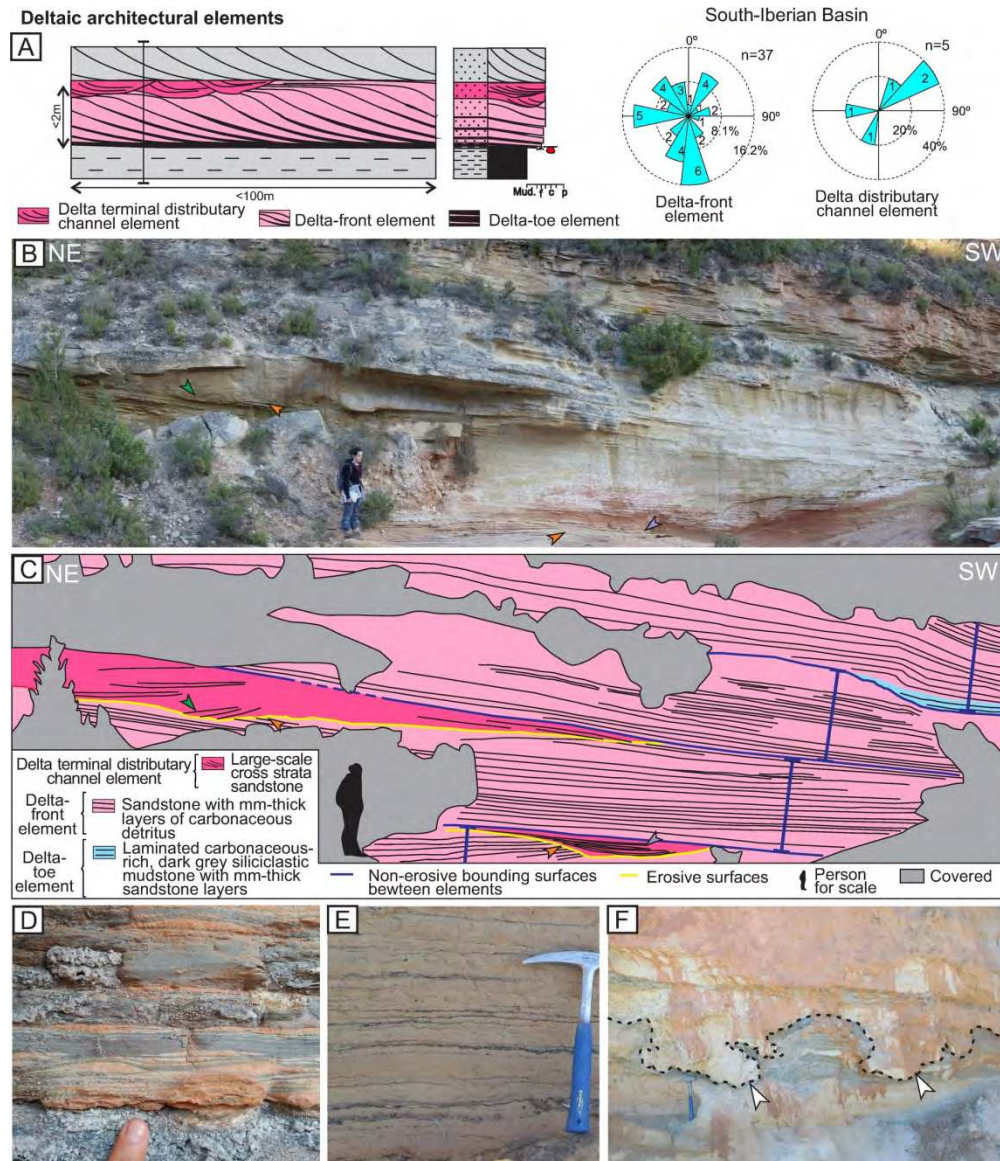


Fig. 10. Deltaic architectural elements. A) Schematic diagram and log of the deltaic elements (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents obtained in clinoforms of the delta-front element and in cross-bedded sets of the delta terminal distributary channel element. B-C) Field photograph (B) and line drawing (C) of four coarsening- and thickening-upwards deltaic successions (marked with blue brackets). Note that the lower and uppermost deltaic successions do not crop out completely. The first three deltaic successions, starting from the base, are made up of laterally-extensive cm-thick, very fine-to fine-grained sandstone layers showing a very low angle inclination and alternating with mm-thick carbonaceous detritus layers, which are interpreted as deposits of the delta front element (see text for details). In the two lowermost deltaic successions, the delta-front deposits are truncated at their uppermost part by the delta terminal distributary channel element (orange arrows). The delta terminal distributary channel element displays erosive surfaces and is filled by sandstone displaying upwards flattening strata or backset strata (purple and green arrows, respectively). The uppermost deltaic succession is made up of carbonaceous-rich, dark-grey siliciclastic mudstone (delta-toe element, blue colour), which changes upwards to alternating sandstone and carbonaceous detritus layers (delta front element). D) Field photograph of the delta-toe element comprising carbonaceous-rich, dark-grey siliciclastic mudstone

interbedded with very fine-grained rippled sandstone. E) Field photograph of cm-thick sandstone layers alternating with mm to cm-thick carbonaceous detritus layers at the lower part of foresets of the delta-front element. F) Field photograph of a sandstone layer at the lowermost part of the delta-front element displaying poorly-preserved dinosaur tracks at the base, which are preserved as convex hyporeliefs or natural casts (white arrows and black dotted line). The dinosaur tracks display elongated shapes, with irregular and deformed outlines and their infill is massive. They penetrate up to 70 cm into the underlying deposit, made up of alternating carbonaceous-rich, dark-grey siliciclastic mudstone and rippled sandstone layers, interpreted as delta toe deposits (see text for details). All photographs were taken at the Riodeva area.

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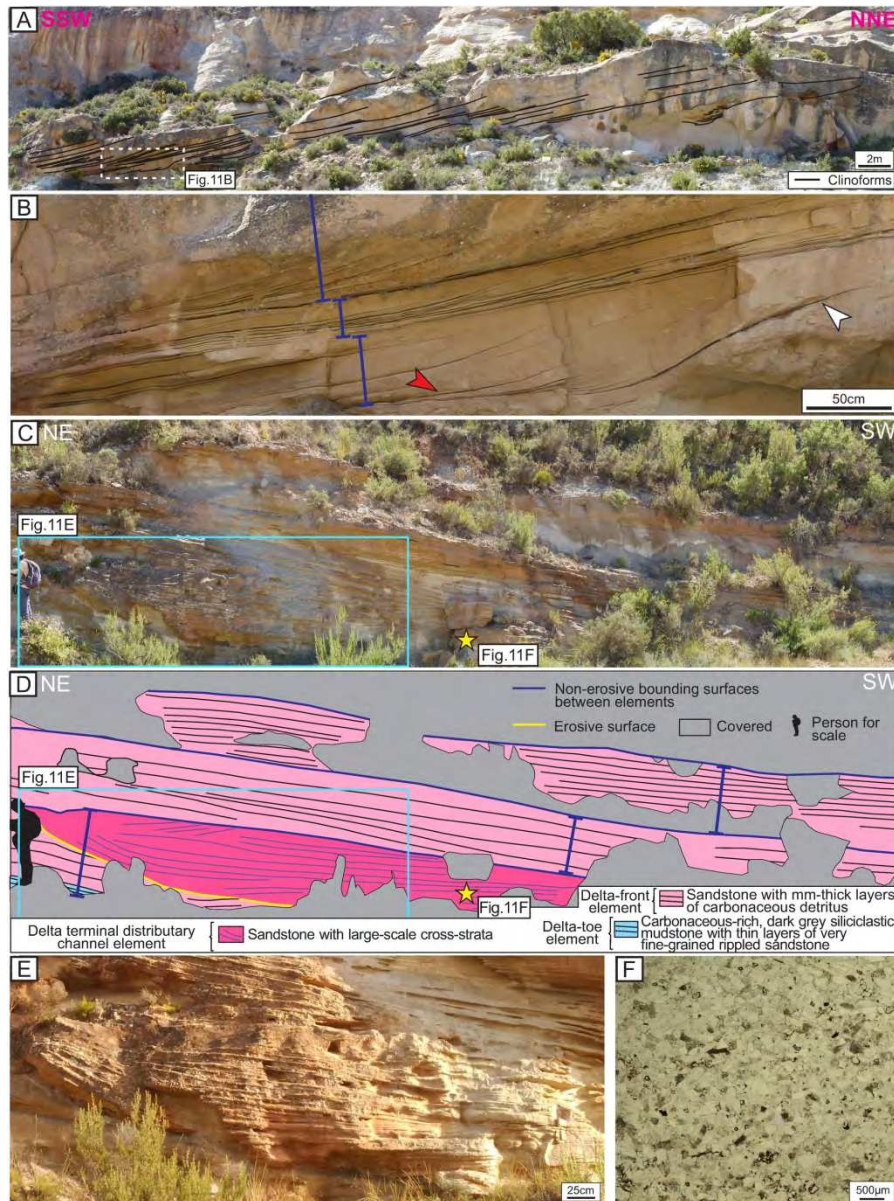


Fig. 11. Deltaic architectural elements. A) Field photograph of sandstone displaying clinoforms. B) Detail of three coarsening- and thickening-upwards deltaic successions (marked with blue brackets) displaying clinoforms. Note that the lower part of foresets are draped by carbonaceous detritus (red arrow) and, locally, these drapes extend upwards to the topsets (white arrow). C-D) Field photograph (C) and line-drawing (D) of three coarsening- and thickening-upwards deltaic successions (marked with blue brackets). Note that deposits of the lowermost succession are truncated by an erosive surface, which incises 1.30 m downwards into the underlying sediments, made up of thinly-bedded sandstone and carbonaceous detritus layers (delta-front element), and it is filled by sandstone displaying large-scale cross strata (delta terminal distributary channel element). The yellow star indicates the position of the sample shown in Fig. 11F. E) Detail of deposits of the delta terminal distributary channel element observed in Fig. 11C-D, displaying an erosive base and formed by large-scale cross strata sandstone. F) Transmitted light photomicrograph of a well-sorted sandstone. The location of the sample is indicated in Fig. 11C-D with a yellow star. All photographs were taken at the Riodeva area.

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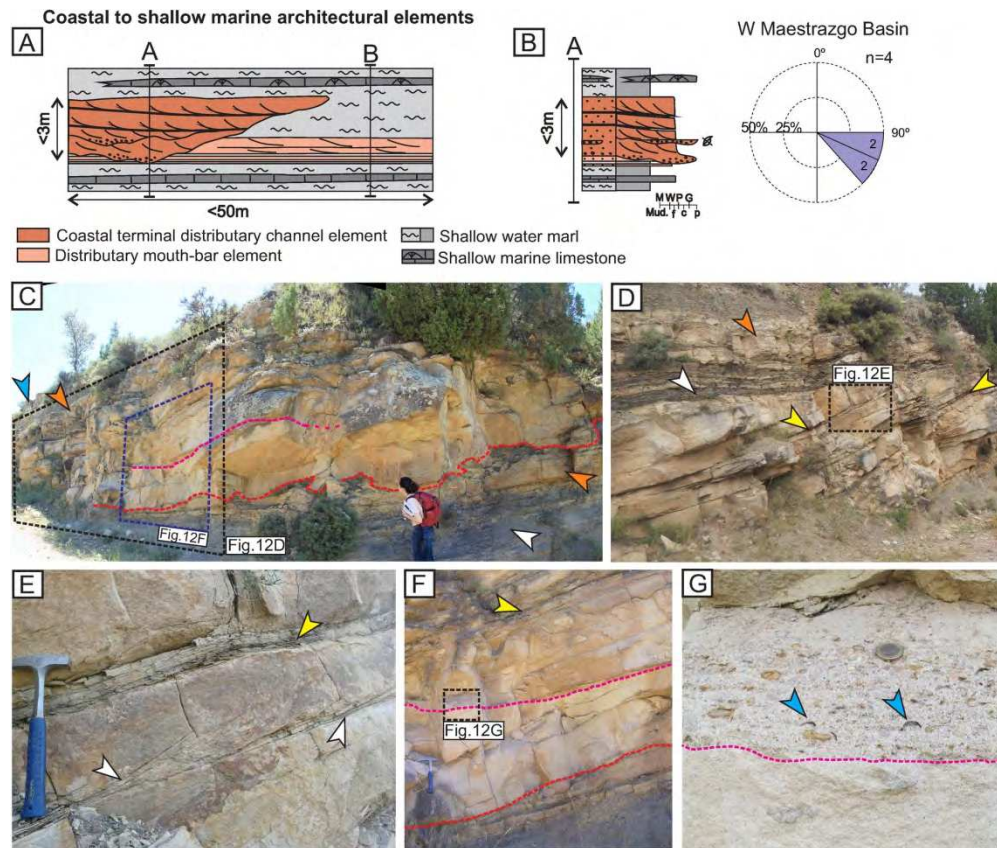


Fig. 12. Coastal to shallow marine architectural elements. A) Schematic diagram of the coastal to shallow marine architectural elements indicating the position of the logs shown in Fig. 12B and 13A. B) Log of the coastal terminal distributary channel architectural element (bracket in the diagram shows the location of the log in Fig. 12A; see Fig. 2 for legend) and palaeocurrents obtained in the W Maestrazgo Basin. C-D) Channelized sandstone (Formiche Alto area) displaying a basal erosive base (red dotted line) and large-scale cross strata. This body is interbedded with marl (white arrows), which, in turn, is interbedded with shallow marine limestone (blue arrow) and distributary mouth-bar sandstone (orange arrows). Note that sandstone displays an internal erosive surface (pink dotted line) filled by poorly-sorted conglomerate and also includes thin layers of carbonaceous-rich marl between the large-scale cross strata sets (yellow arrows). E) Detail of the thin layers of carbonaceous-rich marl located between large-scale cross-strata sets (yellow arrow) and draping the bottomsets and the lower part of foresets (white arrows). See location in Fig. 12D. F) Detail of the internal erosive surface (pink dotted line) filled by poorly-sorted conglomerate (see location in Fig. 12C). G) Field photograph of poorly-sorted mudstone pebbles including fragments of bivalves overlaying the internal erosive surface (pink dotted line). See location in Fig. 12F.

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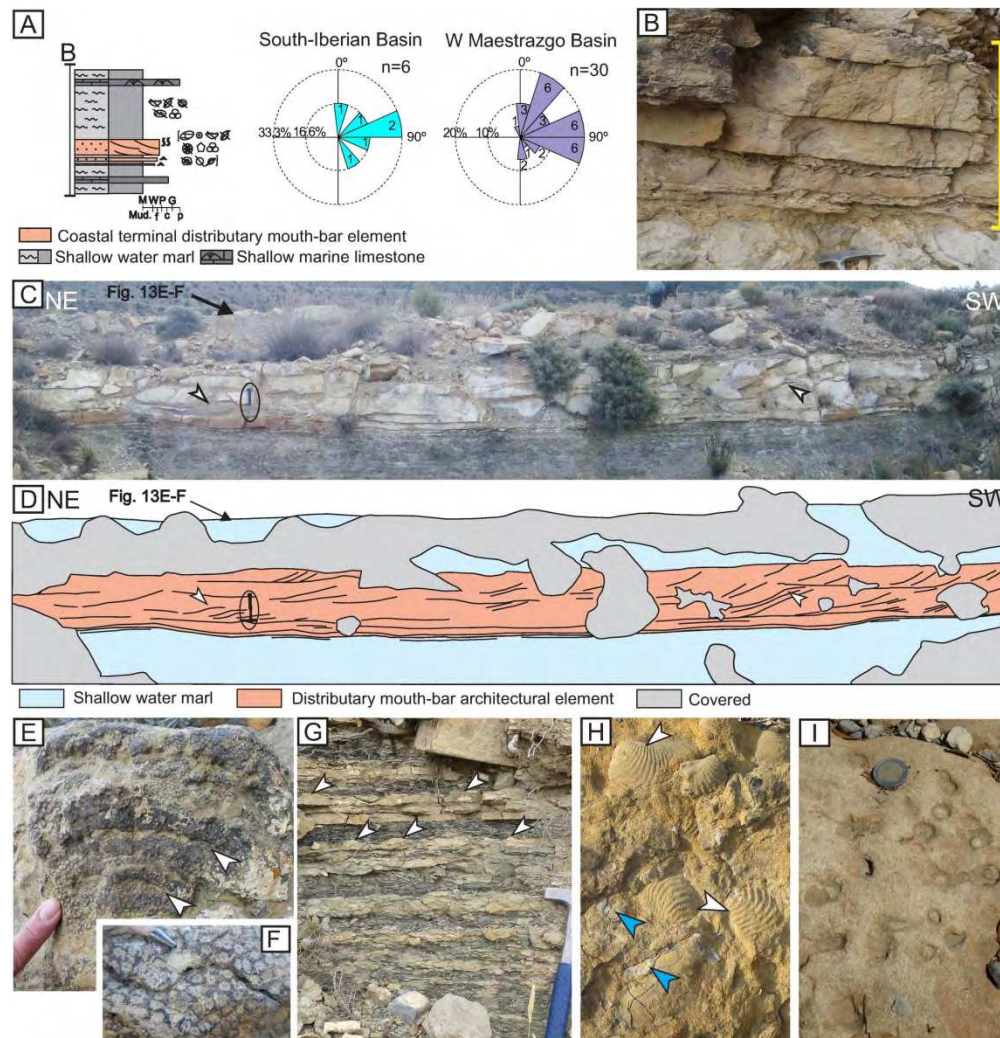


Fig. 13. Coastal to shallow marine architectural elements. A) Log of the distributary mouth-bar element (bracket in the diagram shows the location of the log in Fig. 12A; see Fig. 2 for legend) and palaeocurrents. B) Field photograph (Benagéber area) of a sandstone body displaying a coarsening- and thickening-upwards trend (yellow bracket) and interbedded with shallow marine limestone (greyish strata below and above yellow bracket). C-D) Field photograph (C) and line drawing (D) of the distributary mouth-bar element (Mora de Rubielos area) comprising a non-channelized sandstone body interbedded with marl that includes corals in life position (black arrow indicates location of corals). Note that sandstone displays large-scale and sigmoidal cross strata (white arrows). Hammer for scale. E) Field photograph of colonial corals observed in life position at the Mora de Rubielos area. Note that the white arrows point to its growth lines. See location of the coral at Fig. 13C-D. F) Detail of the septa of the coral shown in Fig. 13E. G) Field photograph (Mora de Rubielos area) of cm-thick sandstone displaying wave ripple strata at the top (white arrows) and interbedded with marl, giving rise to wavy bedding. H) Trigonioids and ostreids observed within a sandstone body (white and blue arrows, respectively) at the Mora de Rubielos area. I) Burrowing traces observed at the top of a sandstone body in the Formiche Alto area.

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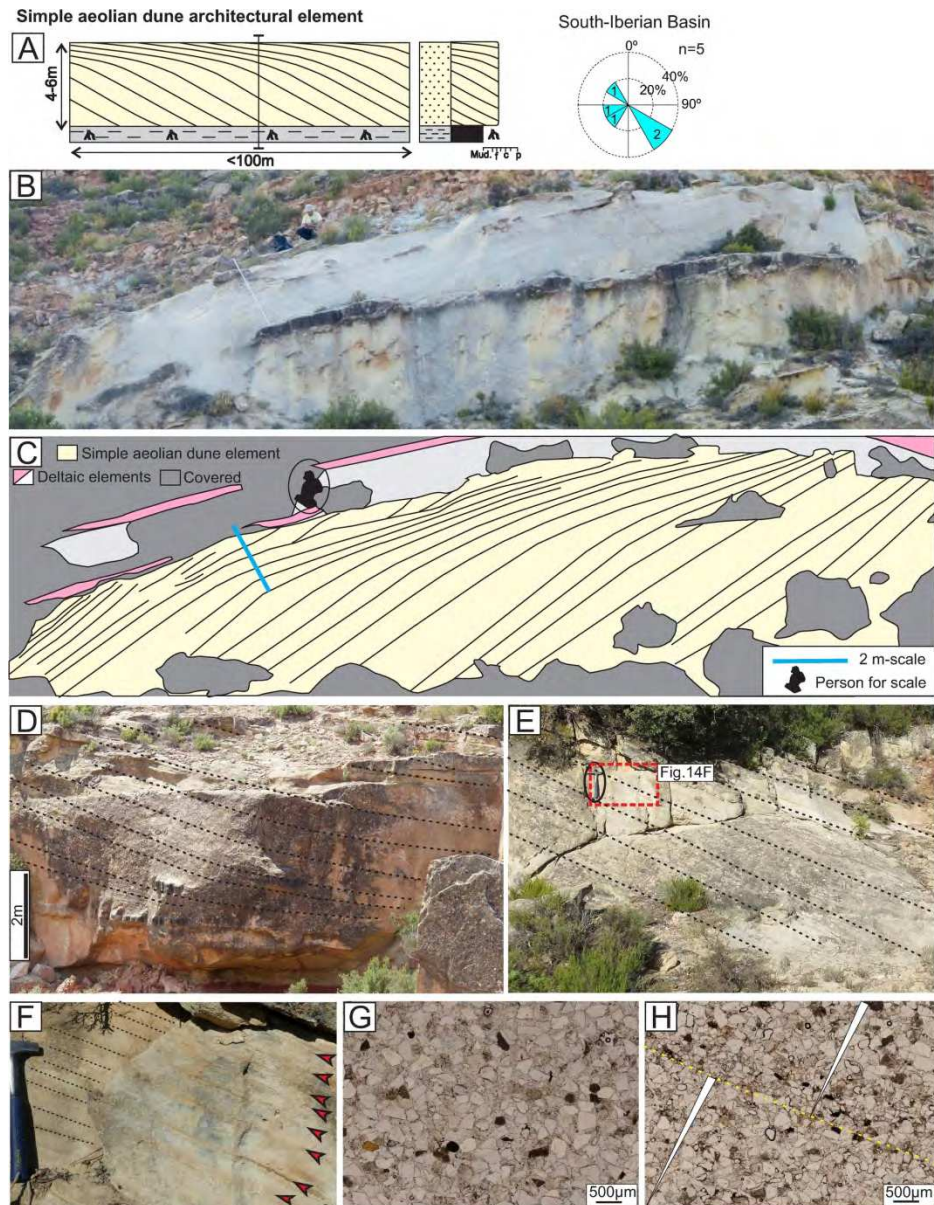


Fig. 14. Simple aeolian dune architectural element. A) Schematic diagram and log of the simple aeolian dune architectural element (bracket in the diagram shows the location of the log, see Fig. 2 for legend) and palaeocurrents. B-C) Field photograph (B) and line drawing (C) of a sandstone body displaying a 6 m-thick large-scale cross strata set. Large-scale cross strata set is made up of convex-up foresets passing upwards to low-angle inclined topsets. D) Field photograph of a metre-thick sandstone body displaying a single set of large-scale cross strata. E) Metre-thick sandstone body comprising a 4 m-thick large-scale cross strata set. Hammer for scale (black circle). F) Detail of large-scale cross strata set observed in Fig. 14E. Large-scale cross strata set is made up of successive cm-thick inversely graded strata. Note that the contact between each stratum is sharp (red arrows). Hammer for scale. G) Transmitted light photomicrograph of simple dune aeolian sandstone displaying well-sorted subrounded to subangular grains. H) Transmitted light photomicrograph of sandstone strata displaying inverse grain size grading. All photographs were taken at the Riodeva area.



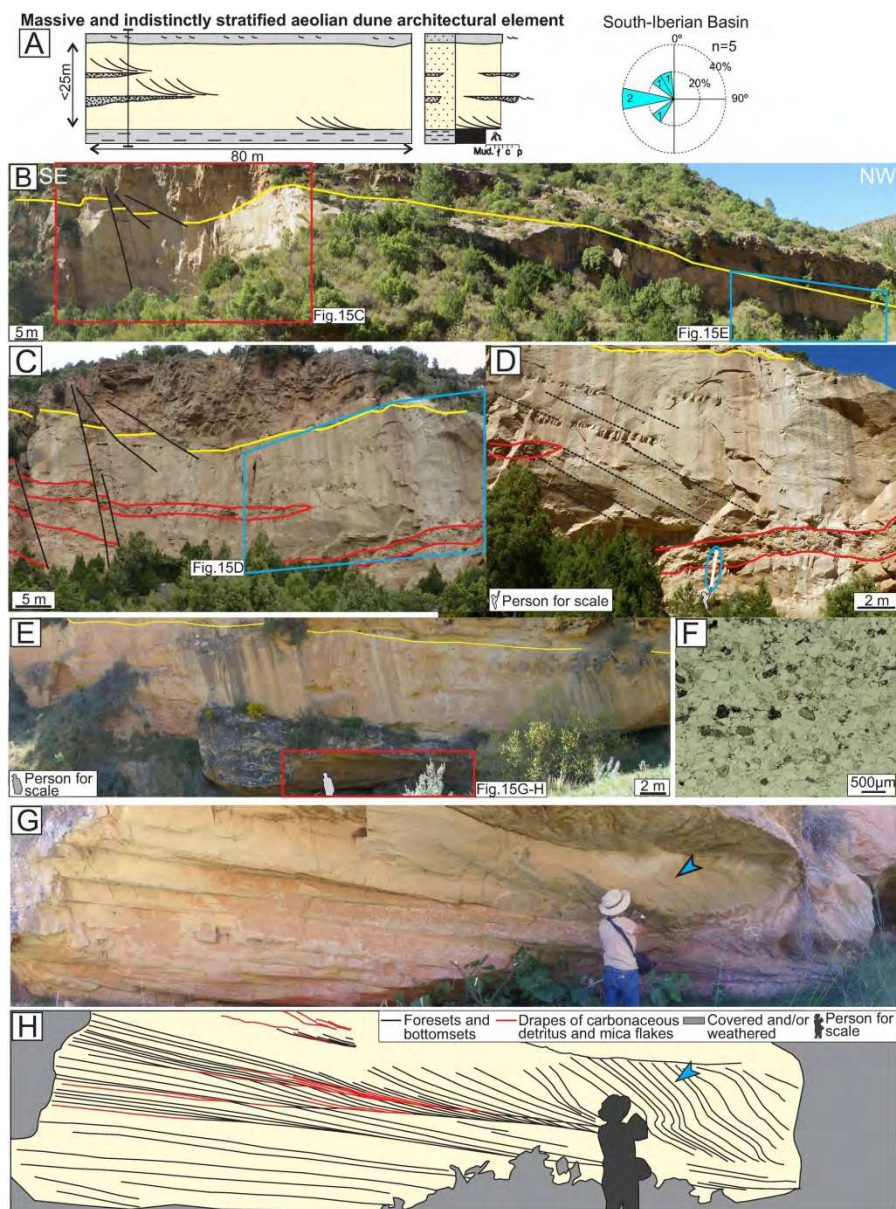


Fig. 15. Massive and indistinctly stratified aeolian dune architectural element. A) Schematic diagram and log of the massive and indistinctly stratified aeolian dune architectural element (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents. B) Field photograph of massive and indistinctly stratified aeolian dune sandstone overlain by the multistorey fluvial channel architectural element (its base is indicated with a yellow line). Black lines represent faults. C) Field photograph of massive and indistinctly stratified aeolian dune sandstone, which is laterally interbedded with conglomerate bodies of the ephemeral fluvial channel architectural element (delimited by red lines). D) Field photograph of massive and indistinctly stratified sandstone interbedded with conglomerate bodies (delimited by red lines). Sandstone displays poorly preserved large-scale cross strata (foresets are outlined with black lines). Note that the blue circle shows a 2 m large pocket rule (white line). E) Field photograph of massive and indistinctly stratified aeolian dune sandstone overlain by the multistorey fluvial channel architectural element (its base is indicated with a yellow line). F) Transmitted light photomicrograph of sandstone displaying subangular to subrounded and well-sorted grains. G-H) Field photograph (G) and line drawing (H) of sandstone displaying large-scale cross strata in which foresets pass downwards to laterally continuous bottomsets. Carbonaceous

detritus and mica flakes drape some bottomsets and the lowermost part of some foresets. Note the high-angle foresets displayed by the cross strata set to the right of the photograph (blue arrow). All photographs were taken at the Riodeva area.

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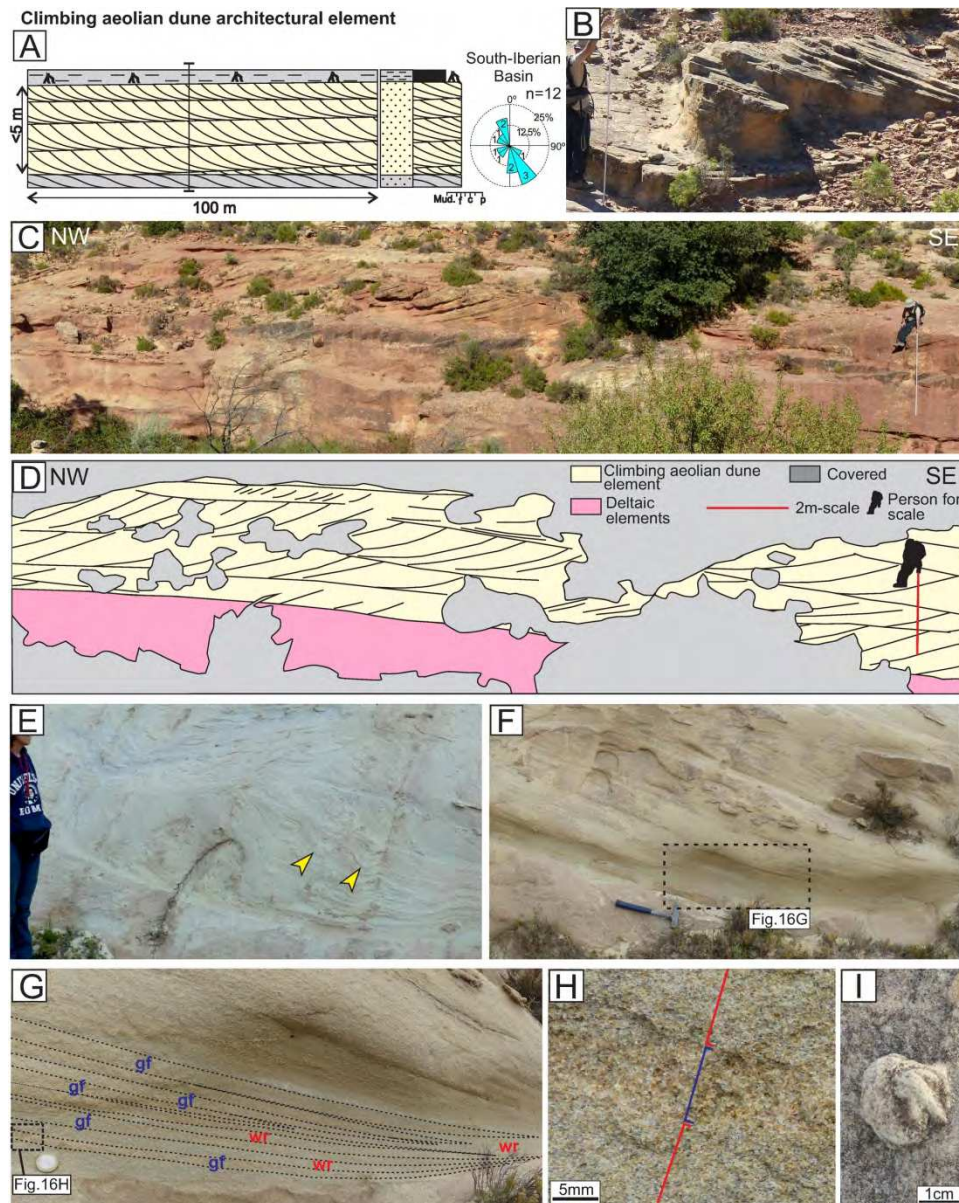


Fig. 16. Climbing aeolian dune architectural element. A) Schematic diagram and log of the climbing aeolian dune architectural element (bracket in the diagram shows the location of the log; see Fig. 2 for legend) and palaeocurrents. B) Field photograph of sandstone displaying a large-scale cross stratified set, at least 2 m thick (note that the person in the photograph is 1.65 m tall). C-D) Field photograph (C) and line drawing (D) of sandstone displaying large-scale tangential cross strata sets. Individual sets are delimited by low-angle inclined bounding surfaces, which dip in the opposite direction to the foresets dip. E) Field photograph of large-scale and high-angle cross strata sandstone whose foresets are slightly deformed (yellow arrows). F) Field photograph of tangential cross strata sandstone. G) Detail of the lower part of foresets and bottomsets of large-scale cross strata sandstone. Foresets comprise cm-thick strata pinching out downwards, which correspond to grainflow strata (gf). Grainflow strata are interbedded with cm-thick strata pinching out upwards, corresponding to wind ripple strata (wr). H) Detail of grainflow strata made up of fine- to medium-grained sandstone (blue bracket) and wind ripple strata made up of very fine- to fine-grained sandstone (red brackets). I) Sandstone pseudomorph after gypsum (desert rose formed by a rosette-like crystal aggregate). All photographs were taken at the Riodeva area.

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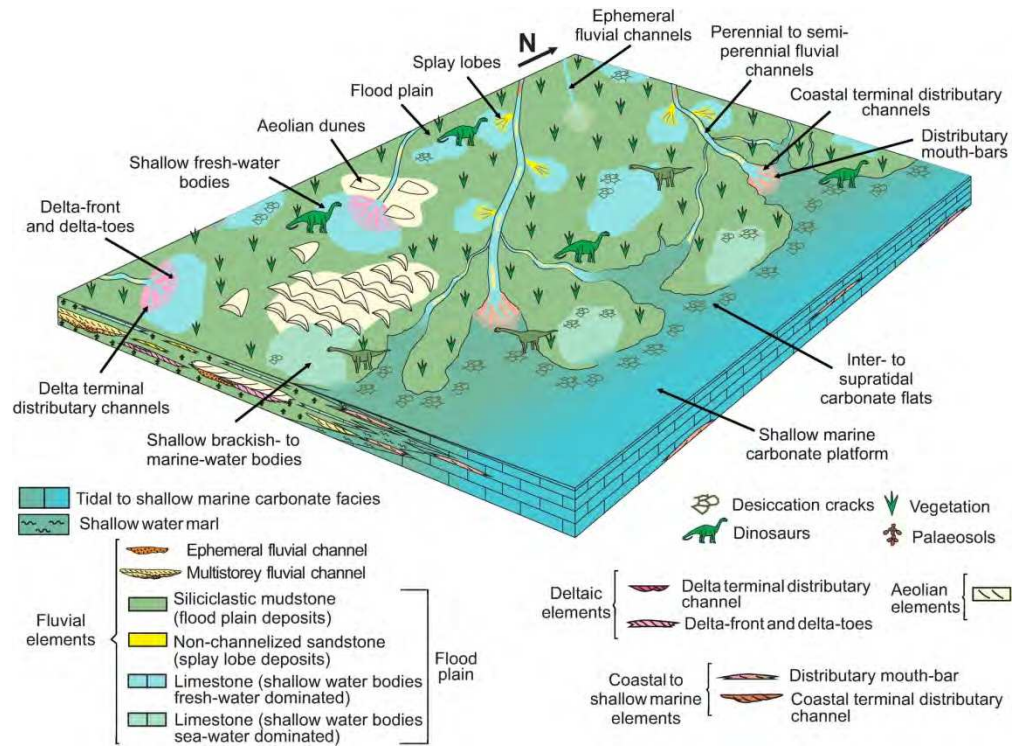


Fig. 17. Reconstruction of the different palaeoenvironments inhabited by dinosaurs of the Villar del Arzobispo Fm and of the lateral relationships between them (not at scale).

164x121mm (300 x 300 DPI)

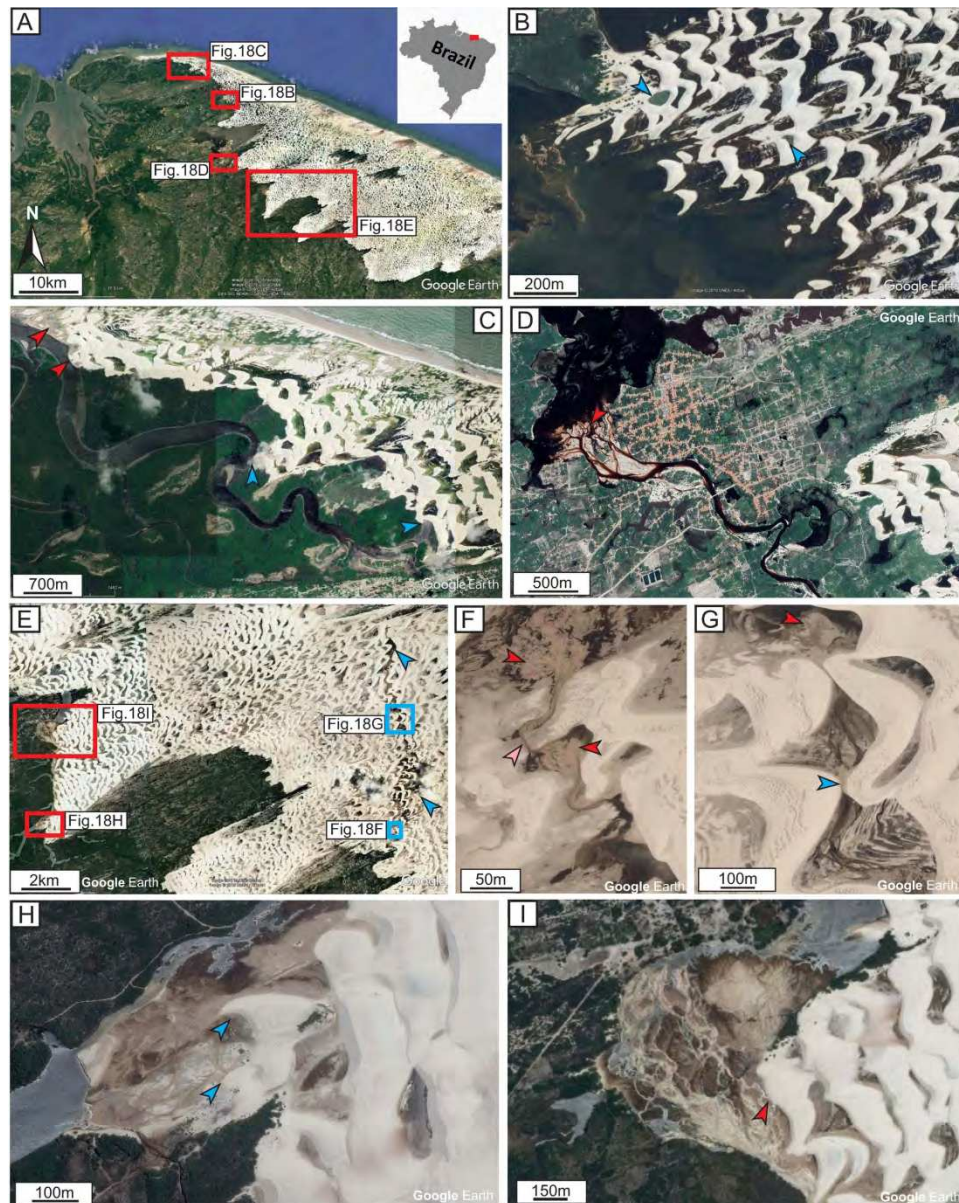


Fig. 18. Interactions between fluvial, tidal, deltaic, and aeolian environments observed in the Lençóis Maranhenses National Park (NE Brazil). Satellite images were taken from Google Earth in 2019. A) The coastal dune field of the Lençóis Maranhenses National Park (to the right) is located next to the estuary of the Mearim River (to the left). B) Aeolian dunes developing in a flooded area, at the end of the dune field. Note that stagnant water bodies develop in the interdune areas (blue arrows). C) Aeolian dunes approaching a tidal channel (blue arrows). Note how the aeolian interdunes may get flooded (red arrows). D) The coastal flood plain is crossed by the Grande River, which flows into a shallow water body in which deltaic sediments are deposited (red arrow). E) The coastal dune field is penetrated by the Negro River (blue arrows) and in its margin small deltas develop in stagnant water bodies (red squares). F-G) Interdune areas crossed by the Negro River. Note that the fluvial channel erodes the aeolian dune sediments in F (pink arrow) and that aeolian dunes migrate over the fluvial channel in G (blue arrow). Note that small deltas develop in the interdune areas (red arrows). H-I) Deltas developing in the margins of the dune field. Note that the aeolian dunes migrate over the delta plain in H (blue arrows) and that the distributary channels rework the aeolian dune sediments in I (red arrow).

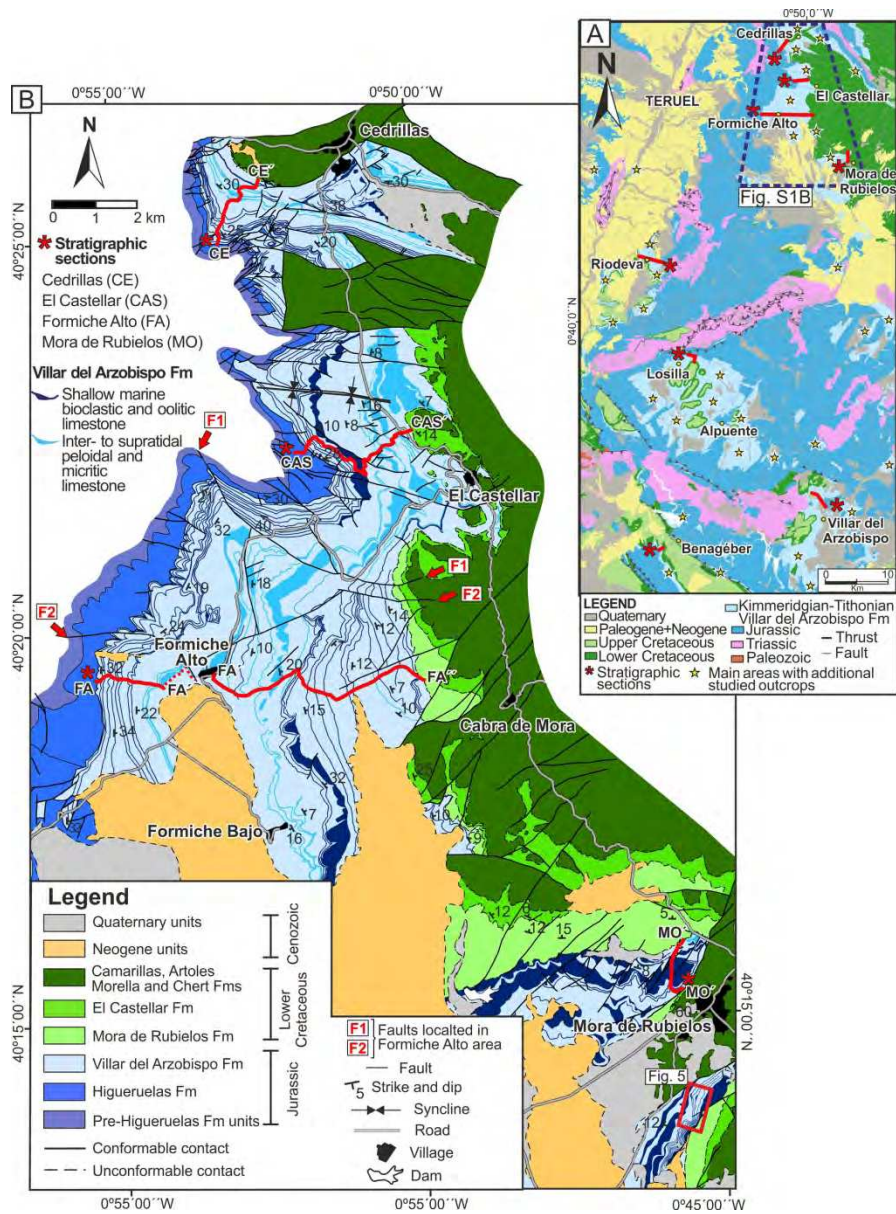
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**Table 1.** Summary of the essentially siliciclastic coastal and alluvial architectural elements of the Villar del Arzobispo Fm in the South-Iberian and western Maestrazgo basins. See Fig. 2 for location of the architectural elements. The references are cited in the main text.

Depositional settings	Architectural elements	Sedimentary features and fossil content	Sedimentary structures	Stratigraphic position and occurrence in sections	Associated deposits	Environmental interpretation
Fluvial	Ephemeral fluvial channel	<p><b>Composition and sorting:</b> very poorly-sorted conglomerate. Commonly clast-supported. Subangular to subrounded mud, carbonate and sandstone clasts (&lt;20 cm), locally rounded quartzite pebbles (&lt;6cm).</p> <p><b>Thickness and vertical arrangement:</b> dm- to m-thick bodies (&lt;3 m) with erosive bases (commonly symmetrical and slightly incisive, locally asymmetrical and very incisive) and short lateral extent (&lt;10 m).</p> <p><b>Fossil content:</b> fragments of tree trunks and dinosaur bones</p> <p><b>Observations:</b> more abundance of quartzite pebbles upwards in the SUP of the South-Iberian Basin sections.</p>	<p><b>Tractive structures:</b> large-scale cross strata (set thickness &lt;3 m)</p> <p><b>Palaeocurrents:</b></p> <ul style="list-style-type: none"> <li>- South-Iberian Basin: transport to the W-NW and the NE-SE.</li> <li>- W Maestrazgo Basin: transport to the S-SW and the SE.</li> </ul>	<p><b>South-Iberian Basin:</b></p> <ul style="list-style-type: none"> <li>- CLP: Riodeva</li> <li>- SUP: Riodeva, Benagéber and Villar del Arzobispo</li> </ul> <p><b>W Maestrazgo Basin:</b></p> <ul style="list-style-type: none"> <li>- CLP: Cedrillas</li> <li>- SUP: Cedrillas, El Castellar and Formiche Alto</li> </ul>	Interbedded with flood plain and massive and indistinctly stratified aeolian dune elements. Overlain by delta-toe and simple and climbing aeolian dune elements.	Ephemeral fluvial channels developed during periods of intense rainfalls and in which conglomerates were deposited under episodic and flash flows.
	Multistorey fluvial channel	<p><b>Composition and sorting:</b></p> <ul style="list-style-type: none"> <li>- Sandstone: medium- to coarse-grained, occasionally fine-grained. Moderately- to poorly-sorted.</li> <li>- Conglomerate: very poorly-sorted, commonly clast-supported. Medium to coarse-grained sandy matrix. Minor pebbly sandstone. Subangular to subrounded mud, carbonate and sandstone clasts (&lt;8cm), locally rounded quartzite clasts (&lt;5cm). Conglomerate overlies erosive bases and internal erosive surfaces.</li> </ul> <p><b>Thickness and vertical and lateral arrangement:</b> m-thick bodies (&lt;15 m) with erosive bases and great exposed lateral extent (&lt;250m). Common fining-upwards trend. Occurrence of large internal erosive surfaces.</p> <p><b>Fossil content:</b> fragments of tree trunks (up to few meters in size) and other plant remains (up to 30 cm in size).</p> <p><b>Observations:</b> more abundance of quartzite pebbles upwards in the SUP of the South-Iberian Basin sections.</p>	<p><b>Tractive structures:</b> large-scale cross strata in sandstone and conglomerate (set thickness &lt;1.5m). Local upwards decrease of set thickness. Locally thin layers of siliciclastic mudstone with abundant carbonaceous detritus are interbedded with cross strata sandstone sets and/or at the lower part of foresets and bottomsets. Occasional supercritical flow sedimentary structures (convex-up low-angle cross strata and scour and fill structures filled by backset and foreset strata that flatten upward in places).</p> <p><b>Palaeocurrents:</b></p> <ul style="list-style-type: none"> <li>- South-Iberian Basin: main transport to the NE-S, minor to the W-N.</li> <li>- W Maestrazgo Basin: transport to the NE, minor to the N and E-SE.</li> </ul>	<p><b>South-Iberian Basin:</b></p> <ul style="list-style-type: none"> <li>- CLP: Villar del Arzobispo</li> <li>- SUP: all sections</li> </ul> <p><b>W Maestrazgo Basin:</b></p> <ul style="list-style-type: none"> <li>- CLP: El Castellar and Formiche Alto</li> <li>- SUP: all sections</li> </ul>	Interbedded with flood plain and simple, climbing and massive and indistinctly stratified aeolian dune elements. Overlying massive and indistinctly stratified aeolian element. Overlain by delta elements.	Perennial to semi-perennial fluvial channels characterized by episodic and seasonal discharge.
	Flood plain	<p><b>Composition, components, texture and/or sorting:</b></p> <ul style="list-style-type: none"> <li>- Siliciclastic mudstone: typically reddish colour, and minor greyish and greenish color.</li> <li>- Sandstone: very fine- to medium-grained. Well- to moderately-sorted.</li> <li>- Limestone: oncolitic and stromatolitic limestone, with variable amounts of quartz grains and local poorly-sorted bioclasts and ooids.</li> </ul> <p><b>Thickness and vertical and lateral arrangement:</b></p> <ul style="list-style-type: none"> <li>- Sandstone: dm- to m-thick bodies (&lt;60cm) with tabular or flat-convex-up geometries and short lateral extent (&lt;40m). Tabular sandstone may be also arranged in coarsening and thickening-upwards bodies (&lt;1.5 m).</li> <li>- Limestone: dm- to m-thick bodies (&lt;30 cm), locally with erosive bases and short lateral extent (&lt;3m)</li> </ul> <p><b>Fossil content:</b> dinosaur bones in siliciclastic mudstone and sandstone, plant remains in sandstone and bioclasts in limestone (fragments of bivalves, including ostreids, scarce benthic foraminifera, echinoid spines, gastropods, ostracods, charophytes and very scarce corals).</p>	<p><b>Tractive structures:</b></p> <ul style="list-style-type: none"> <li>- Sandstone: parallel lamination followed upwards by current ripples (climbing ripples) and locally by wave ripples. Large-scale cross strata, sigmoidal cross strata.</li> </ul> <p><b>Palaeocurrents:</b></p> <ul style="list-style-type: none"> <li>- South-Iberian Basin: main transport to the W-SW, minor to the NE.</li> <li>- W Maestrazgo Basin: main transport to the E-NE.</li> </ul> <p><b>Bioturbation:</b> burrowing traces in sandstone and micritic limestone.</p> <p><b>Subaerial exposure features</b> (top of beds): edaphic features (carbonate nodules in siliciclastic mudstone, mottling and root traces in siliciclastic mudstone and sandstone) and dinosaur tracks in siliciclastic mudstone, sandstone and limestone.</p>	<p><b>South-Iberian Basin:</b></p> <ul style="list-style-type: none"> <li>- CLP: Riodeva and Villar del Arzobispo</li> <li>- SUP: all sections</li> </ul> <p><b>W Maestrazgo Basin:</b></p> <ul style="list-style-type: none"> <li>- CLP: all sections</li> <li>- SUP: all sections</li> </ul>	Interbedded with ephemeral and multistorey fluvial channel, simple and climbing aeolian elements and tidal and shallow marine limestone. Overlying the delta terminal distributary channel, delta-front and distributary-mouth bar elements. Overlain by the delta-toe and the massive and indistinctly stratified aeolian dune elements.	Flood plain located in alluvial to coastal areas that underwent periods of subaerial exposure and paleosol development, as well as deposition of overbank splay lobes during flood events and in which shallow fresh, brackish and marine water bodies developed.

Deltaic	Delta-toe	<p><b>Composition and sorting:</b> - Carbonaceous-rich, dark grey siliciclastic mudstone - Sandstone: very fine-grained. Well-sorted</p> <p><b>Thickness and vertical and lateral arrangement:</b> - Carbonaceous-rich, dark grey siliciclastic mudstone: &lt; 50cm of thickness and great exposed lateral extent (&lt;100m) - Sandstone: mm- to cm-thick discontinuous layers</p> <p><b>Fossil content:</b> plant remains (carbonaceous detritus)</p>	<p><b>Overall thickness and vertical and lateral arrangement:</b> Coarsening- and thickening- upwards dm- to m-thick successions (&lt;2m) with &lt;100m of exposed lateral extension, composed, from base to top, of delta-toe, delta-front and delta terminal distributary channel elements. Vertical stacking of individual deltaic successions producing composite bodies (&lt;10m) with great exposed lateral extent (&lt;200 m).</p>	<p><b>Tractive structures:</b> current ripples in sandstone <b>Bioturbation:</b> Dinosaur tracks</p>	<p><b>South-Iberian Basin:</b> - SUP: Riodeva, Losilla-Alpuente and Villar del Arzobispo <b>W Maestrazgo Basin:</b> - SUP: Cedrillas</p>	Overlying flood plain and ephemeral and multistorey fluvial channel elements. Overlain by delta-front element.	Delta-toe sediments deposited by settling down from suspension of fine material. Siliciclastic input.	Deposition of deltaic sediments in shallow water bodies located in the flood plain. Probably freshwater; marine influence is not discarded.
	Delta-front	<p><b>Composition and sorting:</b> very fine- to medium-grained, well-sorted sandstone. <b>Thickness and vertical and lateral arrangement:</b> dm- to m-thick sandstone (&lt; 2m) and great exposed lateral extent (&lt;100m) <b>Fossil content:</b> plant remains (carbonaceous detritus)</p>		<p><b>Tractive structures:</b> clinofolds with low-angle and large laterally-continuous foresets. Drapes of carbonaceous detritus at the lower part of foresets, locally extend up to the topsets. <b>Palaeocurrents:</b> - South-Iberian Basin: main transport to the W-NW and S, minor to the NE. <b>Bioturbation:</b> local burrowing traces.</p>	<p><b>South-Iberian Basin:</b> - SUP: Riodeva, Losilla-Alpuente and Villar del Arzobispo <b>W Maestrazgo Basin:</b> - SUP: Cedrillas</p>	Overlying delta-toe element. Overlain by delta terminal distributary channel, flood plain and simple or climbing aeolian dune elements.	Sandy delta-front sediments deposited by unconfined flows. Carbonaceous detritus deposited during periods of low flow.	
	Delta terminal distributary channel	<p><b>Composition and sorting:</b> fine- to medium-grained, well-sorted sandstone. <b>Thickness and vertical and lateral arrangement:</b> dm- to m-thick bodies (&lt;1.5m) with erosive bases and short lateral extent (&lt;10m)</p>		<p><b>Tractive structures:</b> Large-scale cross strata. Locally backset or upward flattening strata. <b>Palaeocurrents:</b> - South-Iberian Basin: main transport to the NE and S, minor to the W and SSW</p>	<p><b>South-Iberian Basin:</b> - SUP: Riodeva, Losilla-Alpuente and Villar del Arzobispo <b>W Maestrazgo Basin:</b> - SUP: Cedrillas</p>	Overlying delta-front element. Overlain by flood plain and simple or climbing aeolian dune elements.	Delta terminal distributary channels migrating in a deltaic plain	
Coastal to shallow marine	Coastal terminal distributary channel	<p><b>Composition and sorting:</b> fine- to medium-grained, well-sorted sandstone. Local poorly-sorted conglomerate (mudstone subangular to subrounded mudstone pebbles and scarce bioclasts) with medium- to coarse-grained sandy matrix. <b>Thickness and vertical and lateral arrangement:</b> m-thick bodies (&lt;3m) with erosive bases and &lt;50m of exposed lateral extent. Occurrence of internal erosive surfaces. <b>Fossil content:</b> occasional fragments of bivalves in conglomerate.</p>		<p><b>Tractive structures:</b> large-scale cross strata. Local thin layers of carbonaceous-rich marl interbedded with cross strata sandstone sets and/or at the lower part of foresets and bottomsets <b>Palaeocurrents:</b> -W Maestrazgo Basin: main transport to the E-SE.</p>	<p><b>South-Iberian Basin:</b> - CLP: Villar del Arzobispo <b>W Maestrazgo Basin:</b> - SUP: Formiche Alto and Mora de Rubielos</p>	Interbedded with distributary mouth-bar element and marl.	Coastal terminal distributary channels flowing into coastal and shallow marine areas	
	Distributary mouth-bar	<p><b>Composition and sorting:</b> fine- to medium-grained, well-sorted sandstone <b>Thickness and vertical and lateral arrangement:</b> cm- to m-thick bodies (&lt;2.50m) with flat bases and flat or convex-up tops and short lateral extent (&lt;20m). Occasional coarsening and thickening upwards trend. <b>Fossil content:</b> occasional fragments of ostreids, trigonioids and other bivalves, corals, echinoderms, gastropods, large benthic foraminifera, miliolids, serpulids and plant remains.</p>		<p><b>Tractive structures:</b> - Dm- to m-thick bodies: large-scale cross strata, sigmoidal cross strata, occasional wave and/or current ripples at the top - Cm-thick bodies: wave and/or current ripples at the top, wavy bedding. <b>Palaeocurrents:</b> - South-Iberian Basin: main transport to the E, minor to the N and SE -W Maestrazgo Basin: main transport to the NE and E, minor to the N and S. <b>Bioturbation:</b> burrowing traces at the top</p>	<p><b>South-Iberian Basin:</b> - CLP: all sections - SUP: Losilla-Alpuente and Villar del Arzobispo <b>W Maestrazgo Basin:</b> - CLP: all sections - SUP: all sections</p>	Interbedded with coastal terminal distributary channel element and marl or with tidal and shallow marine limestone.	Distributary mouth-bars formed by the spreading out of an unconfined flow at the terminus of distributary rivers in coastal and shallow marine areas.	

Aeolian	Simple aeolian dune	<p><b>Composition and sorting:</b> fine- to medium-grained, well-sorted sandstone. Locally very scattered rounded to subrounded muddy-soft pebbles and rounded quartzite pebbles (&lt;1.4 cm).</p> <p><b>Thickness and vertical and lateral arrangement:</b> m-thick bodies (&lt;6m) with flat bases and tops and great exposed lateral extent (&lt;100m).</p> <p><b>Fossil content:</b> plant remains (carbonaceous detritus)</p>	<p><b>Tractive structures:</b> single large-scale cross strata sets (&lt;6 m). High angle foresets (&lt;36°). Foresets locally pass upwards to low-angle topsets.</p> <p><b>Palaeocurrents:</b> - South-Iberian Basin: main transport to the SE, W-SW or the NW.</p>	<p><b>South-Iberian Basin:</b> - SUP: Riodeva, Losilla-Alpuente and Benagéber</p>	<p>Interbedded with flood plain element. Locally overlies ephemeral fluvial channel, delta terminal distributary channel or delta-front elements.</p>	<p>Transverse and dome-shaped aeolian dunes migrating in the flood plain</p>
	Massive and indistinctly stratified aeolian dune	<p><b>Composition and sorting:</b> fine- to medium-grained, well-sorted sandstone.</p> <p><b>Thickness and vertical and lateral arrangement:</b> m-thick bodies (&lt;25 m) with flat bases and tops and great exposed lateral extent (&lt;80 m).</p> <p><b>Fossil content:</b> local plant remains (carbonaceous detritus)</p> <p><b>Observations:</b> massive appearance.</p>	<p><b>Tractive structures:</b> local poorly-preserved large-scale cross strata (set thickness &lt;7m), high angle foresets (&lt;30°). Local drapes of carbonaceous detritus and mica flakes at laterally continuous bottomsets and the lower part of foresets.</p> <p><b>Palaeocurrents:</b> - South-Iberian Basin: main transport to the W-NW, minor to the SW.</p>	<p><b>South-Iberian Basin:</b> - SUP: Riodeva</p>	<p>Interbedded with ephemeral fluvial channel element. Overlying coastal flood plain element. Overlain by multistorey fluvial channel element.</p>	<p>Aeolian dunes subjected to episodic flooding, causing the inundation of interdune areas and the development of ephemeral channels between aeolian dunes.</p>
	Climbing aeolian dune	<p><b>Composition and sorting:</b> fine- to medium-grained, well-sorted sandstone. Local very scattered subrounded mud pebbles and rounded quartzite pebbles (&lt;1.5 cm)</p> <p><b>Thickness and vertical and lateral arrangement:</b> m-thick bodies (&lt;5 m) with great exposed lateral extent (&lt;100 m)</p> <p><b>Observations:</b> scarce occurrence of desert roses.</p>	<p><b>Tractive structures:</b> cosets of large-scale cross strata (set thickness &lt;2 m). Low-angle inclined (&lt;10°) and laterally continuous (&lt;50m) set bounding surfaces. High angle tangential foresets (&lt;32°). Local slightly deformed foresets.</p> <p><b>Palaeocurrents:</b> - South-Iberian Basin: transport to the SE or the NW</p>	<p><b>South-Iberian Basin:</b> - SUP: Riodeva and Benagéber</p>	<p>Interbedded with multistorey fluvial channel element. Overlying ephemeral fluvial channel element, delta terminal distributary channel and delta-front elements. Overlain by flood plain element.</p>	<p>Climbing aeolian dunes that migrated in the flood plain</p>



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