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1 **Reconstruction of the sedimentary heterogeneity in outcropping deep-water channel-**  
2 **levee deposits (Taza-Guercif Basin, late Tortonian, NE Morocco)**

3 Invernizzi, D.<sup>1\*</sup>, Pizzutto, M.<sup>1</sup>, Felletti, F.<sup>1</sup>, Pantopoulos, G.<sup>1</sup>, Marini, M.<sup>1</sup>, McArthur, A.<sup>2</sup>

4 <sup>1</sup> Dipartimento di Scienze della Terra “A. Desio”, Università degli Studi di Milano, Milan,  
5 Italy; <sup>2</sup> School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, United  
6 Kingdom

7 *\*Corresponding author: daniele.invernizzi@unimi.it*

8 **Keywords:** *submarine channel, Rifian Corridor, facies architecture, outcrop, lateral*  
9 *accretion packages, statistics, Miocene, Tachrift*

10  
11 **ABSTRACT**

12 In the context of subsurface modelling of deep-water sedimentary systems, it is crucial to  
13 confidently identify turbidite channel-levee architectural elements in ancient strata. This  
14 becomes particularly critical when working with data of limited resolution, such as wireline  
15 well or seismic data. Similarly, in areas with limited outcrop exposure, establishing the  
16 temporal relationships of channel-levee systems relies predominantly on inference.  
17 Moreover, the paucity of well-documented outcrops exhibiting continuous sedimentary  
18 record between channel-fill and overbank sediments remains a challenge.

19 This work presents the sedimentary architecture of channel-levee Complex 7, one of the  
20 late Tortonian (Miocene) slope channel-levee complexes constituting the Tachrift System,  
21 which records the infill of the Taza-Guercif Basin in NE Morocco. The basin was on the  
22 southern margin of an ancient seaway (the Rifian Corridor) connecting the paleo-  
23 Mediterranean Sea and the Atlantic Ocean. The objective of this study is to comprehensively  
24 document the geometry, as well as the vertical and lateral heterogeneity of facies

25 assemblages in the northwestern part of Complex 7. This approach encompasses  
26 geological mapping, detailed facies analysis from thirty-five sedimentary logs, and the  
27 implementation of physical stratigraphic correlations.

28 Facies associations and stratigraphic architecture of Complex 7 reveal an eastward channel  
29 migration and a subsequent increase in flow energy.

30 Due to exceptional 3D exposures, this study offers a detailed sedimentological  
31 characterization of channel fills and their correlative levee deposits. It also provides valuable  
32 insights into the evolution of the parent channel, from its formation to its abandonment, while  
33 facilitating sub-seismic-scale lithological calibration for subsurface analogs.

#### 34 **INTRODUCTION**

35 Over the past decades, there has been notable progress in the sedimentological  
36 comprehension of deep-water channel systems (McHargue et al., 2011; Talling et al., 2012;  
37 Janocko et al., 2013; Talling et al., 2015; Fonnesu and Felletti, 2019; Vendettuoli et al.,  
38 2019; Hubbard et al., 2020; Tek et al., 2020; Reguzzi et al., 2023). Particular interest  
39 concerns the definition and composition of architectural elements of turbidite channel-levees  
40 (Kane et al., 2007, Morris, 2014, de Leeuw et al., 2018, Cunningham and Arnott, 2021, La  
41 Marca et al., 2023; Lewis et al., 2023; Pizzi et al., 2023; McArthur et al., 2024), sedimentary  
42 deposits found on both continental slopes and basin plains (Janocko et al., 2013). These  
43 often relatively coarse-grained architectural elements, characterized by their favorable  
44 porosity and permeability properties, are appealing targets for diverse applications such as  
45 CO<sub>2</sub> sequestration, underground gas storage, and groundwater exploitation (Weimer et al.,  
46 2000; Pettingill and Weimer, 2002; Abreu et al., 2003; Weimer and Pettingill, 2007; Marshall  
47 et al., 2016). As such, the sedimentary heterogeneity of channel-levees is important, as it  
48 plays a central role in the assessment of reservoir volumes and the optimization of

49 production (Kominz et al., 2011; Kane and Clare, 2019; Pohl et al., 2020; Bell et al., 2021;  
50 Valle-Falcones et al., 2023).

51 Despite advances in seismic data acquisition, which yield detailed 3D subsurface images  
52 (Wynn et al., 2007; Janocko et al., 2013; Jobe et al., 2015; Hubbard et al., 2020; Tek et al.,  
53 2021), resolution remains insufficient, and lithological information obtained from boreholes  
54 remains too sparse to comprehensively characterize the sedimentary character of channel-  
55 levee reservoir architecture (Stanbrook and Bentley, 2022). Consequently, comprehensive  
56 insights into the sedimentary heterogeneity and composition of discrete channel-levee  
57 architectural elements are lacking. In this context, well-exposed extensive outcrops are  
58 invaluable sources of information regarding the architecture of channelized turbidites and  
59 their bed-scale heterogeneity (Kane et al., 2007; Brunt et al., 2013; Morris, 2014; Hubbard  
60 et al., 2020; Kneller et al., 2020; Tek et al., 2020; Cunningham and Arnott, 2021; Reguzzi et  
61 al., 2023).

62 Although much work has been done to characterize outcropping channel fills, these are often  
63 of limited extent and lack detail to fully characterize channel fill across and along system,  
64 particularly into their correlative levees (cf. Pirmez and Imran, 2003; Kane et al., 2007;  
65 Vendettuoli et al., 2019; Reguzzi et al., 2023). As such, this study aims to provide a detailed  
66 outcrop characterization of a channel-levee complex to document the internal heterogeneity,  
67 and lateral and vertical stratigraphic evolution, of a well-exposed channel-levee complex.  
68 This complex (Complex 7 hereafter) is one of several superimposed channel-levee  
69 complexes belonging to the relatively fine-grained, sand-rich, Tachrift System, Taza Guercif  
70 Basin, NE Morocco (Fig. 1; Felletti et al., 2020, 2023). Complex 7 is approximately 30 meters  
71 thick and extends along a NW-SE-oriented continuous exposure of c. 2.5 km. Work focused  
72 on the northernmost outcrop of Complex 7, where a continuous 500-meter-wide transect,  
73 oriented approximately perpendicular to the paleoflow (N-NE), allows documentation of the

74 facies, sedimentary units, and facies associations, which are the building blocks of the  
75 channel-levee complex; from the channel axis into the correlative overbank.  
76 Characterization of the sedimentology of this channel-levee complex permits reconstruction  
77 of the evolution from a meandering to sinuous channel system, with implications for the  
78 distribution of heterogeneity and connectivity of sandstone in channel-levee systems.

## 79 **GEOLOGICAL SETTING**

### 80 *The Taza-Guercif Basin*

81 The Taza-Guercif Basin (NE Morocco, Fig.1A) is a remnant, together with the Gharb and  
82 Fes-Meknes Basins, of the Rifian Corridor (Capella et al., 2018), an ancient seaway that  
83 connected the Atlantic Ocean with the Mediterranean Sea during the Late Miocene (Bernini  
84 et al., 2000; Gelati et al., 2000). The Taza-Guercif Basin (Fig.1B) originated in the early  
85 Tortonian due to the combination of the advancing thrust sheets of the Rifian system to the  
86 north and the strike-slip tectonics in the Middle Atlas chain (Bernini et al., 2000; Capella et  
87 al., 2018; Gelati et al., 2000; Sani et al., 2000; Capella et al., 2018). The basin overlies a  
88 Cretaceous to Early Miocene unconformity resulting from tectonic inversion of Jurassic rift  
89 faults of the Middle Atlas (Bernini et al., 2000; de Lamotte et al., 2009). The marine  
90 transgression in the basin began during the late Tortonian period, marked by sedimentation  
91 of the Ras el Ksar Formation, a shallow marine deposit up to 500 meters thick (Fig. 1C;  
92 Krijgsman et al., 1999).

93 Continued transgression led to the deposition of the Melloulou Formation, characterized by  
94 interbedded hemipelagic marlstones and turbidites, recording the basin-deepening and  
95 sedimentation rates during the Tortonian (Fig. 1C; Krijgsman et al., 1999; Bernini et al.,  
96 2000; Gelati et al., 2000; Sani et al., 2000). In the early Messinian, a tectonically controlled  
97 regression resulted in deposition of the Gypsiferous marlstones and the sand/mudstone  
98 alternation of the Kef Ed Deba Formation (Gelati et al., 2000; Sani et al., 2000). Continued

99 uplift from 6.7 Ma resulted in termination of marine sedimentation (Krijgsman et al., 1999;  
100 Krijgsman and Langereis, 2000; Capella et al., 2018).

101

102

103

### *The Tachrift System*

104 The Tachrift System, along with the El Rhirane System, constitutes one of the two  
105 turbiditic series in the Melloulou Formation, exposed to the east and west of the Zobzit River,  
106 respectively (Fig. 1B, C). The Tachrift System was mapped as nine vertically stacked  
107 channel-levee complexes (*sensu* Sprague et al., 2005; Felletti et al., 2020; 2023; Reguzzi  
108 et al., 2023; Zuffetti et al., 2023), each separated by meters-thick marlstones (Felletti et al.,  
109 2020, 2023). The Tachrift System spans a period of approximately 0.5 million years, dating  
110 from 7.7 to 7.2 million years ago (Krijgsman and Langereis, 2000).

111 The focus of this paper is the northernmost outcrop of channel-levee complex 7 (Fig. 1C) of  
112 the Tachrift System (Felletti et al., 2020). Interpretations suggest that these complexes  
113 represent the sequential deposits of channel systems originating from the south, evolving  
114 along a basinal slope dipping northward in the Taza-Guercif Basin (Gelati et al., 2000; Pratt  
115 et al., 2016).

116 Recent studies on the Tachrift System addressed the sedimentary architecture of selected  
117 parts of channel-levee complexes 4-6, describing laterally accreted deposits accumulated  
118 at bends of sinuous meandering channels as the dominant channel-filling element (Reguzzi  
119 et al., 2023; Zuffetti et al., 2023; Marini et al., this volume; Pantopoulos et al., this volume).

120

## **MATERIAL AND METHODS**

121 The ca. 500-meter-wide part of outcrop belonging to Complex 7 (Fig. 2A), located in the  
122 northwesternmost area, was investigated through the acquisition of thirty-five detailed  
123 stratigraphic logs acquired along a section parallel to strike, roughly perpendicular to

124 direction of depositional flow (Fig. 2B). To achieve high resolution and precision, the logs  
125 were measured at an average spacing of 25 meters and geolocated using a Garmin GPS.  
126 A high-precision Jacob's staff with a laser pointer (Patacci, 2016), clinometer, and compass  
127 allowed accurately rapid long-distance measurements, i.e., of mudstone-rich intervals.

128 Logs were described at centimeter resolution with particular attention paid to recording mud-  
129 clast frequency and composition, sedimentary structures, fossil fragments, trace-fossil type  
130 and intensity, and organic matter. Also, the bed-base character (linear, undulating, or  
131 erosional) and associated paleocurrent information were recorded.

132 Correlations between logs were traced physically by walking out beds and tracing beds in  
133 photo-panels. In the rare absence of lateral outcrop continuity, correlations were achieved  
134 by comparison of stratigraphic patterns and facies associations. Subsequently, logs were  
135 digitized enabling quantitative data extraction, including bed thickness, grain, etc., which  
136 was conducted utilizing EasyCore®.

137 Various parameters were computed from field data to explore the internal heterogeneity of  
138 the studied complex. These parameters are: i) proportion of sedimentary structures, ii) net-  
139 to-gross (hereafter, NTG), iii) amalgamation ratio, iv) mud-clast-horizon thickness  
140 percentage, v) mean and basal grain size, vi) and bed thickness.

141 Sedimentary-structure proportions were determined by calculating the percentage of  
142 observed thickness of sedimentary structures in a specific interval. In this work the NTG was  
143 computed as the ratio of total sandstone and conglomerate thickness to total stratigraphic  
144 thickness for each log (*sensu* Macdonald et al., 2011; Kus et al., 2022). The amalgamation  
145 ratio was defined as the ratio between the number of amalgamation surfaces and the total  
146 number of event beds in a given stratigraphic interval (*sensu* Romans et al., 2009; Kus et  
147 al., 2022). The mud-clast-horizon thickness percentage is expressed as the percentage of  
148 the cumulative mud-clast-layer thicknesses vs. the stratigraphic thickness of the studied unit,

149 e.g., when stating mud-clasts reach 50%, this means that 50% of the unit thickness contain  
150 mud-clasts. For each log, grain-size data from the basal part of each bed and successive  
151 measurements at 1 mm intervals from the base to the top of each bed were utilized to  
152 calculate data on basal and mean grain size. Bed-thickness data were obtained by  
153 measuring sandstone and mudstone bed thicknesses with a resolution of 1 cm. Data plotting  
154 and analyses were conducted using Excel.

155 A deep-water “system”, here the Tachrift System, refers to a succession of multiple channel  
156 complexes (*sensu* Sprague et al., 2005) separated by fine-grained sediment, here  
157 marlstones, and according to Mutti (1992) and Normark et al. (1993) represents an ancient  
158 turbidite system, that is, the fossil remains of an entire episode of clastic accumulation in the  
159 deep sea. As defined by Sprague et al. (2002), Campion (2005) and Sprague et al. (2005),  
160 discussed by Pickering and Cantalejo (2015), and utilized by earlier works in the Taza-  
161 Guercif Basin (Felletti et al., 2020, 2023; Reguzzi et al., 2023), the term “complex” is used  
162 to describe a high-level assemblage of multiple channel fills, bounded below and above by  
163 significant hemipelagic deposits; hence this term is appropriate for the channel complex  
164 studied here, since it refers to packages with a scale similar to that of Complex 7 (Fig. 2;  
165 Gardner and Borer, 2000; Sprague et al., 2005; Cullis et al., 2018). The term “Unit” refers to  
166 a stratigraphic unit, with variable thickness and represents deposition during a given phase  
167 of channel evolution, comparable to a channel fill of Sprague et al. (2005). A unit is  
168 composed of a few to several architectural elements, each of which may be the preserved  
169 product of deposition in one more seafloor channels and their overbank. Architectural  
170 elements are the interpreted depositional bodies related to deposition from different types  
171 of channelized and overflowing flows, e.g., erosional channel-fills, lateral accreting  
172 packages, levees etc. Hence, any unit may be composed of multiple architectural elements.

173 The term “channel” has no hierarchical implications and refers to a geomorphological  
174 element of the seafloor.

175

176

## RESULTS

177 Complex 7 is here divided into five units based on physical correlations, facies, facies  
178 associations, and the hierarchical arrangement of major stratigraphic surfaces that can  
179 display erosional, depositional, or a combination of both features (Fig. 2B).

180

### *Sedimentary Facies*

181 Ten distinct sedimentary facies were identified based on lithology, grain size, sedimentary  
182 structures, thicknesses, and the ratio of sandstone to mudstone (Fig. 3). Among these  
183 facies, three are chaotic deposits (f1a, f1b, and f1c), one is a poorly sorted conglomerate  
184 (f2), five facies consist of sandstones (f3 to f7), and one relates to mudstones (f8).

185

#### Sand-dominated chaotic (f1a)

186 Observations: Facies f1a consists of sand-rich chaotic deposits (Figs. 3, 4A) ranging in  
187 thickness from 0.5 to 1 meter. Clasts comprise plastically deformed sandstones and  
188 polygenic granules to cobbles of Jurassic carbonates and sandstones. In the sand-rich  
189 matrix, mud-clasts ranging in diameter from 1 to 5 centimeters and rounded polygenic extra  
190 clasts (granules and pebbles) are observed. The base is erosional, and the top is commonly  
191 capped by mudstones.

192

*Process interpretation:* Cohesive, plastic, laminar sand-dominated debris flows, with a  
193 mixture of exotic, but mainly reworked, clasts are supported by the cohesiveness of the  
194 flow (Lowe, 1982).

195

#### Mud-dominated chaotic (f1b)

196 Observations: Facies f1b consists of mud-rich structureless deposits with thickness ranging  
197 from 1.5 to 3 meters (Figs. 3, 4B). Mud clasts, polygenic granules to pebbles clasts, and  
198 biogenic fragments (shells and corals) are observed in the matrix. Decimetric boulders of  
199 well-cemented, very fine to fine sandstone are often immersed in the matrix. The bases are  
200 commonly erosional, and the tops of these deposits are always eroded.

201 *Process interpretation:* Deposition due to a cohesive, plastic, laminar mud-dominated  
202 debris flow (Lowe, 1982).

203

204 Debrites (f1c)

205 Observations: This facies consists of sand-rich to silt-rich mudstones, with thickness ranging  
206 from 0.1 to 0.5 meters (Fig. 3). Occasionally, wood, coal fragments, and extraclasts  
207 (granules) from Jurassic carbonates and sandstones are observed. These deposits are non-  
208 graded, typically extremely bioturbated, and oxidated. No other sedimentary structures are  
209 recognizable. The base is commonly erosional, and the top of these deposits usually show  
210 erosional features.

211 *Process interpretation:* *En masse* freezing of a cohesive debris flow. During deposition the  
212 grains of different sizes were not segregated by differential setting (Talling et al., 2012).

213 Poorly sorted conglomerate (f2)

214 Observations: Poorly sorted, clast-supported granule to pebble conglomerate (Figs. 3, 4C).  
215 This facies is found in a single horizon of variable thickness, up to 1 meter. Polygenic clasts  
216 from the Jurassic basement are typically well-rounded with high sphericity. Clast contacts  
217 are tangential and rarely linear. Clast sorting varies from well to poorly sorted moving away  
218 from log-section 28.5 (Fig. 2). Rare clast imbrication was recorded. Fossil fragments,  
219 including shells, as well as reworked corals, are noticeable. The base of this horizon shows

220 erosional features. The top is normally eroded with preservation of rare thin mud-cap (a few  
221 centimeters).

222 *Process interpretation:* Traction-carpet sedimentation from a largely bypassing high-density  
223 turbidity current (Mutti and Normark, 1987).

224 Very thick-bedded massive amalgamated sandstone (f3)

225 Observations: Amalgamated sandstone beds of varying thicknesses, from 1 to 3 meters  
226 (Figs. 3, 4D). Consisting of coarse-to-medium to-coarse-grained, massive sandstones,  
227 normally grading to finer grain sizes towards the bed top. In these layers, coarse-grained  
228 lenses up to 0.5 meters thick, along with millimeter-scale (from 2 to 10 mm) traction-carpets  
229 were observed. Occasionally, reworked coral remains and shell fragments are observed.  
230 Beds often show mud-clast breccias near their erosional bases, and dispersed mud-clasts  
231 can be observed through the whole beds. The tops of these layers are frequently  
232 bioturbated.

233 *Process interpretation:* Rapid deposition from an unsteady but fully turbulent sand-rich high-  
234 density turbidity current (Lowe, 1982; Talling et al., 2012).

235 Thick-to medium-bedded amalgamated sandstones (f4)

236 Observations: The main differences between facies f4 and f5 is the thickness of the  
237 sandstone beds. F4 consists of medium-to coarse-grained sandstones, normally grading  
238 upwards to fine-grained sandstones, typically amalgamated, with a thickness ranging from  
239 0.5 to 1.5 meters (Figs. 3, 4E). In coarse-grained intervals, bioclastic fragments are often  
240 observed. Mud-clast breccias are common near erosional bases. At the top of this facies,  
241 low-angle and planar-parallel millimetric-scale lamina are composed of coarser sandstones.

242 *Process interpretation:* Loss of capacity, along with a lack of flow steadiness, of a medium-  
243 density turbidity current allowed deposition of this facies (Lowe, 1982; Mulder and  
244 Alexander, 2001).

#### 245 Medium-bedded structured sandstones (f5)

246 Observations: This facies consists of medium-coarse to fine sandstones, typically graded,  
247 with a thickness ranging from 0.15 to 0.5 meters (Fig. 4F). This facies is characterized by  
248 planar parallel and low-angle lamina usually observed at the base and towards the middle  
249 of the beds. The bases of the beds show erosional features and may display sole marks,  
250 such as flute and groove marks. Usually, near the top of the bed, millimeter-scale mud-  
251 clasts, pervasive bioturbation, oxidation, and fragments of oxidized wood are observed.  
252 Beds often tend to split and amalgamate laterally. Overlying the sandstone part of beds a  
253 mud-cap of maximum 20 cm in thickness is often present.

254 *Process interpretation:* Waning, low- to high-density turbidity currents (Lowe, 1982; Li et  
255 al., 2016).

#### 256 Thin-bedded laminated sand-mud couplets (f6)

257 Observations: Facies f6 is composed of medium-to-fine to very-fine sandstones, with bed  
258 thickness ranging from 0.05 to 0.2 meters (Fig. 4G). Planar-parallel lamination is common  
259 and usually oxidized. These beds are normally separated by thin (0.01 to 0.05 m),  
260 bioturbated mud caps; rare amalgamations are observed. Bases are sharp, flat, and  
261 depositional. Ripples are rarely observed at the top of beds.

262 *Process interpretation:* Low-density waning flow (Lowe, 1982).

#### 263 Very thin-bedded sand-mud couplets (f7)

264 Observations: Facies f7 is composed of fine to very-fine sandstones, ranging from 0.02 to  
265 0.1 meters thick (Figs. 3, 4H). Sandstones are capped by a bioturbated mud-cap 0.02-0.1  
266 meters thick. Rarely, these sandstones beds are characterized by planar-parallel lamination,  
267 and bioturbation is often present, affecting the entire bed thickness. Beds are often oxidized.  
268 Beds bases and tops are sharp, flat, and parallel.

269 *Process interpretation:* Slow deposition from low-density turbidity currents (Lowe, 1982;  
270 Mulder and Alexander, 2001).

271 Marlstone (f8)

272 Observations: Facies f8, is composed of gray, massive, non-graded calcareous mudstone in  
273 packages ranging in thickness from a minimum of 0.01 meters to a maximum of 10 meters  
274 (Fig. 3). Locally it contains fossils fragments, bioturbation, and oxidized layers.

275 *Process interpretation:* Hemipelagic background sedimentation and deposition from the  
276 least concentrated part of a low-density turbidity current (Mutti, 1992).

### 277 *Sedimentary Facies Association*

278 Six distinct facies associations (FAs) have been identified and grouped in three categories  
279 based on their distinct depositional styles: 1) erosional channel-fill elements (FA1 and FA2,  
280 Figs. 5 A, B); 2) laterally accreting elements (FA3, FA4, and FA5, Figs. 5A, C); 3) and  
281 overbank elements (FA6, Figs. 5A).

282 Erosional channel-fill elements

283 *FA1: Channel axis*

284 *Observation:* FA1 is characterized by thick sandstone bedsets and chaotic deposits (facies  
285 f3 and f1a, f1b; Figs. 5A, B, 6). The sandstones have variable thickness ranging from 1  
286 meter to approximately 3 meters with a NTG of 100% (Fig. 5A). The sandstone bedsets

287 exhibit erosional bases showing a high presence of mud-clast breccias (f3; Fig. 5A). The  
288 amalgamation rate is 100% (Fig. 5A).

289 The chaotic deposits (facies f1a; Figs. 7A, B, C) have variable thickness ranging from 1 to  
290 2 meters and erosional bases. Inside these deposits, sandy rafts, fossil fragments, and  
291 pebbles in muddy matrix are frequently found.  
292 FA1 is observed in the central part of the studied transect in between logs 32 and 40 (Fig.  
293 6).

294 *Interpretation:* The presence of chaotic deposits and thick amalgamated sandstones,  
295 combined with the absence of thinner-bedded facies and gently dipping erosional surfaces  
296 that could represent lateral migration, suggests that deposition was largely from the basal  
297 parts of mainly bypassing, erosive, high-density flows in the channel axis. Such flows are  
298 unlikely to construct highly sinuous channel fills; rather, they are interpreted as fill of a  
299 relatively straight erosional channel (e.g., Camacho et al., 2002; Fildani et al., 2013).

300 *FA2: Channel margin*

301 *Observation:* FA2 is characterized by sandstone bedsets (facies f3, f4 and f5; Figs. 5A, B,  
302 6, 7A, D) with variable thickness, from 0.3 to 1.5 meters and an amalgamation ratio ranging  
303 from 90 to 100% (Figs. 5A, B). NTG ranges between 80% and 100% (Figs. 5A, B). Contacts  
304 are typically erosional. The main facies in this association are f3 and f4, with sporadic  
305 debrites (f1c). At the top of this facies association, fine-to medium-grained beds from facies  
306 f5 can be observed.  
307 FA2 can be observed in logs 32 and 28 to the western side of the channel (Fig. 6). To the  
308 eastern flank, FA2 is observed from logs 39 to 45.5 (Fig. 6).

309 *Interpretation:* The less amalgamated configuration of this association is interpreted as the  
310 deposition at the channel margin of a confined channel and may be related to a gradual

311 filling of the erosional channel (FA1) and a consequent spill-out of the flow (e.g., Camacho  
312 et al., 2002; Fildani et al., 2013; Hubbard et al., 2014).

### 313 Laterally accreting elements

314 These elements show a sigmoidal geometry in cross-sectional view, roughly perpendicular  
315 to the main paleoflow direction, towards the north (Figs. 6, 7E). Differences in facies  
316 distribution, NTG, basal grain size, and amalgamation rate help in recognizing three facies  
317 associations (FA3, FA4, and FA5; Fig. 5A) representing different part of a sigmoid (Fig. 5C).

#### 318 *FA3: Top-set*

319 *Observation:* FA3 is characterized by fine to medium sandstone bedsets with a variable  
320 thickness ranging from 0.2 meter to 1 meter in logs 20 and 26 (log 18, Figs. 5C, 6, 7E, C).  
321 Sandstone bases are predominantly depositional, with sporadic erosional surfaces. The  
322 basal grain size ranges from medium to fine. Thin sandstone beds are intercalated with  
323 bioturbated mudcaps of similar thickness (facies f6 and f7; Fig. 7F). The NTG and the  
324 amalgamation ratio range between 30% and 40% (Fig. 5A). Occasionally, corresponding  
325 with erosional basal surfaces, debrites (f1c), up to 50 cm thick, are observed.

326 This FA3 is present between logs 17 and 30 in the western sector and between logs 39 and  
327 49 in the eastern sector (Fig. 6).

328 *Interpretation:* FA3 is interpreted as the top-set, the region of the laterally accreted sigmoid  
329 that lays above the inner bank (*sensu* Abreu et al., 2003; Li et al., 2018; Arnott et al., 2021;  
330 Reguzzi et al., 2023).

#### 331 *FA4: Middle-set*

332 *Observation:* FA4 comprises facies f3, f4, and occasionally at the top the thin-bedded f5  
333 (Figs. 5A, C, 7E). This association consists of amalgamated sandstone bedsets with a

334 variable thickness ranging from 0.15 meters to 1.5 meters. Typically, the sandstones are  
335 normally graded, with basal grain sizes ranging from coarse to fine sand (Fig. 5 A-C). The  
336 NTG ranges between 80% and 100%, and the amalgamation rate ranges between 80% and  
337 100% (Fig. 5A). The bases of sandstone bedsets are mostly erosional. Near these bases,  
338 thin conglomeratic horizons (f2) are rarely observed. Sedimentary structures in this  
339 association are dominated by parallel and low-angle lamina. This FA is observed along the  
340 whole studied transect (Fig. 6).

341 *Interpretation:* The thick, amalgamated sandstone bedsets are interpreted as the middle part  
342 (middle-set) of the sigmoid, representing lateral accretion of the channel (*sensu* Abreu et  
343 al., 2003; Li et al., 2018; Arnott et al., 2021; Reguzzi et al., 2023).

344

345 *FA5: Toe-set*

346 *Observation:* FA5 comprises amalgamated sandstones with a thickness ranging from 0.3 to  
347 1.5 meters (Fig. 5 A-C). The thickness of the layers is influenced by frequent erosional  
348 surfaces in this facies association. Sandstones vary from medium to coarse, and the beds  
349 are typically normally graded (Fig. 5 A-C). The NTG and the amalgamation ratio range  
350 between 90 and 100% (Fig. 5 A-C). The main facies of this association is f4 with local poorly  
351 sorted conglomerates of f2 (Fig. 7G-H). This FA is observed between logs 30 and 28 and  
352 from logs 26 to 24 (Fig. 6). Higher in the stratigraphy it is observed between logs 27 and 33  
353 and from logs 35 to 46 (Fig. 6).

354 *Interpretation:* this FA is interpreted as the toe-set, representing the downlap termination of  
355 the sigmoid (*sensu* Abreu et al., 2003; Li et al., 2018; Arnott et al., 2021; Reguzzi et al.,  
356 2023).

357 These FA 3-5 usually are larger than the erosional channel-fill elements, with thickness in  
358 the range of 1 to 2.5 meters and widths of ca. 300 meters. These sigmoidal elements record  
359 the incremental deposition in the inner bank during the migration of the channel and can be  
360 interpreted as lateral accretion packages (LAPs; *sensu* Abreu et al., 2003; Hubbard et al.,  
361 2009; Li et al., 2018; Arnott et al., 2021; Reguzzi et al., 2023)

362 Overbank elements

363 *FA6: Overbank (levee/terrace)*

364 *Observation:* FA6 comprises alternations of sandstone and mudstone layers (f6 and f7) with  
365 thickness ranging from 0.01 to 0.2 meters, with a NTG ranging from 20 to 30% and an  
366 amalgamation ratio of 0-20% (Figs. 5A, 6). The basal grain size varies from fine to very fine  
367 (Fig. 5A).

368 FA6 crops out between logs 17 and 30 on the western flank of the channel and between  
369 logs 45.5 and 49 to the eastern flank (Fig. 6). This FA is observed in the lower part of the  
370 stratigraphy between logs 17 and 30, to the west of the channel occurs between logs 17 and  
371 32, east of the channel between logs 45 and 49 and in the upper part this FA is observed  
372 along the whole transect (Fig. 6).

373 *Interpretation:* This FA is interpreted as overbank deposits formed due to overspill of the  
374 upper, low-density part of turbidity currents passing through adjacent channels and forms  
375 the levee to Complex 7 (*sensu* Piper et al., 1999; McHargue et al., 2011; Li et al., 2018;  
376 Reguzzi et al., 2023). Although these are likely levees, with no larger-scale confinement  
377 identified, they may also represent terraces (e.g., Hansen et al., 2017).

378

379

### *Stratigraphic Framework*

380 Based upon the facies and correlation across thirty-five sedimentary logs, the stratigraphic  
381 framework can be divided into five units (1A, 1B, 2B, 2C, and 3; Fig. 8), each separated by  
382 basal erosional and/or depositional surfaces (S1-S2-S3-S4-S5, Fig. 8). Beds and packages  
383 of beds can be correlated tens of meters laterally (Fig. 8). The main characteristics of each  
384 unit are outlined below, from the lowermost unit to the top of the complex. Statistics were  
385 computed for key sedimentological variables (sedimentary structures, NTG, amalgamation  
386 %, mudclast horizons %, bed basal grain size, bed mean grain size, sandstone thickness,  
387 and mudstone thickness) for each sedimentary log and are then plotted by unit. The results  
388 of the statistical analysis enabled quantification of stratigraphic trends and differences  
389 between the units.

390 Unit 2A (Fig. 2) is not described in this paper, because its deposits are not documented in  
391 the transect of Complex 7 analyzed here.

392

#### 393 Unit 1A

394 Observations: Unit 1A overlies a 10-m-thick interval of hemipelagic marlstones that  
395 separates Complex 7 from the underlying Complex 6 (Figs. 8, 9A, 10A). This unit has a  
396 thickness ranging from a minimum of 4.6 meters (log 19) to a maximum of 5.9 meters (log  
397 22). In general, the thickness of the unit remains constant across the entire transect,  
398 although a slight reduction in thickness is observed moving eastward toward log 30 (Fig. 8).  
399 This unit is characterized by a vertical stacking of four small-scale (about 200 meters wide)  
400 lenticular bodies, consisting of amalgamated sandstone beds (facies f3 and f4; Fig. 9A and  
401 9B) with a thickness ranging from 20 cm (log 20; Fig. 10A) to approximately 2 meters (log  
402 17; Fig. 10A). Thin-bedded heterolithic intervals (facies f6 and f7, Fig. 9C, D, E) are  
403 intercalated within the amalgamated sandstone layers (Fig. 9B, C). The thin-bedded

404 heterolithic intervals show a variable thickness ranging from 30 to 90 cm and an average  
405 NTG of 20%.

406 Massive sandstone is the most common structure in this unit, with an abundance of ca. 60%  
407 and a general decreasing trend from the west to the east (Fig. 10B). In contrast, the thin  
408 beds show an increase toward the east, from log 17 to log 30 (Fig. 10B). The NTG (Fig.  
409 10B) remains relatively constant (c. 70%) along the entire transect. In log 28, there is a  
410 minimum of 60%, while the maximum NTG is observed in log 28.5 at 80%. The  
411 amalgamation rate remains stable along the studied transect (between logs 17 and 31) with  
412 values between 20% and 40% in this unit (Fig. 10B). Higher values (c.a. 35%) are observed  
413 in logs 19 and 22, and lower value (ca. 15%) in log 28. Mud-clast-horizon percentage  
414 exhibits low values (less than 10%), coupled with a trend of low values of amalgamation and  
415 NTG (Fig. 10B). The mean grain size of beds shows a clustering around 0.2 mm, with few  
416 outliers reaching 0.6 mm and 0.8 mm in logs 22 and 24 respectively (Fig. 10C). The basal  
417 grain size is always slightly larger than the mean grain size of the bed (indicating normal  
418 grading), and shows a slightly decreasing trend, from 0.4 mm in log 17, to 0.2 mm in log 22.  
419 To the east of log 22 the trend is more stable.

420 Although layers up to 1 meter thick were observed, the average thickness of sandstone beds  
421 (c. 10 cm) is consistently greater than that of intercalated mudstones, with a higher  
422 dispersion of values towards the West (Fig. 10D). The mean thickness of mudstone intervals  
423 is ca. 5 cm, with a stable trend for the studied transect (Fig. 10D). The apparently stationary  
424 sand-thickness distribution reflects the tabularity of sandstone and mudstone beds at the  
425 scale of the transect with no particular changes in the vertical stacking of the Unit (Fig. 10D).

426 Interpretations: The stable trend of the three mentioned parameters (Fig. 10B) is likely  
427 related to the development of small-scale channels that migrated laterally toward the east  
428 and aggraded vertically, separated by intervals with thin-bedded layers. Such small-scale

429 channels have been recorded in the basal interval of other channel complexes in this system  
430 (Reguzzi et al., 2023; Marini et al., this volume; Pantopoulos et al., this volume). Another  
431 hypothesis is that these deposits could be related to distributary channels of frontal splays  
432 (e.g., Posamentier and Kolla, 2003).

### 433 Unit 1B

434 Observations: Unit 1B is bounded below by the surface S2 and above by S3 (Figs. 8, 9A).  
435 The thickness of this unit ranges from 8.30 meters (log 46; Fig. 8A) to 1.70 meters (log 33;  
436 Fig. 11A). The unit is characterized by sigmoidal-shaped amalgamated sandstones, laterally  
437 stacked with inclined bedding towards northeast (with an angle of c. 45° to the average  
438 paleocurrent direction, directed northward; Figs. 11A, 9A). Several changes in thickness,  
439 facies, and grain size are observed across a sigmoid. Usually, the bathymetrically elevated  
440 part of the sigmoid (FA3, top-set) is characterized by thin-bedded, fine-grained (facies f6  
441 and f7), heterolithic intervals (ca. 80 centimeter in thickness in log 7), with NTG ranging from  
442 0 to 20% (Fig. 11A). The middle part (ca. 2 meters in thickness in log 24) of the sigmoid  
443 (FA4, middle-set) is composed of thick, amalgamated sandstone beds (facies f3, f4)  
444 displaying a NTG of 80-100% and an amalgamation ratio ranging between 80 and 100%  
445 (Figs. 9A, 9B). The bathymetrically lowest part of the sigmoid (1 meter thick in log 28.5; FA5,  
446 toe-set) shows erosional features and is composed of amalgamated sandstone beds (f4)  
447 with conglomeratic basal lags (f2) and chaotic deposits (f1c); the NTG is 90 to 100% and  
448 the amalgamation percentage is 90-100%. The percentage of mud-clast horizons is around  
449 20%, concentrated primarily at the base of the middle part of the sigmoid.

450 The most common sedimentary structure in Unit 1B is massive sandstone, with a mean  
451 abundance of 70% in the whole studied transect (Fig. 11B). The only exception is in log  
452 28.5, where the value of massive sandstone is c. 20%, coupled with an increase in chaotic  
453 levels up to 40% of this unit (f1c) and coarser grain sizes (conglomeratic basal lags; f2). This

454 behavior can be explained by considering that this log samples a sigmoidal structure in its  
455 lower part (FA5, toe-set). Thin-bedded intervals (f6-f7) have lower values with respect to  
456 Unit 1A, never reaching 20%. In logs 21, 28, 44, 46, and 47 the thin-bedded abundance is  
457 0%, suggesting the hypothesis that these logs intersect a sigmoid exclusively in its middle  
458 and basal parts.

459 The NTG (Fig. 11B) is stationary along the transect at c. 90% with the exception of log 38,  
460 where the NTG reaches the 100%, although between logs 19 and 23 NTG decreases to c.  
461 80% as the upper part of some sigmoidal structures (top-set) is partially intersected. The  
462 percentage of amalgamation varies from 40% in log 17 to 100% in log 38. This behaviour  
463 can be explained by considering that individual logs intersect different parts of sigmoidal  
464 structures (i.e., top-set, middle-set, and toe-set) that are juxtaposed vertically and  
465 horizontally. Similar behavior is observed for the percentage of mud-clast horizons, where  
466 the values range between 10 and 40% for this unit (log 24; Fig. 11B).

467 The mean grain size shows a stationary trend with few variations fluctuating around 0.2 and  
468 0.5 mm; all along the studied transect (Fig. 11C). Few beds have grain sizes reaching 5 to  
469 7 mm, those that do are observed in logs 26, 27, and 28.5, which represent the basal lags  
470 of the sigmoidal structures. The basal grain sizes, when compared to the average values of  
471 the beds, are higher (around 0.5 mm) and with less dispersion (Fig. 11C), indicating normal  
472 grading in beds; higher values are observed in logs 26 (9.5 mm) and 28.5 (6.0 mm), which  
473 represents the conglomeratic basal lag (f2) at the base of the sigmoidal structures (FA 5 –  
474 Toe-set).

475 The average thickness of the sandstones is around 20 cm, with a wide dispersion reaching  
476 up to 1.40 m in log 38 (Fig. 11D). These relatively high values of sandstones thickness are  
477 accompanied by low thicknesses of the muddy division, averaging around 10 cm (Fig. 11D).

478 The similarity in the plots in Figure 11B reflects the configuration of the Unit 1B, usually  
479 composed of thick, vertically stacked sandstones. Slight differences are observed between  
480 the western and the eastern part of the outcrop. The higher values in the eastern sector  
481 (between logs 38 and 47) are explained by the decrease of thin-bedded heterolithic facies  
482 and the predominance of massive sandstones.

483 Interpretations: Outcrop observations supported by statistical analysis point to Unit 1B as  
484 the result of progressive lateral expansion and migration towards the east. This is  
485 approximately perpendicular to the average paleocurrent direction and is interpreted as the  
486 result of meandering channels, producing groups of sigmoidal-shaped beds (LAPs, lateral  
487 accretion packages; *sensu* Abreu et al., 2003; Arnott, 2007; Li et al., 2018).

#### 488 Unit 2B

489 Observations: Unit 2B is bounded by two surfaces, S3 and S4 (Figs. 8, 9A). Surface S3  
490 shows erosional features from logs 28.5 to 47 (Fig. 12A), while in its westernmost part  
491 (between logs 17 and 28.5) the surface can be considered depositional (Figs. 8, 13A).  
492 Similarly, surface S4 can be considered erosional at the scale of the logged transect, except  
493 for its westernmost part (from log 17 to log 24). The minimum thickness of this unit is  
494 documented in log 20 (1.0 meter), while its maximum thickness, 3.0 meters, is recorded in  
495 log 45. In an east-west orientation, perpendicular to the average paleocurrent direction, the  
496 unit shows a symmetrical channelized geometry (FA1 – Channel axis), with a deep incision  
497 (10 meters) between logs 28 and 40 and the flanks more gently ascending towards log 17  
498 to the west and log 49 to the east (Fig. 12A). At the point of deepest incision, between logs  
499 33 and 37, the unit is characterized by chaotic deposits (facies f1a and f1b; Fig 12B) ranging  
500 in thickness between 0.5 to 2.0 meters. West of the central part of the incision (between logs  
501 29 and 32), thick layers of amalgamated sandstones are observed (facies f3 and f4; Fig.  
502 12C), gradually pinching out with onlap geometries (Fig. 12D and 12E). Farther to the west

503 (from log 28.5 to 17; Fig. 12F), the unit is characterized by heterolithic thin beds belonging  
504 to facies f6 and f7 (Fig. 12F). Similar characteristics are observed to the east of the deepest  
505 incision, where thick amalgamated sandstones (from log 37 to 49, facies f3 and f4; Fig. 12G)  
506 gradually transition to and alternate with heterolithic intervals (Fig. 12G). The thin beds  
507 exhibit relatively high proportions of this unit (Fig. 13B) on both the west (around the 50%  
508 between logs 19 and 28.5) and east sides (60% towards log 48) of the incision, while in the  
509 central part of the transect these decrease, reaching 0% in log 32. The NTG % and  
510 amalgamation % illustrate this pattern (Fig. 13B). In the central incisional area (log 38),  
511 values of NTG % and amalgamation % are near 100% and gradually decrease towards  
512 lateral positions (0% NTG and amalgamation towards the west in log 19, and 50% NTG and  
513 0% amalgamation at log 48 towards the east, which seems more sand prone; Fig. 13B). The  
514 percentage of mud-clast horizons consistently remains below 10% of the unit. Only in the  
515 most axial zones of the incision does mud-clast content increase, reaching up to 80% of the  
516 thickness of this unit in log 38 (Fig. 13B). The mean and basal grain size of beds (Fig. 13C)  
517 show a clear trend that becomes coarser (0.6 mm in log 38) and more dispersed towards  
518 the center of the incision and decreases symmetrically towards both sides of the incision  
519 (0.2 mm in log 19 and log 48).

520 As with the other statistics (Fig. 13D), the thickness of the sandstones shows higher medians  
521 (max value of 35 cm in log 38) and dispersion at the center of the incision, progressively  
522 decreasing towards the more marginal areas (2.0 cm in log 19 and 48). The presence of  
523 thick, amalgamated sandstone layers (which can reach up to 70 cm in thickness) is  
524 highlighted by the widened dispersion of the boxplots in the central part of the transect,  
525 which also correspond to a minimum thickness of the mudstone layers (median value around  
526 2.0 cm between logs 38 and 32; Fig. 13D).

527 Interpretations: The sedimentological characteristics are the result of persistent erosion into  
528 the pre-existing sandstone of Unit 1B. Here, parts of the transiting flows were deposited in  
529 its central and erosional parts (FA1, thick amalgamated layers, coarser and widely dispersed  
530 grain sizes, abundance of mud clasts). Away from the axial zone, there is a facies transition  
531 towards thinner and finer layers, which represent the margins of the channel (FA 2, Channel  
532 margin).

### 533 Unit 2C

534 Observations: Unit 2C is bounded by two main surfaces (S4 and S5) that exhibit erosional  
535 characteristics along almost the entire length of the transect, oriented orthogonally to the  
536 average paleocurrent direction (Fig. 8; 12A). Significant basal erosion (S4) is discernible  
537 between logs 31 and 40, where the unit achieves a maximum thickness of 6.4 meters at log  
538 34 (Fig. 11A). This deep incision diminishes in depth towards the eastern and western end  
539 of the transect (Fig. 8 and 14A). To the east of log 45, the unit is no longer present due to  
540 erosion by the Unit 3 (Fig. 12G).

541 Unit 2C is characterized by the presence of thick amalgamated sandstone beds (f3; logs 31  
542 to 40) in its thickest part, showing onlap terminations (Fig. 12A). The complex geometries of  
543 these layers are the result of erosion consistently occurring at the bases and tops of these  
544 beds (Figs. 8, 14A). Chaotic levels are present at the base of the unit, from log 38 to log 45,  
545 reaching 25% of the thickness of the unit thickness. Conversely, the upper part of the unit  
546 exhibits a well-developed transition from thick and amalgamated beds to gradually thinner  
547 heterolithic intervals (f6 and f7 in logs 17 to 27).

548 The relative proportion of thin-bedded heterolithics decreases toward the axial part from  
549 70% in log 19, to 0% in log 31 (Fig. 11B). In the same part of the transect, this trend  
550 correlates with an increase of: i) massive sandstones from 50% in log 20 to 100% in log 36  
551 (Fig. 14B); ii) massive sandstone with traction-carpet (maximum frequency -30%; Fig. 14B);

552 iii) NTG % (from 15% in log 19 to 100% in between log 32 and 44; Fig. 14B); iv)  
553 amalgamation % (value rapidly increases from 0% to above 80% between logs 31 and 44;  
554 Fig. 14B); v) the median of the mean grain size of the beds, increasing from 0.2 mm between  
555 logs 19 and 25 to a maximum value of 0.5 mm in log 33 (some outliers reaching values of  
556 1.2 mm and 0.9 mm are observed in logs 27 and 34 respectively; Fig. 14C); and vi) basal  
557 grain size (maximum values are around 0.7 mm recorded in between logs 32 and 35; Fig.  
558 14C). Outlier values in basal grain size are observed in logs 26 and 42, ca. 1.2 mm and 1.3  
559 mm, respectively (Fig. 14C). The percentage of mud-clast horizons reaches its highest  
560 values (around 60%) toward the marginal parts of the incision (log 30 and log 41), while  
561 having lower values (around 20%) in its more axial parts (Fig. 14B).

562 Sandstone-thickness distribution shows a symmetrical trend with respect to the axis of the  
563 main incision (Fig. 14D). Bed-thickness plots show low values and low dispersion (less than  
564 25 cm) between logs 19 and 30. Values increase abruptly (up to 1.0 m) between logs 31  
565 and log 39, where there is greater range of values, which can exceed 2.5 meters in  
566 thickness. The median thickness of mudstone intervals consistently has values below 20  
567 cm, associated with a very low range of values (Fig. 14D).

568 Interpretations: Unit 2C represents multiphase infill of a channel, which eroded the  
569 underlying Unit 2B. In its initial stages of development, the flows were mainly contained  
570 within the channel. Subsequently, there is evidence of gradual filling and consequent lateral  
571 expansion, leading to the formation of overbank deposits, preserved on the western margin.

### 572 Unit 3

573 Observations: Unit 3 lies above the erosional surface S5 (Figs. 8, 12A). The top of the unit  
574 is represented by a thin sandstone, which is laterally correlated along the entire transect,  
575 capping Complex 7. Above this, deposition is exclusively characterized by thick marls (f8)  
576 interspersed with thin-bedded turbidites. The thickness of Unit 3 ranges from 0.4 (log 17) to

577 2.8 meters in log 32 (Fig. 15A). The greatest thickness occurs where surface S5 eroded the  
578 underlying Unit 2C most extensively, between logs 28 and 49 (Fig. 15G). Correlation shows  
579 that this incision is filled by thick beds of amalgamated sandstones with erosional bases and  
580 truncated tops (facies f3 and f4; Figs. 8, 12A, F, G), which can reach up to 80% of the  
581 thickness of this unit, as observed in log 42. In some cases, they exhibit sigmoidal  
582 geometries, dipping towards the east (Figs. 12F, G, 15A). An eastward migration of these  
583 sigmoidal forms is commonly observed. Chaotic facies are observed above erosional surfaces from  
584 log 40 to 49, with percentages of the thickness of chaotics fluctuating between 10 and 20%,  
585 with a maximum of 50% of the thickness of this unit in log 45 (Fig. 15B).

586 Thin-bedded heterolithics (f6 and f7; Fig. 15G) are present in various stratigraphic levels in  
587 the whole transect, with the percentage of their thickness fluctuating around 10 to 20% of  
588 the unit, except for log 28 and 45, where the value is around 50% of the thickness of this  
589 unit (Fig. 15B).

590 NTG, amalgamation % and mud-clast-horizon thickness % remain high, with significant  
591 variations and without any apparent trend (Fig. 15B). NTG shows some fluctuation above  
592 the 60%, with a minimum value in log 39 (c. 60%) and a maximum value of c. 95% in logs  
593 47 and 49 (Fig. 15B). Minimum amalgamation values (10%) are in logs 35 and 36 and rapidly  
594 increase from 15% to 90% in logs 45 and 49 (Fig. 15B). The mud-clast-horizon thickness %  
595 ranges between 10% and 30% along the studied transect (Fig. 15B). Minimum values (0%)  
596 are recorded in logs 27 and 28, while the maximum (40%) is recorded in log 49 (Fig. 15B).  
597 The high range of these three variables across the transect, without any recognizable trend,  
598 can be explained by considering that subsequent logs sample different positions of laterally  
599 accreted small-scale elements (Fig. 15B).

600 The same reasoning, of sampling different parts of LAPs, can be extended if we consider  
601 the grain size (Fig. 15C) and bed thickness (Fig. 15D). The median value of the mean grain

602 size remains constant around 0.2-0.3 mm along the whole transect, although its variability  
603 is high. A few outliers above 1.3 mm are measured in logs 35 and 45.5. The basal grain size  
604 is consistently larger than the mean grain size of the bed and clusters around 0.4 mm (Fig.  
605 15C). Outliers reaching 1.5 mm and 2 mm are observed between logs 31 and 37.

606 The median of sandstone thickness remains around 10 cm and is consistently greater than  
607 the thickness of mudstone intervals (ca. 5 cm). The higher values are noted between logs  
608 31 and 40. Outliers, with values exceeding 80 cm, are observed in logs 29 and 34.

609 Interpretations: Unit 3 represents the result of progressive lateral expansion and migration  
610 towards the east, approximately perpendicular to the average paleocurrent direction of  
611 meandering channels, producing groups of sigmoidal-shaped beds (LAPs) similarly to other  
612 documented channel fills (e.g., Jobe et al., 2010). This last phase of channel construction  
613 restored the depositional style observed in Unit 1B. Following this unit, a sharp deactivation  
614 of the complex occurred, representing either abandonment or avulsion of the channel.

615

## DISCUSSION

616

### *Spatio-Temporal Evolution of the Channel-Levee Complex*

617 This study presents a detailed characterization of the sedimentary fill of an exceptionally  
618 exposed channel-levee complex, which allows a reconstruction of its spatio-temporal  
619 evolution, from inception to abandonment (Fig. 16). The stratigraphic evolution of Complex  
620 7 can be subdivided into three phases corresponding to the main evolutionary steps of  
621 complex 7, with each phase being the timespan of the broad units, i.e., Phase 1 = Unit 1A  
622 and 1B, Phase 2 = Unit 2B and 2C, and Phase 3 = Unit 3

623 The channel dimensions described here refer exclusively to the preserved and outcropping  
624 parts of channel fills, which were generated by multiple seafloor channels. However, these  
625 channel-fill dimensions do not correspond to the dimensions of the individual channels that

626 constructed them, with seafloor channels representing only fleeting images of transient,  
627 often erosional, and as such the compound and partial remnants of geomorphic channels.

#### 628 *Phase 1*

629 This phase represents the initiation of deposition of the channel complex, directly overlying  
630 a 10-meter-thick marlstone interval that separates Complex 7 from the underlying channel-  
631 levee complex 6 (Fig. 16A; Zuffetti et al., 2023). Phase 1 is marked by the presence of  
632 relatively thin channelized sandstone deposits (0.1 to 0.6 meters thick, tens of meters wide)  
633 belonging to Unit 1A, intercalated with mudstones (up to 0.8 meters thick). These channel  
634 fills are thought to represent a narrow, sinuous and meandering channel migrating towards  
635 the E.

636 These small-scale channel fills ca. 200 meters wide and 1-meter-thick, may represent a  
637 gradual initiation of the system, with through-going channels, recording the first channel  
638 activity within the complex, propagating through the area during a time of sedimentation  
639 characterized by waxing flow (e.g., McHargue et al., 2011). A similar initiation was  
640 documented by Reguzzi et al. (2023).

641

642 After Unit 1A, Unit 1B represents the result of progressive lateral expansion towards the  
643 SSE during Phase 1. Unit 1B deposits are interpreted to represent LAPs formed channels  
644 larger than those of the Unit 1A. Ongoing deposition in the inner bank and subsequent  
645 erosion of the outer bank, accompanied by overspilling at correlative levees, documents  
646 channel migration towards the SSE, approximately perpendicular to the main paleoflow  
647 direction (Fig. 16B).

648 The spatial arrangement of these laterally migrating channels implies an increase in  
649 sediment supply when compared to Unit 1A. The increasing sediment flux was likely

650 constant to generate and maintain a meandering channel (*sensu* at grade channels of Abreu  
651 et al., 2003; Kneller, 2003).

652 Similar deposits resulting from meandering channels are well-documented in both outcrop  
653 (e.g., Abreu et al., 2003; Arnott et al., 2021; Li et al., 2018) and subsurface (e.g., Janocko  
654 et al., 2013; Reimchen et al., 2016) investigations. They are generally characterized by  
655 gently dipping, sigmoidal-like sandstone beds with erosional bases, formed by a variety of  
656 flow processes involving flow separation, bed-load transport, and waning-stage suspended-  
657 load fallout (Dykstra and Kneller, 2009), which laterally migrate in a channel in a fashion  
658 similar to fluvial point bars (Abreu et al., 2003; Arnott, 2007; Dykstra and Kneller, 2009). A  
659 variety of evolutionary models have been proposed regarding infilling of laterally migrating  
660 channels, highlighting the importance of autogenic and allogenic factors such as channel  
661 avulsion, tectonics, sediment supply, channel confinement etc. (Hubbard et al., 2008;  
662 Hansen et al., 2015). Based on the aforementioned evolutionary models, the presence of a  
663 number of channel-fill and overbank architectural elements have been proposed associated  
664 with channelized features ranging in scale from individual channel-fill elements to channel  
665 complexes. Such architectural elements represent either smaller-scale channel fills,  
666 terraces, or internal levees constructed within the channel or external levees and splays  
667 beyond the channel (Hansen et al., 2015; Hansen et al., 2017). Other proposed models  
668 favor the effects of punctuated lateral incision and bench formation at the inner bank of the  
669 thalweg instead of lateral point-bar-like migration for the infilling of laterally migrating  
670 channels (e.g., Maier et al., 2012).

## 671 *Phase 2*

672 The youngest stage of this phase (Unit 2A; Fig. 2) is not described in this paper since their  
673 deposits are not documented in the transect of Complex 7 analyzed here.

674 Phase 2, corresponding to units 2B and 2C, is marked by a significant change in depositional  
675 style from the meandering channels of phase 1 to an erosionally confined channel-fill, the  
676 base of which is marked by a chaotic mass-transport deposit (Fig. 16C). In this context, parts  
677 of the channel-transiting flows were deposited in the central part of the thalweg, which is  
678 characterized by thick amalgamated and mud-clast rich sandstones with relatively coarse  
679 grain size. Away from the thalweg, there is a facies transition towards thinner and finer  
680 layers, representing the marginal deposits of the channel fill. Channel margins pass to inner-  
681 levee deposits laterally away from the channel fill, presumably generated by the overflow of  
682 the upper part of the flows in the main channel area (e.g., Hansen et al., 2015).

683 These deposits, belonging to Unit 2B, may represent the infill of the last open channel of the  
684 meandering channel phase (e.g., Janocko et al., 2013). However, continued lateral  
685 migration to the SSE is documented during the previous phase (1, Unit 1B), before a distinct  
686 switch in the focus of channelized flow back towards the NNW in Phase 2, with cutting of an  
687 erosional channel into the pre-existing deposits. As such, Phase 2 represents an erosionally  
688 confined channel-fill type entrenched into older meandering channel fills (Fig. 16C, e.g.,  
689 Champion et al., 2000; Cronin et al., 2000). This shift could be attributed to both allocyclic  
690 (e.g., increased sediment supply, base-level fall, tectonic activity) or autocyclic (e.g., channel  
691 avulsion) controls.

692 The transition from channel-axis to channel-margin facies documented by Unit 2B shows  
693 similarity with the transition between channel axis and channel margin in the Cretaceous  
694 Tres Pasos Formation slope system proposed by Macauley and Hubbard (2013), where  
695 transition records axis to off-axis channel flows, with the axis dominated by bypassing flows  
696 (e.g., Hubbard et al., 2014), with deposition concentrated at the channel margins (e.g.,  
697 Hubbard et al., 2020).

698 The upper part of Phase 2 is characterized by a more rapid filling of the channel, which had  
699 eroded into the Unit 2B. In its early stages, flows were predominantly contained within pre-  
700 existing erosional confinement created from Unit 2B deposition (Fig. 16D). Subsequently,  
701 there is clear evidence of more gradual infilling by thick and amalgamated sandstone beds,  
702 belonging to Unit 2C, of the pre-existing topography produced by both erosion and build-up  
703 of the margin during bypass (Hubbard et al., 2014). As accommodation decreased, flows  
704 started to overspill and allowed consequent lateral expansion, resulting in formation of  
705 channel margins and levees. The incremental filling of the channel could be related to a  
706 decrease in flow energy, resulting in deposition instead of bypass.

707 Subsurface data from seismic profiles of turbidite channels in the Niger Delta continental  
708 slope (Liu et al., 2013), record a channelized stratigraphic organization which is similar to  
709 that represented by Unit 2C sediments.

### 710 *Phase 3*

711 The confined deposition represented by the later stage of Phase 2 was interrupted by further  
712 channel erosion, as recorded by lateral accretion packages of a newly formed meandering  
713 channel migrating towards the SSE (Unit 3; Fig. 16E).

714 This final phase of channel evolution restored the depositional style observed in the late  
715 stage of Phase 1 (Unit 1B). The return to a depositional style characterized by laterally  
716 migrating channels could be a result of a reducing accommodation, coupled with an  
717 occurrence of a period of steadiness in the equilibrium profile (*sensu* Kneller, 2003).

718 In the upper stratigraphic levels of the complex, a transition into thin-bedded turbidites is  
719 recorded which might be related to deactivation or avulsion phase of the channel system.

### 720 *Implications for the Distribution and Connectivity of Sandstone in Channel-Levee Systems*

721 Hydrocarbon production from subsurface reservoirs belonging to deep-marine channel-  
722 levee complexes has increased during the last decades (e.g., Aniekwena et al., 2003; Godo,  
723 2006; Shao et al., 2024), demonstrating their importance not only for hydrocarbons but also  
724 as valuable assets for CO<sub>2</sub> sequestration and underground gas storage (Weimer et al., 2000;  
725 Pettingill and Weimer, 2002; Abreu et al., 2003; Weimer and Pettingill, 2007; Marshall et al.,  
726 2016). Hence, a reduction of uncertainty and reliable estimation of reservoir quality and  
727 connectivity is crucial for maximizing production in channel-levee reservoirs characterized  
728 by complex vertical and lateral juxtaposition of a large variety of thick-bedded, coarse-  
729 grained vs. thin-bedded, fine-grained facies (e.g., channel, channel margin, to overbank  
730 deposits). The complex architecture and stacking pattern described from Tachrift Complex  
731 7 can be used as a general guide for the estimation of reservoir characteristics (NTG, facies,  
732 connectivity) in similar relatively fine-grained, sand-rich, deep-water slope channel-levee  
733 reservoirs and their specific architectural elements (Alpak et al., 2013; Zhang et al., 2017;  
734 Jackson et al., 2019).

735 The observed architectural framework of Complex 7 arose from the evolution of initially  
736 isolated channels, through meandering to sinuous channels, interrupted by a phase of  
737 erosionally confined deposits, before re-establishment of meandering channels before  
738 abandonment. The result is the vertical and lateral juxtaposition of various depositional  
739 elements, including erosional channel fill, laterally accreting channel fill, and overbank  
740 elements. Due to their distinct sedimentological and stratigraphic attributes, each element  
741 recognized in this study would have different reservoir characteristics, including vertical and  
742 lateral connectivity (Table 1).

743

744

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746

747 Erosional channel-fill elements:

748 This element exhibits a predominance of medium- to very-coarse sandstone bodies (1.5 to  
749 9 meters thick and 50 to 200 meters wide in a direction perpendicular to the paleocurrent),  
750 arranged in amalgamated and poorly stratified sandstones towards the channel axis (FA 1)  
751 and less amalgamated sandstones in the channel margins (FA 2). They would result in a  
752 volumetrically significant reservoir, where a paucity of interbedded fine-grained layers (NTG  
753 > 0.9) result in high vertical and lateral connectivity. Thin-bedded and fine-grained horizons  
754 are observed mainly at the lateral extremes of the channel complex, where sandstones of  
755 the channel margin pinch-out (FA 2).

756 Amalgamated sandstone beds often display abundant mud-clast layers or are interstratified  
757 with laterally persistent mud-clast breccias (Figs. 13B, 14B). The frequency of these levels  
758 indicates that they would not constitute a permeability barrier, although they may create a  
759 tortuous network of permeable conduits (Fig. 14B). However, while reservoir continuity is  
760 not affected, total reservoir sandstone volume would be reduced because of abundant  
761 mudstone clasts (NTG 0.7 – 0.8) and critically may be overrepresented or misinterpreted as  
762 shale-facies if particularly abundant in well bores (e.g., Stanbrook and Bentley, 2022).

763 The presence of c. 2-meters-thick, chaotic deposits (facies 1a and 1b, Unit 2B) at the base  
764 of the axial channel fill with a horizontal distribution of a few tens of meters can negatively  
765 influence the connectivity of the reservoir or even constitute a permeability barrier (e.g.,  
766 Schwarz and Arnott, 2007).

767 These architectural elements stack vertically in units 2B and 2C to form a single “reservoir”  
768 at least 6 meters thick and up to 250 meters wide and is entirely interconnected, with  
769 erosional surfaces placing underlying sandstones in direct contact with overlying and lateral

770 sandstones (Fig. 6). The same architectural element is recognizable in Unit 1A, but in this  
771 case they form small, isolated channel fills at least 200 meters wide and up to 1.5 meters  
772 thick, encased in heterolithic strata and are not interconnected.

773

774 Laterally accreting elements:

775 Single lateral accreting elements exhibit a thickness of 1 to 2.5 meters and good lateral  
776 continuity (perpendicular to the paleocurrent) ranging from 90 to 450 meters, generating a  
777 potential reservoir architecture that is often a few meters thin but with high lateral continuity.  
778 Typically, these elements are characterized by laterally stacked sigmoidal bodies, which  
779 display distinct characteristics in different positions of the sigmoid, which can enhance or  
780 reduce the reservoir quality. Lateral accretion packages show amalgamation downdip, but  
781 are commonly separated by laterally extensive, thin-bedded intervals diminishing their  
782 vertical connectivity. The toe-set (FA5) is usually composed of coarse and amalgamated  
783 sandstones with good connectivity. The middle-set (FA4) consists of amalgamated thick-  
784 bedded sandstones, occasionally exhibiting discontinuous horizons of thin beds that form  
785 local permeability barriers but do not affect the potentially high lateral and vertical  
786 connectivity of these thick sandstones. The top-set (FA3), on the other hand, provides low  
787 lateral and vertical connectivity values due to the presence of thin-bedded sandstones and  
788 mudstones.

789 The presence of mud-clast horizons in the amalgamated sandstones belonging to FA 4 and  
790 FA 5 (Figs. 11B, 15B), does not represent permeability barriers but may affect the overall  
791 quality and volume of the reservoir (e.g., Schwarz and Arnott, 2007). Since the presence of  
792 mud-clast-horizon thickness displays values lower than 40% of the studied interval (Figs.  
793 11B, 15B), we can assume that the impact of mud-clast horizons on the reservoir volumes  
794 would be negligible.

795 The laterally accreted architectural elements (FA3, FA4, and FA5) are laterally stacked in  
796 Unit 1B, forming a potential reservoir up to 5 meters thick and at least 500 meters wide (Fig.  
797 6). Unit 3 also shows a similar laterally stacked architectural element generating a potential  
798 reservoir 3 meters thick and 300 meters wide (Fig. 6).

799

800

801 Overbank elements:

802 Impermeable layers that may form barriers to fluid migration are present in the complex,  
803 represented by horizons, up to 5 m thick, of thin-bedded siltstones or sandstones and  
804 mudstones (NTG < 30%). These heterolithic intervals extend laterally from 50 to 300 meters  
805 away from the channel fill in units 2B and 2C. They typically pinch out toward the channel  
806 axis due to channel erosion. These laterally extensive and often thick barriers would affect  
807 reservoir performance and connectivity, but they are unlikely to vertically compartmentalize  
808 the reservoir due to subsequent channel erosion.

809 These low-permeability intervals range in thickness from 2 to 5 meters and in lateral extent  
810 from 50 to 300 meters. The three described elements have distinct reservoir characteristics  
811 in terms of connectivity and continuity. Considering the lateral and vertical juxtaposition of  
812 elements, it is observed that erosional channel-fill and laterally accreting elements have very  
813 good reservoir attributes and are interconnected, creating a continuous reservoir. They are  
814 the most common elements and represent 60% of the gross channel-complex sandstone  
815 (Table 1). By contrast, the basal part of the complex is composed of small channels not  
816 connected to each other. Different scales of permeability-barrier-type facies (overbank  
817 elements) were identified and represent 40% of the exposed and preserved outcrop of  
818 Complex 7 (Table 1).

819 What can be inferred from the 2D correlation panel (Fig. 6), and considering the three-  
820 dimensionality as sketched in Figure 16, is that the channel complex would represent an  
821 individual fluid flow cell where only non-areally extensive permeability barriers (40%; Table  
822 1) are present. However, ongoing larger-scale work (covering the entire lateral extent of  
823 Complex 7) leads us to believe that extensive thin-bedded elements developed during local  
824 channel-complex abandonment and mud-rich debrites constitute kilometer-scale barrier-  
825 type facies that would effectively compartmentalize the channel complex.

826 Kilometer-scale marlstone-rich intervals likely represent effective permeability barriers  
827 between channel complexes. These thick (up to 10 meters) laterally persistent marls (facies  
828 f8) and siltstone-rich thin beds separate Complex 7 from the underlying and overlying  
829 channel-levee complexes. These marlstone-rich intervals would constitute intraformational  
830 seals that would prevent connectivity between channel complexes and pressure  
831 communication in analogous reservoirs.

## 832 **CONCLUSIONS**

833 The late Tortonian channel fills described here represent Channel Complex 7 of the Tachrift  
834 System, Taza-Guercif Basin, NE Morocco. The studied outcrops represent an exceptionally  
835 exposed part of deposition in and adjacent to a long-lived sediment pathway that  
836 accumulated 30 m of predominantly sandstone in a deep-marine slope setting. Based on  
837 correlations along a NW-SE-oriented continuous 500-meters-wide outcrop transect,  
838 perpendicular to the main paleocurrent direction, the studied part of Complex 7 has been  
839 divided into five vertically stacked sedimentary units, each consisting of a unique  
840 assemblage of facies, with different internal geometries and bounding surfaces. Statistics  
841 compiled for key sedimentological variables enabled quantification of vertical and lateral  
842 heterogeneity of facies assemblages and trends between the units.

843 An idealized evolution of the channel complex begins with the development of small, isolated  
844 channel fills, followed by eastward laterally accreting packages deposited in a highly sinuous  
845 channel. This phase was interrupted by erosion from a relatively linear channel and greater  
846 sediment bypass, followed by filling of the erosional channel with amalgamated and non-  
847 amalgamated elements and the development of overbank levees. The late stage of the  
848 channel complex is represented by an episode of reincision before reestablishment of  
849 laterally accreting packages deposited in sinuous channels. Final deactivation of the channel  
850 complex was followed by accumulation of a laterally extensive and c. 10-meters-thick  
851 marlstone alternating with thin-bedded sandstones and mudstones interpreted to reflect  
852 distal overbank deposition associated with another distant channel.

853 Six distinct facies association were identified and grouped in three categories based on their  
854 distinct depositional styles: (i) erosional channel-fill elements, (ii) laterally accreting elements  
855 and (iii) overbank elements.

856 Each of these depositional elements have distinct reservoir attributes (heterogeneity,  
857 connectivity, and continuity), with implications for reservoir properties in analogous systems.  
858 Laterally accreting elements and erosional channel-fills elements show good reservoir  
859 properties (Table 1), being interconnected, and containing 60% of the gross channel-  
860 complex sandstone, creating a single fluid-flow cell where only non-areally extensive  
861 permeability barriers are present. The latter are represented principally by overbank and  
862 chaotic deposits, representing 40% of the studied channel complex.

863 This study illustrates the detailed stratigraphic complexity, evolution, and reservoir  
864 characterization that can be expected in turbidite-dominated slope channel systems.  
865 Moreover, it is a potential analogue for similar systems developed on continent-margin  
866 basins that until now were characterized primarily by lower-resolution subsurface data.

867

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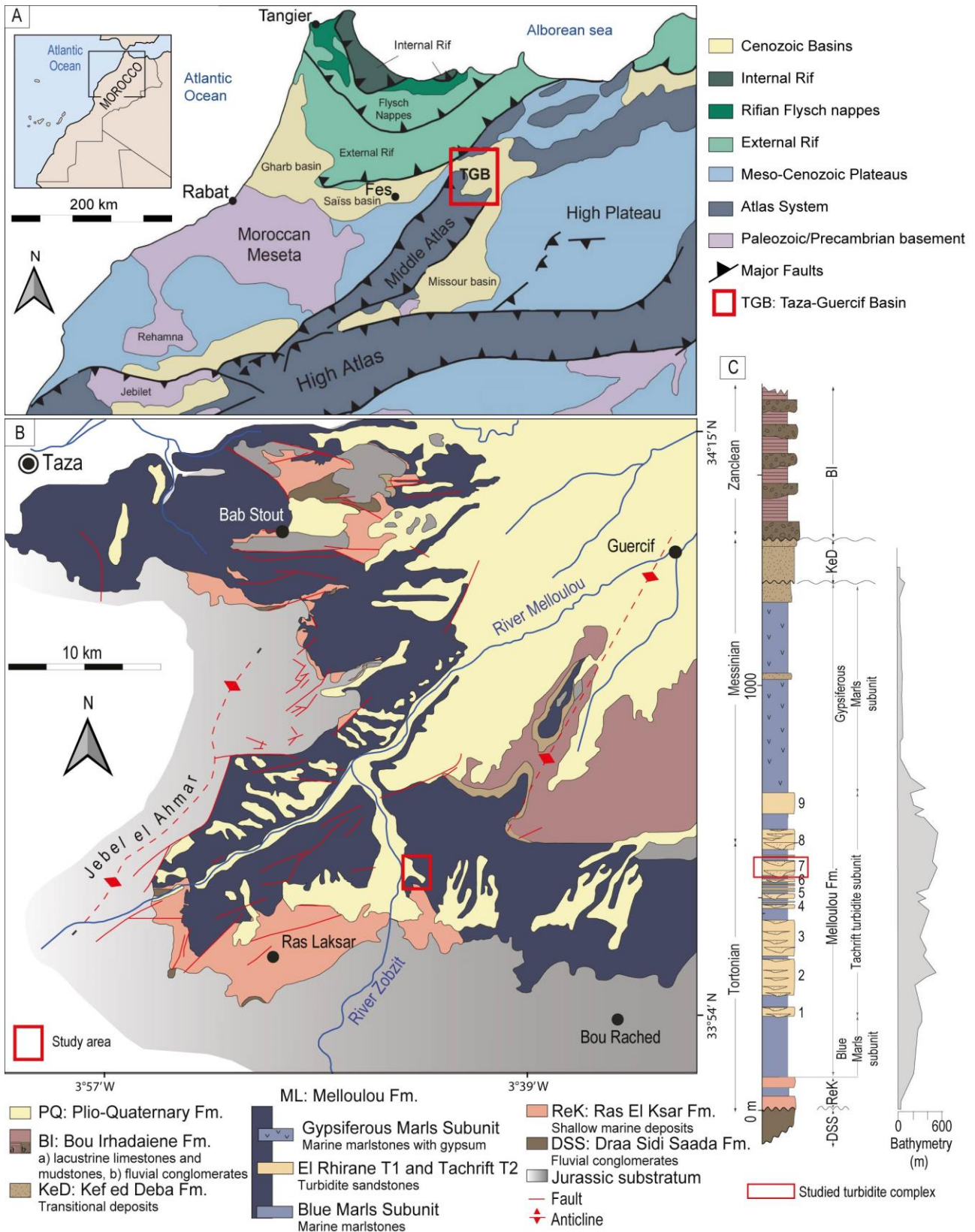
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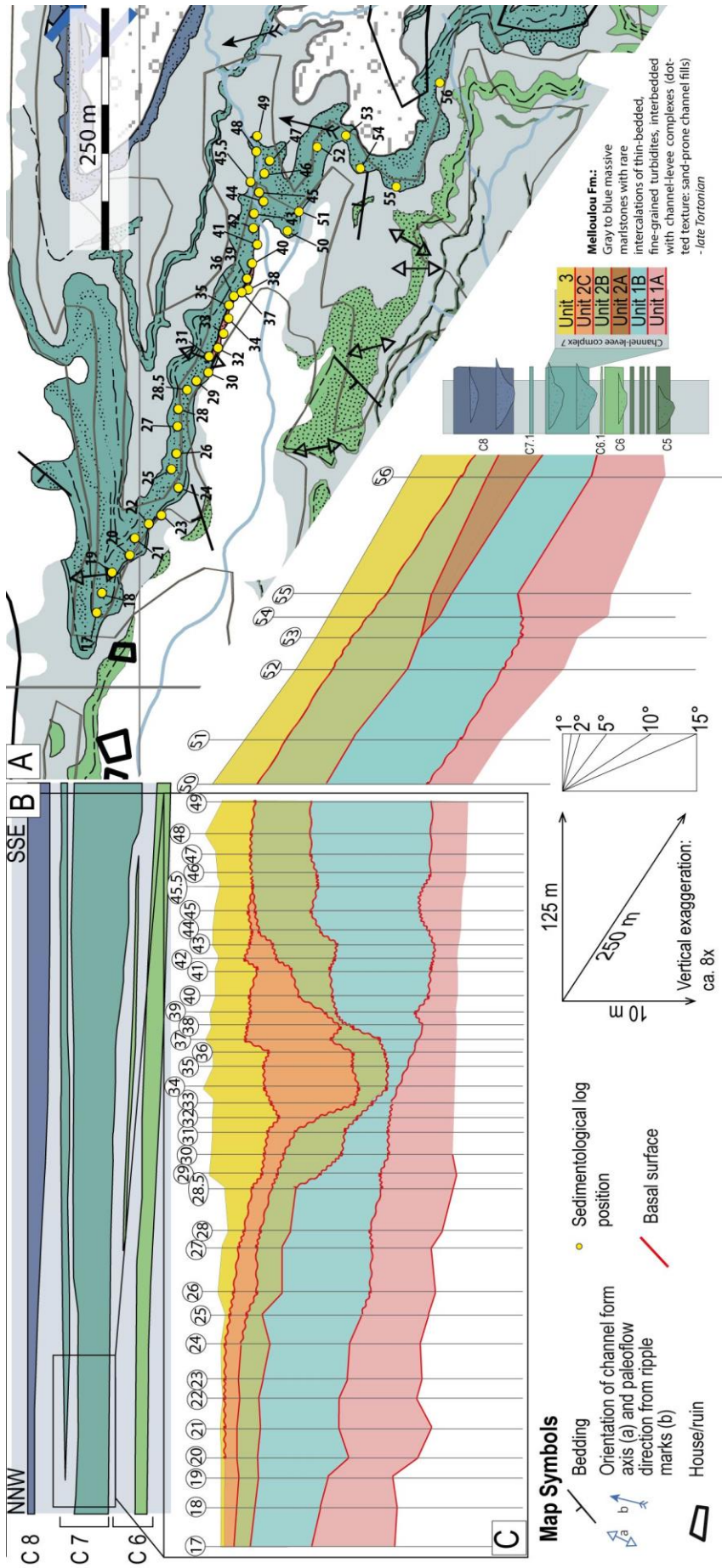
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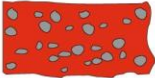
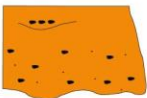
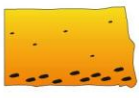




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1201 **Fig. 1:** A) Geological map of northern Morocco illustrating key structural elements, main  
 1202 terrains, and Cenozoic basins, with inset showing location in Morocco (modified after Hafid  
 1203 et al., 2006). B) Geological map of the Taza-Guercif Basin (TGB) with study area in red box

1204 (modified, after Bernini et al., 1994). C) Stratigraphy of the Zobzit section with  
1205 paleobathymetry and the nine channel-levee complexes of Felletti et al. (2020) (modified  
1206 after Krijgsman et al., 1999).



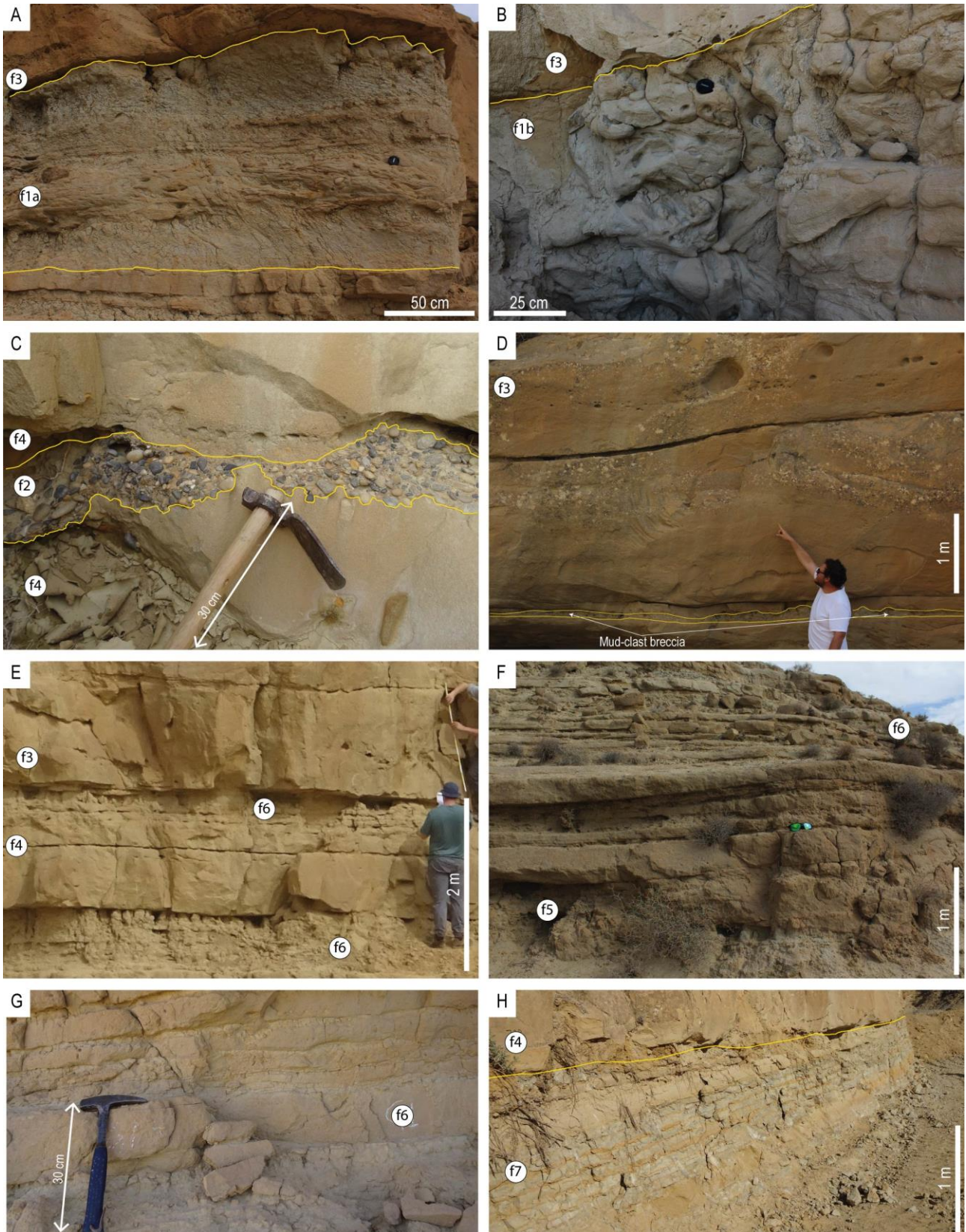
1208 **Fig. 2:** A) Geological map showing the Complex 7 outcrop and location of sedimentary logs  
1209 (modified after Felletti et al., 2020). B) Stratigraphic cross section showing the stratigraphic  
1210 relationship between complexes 6, 7, and 8. C) Correlation panels for Complex 7; this work  
1211 focuses on the NE outcrop in between the log 17 and log 49.

Facies	Code	Name	Thickness [cm]	Grain size	Sedimentary features	Process
	f1a	Sand-dominated chaotic	50-100	/	Plastically deformed sandy beds, granules to cobbles polygenic extra clasts, bioturbation and shell fragments.	Deposition due to a cohesive, plastic, laminar sand-dominated debris flow. (Lowe, 1982)
	f1b	Mud-dominated chaotic	150-300	/	Mud clasts, polygenic granules to pebbles clasts and biogenic fragments. Decimetric sandstone boulders.	Deposition due to a cohesive, plastic, laminar mud-dominated debris flow. (Lowe, 1982)
	f1c	Debrisites	10-50	/	Ungraded, extremely bioturbated and oxidated. Wood, coal fragments, and extraclasts.	Deposited due to <i>en masse</i> freezing of a cohesive flow. During deposition the grains of different sizes were not segregated by differential setting. (Talling et al., 2012)
	f2	Poorly sorted conglomerate	1-100	cS-Cobbles	Poorly sorted, clast-supported granule to pebble-grained conglomerate. Polygenic clasts. The contacts are tangential and rarely linear. Well-rounded with high-sphericity clasts. Fossil fragments.	The deposition is attributed to traction-carpet sedimentation from a largely bypassing high-density turbidity current. (Mutti and Normark, 1987)
	f3	Very thick-bedded massive amalgamated sandstones	S:100-300 M:0	mcS-cS	Massive sandstones. Coarse-grained lenses. Normal grading. Traction carpets. Reworked corals and shell fragments. Mud clast breccias near their erosional bases.	Rapid deposition from an unsteady but fully turbulent sand-rich high-density turbidity current. (Lowe, 1982; Talling et al., 2012)
	f4	Thick-to medium-bedded amalgamated sandstones	S:50-150 M:0-20	mS-cS	Medium-to coarse-grained sandstones, typically amalgamated. Mud-clast breccias are observed near erosional bases. Bioclastic fragments. At the top, planar-parallel laminations.	Loss of capacity, along with a lack of flow steadiness, of a medium-density turbidity current allowed deposition of this facies. (Lowe, 1982; Mulder and Alexander, 2001)
	f5	Medium-bedded structured sandstones	S:15-50 M:0-20	fS-mcS	Plane-parallel and low-angle laminations. Flute and groove marks. Pervasive bioturbation, oxidation, and bioclastic fragments.	Deposition related to a waning, low-to-high-density turbidity currents. (Lowe, 1982; Li et al., 2016)
	f6	Thin-bedded laminated sand-mud couplets	S:5-20 M:1-5	vfS-mfS	Plane-parallel lamination. Bioturbated mud caps. Ripples are rarely observed at the top of beds.	Deposition from low-density waning flow. (Lowe, 1982)
	f7	Very thin-bedded sand-mud couplets	S:2-10 M:2-10	vfS-fS	Plane-parallel laminations are rarely observed. Bioturbation and oxidation.	The deposition is attributed to slow deposition from low-density turbidity currents. (Lowe, 1982; Mulder and Alexander, 2001)
	f8	Marlstone	S:0 M:1-1000	Mud	Gray in color. Massive. Fossils fragments. Bioturbated.	This facies is interpreted as hemipelagic background sedimentation and also from deposition from the least concentrated part of a low-density turbidity current. (Mutti, 1992)

Not to scale

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1213 **Fig. 3:** Summary of sedimentary facies recognized in channel-levee Complex 7. S:  
1214 sandstone; M: Mudstone

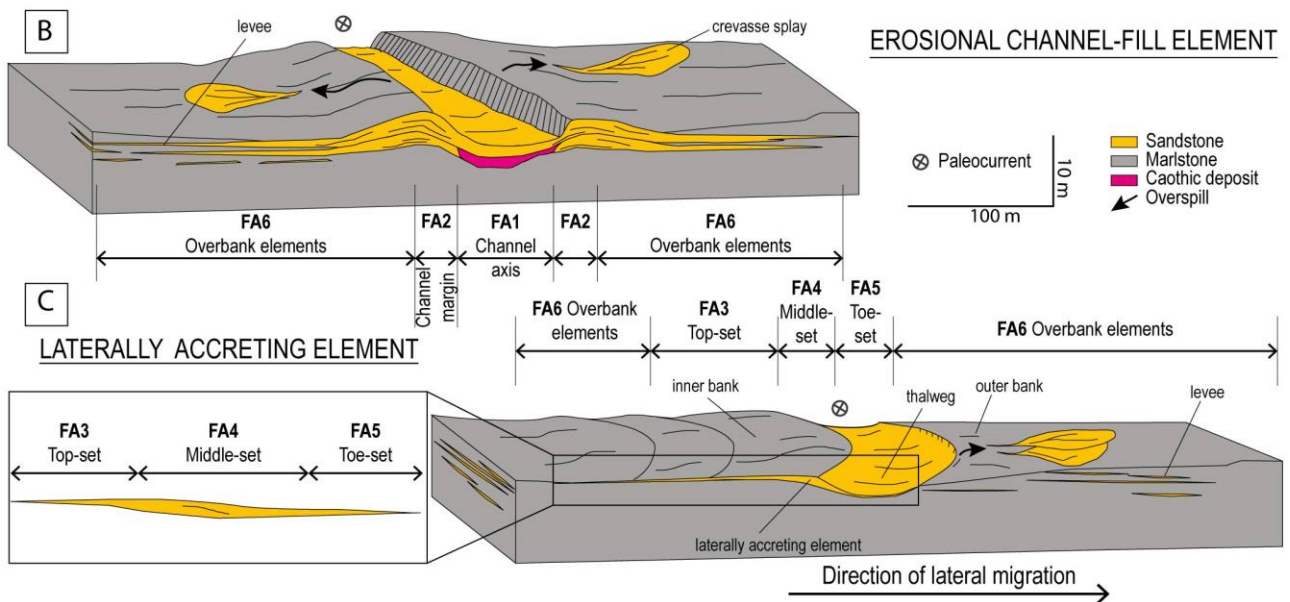


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1216 **Fig. 4:** A) Chaotic facies 1a with deformed sandstone rafts, bioturbation, and oxidation  
 1217 crusts. B) Chaotic facies 1b structureless. C) Conglomerate of facies f2, polygenic grains  
 1218 ranging in size from granules to pebbles. D) Sand beds of facies f3, structureless; the base

1219 of this layer is erosional, and a mud-clast breccia is observed. E) Facies f4, characterized  
1220 by an alternation of sand beds with variable thickness ranging from 40 cm to a maximum of  
1221 150 cm and thin mud-caps (maximum thickness around 20 cm). F) Facies f5, showing  
1222 sandstone bed with thickness ranging from 15 to 50 cm and thin mud-caps. G) Sandstone  
1223 beds in facies f6 (thickness ranging from 5 to 20 cm) separated by mud-cap (1-5 cm). H)  
1224 Facies f7, characterized by an alternation of sand and mud with comparable thicknesses  
1225 (from a few cm to a maximum of 10 cm).

A	Log	Element Facies	NTG	Basal grainsize	Amalgamation %	Thickness [m]	Width [m]	Interpretation	Stratigraphic unit
FA 1		f1a; f1b; f3	100	mcS	100	1.5-9	100-200	Channel axis	2B; 2C
FA 2		f4; f5	80-100	mcS	90-100	1.5-6	50-150	Channel margin	2B; 2C
FA 3		f1c; f5; f6	30-40	fmS	30-40	0.3-0.8	150-200	Top-set	1A; 1B; 3
FA 4		f2; f3; f4; f5	80-100	mS	80-100	1.5-2.5	150-450	Middle-set	1A; 1B; 3
FA 5		f4; f2	90-100	cS	90-100	0.6-1	90-150	Toe-set	1A; 1B; 3
FA 6		f6; f7	20-30	fS	0-20	1-4	>500	Overbank (levee, crevasse, and terrace)	2B; 2C



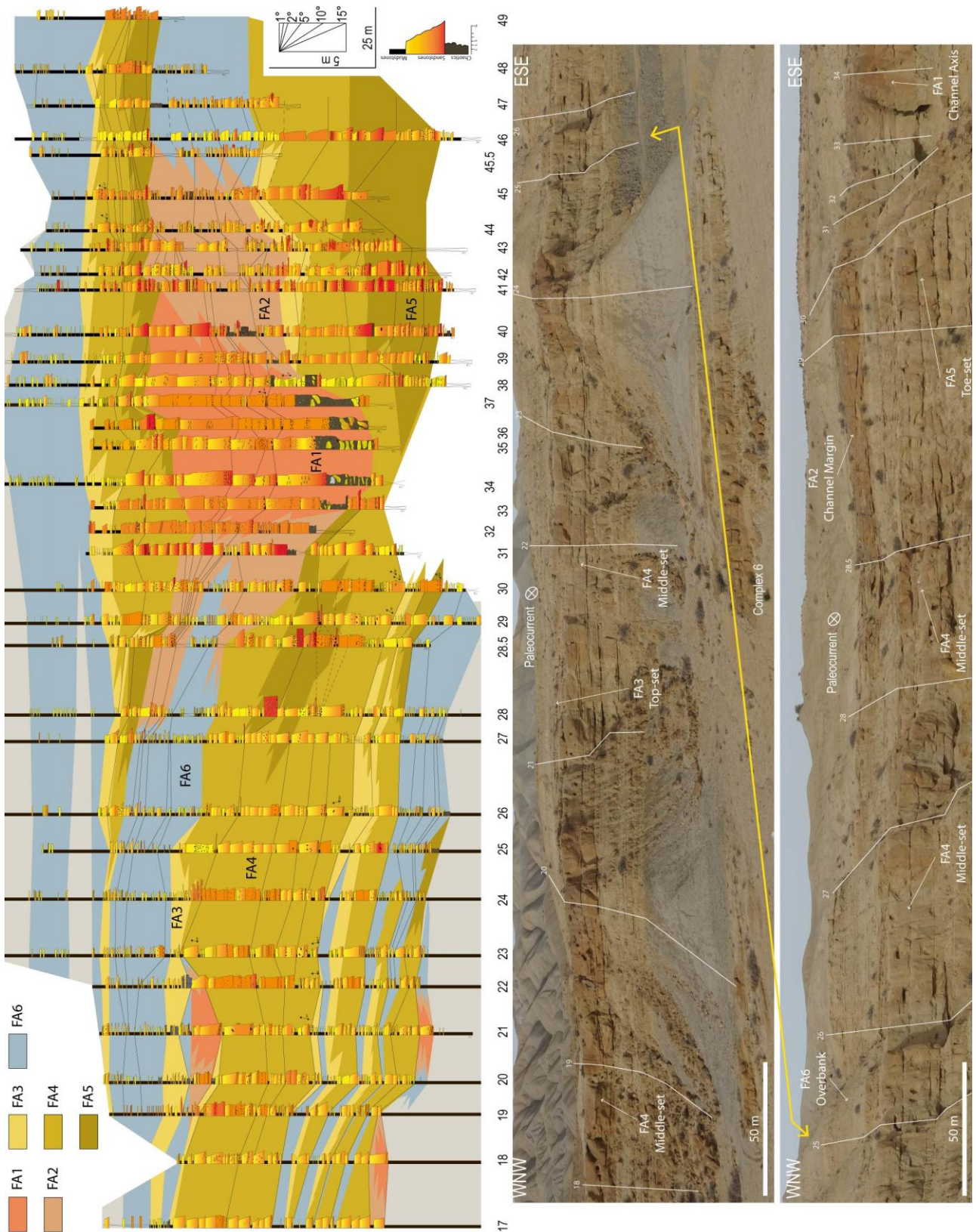
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1227 **Fig. 5:** A) Main features of the six facies association recognized in this work. B) Erosional  
1228 channel-fill element depositional style. C) Laterally accreting element depositional style.

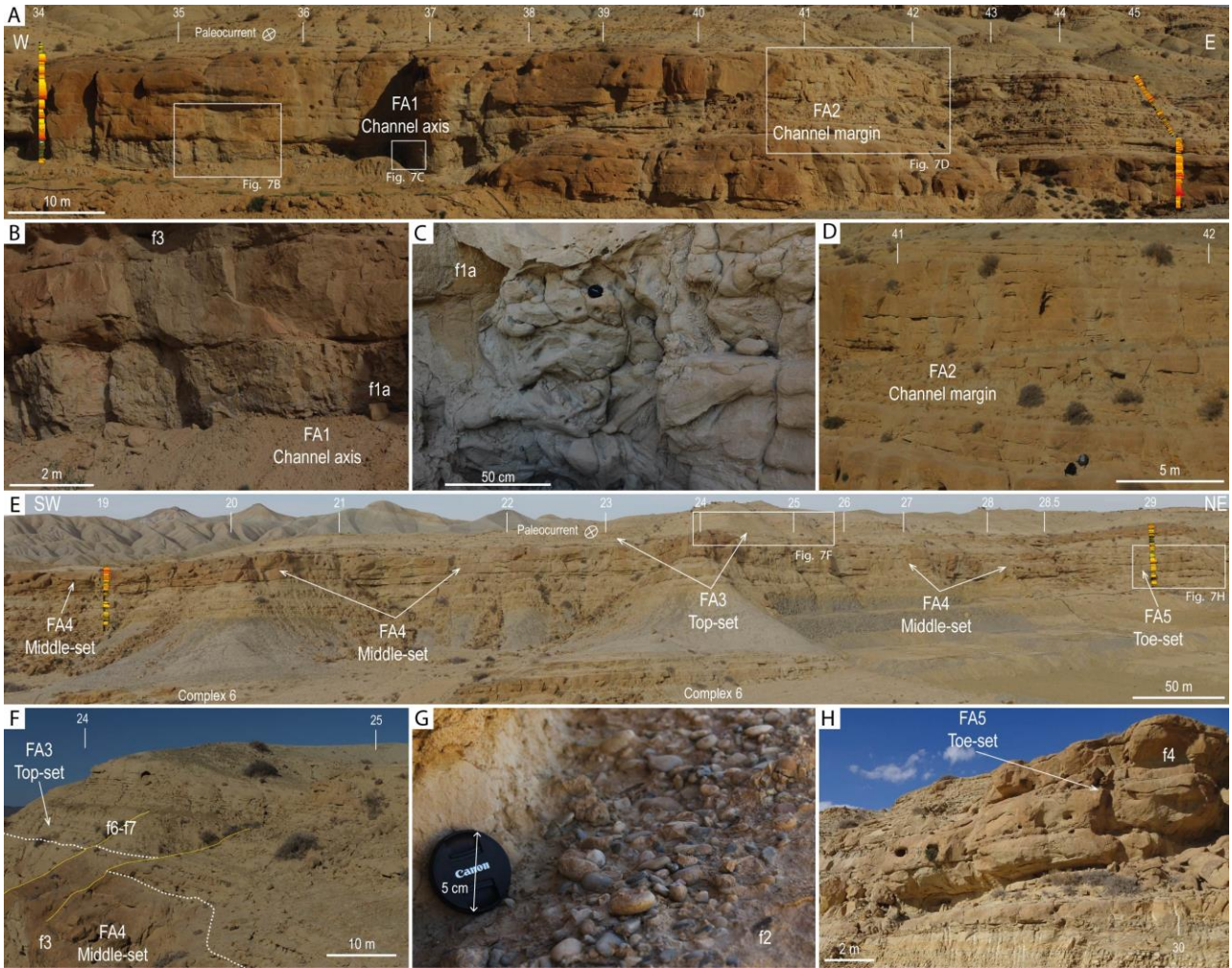
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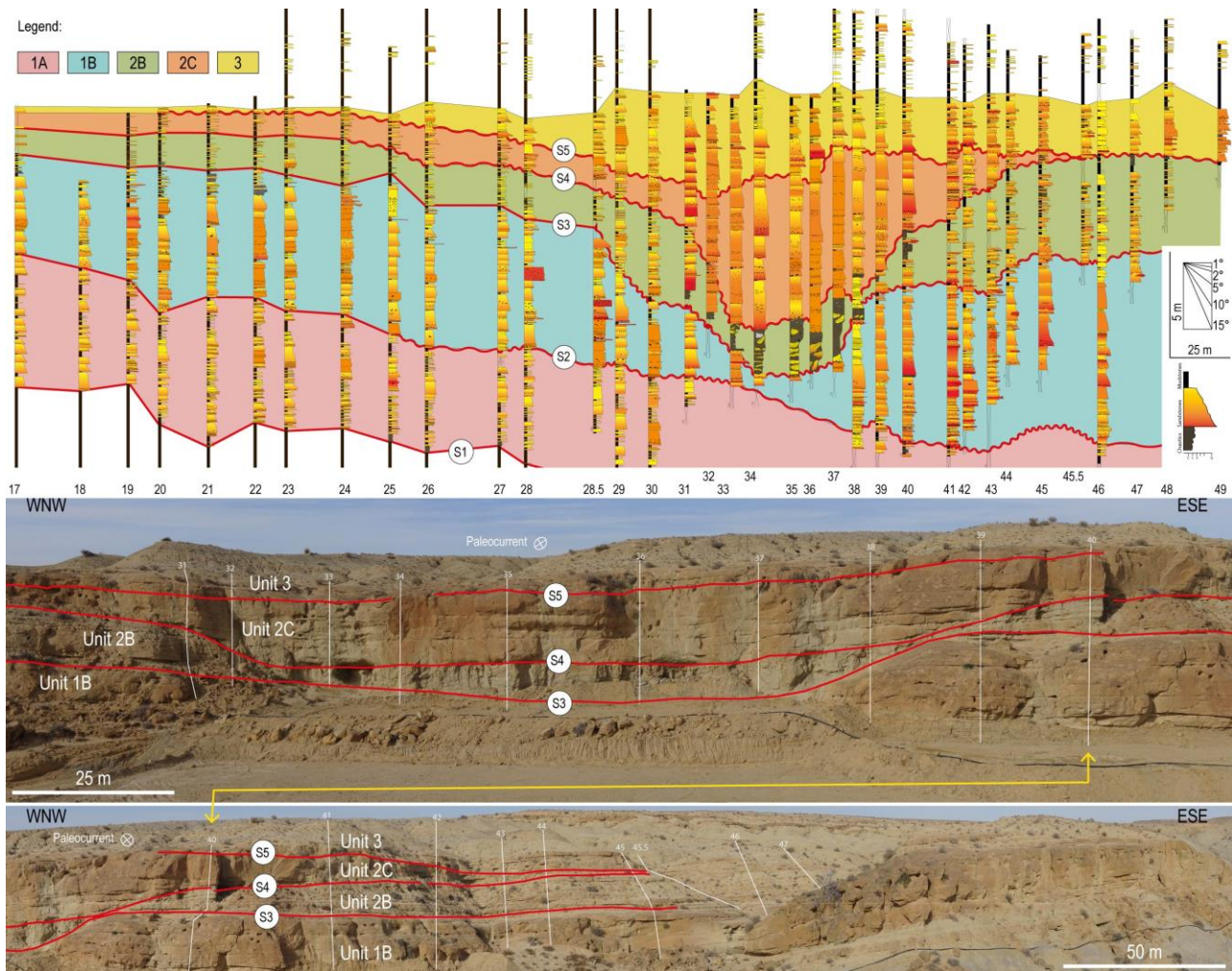


**Fig. 6:** Correlational panel showing the subdivision in facies association of the outcrop. The two panoramic pictures below show the distribution of the facies association in outcrop view.



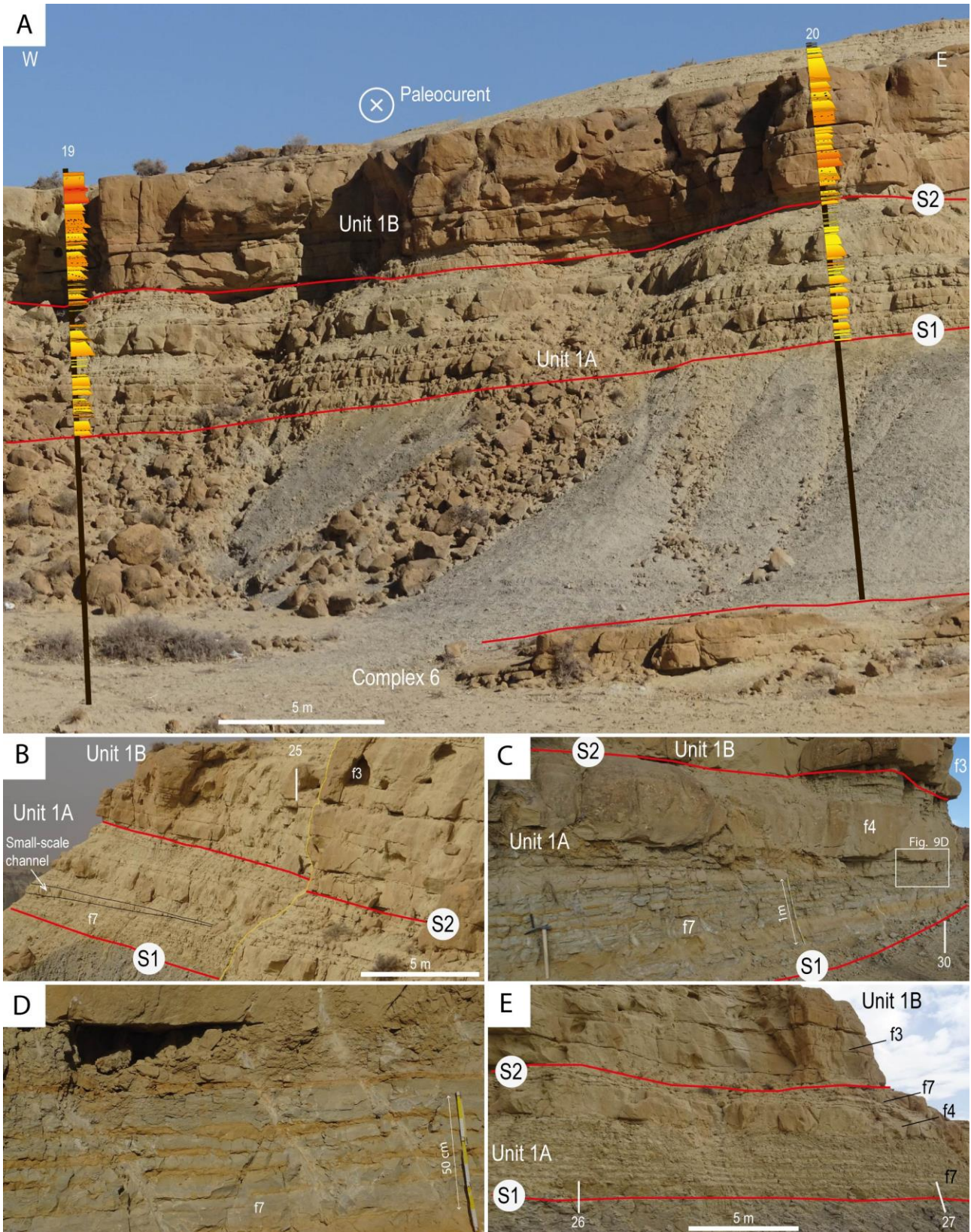
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1233 **Fig. 7:** A) Panoramic view of the erosional channel-fill element, with thick sand beds and  
 1234 chaotic deposits of FA1 (Channel axis) and less amalgamated beds of FA2 (Channel  
 1235 margin). B) Detail of the two facies (f1a and f3) composing FA1. C) Chaotic deposits (facies  
 1236 f1a) belonging to FA1. D) Characteristic less amalgamated beds (facies f4 and f5) of FA2.  
 1237 E) Panoramic view of the laterally accreting element. F) FA3 characterized by thin beds  
 1238 (facies f6-f7). G) Facies f2 at the base of FA5. H) Amalgamated beds with erosional bases  
 1239 of facies f4, characteristic of FA5.



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1241 **Fig. 8:** Correlational panel showing the subdivision in units. The two panoramic pictures  
 1242 show the units in outcrop view. S1, S2, S3, S4, and S5 basal surfaces separating the units.



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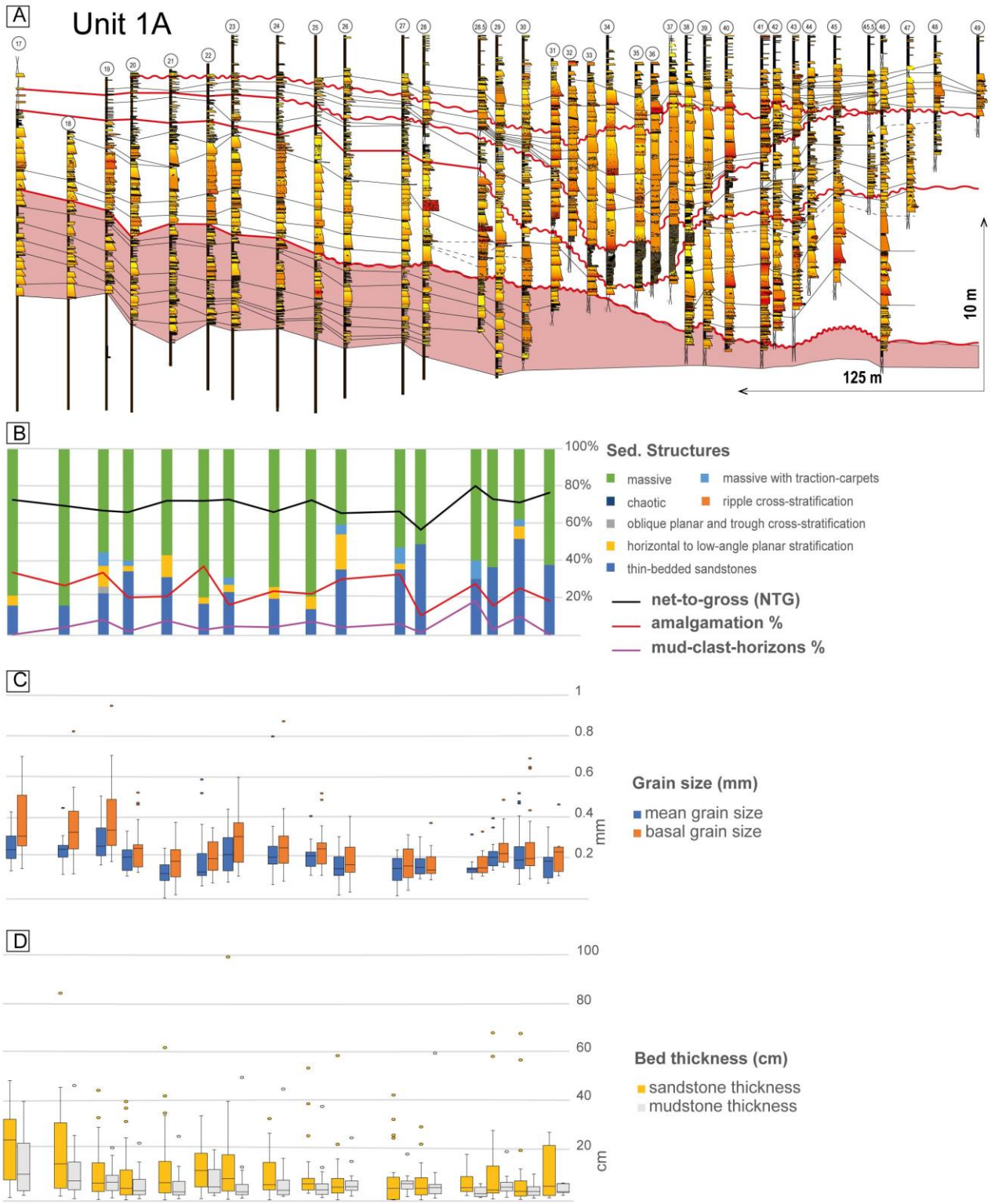
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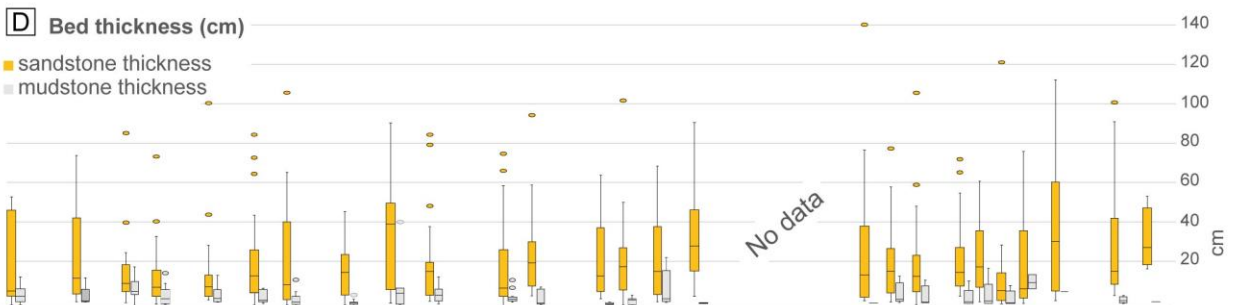
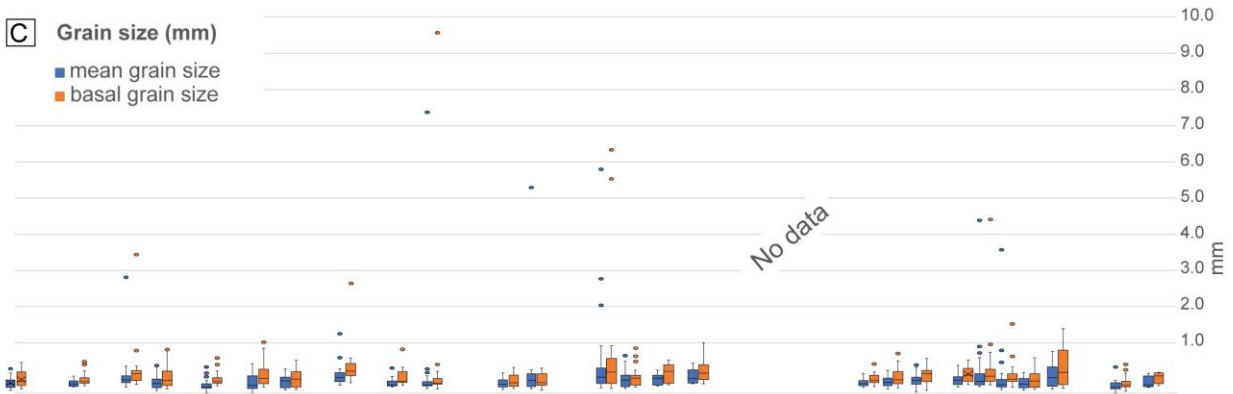
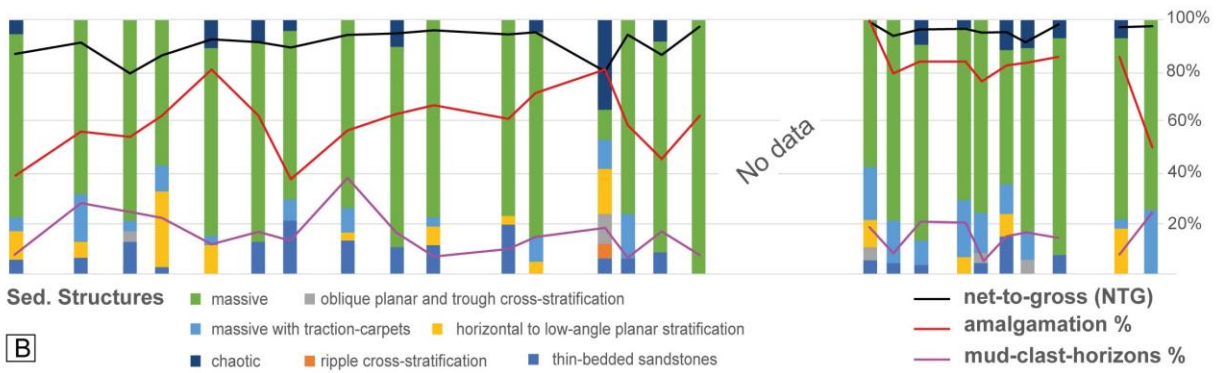
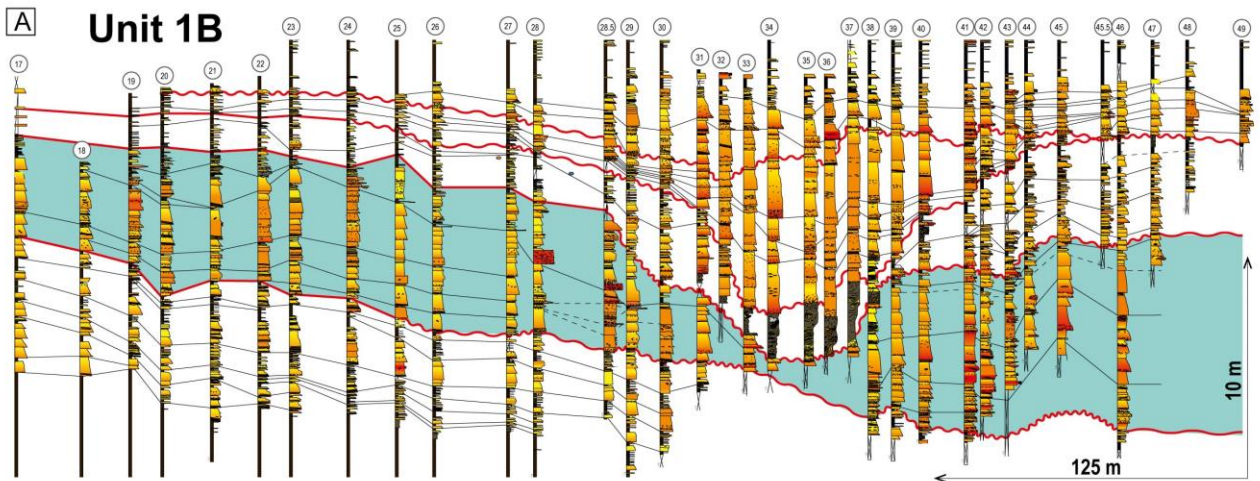
**Fig. 9:** A) View of units 1A and 1B (paleocurrent directed northward). B) Detail showing the channelized geometry of one of the sandy beds in Unit 1A interbedded with thin heterolithic beds (f7). C) View of Unit 1A composed of vertically stacked thin beds (f7) and thick

1247 sandstones (f4). D) Detail of thin beds (belonging to facies f7) in Unit 1A. E) Differences  
 1248 between Unit 1A with thin heterolithic beds and thick sandstone bodies, and Unit 1B  
 1249 composed of thick sandstone bodies.

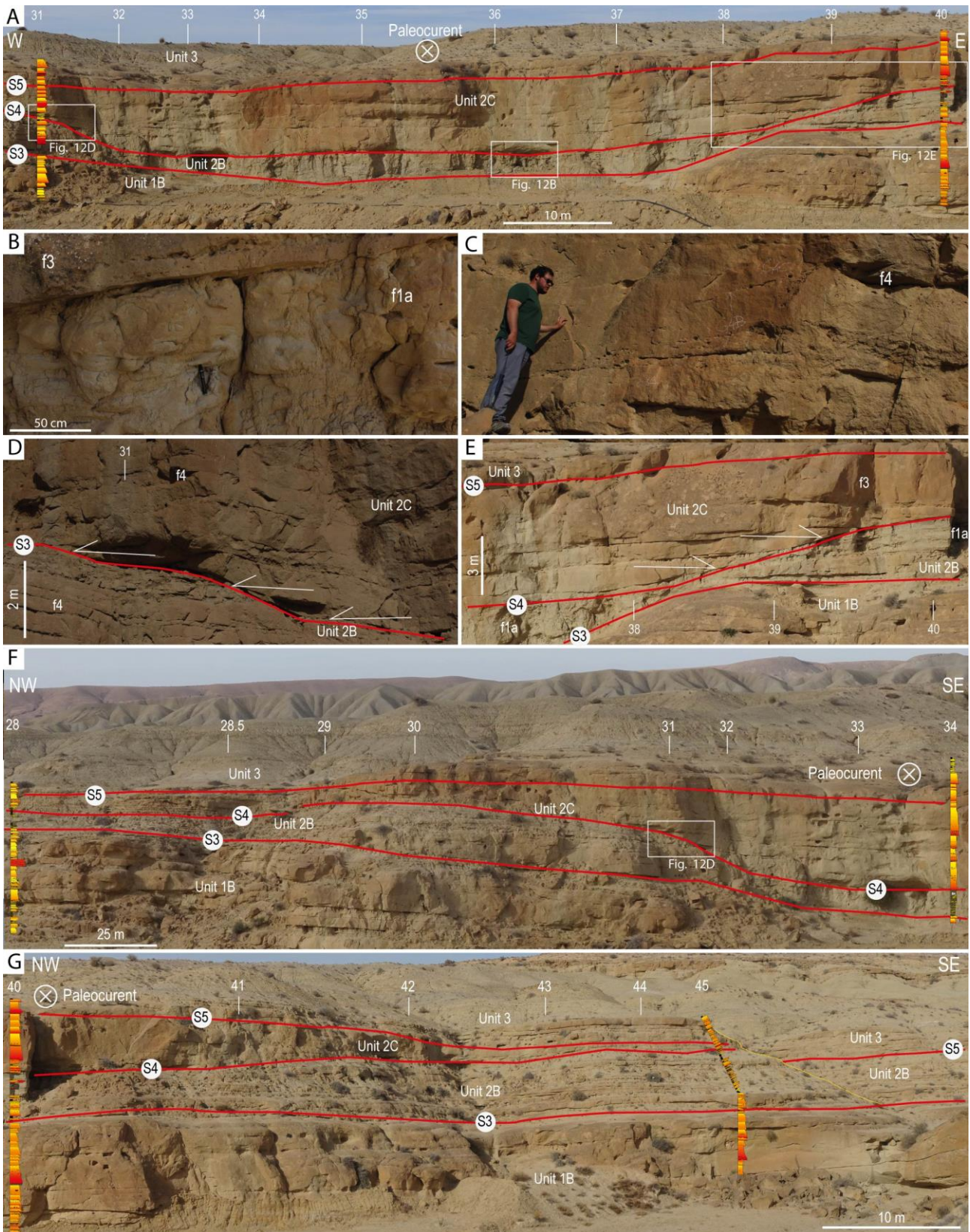


1250

1251 **Fig. 10:** A) Correlation panel with Unit 1A highlighted. B) Bar chart showing the percentage  
1252 presence of sedimentary structures in Unit 1A, with the three line diagrams illustrating the  
1253 percentage of NTG, amalgamation rate, and mud-clast horizons along the analyzed transect  
1254 of Unit 1A. C) Box plots displaying the average grain size and basal grain size of the  
1255 sandstone beds in Unit 1A. D) Box plots showing the thickness of sandstone and mudstone  
1256 beds in Unit 1A. X axis of the plots refers to the measured logs shown just above in the  
1257 correlation panel; Y axis refers to the entire unit; in the boxplots, dots refer to outlier values.



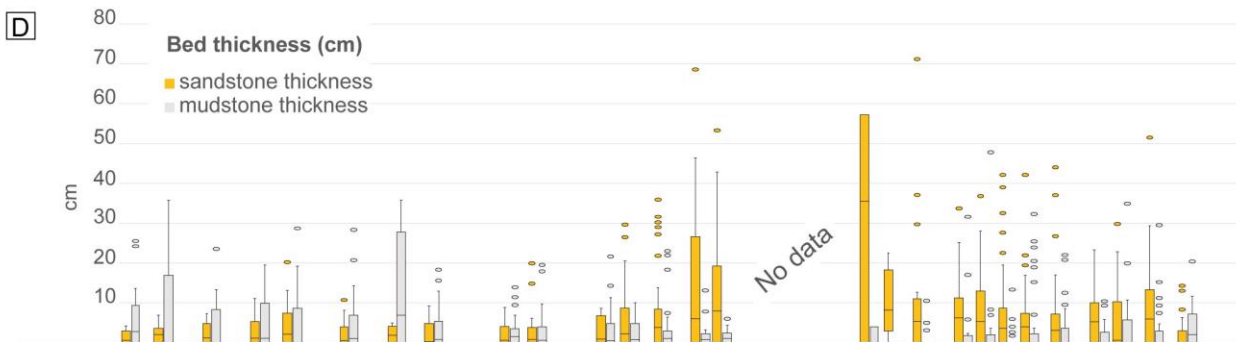
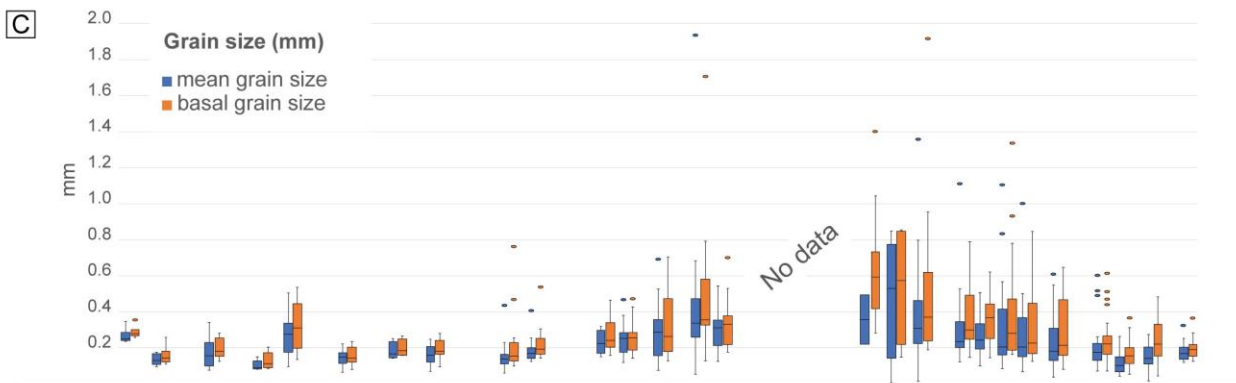
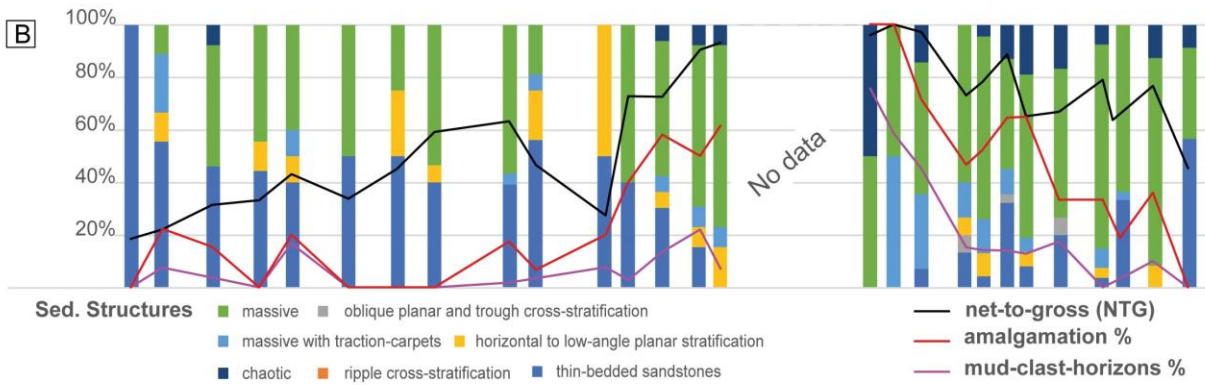
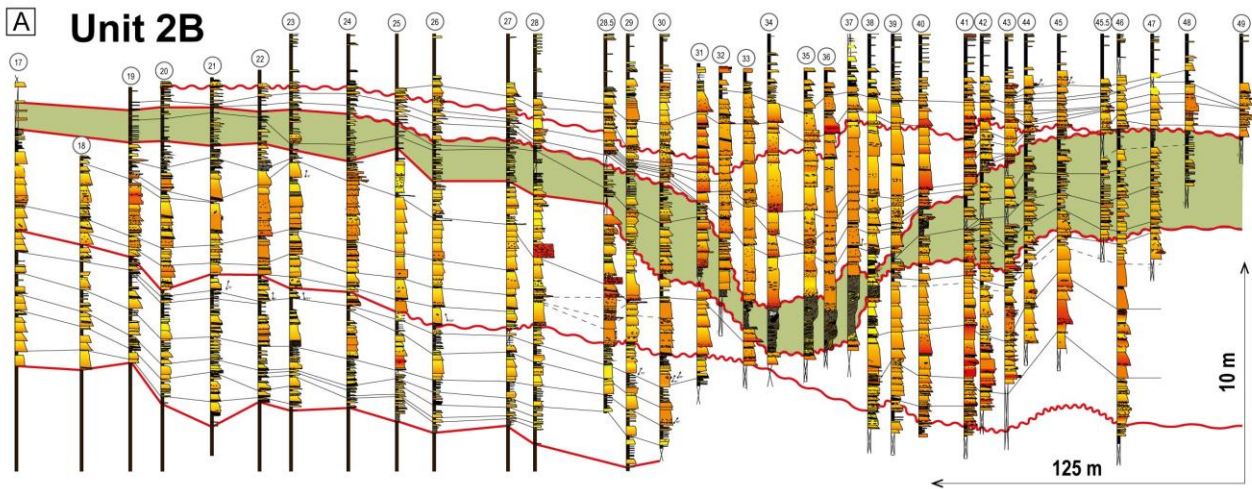
1259 **Fig. 11:** A) Correlation panel with Unit 1B highlighted. B) Bar chart showing the percentage  
1260 presence of sedimentary structures in Unit 1B, with the three line diagrams illustrating the  
1261 percentage of NTG, amalgamation rate, and mud-clast horizons along the analyzed transect  
1262 of Unit 1B. C) Box plots displaying the average grain size and basal grain size of the sand  
1263 beds in Unit 1B. D) Box plots showing the thickness of sand and mud beds in Unit 1B. X  
1264 axis of the plots refers to the measured logs shown just above in the correlation panel; Y  
1265 axis refers to the entire unit; in the boxplots, dots refer to outlier values.



1266

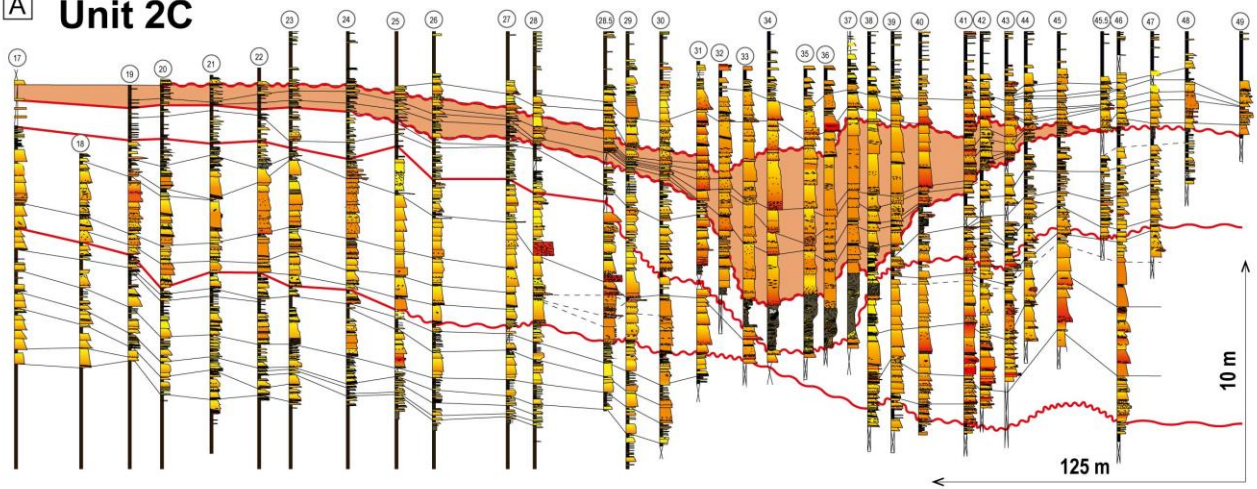
1267 **Fig. 12:** A) Channel-fill displaying the zone with chaotic deposits of Unit 2B and the sandier  
 1268 thick-bedded zone of Unit 2C, along with part of Unit 3. B) Detail of chaotic deposits (f1a)  
 1269 and amalgamated sand beds (f3) in Unit 2B. C) Sandstone beds belonging to Unit 2B (f4).

1270 D) Onlap relationships of Unit 2C against Unit 2B (S4 surface). E) Onlap relationships of  
1271 Unit 2C against S4 surface. F) Western part of the channel of units 2B and 2C. Unit 3 at the  
1272 top with thin bedded horizons. G) Eastern flank of the channel, showing the transition from  
1273 thick sandstones (f3 and f4) of Unit 2C to thin beds (f6 and f7) and the erosion of Unit 3.

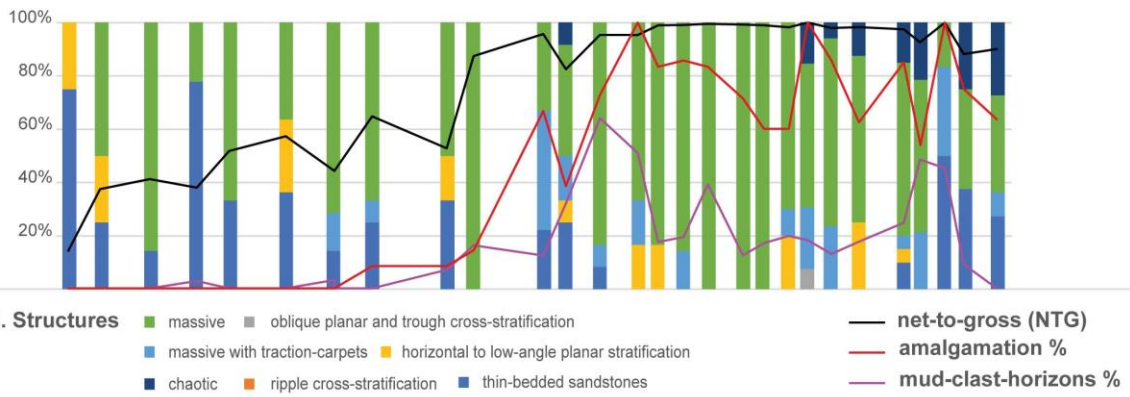


1275 **Fig. 13:** A) Correlation panel with Unit 2B highlighted. B) Bar chart showing the percentage  
1276 presence of sedimentary structures in Unit 2B, with the three line diagrams illustrating the  
1277 percentage of NTG, amalgamation rate, and mud-clast horizons along the analyzed transect  
1278 of Unit 2B. C) Box plots displaying the average grain size and basal grain size of the sand  
1279 beds in Unit 2B. D) Box plots showing the thickness of sand and mud beds in Unit 2B. X  
1280 axis of the plots refers to the measured logs shown just above in the correlation panel; Y  
1281 axis refers to the entire unit; in the boxplots, dots refer to outlier values.

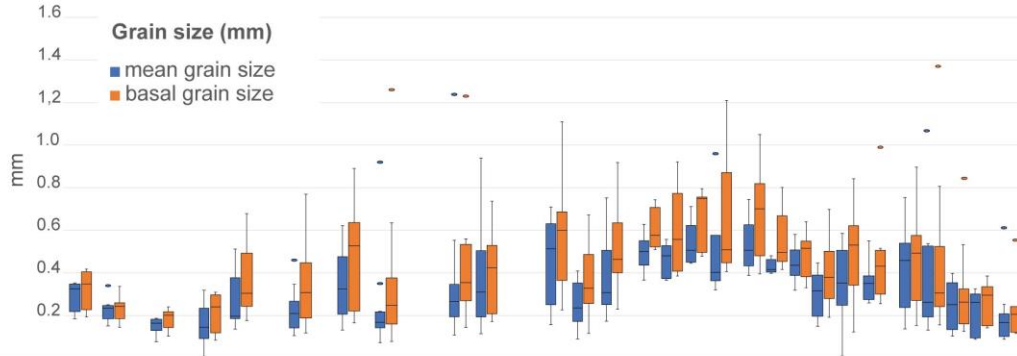
**A Unit 2C**



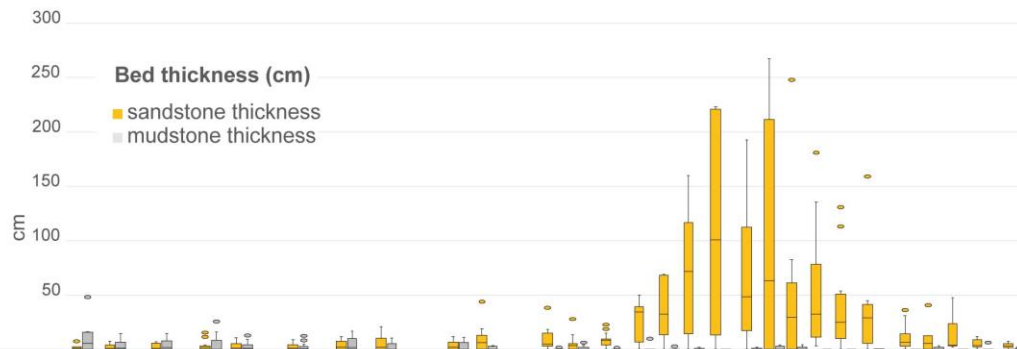
**B**



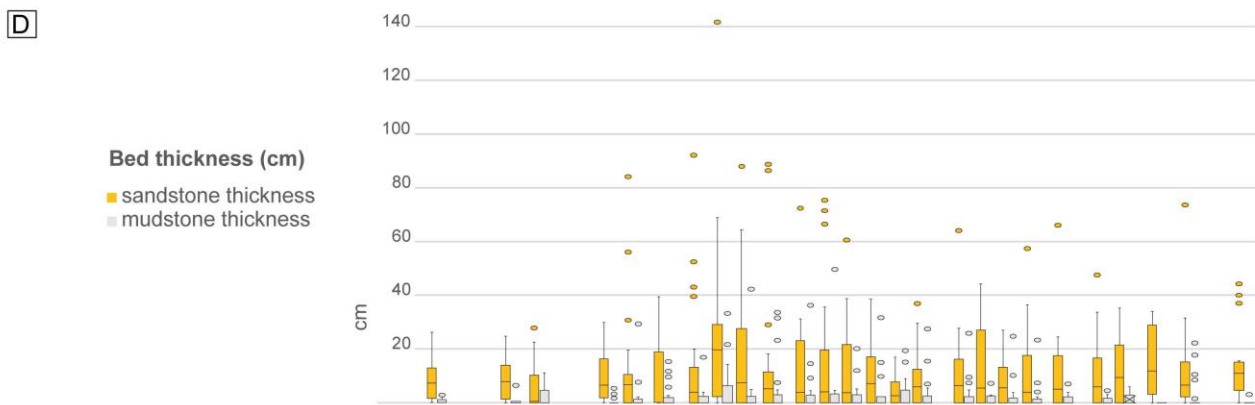
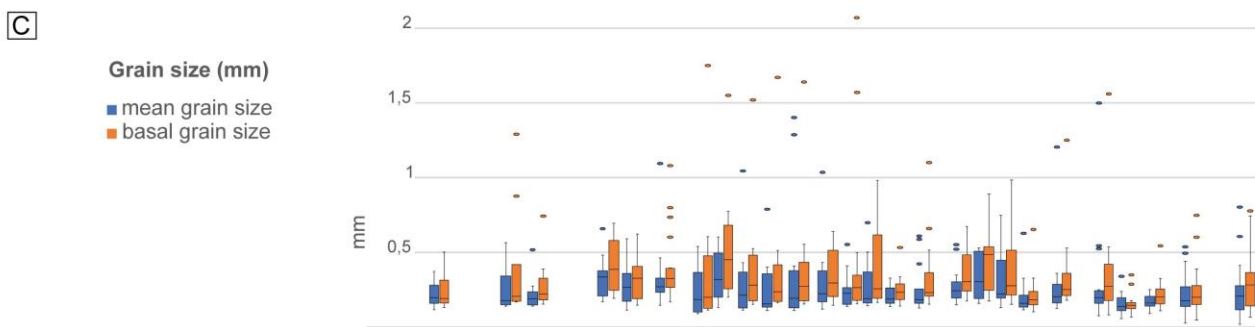
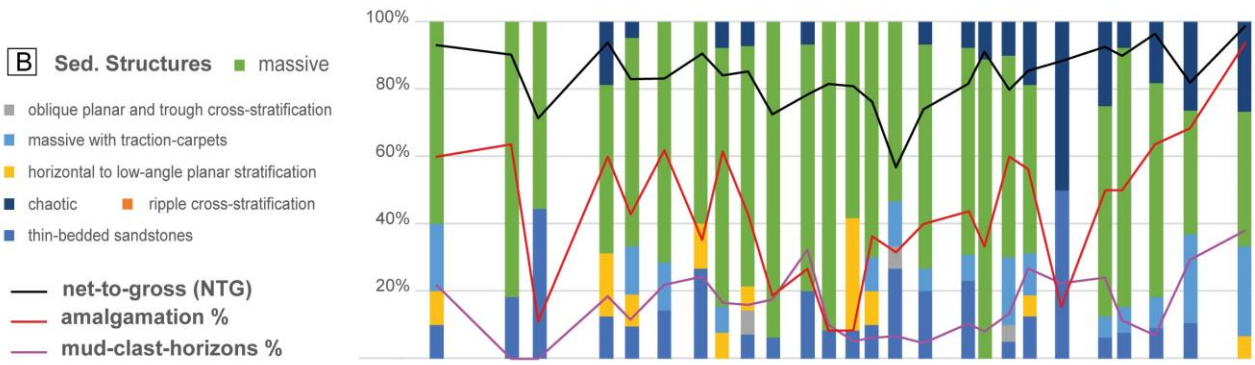
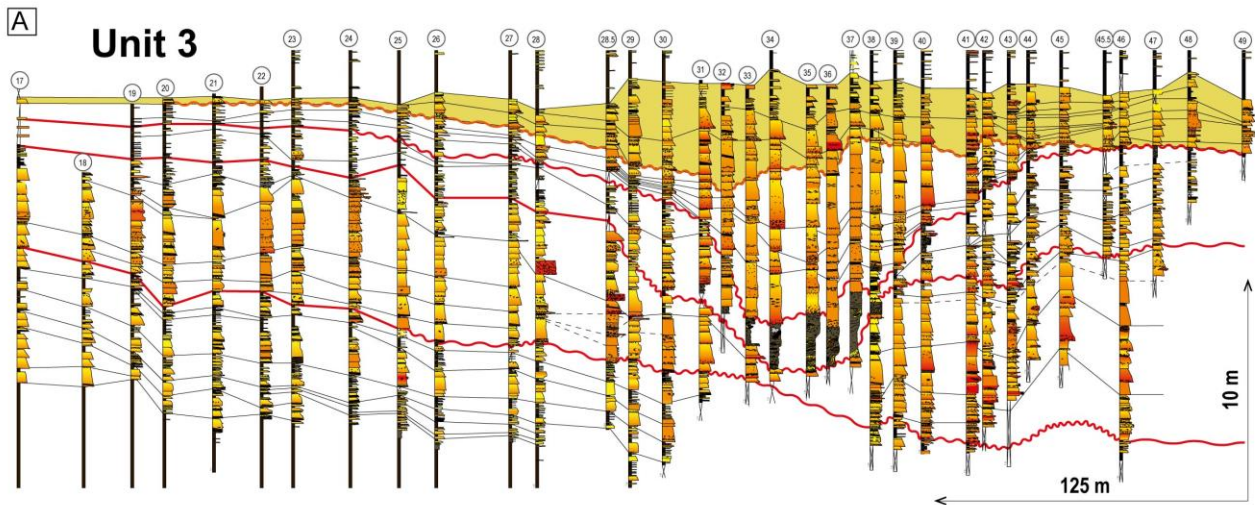
**C**



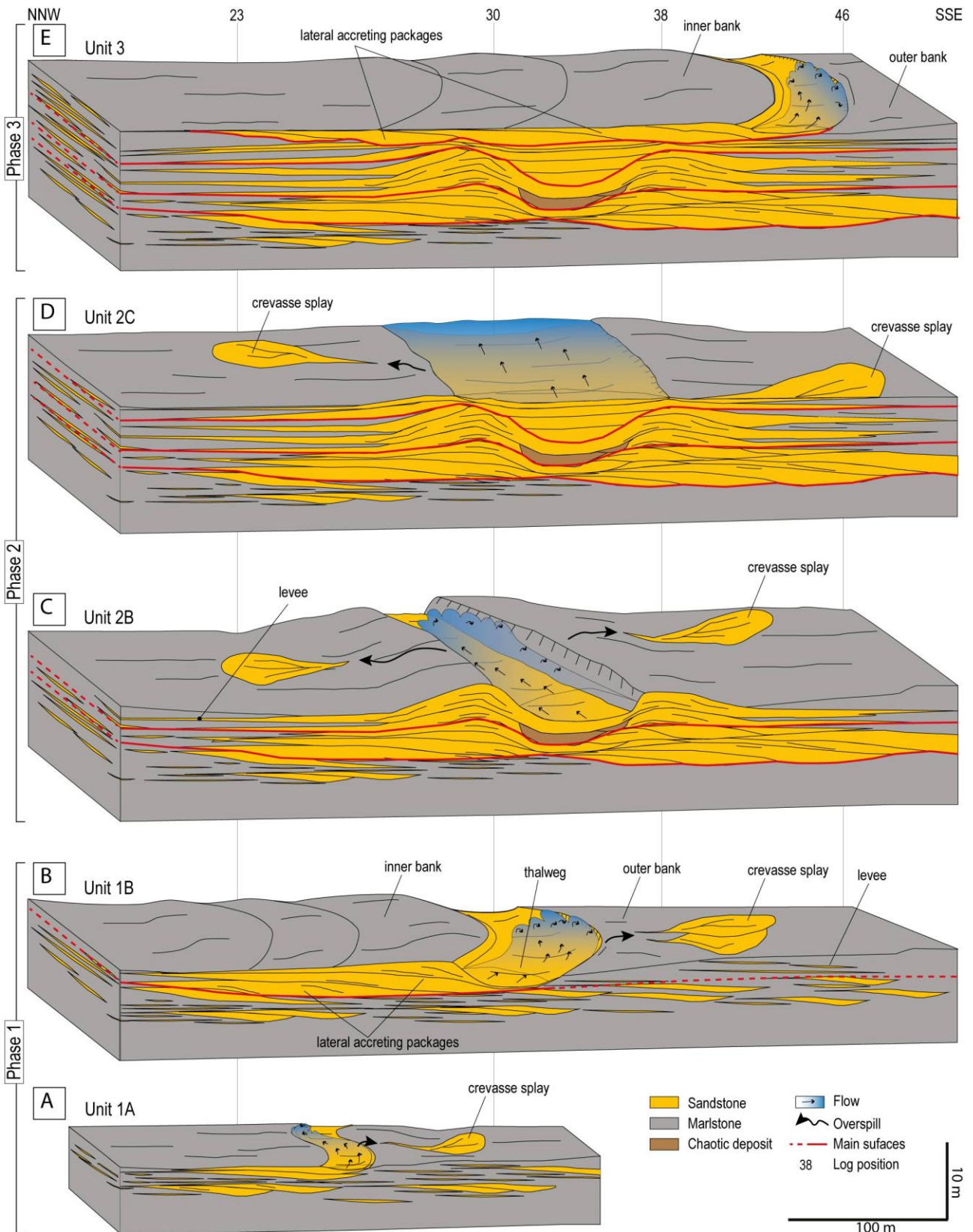
**D**



1283 **Fig. 14:** A) Correlation panel with Unit 2C highlighted. B) Bar chart showing the percentage  
1284 presence of sedimentary structures in Unit 2C, with the three line diagrams illustrating the  
1285 percentage of NTG, amalgamation rate, and mud-clast horizons along the analyzed transect  
1286 of Unit 2C. C) Box plots displaying the average grain size and basal grain size of the sand  
1287 beds in Unit 2C. D) Box plots showing the thickness of sand and mud beds in Unit 2C. X  
1288 axis of the plots refers to the measured logs shown just above in the correlation panel; Y  
1289 axis refers to the entire unit; in the boxplots, dots refer to outliers values.



1291 **Fig. 15:** A) Correlation panel with Unit 3 highlighted. B) Bar chart showing the percentage  
1292 presence of sedimentary structures in Unit 3, with the three line diagrams illustrating the  
1293 percentage of NTG, amalgamation rate, and mud-clasts horizons along the analyzed  
1294 transect of Unit 3. C) Box plots displaying the average grain size and basal grain size of the  
1295 sand beds in Unit 3. D) Box plots showing the thickness of sand and mud beds in Unit 3. X  
1296 axis of the plots refers to the measured logs shown just above in the correlation panel; Y  
1297 axis refers to the entire unit; in the boxplots, dots refer to outliers values.



1298

1299 **Fig. 16:** Evolutionary model of the seafloor channels across the Complex 7 from Phase 1 to  
 1300 Phase 3. A) Initiation of the deposition; B) lateral expansion and channel migration; C)  
 1301 channel erosion; D) channel filling; E) lateral migration.

1302 **Table 1:** Reservoir characteristics and distribution of the various architectural elements  
 1303 recognized in the studied part of Complex 7.

Architectural Element	NTG	Bed lateral continuity	Thickness	Sandstone connectivity	Facies	Facies Associations	Element area (%) vs. total complex area
Erosional channel-fill	> 0.9	Moderate (< 200 m)	1.5-9 m	Very good vertical and lateral connectivity due to paucity of fine-grained layers	f1a, f1b, f3, f4, and f5	FA1 and FA2	25
Laterally accreting	0.3-1.0	Moderate to fairly good (> 200 m)	1-3 m	Low connectivity in top-set part (FA 3) and good vertical and lateral connectivity in middle- and toe-set (FA 4 and FA 5)	f1c, f2, f3, f4, f5, and f6	FA3, FA4, and FA5	35
Overbank	0.2-0.3	Moderate to fairly good (> 200 m)	up to 5 m	Mud-rich intervals result in poor vertical and lateral connectivity	f6 and f7	FA6	40

1304