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## Preservation and distribution of detrital clay coats in a modern estuarine heterolithic point bar in the Gironde estuary (Bordeaux, France)

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1 **Preservation and distribution of detrital clay coats in a modern estuarine heterolithic point**  
2 **bar in the Gironde estuary (France)**

3

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16

**ABSTRACT**

17 Estuaries provide an excellent depositional environment to study the interaction between  
18 minerals (clays, quartz sands...) and biofilms. The estuary bottom is largely covered by  
19 biofilms that impact sediment stability, the mud and clay-coat content in sands, and  
20 sedimentary-structure stability, thus influencing sandstone properties during burial.

21 Although numerous oil, gas, and geothermal reservoirs are exploited in estuarine  
22 heterolithic point bars, many questions remain about the origin of reservoir properties and  
23 heterogeneities in these sedimentary bodies. In order to better understand the sedimentary  
24 and microbiologic processes in estuarine systems and to better predict the reservoir quality  
25 of estuarine sandstones, this study characterizes a modern heterolithic point bar located in  
26 the Garonne estuarine channel at various scales, ranging from the microscopic (thin section)

27 to the macroscopic (core) scale. Three piston cores 4.5 to 6.8 m long were drilled in the  
28 Bordeaux North Point Bar. Three main facies were identified in these cores: (1) sandy gravel;  
29 (2) heterolithic, medium-grained sand dunes; and (3) thin heterolithic, fine-grained sand  
30 beds with mud drapes. The sands are classified as lithic arkoses to feldspathic litharenites.  
31 Detrital clay grain coats, which at deep burial depths are transformed to permeability  
32 preserving authigenic chlorite coatings, are observed from the base to the top of the point  
33 bar. These detrital clay grain coats are mainly composed of smectite, illite, kaolinite, and  
34 chlorite, intermixed with other components, such as diatoms or pyrite. Biofilms of  
35 exopolymeric substances (EPSs), mostly produced by diatoms, are believed to control the  
36 adhesion of the clay coats to the surface of sand grains. Quantification by thin section shows  
37 that on average; about 30% of the sands are coated in the point bar. The proportion of clay-  
38 coated grains appears to be independent of facies. Radiocarbon age dating measured on  
39 organic matter point to significant vertical mixing, highlighting the significance of erosion  
40 and redeposition. The activities of  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  indicate a vertical sedimentation rate of  
41 *ca.*  $0.02 \text{ m.yr}^{-1}$  in the muddy chute channel. These ages, coupled to historical maps, suggest  
42 that the present-day point bar has developed over the last 300 years with a vertical  
43 sedimentation rate ranging from  $0.015$  to  $0.036 \text{ m.y}^{-1}$  and a lateral migration rate of about  $1$   
44  $\text{m.y}^{-1}$ . The combination of sedimentary geology, thin-section petrography, and mineralogy at  
45 high spatial and temporal resolutions highlights the potential of this study area as a modern  
46 analogue for ancient tidally influenced point-bar deposits associated with clay coatings.

47 **Key words:** Facies, Sand, Clay coats, Estuary, Point bar, Gironde, Reservoir analogue,  
48 Petrography

49

50

## INTRODUCTION

51 Estuaries provide an excellent depositional environment to study the interaction between  
52 minerals (clay coating, quartz sands...) and biofilms, mostly produced by diatoms (Smith and  
53 Underwood, 1998; Decho, 2000; Wooldridge et al., 2017a; Virolle et al., 2019a; Duteil et al.,  
54 2020). Estuarine biofilms consist of exopolymeric substances (EPSs), composed of  
55 polysaccharides, proteins, lipids, and nucleic acids, and reactive groups, such as carboxyl or  
56 sulfate (Stoodley et al., 2002; Braissant et al., 2007; Duteil et al., 2020). The reactive groups  
57 in EPSs formed in shallow marine and coastal environments adhere to mineral surfaces (e.g.,  
58 clays and sands; Duteil et al., 2020), changing the properties of sediments (Malarkey et al.,  
59 2015) and also adsorbing metals (Decho, 2000; Pace et al., 2018). The estuary bottom is  
60 largely covered by biofilms that influence sediment stability (Decho, 2000; Malarkey et al.,  
61 2015; Shchepetkina et al., 2017, 2018). Biofilms and their EPSs may also play a significant  
62 role in Precambrian stratigraphy and sedimentary environmental interpretations, influencing  
63 both sediment stability and sedimentary-structure stability (Decho, 2000; Sarkar et al., 2005;  
64 Malarkey et al., 2015; Shchepetkina et al., 2017, 2018). EPS is believed to support  
65 attachment of organisms to the mud sediment and as a protective cocoon to shelter the  
66 organisms against desiccation and erosion (Decho, 2000). Many studies show that tidally  
67 influenced point-bar deposits form moderate- to high-quality reservoirs (Martinius et al.,  
68 2005; Finotello et al., 2018). Common internal depositional features in point-bar reservoirs  
69 are lateral-accretion surfaces and associated bedding features that create intermediate-  
70 scale heterogeneities (Jordan and Pryor, 1992; Pranter et al., 2007; Cosma et al., 2019; La  
71 Croix et al., 2019). Although porosity and permeability in sandstone reservoirs, including  
72 tidally influenced point bars in estuaries, could be damaged by quartz overgrowth, it is  
73 widely accepted that authigenic clay chlorite coatings help inhibit quartz cement and  
74 preserve deep-reservoir quality (Ehrenberg, 1993; Bloch et al., 2002; Worden and Morad,

75 2003; Saïag et al., 2016; Worden et al., 2020). Recently, clay coats have been documented in  
76 modern shallow-marine deposits of estuaries and estuarine channels (Wooldridge et al.,  
77 2017b; Griffiths et al., 2018, 2019b, 2019a; Virolle et al., 2019a). These coats appear to have  
78 formed by thermally driven transformations of clay-mineral precursors (Aagaard et al., 2000;  
79 Haile et al., 2015; Worden et al., 2020). In modern estuarine environments, clay minerals are  
80 found in the sediment during or just shortly after deposition, and EPS appears to play an  
81 important role in binding detrital clay to sands (Dowey et al., 2017; Jones, 2017; Griffiths et  
82 al., 2019b; Wooldridge et al., 2019a; Virolle et al., 2019a; Duteil et al., 2020). These initial  
83 detrital clay minerals are believed to initiate chloritization by promoting the formation of  
84 clay-mineral precursors (e.g., berthierine) (Beaufort et al., 2015; Virolle et al., 2019b;  
85 Worden et al., 2020). Recent studies of modern analogues such as the Ravenglass (United  
86 Kingdom), Gironde (France) and Petitcodiac (Canada) estuaries show that tidal bars in the  
87 inner estuary and tidal marshes contain well developed detrital clay coats (Shchepetkina et  
88 al., 2017, 2018; Griffiths et al., 2018; Wooldridge et al., 2019a; Virolle et al., 2020).

89 However, few studies have focused on documenting the grain-size distribution, mineralogy,  
90 presence, and distribution of clay coats in point bars deposited in the estuarine channels up  
91 to the fluvial–estuarine transition zone, except for studies on the Ogeechee River (USA)  
92 (Shchepetkina et al., 2016a), the Petitcodiac River Estuary (Shchepetkina et al., 2017, 2018),  
93 the channel parts of the Ravenglass estuary (Griffiths et al., 2018, 2019b, 2019a) and the  
94 Garonne estuarine channel, located in the upstream part of the Gironde estuary (Virolle et  
95 al., 2019a). To date, no study has evaluated the influence of point-bar architecture on clay-  
96 coat distribution. Therefore, comprehensive models of detrital-clay coating processes,  
97 distribution, preservation, and heterogeneity in these challenging heterolithic point bars are  
98 still needed.

99 This study focused on the modern Bordeaux North heterolithic point bar, located in the  
100 Garonne estuarine channel (SW France). The objective was to characterize the point-bar  
101 heterogeneity from large-scale (i.e., hundreds of meters) to microscale and to discuss the  
102 factors potentially influencing clay-grain-coat occurrences and reservoir potential. This  
103 primary goal of this study is to provide a better understanding of the distribution and  
104 prediction of porosity and permeability in deeply buried tidally influenced sandstone  
105 reservoirs.

106

107

### **GEOLOGICAL SETTING**

108 The Gironde estuary (Nouvelle Aquitaine; southwestern France) is one of the largest  
109 estuaries in Europe with a surface area of 630 km<sup>2</sup> (Sottolichio et al., 2011) (Fig. 1A). The  
110 estuary is divided into three morphological zones: (1) the Garonne and Dordogne estuarine  
111 (meandering) channels, characterized by the deposition of sandy heterolithic point bars; (2)  
112 the inner estuary funnel, where the tidal bars of the bay-head delta are deposited; and (3)  
113 the outer estuary funnel, consisting in a wide muddy central basin with tidal bars and a large  
114 tidal inlet channel at its seaward extremity (Fig. 1A; Allen, 1991; Allen and Posamentier,  
115 1993; Féliès and Tastet, 1998; Billy et al., 2012; Chaumillon et al., 2013; Virolle et al., 2020).

116 The Bordeaux North point bar is located in the Garonne estuarine channel. It is a sinuous  
117 single channel, 85 km long, which extends inland from the landward extremity of the estuary  
118 funnel to the upstream tidal limit located 160 km from the estuary mouth (Fig. 1A). It is  
119 characterized by its low gradient and narrow channel (about 500 m at Bordeaux). Several  
120 point bars are observed along the meanders. These point bars are heterolithic and are  
121 composed of fluvial sand dunes and amalgamated slack-water mud drapes (Allen, 1991;  
122 Virolle et al., 2019a). The Bordeaux North point bar is located 94 km upstream from the

123 estuary mouth, north of the city of Bordeaux. It is about 1100 m long and 200 m wide (Fig.  
124 1B, C). It has been deposited in the lower part of the intertidal zone, including the entire  
125 subtidal zone, down to the thalweg of the channel. The intertidal part of the point bar is  
126 covered by (1) a network of small dunes, which can be observed from the low-tide limit to  
127 the crest of the bar, and (2) a muddy chute channel, around 100 m wide, located between  
128 the crest of the point bar and the channel bank. The channel banks are composed of a 3-m-  
129 thick section of muddy estuarine coastal-plain sediments that were deposited up to the  
130 high-tide limit. The Garonne river's discharge rate varies seasonally, reaching the highest  
131 values in January–February and the lowest in August–September (Coynel et al., 2004). The  
132 Gironde is well known for its well-developed Turbidity Maximum Zone (TMZ). In the TMZ,  
133 concentration of suspended particle matter (SPM) is reported to be a few  $\text{g.l}^{-1}$  in surface  
134 waters, but in the fluid mud zone (FMZ) near the estuary bottom, the concentration of fine  
135 particles ( $< 4 \mu\text{m}$ ) can reach 100–300  $\text{g.l}^{-1}$  (Castaing and Allen, 1981; Sottolichio et al., 2011;  
136 Etcheber et al., 2011). Jalon-Rojas et al. (2015) reported that the TMZ today in the Garonne  
137 channel near Bordeaux seems independent of salinity and density currents.

138

139

## MATERIAL AND METHODS

140 This study is mainly based on a new set of shallow piston cores (Fig. 1). Coring was  
141 conducted along an east–west transect perpendicular to the long axis of the bar, which has  
142 developed almost parallel to the direction of tidal currents. Three cores were drilled in 2016  
143 and 2017 in the heterolithic point bar: 1) Bo-2016-E at the east; 2) Bo-2016-W at the west;  
144 and 3) Bo-2017-C in the center of the cross section (Fig. 1C). The length of the cores varies  
145 from 4.44 m to 6.70 m. Core spacing is about 60 m (Fig. 1B, C). A portable vibro-corer was  
146 used to recover these cores (De Resseguier, 1983) (Fig. 2). During coring, the core barrel is

147 hammered without any rotation. A fixed piston is maintained with a cable in order to  
148 prevent deformation and fluidization due to water escape, thus preserving the delicate  
149 sedimentary structures. A reference line indicating the ebb direction of the tide is marked  
150 along the entire core section to facilitate orientation of the dune bedding (ebb and flood)  
151 after core extraction in the field.

152 Forty-three plugs (diameter 4 cm) were sampled from the cores. Thin sections of epoxy-  
153 impregnated sediment samples were observed under a Nikon Eclipse Ci-POL (Nikon, Tokyo,  
154 Japan) and a Leica DM 750P (Leica Microsystems, Wetzlar, Germany) polarizing microscope.  
155 Since "clay" may refer to both grain size and mineralogy, this study uses the term "clay  
156 fraction" to define the < 2  $\mu\text{m}$  fine-grained sediment (Grim, 1942). In each thin section, the  
157 relative surface area (%) of macroporosity and the sediment composition (coated and non-  
158 coated quartz grains, feldspars, lithics, pyrite, bioclasts, micas, and clay matrix) were  
159 quantified using random grid point counting with JmicroVision Image analysis software  
160 (Roudit, 2007). Five grain classes were identified (following the classification defined by  
161 Wooldridge et al. (2019b)): (1) absence of clay coats; (2) 1–5% of the grain surface coated;  
162 (3) 5–15% of the grain surface coated; (4) 15–30% of the grain surface coated; and (5) more  
163 than 30% of the grain surface coated. Scanning electron microscope (SEM) observations,  
164 coupled with energy dispersive X-ray spectrometry (EDS), were made on individual sand  
165 grains with a Phenom X Pro SEM (Phenom-World B.V., Eindhoven, Netherlands). Cryo-  
166 scanning electron microscopy (cryo-SEM) analyses were also conducted on select samples to  
167 document EPS and clay minerals attached to the sand grains. Grain size was determined on  
168 78 samples using a Mastersizer 2000 laser granulometer (Malvern, Worcestershire, UK).

169

170 The relative weight percentage of the clay fraction of homogenized sediment subsamples  
171 was also measured on 78 samples. It was expressed as a weight percentage of the sample  
172 (wt.%). The compositions of the clay fraction ( $< 2 \mu\text{m}$ ) were determined by X-ray diffraction  
173 (XRD) using a PANalytical X'Pert Pro X-ray diffractometer (PANalytical, Almelo, Netherlands).  
174 Samples analyzed by XRD analyses included modern mud pebbles in dunes, clay drapes and  
175 coats. Semiquantitative estimates of clay minerals (smectite, illite, kaolinite, and chlorite)  
176 were made using Macdiff software. These were based on the peak area of the ethylene-  
177 glycol diffractograms summed to 100% (the relative error for the peak area is  $\pm 5\%$ )  
178 (Petschick, 2002).

179 Short-wavelength infrared (SWIR) spectroscopy was performed on 318 core samples (103  
180 from Bo-2016-E and 215 from Bo-2016-W). Samples for SWIR were collected every 2 cm.

181 Macroscopic fragments of organic matter (wood, leaves, or seed debris) were sampled for  
182 radiocarbon dating. The age dating on 27 samples was made using the mass spectrometer  
183 accelerator at the Adam Mickiewicz University in Poznań (Poland) and at Paris-Saclay  
184 University (Gif-sur-Yvette, France). In all, 228 dried sediment samples from the top 130 cm  
185 of core Bo-2016-W were analyzed in 2017 for  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$ , and  $^{137}\text{Cs}$  by direct gamma assay  
186 at the Environmental Radioactivity Laboratory at the University of Liverpool (England) using  
187 an Ortec HPGe GWL series well-type coaxial-low background intrinsic germanium detector  
188 (Appleby et al., 1986). Isotope  $^{210}\text{Pb}$  was identified from its gamma emissions at 46.5 keV,  
189 and  $^{226}\text{Ra}$  by the 295 keV and 352 keV gamma rays emitted by its daughter isotope  $^{214}\text{Pb}$   
190 (after three weeks of storage in sealed containers to allow for radioactive equilibration).  
191 Isotope  $^{137}\text{Cs}$  was measured at 662 keV. Unsupported  $^{210}\text{Pb}$  activities were calculated by  
192 subtracting  $^{226}\text{Ra}$  activity from total  $^{210}\text{Pb}$  activity. The absolute efficiencies of the detectors  
193 were determined using calibrated sources and sediment samples of known activity. Eight

194 Corrections were made for the effect of self-absorption of the low energy gamma rays  
195 within the sample (Appleby et al., 1992).

196 Appendix 1 contains the raw XRD values obtained for the clay fraction and raw Image  
197 Analysis data on the framework mineralogy of each sample.

198

199

## RESULTS

200

### *Facies Characterization of the Heterolithic Point Bar*

201 Table 1 summarizes the facies descriptions for each point-bar core (from the bottom to top).

202 The sandstones range from lithic arkose to feldspathic arkose (Classification of Folk, 1974)  
203 with an average grain composition of quartz (37%), feldspars (11%), lithics (wood debris, soft

204 mud clasts) (14%), carbonates (3%), clays (17%), and micas (5%) (Table 2, Fig. 3A). The

205 average mean grain size in the point-bar deposits is 223  $\mu\text{m}$ . The vertical grain-size profiles

206 show an overall fining-upward trend, ranging from pebbles and coarse-grained sands at the

207 base of the bar (facies F1) to fine-grained sands and mud at the top of the point bar (facies

208 F3). These three facies form the dominant vertical facies association, with F1 at the base to

209 F3 at the top of the heterolithic point bar (Fig. 2). The heterolithic point bar has further been

210 divided into (1) lower point bar (deeper than 3 m below the low water of spring tides),

211 composed mainly of facies F1 and F2, (2) upper point bar, composed mainly of facies F2 and

212 F3, and (3) chute channel deposits composed of the clayey facies F3 only. High resolution

213 photographs of cores are available in Appendices 2, 3, and 4.

214

215

### **Facies F1: Sandy Gravels**

216 Observations: Facies F1 is composed of pluri-centimetric to pluri-decimetric beds of coarse-

217 grained sands, gravels, and lithics (soft mud clasts and organic fragments (wood)), which are

218 bounded by basal erosional surfaces. No sedimentary structures are visible. Locally, horizons  
219 rich in organic matter are observed, composed mainly of wood debris, leaves, and seeds. In  
220 the channel thalweg at the base of the core, Bo-2016-W, this facies is composed entirely of  
221 pebbles (Fig. 4).

222 Interpretation: The coarse-grained deposits of facies F1 are believed to have been deposited  
223 during floods stage, when current velocities are highest, whereas the organic-matter debris  
224 was deposited during waning flood currents. The pebble bed observed at the base of core  
225 Bo-2016-W is interpreted as the upper part of a channel lag deposit.

226

#### 227 **Facies F2: Heterolithic medium-grained sand dunes**

228 Observations: Facies F2 is heterolithic. It is made up of decimeter-thick beds of sand dunes,  
229 interbedded with centimeter- to decimeter-thick muddy beds. The sand beds are composed  
230 of small- to medium-size dunes (preserved dune set height: 10–30 cm). Their foresets and  
231 bottomsets are underlined by mud pebbles and mud drapes. The mud pebbles are  
232 subrounded and centimeters thick; mud drapes are a few millimeters thick on the foresets,  
233 but up to half a centimeter thick in the bottomsets of the dunes, where they appear to be  
234 amalgamated (Fig. 2). Mud-drape couplets (Visser, 1980; Féliès et al., 1999) are preserved in  
235 the dune foresets and bottomsets. The bidirectionality of tidal currents can be observed at  
236 the dune scale with: (i) flood- and ebb-oriented tidal bundles on dune foresets; and (ii)  
237 reactivation surfaces (De Mowbray and Visser, 1984) generated by the subordinate currents,  
238 which have eroded the dominant current bundle. Muddy beds are composed of  
239 amalgamated millimeter to centimeter-thick individual mud drapes. No bioturbation was  
240 observed.

241 Interpretation: The internal stratification of the sand dunes proves that they were deposited  
242 by bidirectional tidal currents, whose velocities exceeded the dune migration threshold. The  
243 mud drapes were deposited during slack-water periods in very turbid waters. The apparent  
244 lack of bioturbation is typical for estuarine high-turbidity fresh-water estuarine deposits (La  
245 Croix et al., 2015).

246

247 - **Facies F3: Heterolithic fine-grained sands beds and mud drapes**

248 Observations: Facies F3 is heterolithic and consists of thin fine-grained sand beds (mostly  
249 ripples and linsen), interbedded with centimeter-thick mud layers composed of  
250 amalgamated, millimeter-thick individual mud drapes. This facies is characterized by its  
251 classic lenticular bedding. Neap-spring-cycle deposits (Boersma and Terwindt, 1981) a few  
252 decimeters thick have also been described. The spring-tide deposits consist of centimeter-  
253 thick, fine-grained sandy ripples interbedded with thin mud drapes. The neap tide deposits  
254 consist of fine-grained silty linsen interbedded with thicker mud drapes. These deposits have  
255 been previously described by Musial et al. (2012).

256 A subfacies of facies F3 is the chute channel deposits, which are located on the western side  
257 of the point bar, between the crest of the point bar and the estuarine bank (see core Bo-  
258 2016-W location in Fig. 1C and Fig. 2). The chute channel deposits are 3 m thick (Fig. 4). They  
259 are characterized by alternating beds of fluid mud (centimeters to decimeters thick) and  
260 beds of fine-grained thin sand ripples, linsen, and mud drapes (decimeters thick). A few beds  
261 of coarse-grained sand and pebbles (centimeters thick) are occasionally observed.

262 Rare bioturbation was observed on the surfaces of the mud drapes, generated by  
263 millimetric-size small horizontal burrowing worms.

264 Interpretation: The ripples and linsen were deposited by tidal currents, whose velocities only  
265 just exceeded the ripple migration threshold. The thick mud drapes were deposited in highly  
266 turbid waters, during long slack-water periods. The preservation of neap-spring-cycle  
267 deposits indicates a very high rate of sedimentation with sufficient accommodation space.  
268 The subfacies F3 chute-channel deposits are representative: (1) periods of very low current  
269 velocities during which the fluid mud layers were deposited, or (2) periods of very high  
270 current velocities, attained during high flood stage, resulting in the deposit of coarse-grained  
271 sand and pebbles beds [were deposited] in the chute channel. The crypto-bioturbation  
272 present at the surface of the chute channel is typical of estuarine high-turbidity fresh-water  
273 estuaries.

274

275 - **Facies F4: Admixed sand and mud facies**

276 Observations: Facies F4 was encountered only in core Bo-2016-E, from the surface of the  
277 point bar to a depth of 235 cm (Table 1, Fig. 4). It is a mixture of mud and sand,  
278 characterized by very disturbed bedding with a lot of brick and shipyard bolts debris.

279 Interpretation: Facies F4 is made up of anthropized dredging deposits. This facies is confined  
280 to a small area on the western side of the point bar.

281

282 *Contribution of Radiometric Age Datings*

283 - **<sup>14</sup>C Datings**

284 Twenty-one <sup>14</sup>C dates were obtained on the three cores (Bo-2016-W; Bo-2017-C; Bo-2016-E).  
285 Results revealed very heterogeneous ages, ranging from 6,280 years before present (BP) to  
286 the present (Fig. 4). Except for two ages older than 1,000 years BP, the predominant ages in

287 the upper part of the tidal bar (between 0 and 4.5 m below the low-water spring-tide level  
288 (LWST)) are younger than 400 years BP.

289

290 - **<sup>210</sup>Pb Activity**

291 The results of <sup>210</sup>Pb analyses conducted on core Bo-2016-W are given in Table 3 and figure  
292 5A. Total <sup>210</sup>Pb activity significantly exceeds that of the supporting <sup>226</sup>Ra in samples down to  
293 a depth of around 90 cm. Unsupported <sup>210</sup>Pb concentrations are very low, with a maximum  
294 value of just 38 Bq kg<sup>-1</sup>. The total <sup>210</sup>Pb activity exhibits some variation with depth. Between  
295 the surface and 50 cm depth, the total activity fluctuates between 45 and 80 Bq kg<sup>-1</sup>. From  
296 50 to 110 cm deep, it decreases steadily from 70 to 20 Bq kg<sup>-1</sup> before stabilizing around 40  
297 Bq kg<sup>-1</sup> between 110 cm and 140 cm deep (Fig. 5A).

298

299 - **<sup>137</sup>Cs Activity**

300 The <sup>137</sup>Cs analyses obtained from core Bo-2016-W is around 6000 Bq m<sup>-2</sup>. <sup>137</sup>Cs activity in this  
301 core has a well-defined peak at a depth of 28 cm (Table 3, Fig. 5A), reaching a maximum  
302 value of 8.4 Bq kg<sup>-1</sup>. Between 28 to 110 cm, activity fluctuates between 4 and 6 Bq kg<sup>-1</sup>. A last  
303 peak at 5.7 Bq kg<sup>-1</sup> is observed at 108 cm depth, before it decreases to almost 0 Bq kg<sup>-1</sup> from  
304 116 to 234 cm deep (Table 3). Between the surface sample and 28 cm deep, <sup>137</sup>Cs activity  
305 ranges from almost 2 to more than 8 Bq kg<sup>-1</sup>.

306

307 *Characterization of Detrital-Clay Grain Coat*

308 Detrital-clay grain coats are present throughout the heterolithic point bar (down to ca. 7 m  
309 deep). Clay grain coats were observed around various framework grains (quartz, micas,  
310 feldspars, and lithics, except the Channel lag facies F1; Figs. 3B-G). The detrital-clay grain

311 coats are mainly composed of clay minerals with minor amounts of silt-size quartz grains,  
312 coccoliths, diatoms, and framboidal pyrite (Fig. 3F-H). Both optical microscopy and SEM  
313 observations show that diatoms are embedded in the detrital clay grain coats from the  
314 surface to several meters below the tops of the cores (Figs. 6A-E).

315 Various textures were observed, ranging from (1) continuous to discontinuous clay drapes, 5  
316 to 50  $\mu\text{m}$  thick, partially to totally cover the surface of the detrital grains (Fig. 3E); (2)  
317 aggregates of detrital-clay coats in aggregates scattered on the surface of sand grains (Figs.  
318 3D, 3F); (3) detrital-clay bridges between sand grains (Fig. 3C); to (4) detrital-clay ridges  
319 where the clay minerals are oriented at high angles to the surfaces of detrital sand grains.  
320 The detrital-clay grain coats are typically less than 1 millimeter thick, ranging mainly from 10  
321 to several hundred  $\mu\text{m}$ . All these clay coat textures were observed in all facies (Fig. 3).

322 Detrital sand grains on average represent 70% of the sample composition, and 31% of the  
323 grains are coated (Table 2, Fig. 7). Vertically, the total number of coated grains ranges from  
324 19% to 48% (Table 2; Fig. 8). In each facies, the coated grain-content is very homogeneous:  
325 sandy gravel facies (F1) = 29%; heterolithic, medium-grained sand dune facies (F2) = 31%,  
326 and heterolithic, fine-grained sand bed and mud drape facies (F3) = 32% (Fig. 7, Table 2).  
327 Coat coverage is relatively homogeneous for all cores (Fig. 9). For the finer sand of the  
328 heterolithic facies (F3), the two predominant classes of clay grain-coat-coverage are 5–15%  
329 and 15–30%. In facies F1 and F2, more than 20% of the grain are coated, with a coverage  
330 ranging from 1 to 15% (Fig. 7). Overall, there is no correlation between clay fraction and the  
331 percentage of coated grain (Fig. 9A, B).

332

333

### *Characterizations of Clay Fractions and Clay Assemblages*

334 The clay fraction is related to the amount of muddy deposits (muddy layers or clay drapes)  
335 and coats in a sample. On average, the total clay content makes up about 20 wt.% of the  
336 sample (Table 2; Figs 8, 9B). In facies F1 and F2, the amount of clay is very consistent (18%),  
337 but it is slightly higher in facies F3 (25%) (Fig. 9B). The muddy chute-channel subfacies (F3)  
338 has a higher clay content (38 wt.%), as shown in Figs. 8 and 9B (Table 2). It should be noted  
339 that the clay-fraction content in facies F3 might be slightly underestimated because of bias  
340 in sample selection (most of the samples were extracted from sandy ripples).

341 Based on XRD analysis, the clay-mineral assemblage is composed of four main clay minerals:  
342 chlorite, illite, kaolinite, and smectite (Fig. 10, Table 2). Chlorite is characterized by  
343 diffraction peaks at 14.10 Å (001), 7.05 Å (002), 4.73 Å (003), and 3.54 Å (004). The illite  
344 diffraction pattern exhibits diffraction peaks around 9.99 Å (001), 4.99 Å (002), and 3.33 Å  
345 (003). Kaolinite displays a (001) diffraction peak at 7.16 Å and a (002) diffraction peak at 3.57  
346 Å. Smectite is identifiable after ethylene-glycol saturation, with a (001) diffraction peak close  
347 to 17 Å. Smectite is mainly dioctahedral smectite (Latouche, 1971). Smectite (7%) and illite  
348 (8%) have the highest surface areas (on the diffractogram), while chlorite and kaolinite have  
349 a much lower surface area (average of 2%; Fig. 9C-F, Table 2). Clay assemblages are relatively  
350 homogeneous between facies, except for facies F3 in core Bo-2016-W (the muddy chute-  
351 channel subfacies) where the abundance of all clay minerals is systematically higher:  
352 smectite (14%), illite (16%), kaolinite (4%), and chlorite (3%) (Fig. 9C-F).

353 Short-wavelength infrared (SWIR) measurements were made along cores Bo-2016-W and  
354 Bo-2016-E. Of particular interest were three bands: (1) the water-absorption band, which  
355 can be correlated with the presence of swelling minerals such as smectite, and (2) the 2200  
356  $\text{cm}^{-1}$  ( $\text{Al}_2\text{OH}$ ) and 2253  $\text{cm}^{-1}$  bands, both of which mainly characterize aluminous phases, such  
357 as micas or clay minerals. In core Bo-2016-E, none of the bands show significant variation

358 with depth or even between facies in core Bo-2016-E (Fig. 8). In core Bo-2016-W, each of the  
359 three bands displays a slightly increasing trend with depth, coupled with higher fluctuations  
360 (Fig. 8).

361

362

## DISCUSSION

363

### *Age Model of Cores*

364 Previous studies have used  $^{137}\text{Cs}$ – $^{210}\text{Pb}$  chronologies to reconstruct the morphological  
365 evolution of point-bar deposits through time (D'Alpaos et al., 2017). In montmorillonite,  
366 vermiculite, kaolinite, and illite, the isotope  $^{137}\text{Cs}$  is essentially fixed on particles of  
367 permanent charge due to cationic exchange on the mineral compounds (Grousset et al.,  
368 1999). The isotope  $^{137}\text{Cs}$  is mostly incorporated into the illitic clay matrix of the Gironde  
369 suspended matter and is therefore difficult to desorb. This is why it was relevant to carry out  
370  $^{137}\text{Cs}$ – $^{210}\text{Pb}$  dating in the muddy deposits of the chute channel enriched in smectite  
371 (montmorillonite) and illite (Fig. 5A). Calibrations were made by comparisons with Grousset  
372 et al. (1999) and Jouanneau et al. (1999), who studied a core located 3 km upstream in the  
373 flood-tide dock of Bordeaux (Fig. 1B).

374 The atmospheric initiation of radioactive fallout since 1952 is responsible for the increase in  
375  $^{137}\text{Cs}$  activity in sediments, reaching a  $^{137}\text{Cs}$  peak in 1964 (e.g., Monna et al., 1999; Evrard et  
376 al., 2020). The beginning of this increase can be seen at *ca.* 124 cm with a small  $^{137}\text{Cs}$  peak at  
377  $0.4 \text{ Bq kg}^{-1}$  (Fig. 5A, B). The peak of  $^{137}\text{Cs}$  activity at  $5.7 \text{ Bq kg}^{-1}$  recorded at 108 cm below the  
378 top of core could correspond to the year 1964, which was marked by the maximum impact  
379 of nuclear tests in the northern hemisphere (Pourchet et al., 1989; Williams and Hamilton,  
380 1995; Jouanneau et al., 1999; Monna et al., 1999) (Fig. 5A, B). This increase in  $^{137}\text{Cs}$  activity  
381 from the mid-1950s to 1964, also corresponds to an increase in cadmium (Cd) in the estuary,

382 suggesting an increase in river inputs (Grousset et al., 1999; Jouanneau et al., 1999). In the  
383 Bordeaux dock core,  $^{137}\text{Cs}$  reaches a maximum at 3 dpm  $\text{g}^{-1}$  ( $50 \text{ Bq kg}^{-1}$ ) for 1964 (Jouanneau  
384 et al., 1999), whereas  $^{137}\text{Cs}$  reaches  $120 \text{ Bq kg}^{-1}$  in Lake Geneva (Switzerland) for the same  
385 year (Monna et al., 1999). The presence of small but significant concentrations of  $^{137}\text{Cs}$  down  
386 to a depth of 110 cm suggests that all sediments above this depth postdate the large-scale  
387 release of this artificial radionuclide into the global environment from the mid-1950s  
388 onwards (Fig. 5A-B). This is consistent with the suggestion that the greatest depth ( $\sim 90 \text{ cm}$ )  
389 at which significant amounts of unsupported  $^{210}\text{Pb}$  could be detected was likely to span at  
390 most 2–3  $^{210}\text{Pb}$  half-lives (40–60 years). According to the age model of the core from the  
391 dock of Bordeaux, a second  $^{137}\text{Cs}$  peak occurs in the 1970s (Grousset et al., 1999). The peak  
392 found at 84 cm ( $5.7 \text{ Bq kg}^{-1}$ ) in core Bo-2016-W (Fig. 5A-B) could also correspond to this  
393 event.

394 The third  $^{137}\text{Cs}$  peak (ca.  $20 \text{ Bq kg}^{-1}$ ) recognized in the Bordeaux dock core corresponds to the  
395 Chernobyl accident that occurred in 1986 (Grousset et al., 1999). The third peak ( $6.5 \text{ Bq kg}^{-1}$ )  
396 is also found 60 cm deep in core Bo-2016-W (Fig. 5A-B). The fourth  $^{137}\text{Cs}$  peak ( $8.4 \text{ Bq kg}^{-1}$ )  
397 found at 28 cm is not attributed to a known discharge, source or event. The temporal  
398 evolution of  $^{210}\text{Pb}$  element is characterized by great variability in the upper part of the chute  
399 channel between 20 and 30 cm, possibly suggesting sediment remobilization (Fig. 5A).

400 Placing year 1964 at 108 cm and 1986 at 60 cm, the average sedimentation rate can be  
401 estimated to be ca.  $2 \text{ cm.y}^{-1}$  (Fig. 5C). The results from  $^{210}\text{Pb}$  total activity are consistent with  
402  $^{137}\text{Cs}$  activity, as the first 110 centimeters of the core would be less than 60 years old (Fig.  
403 5A, B). By anchoring years 1964 at 108 cm and 1986 at 60 cm, and applying a sedimentation  
404 rate of  $2 \text{ cm y}^{-1}$ , the sample at 12 cm which contains significantly higher concentrations of

405 uranium-series radionuclides appears to have been deposited to around 2010. The samples  
406 at 26–28 cm contained the highest  $^{137}\text{Cs}$  concentration, suggesting that they were deposited  
407 around 2002.

408 Radiocarbon ages dating was performed on the three cores at all depths. These ages are  
409 very heterogeneous, ranging from  $6280 \pm 30$  years BP to modern (Fig. 4). Results may  
410 depend on the nature of organic remains. Fine organic debris, such as leaves and twigs, are  
411 assumed to record ages close to the age of sediment deposition (because they are  
412 seasonally produced and readily decomposed (Kochel and Baker, 1988; Webb et al., 1988)  
413 and therefore are believed to yield the most accurate  $^{14}\text{C}$  dates in fluvial deposits (Ely et al.,  
414 1992). Detrital wood and charcoal  $^{14}\text{C}$  ages may predate fluvial deposits by centuries after  
415 sedimentation and can be remobilized giving erroneous ages of deposition (Long and  
416 Rippeteau, 1974; Blong and Gillespie, 1978; Ely et al., 1992). In the Bordeaux North point  
417 bar, radiocarbon ages measured on seeds and leaf debris are younger than 400 years (Fig. 4).  
418 The top 110 cm of the well-calibrated core Bo-2016-W, yielded two  $^{14}\text{C}$  ages (modern and  
419  $195 \pm 30$  years BP). This suggests that the youngest age obtained provides information about  
420 sediment age. Older  $^{14}\text{C}$  ages suggest that old organic matter has been remobilized and  
421 transported into the estuary (Virolle et al., 2020). In core Bo-2016-W, an age of  $70 \pm 30$  years  
422 BP was obtained at a depth of 3.1 m (in the upper section of the point bar) (Fig. 4),  
423 suggesting that the top 3 m is relatively young, probably deposited during the last century.  
424 This suggests a sedimentation rate of *ca.*  $3 \text{ cm y}^{-1}$ . In core Bo-2016-W, an age of  $355 \pm 30$   
425 years BP at a depth of 5.3 m suggests that the sedimentation rate for the top 5 m was  
426 around  $1.5 \text{ cm y}^{-1}$ . In core Bo-2017-C, leaf fragments at a depth of 3.2 m yielded an age of  
427  $170 \pm 20$  years BP at the top of the lower point bar (Fig. 4). This age suggests that the top  
428 3 m was also relatively young, probably deposited in the two last centuries, and

429 corresponding to a sedimentation rate of *ca.* 1.9 cm y<sup>-1</sup>. In core Bo-2016-E, the age 95 ± 30  
430 years BP in the lower point bar (depth of 3.4 m) (Fig. 4) suggests a sedimentation rate of 3.6  
431 cm y<sup>-1</sup> in the upper point bar. A recent study reports that the sedimentation rate is about 1–  
432 3 mm.y<sup>-1</sup> in a tidal point bar of the lagoon of Venice (Donnici et al., 2017). The sedimentation  
433 rate in the Bordeaux point bar is higher by a factor of ten.

434 Radiometric ages (<sup>14</sup>C, <sup>137</sup>Cs, and <sup>210</sup>Pb) suggest that the formation of the Bordeaux North  
435 point bar is relatively young and rapid (< 300 years). This is consistent with lateral migration  
436 studies which document that the point bar has migrated about 200 m since the period  
437 1820–1866, yielding a lateral-accretion rate of 1 m.y<sup>-1</sup> (Fig. 11). In comparison, detailed  
438 studies of the tidal point bars of the Venice Lagoon show lateral-accretion rates of only 0.1  
439 to 0.25m.y<sup>-1</sup> (Donnici et al., 2017; D’Alpaos et al., 2017; Ghinassi et al., 2018).

440

#### 441 *Origin of Detrital-Clay Grain Coats*

442 Grain coats observed in the Gironde estuary are mainly composed of clay minerals (Fig. 6).  
443 As described in Virolle et al. (2019a), these clay minerals are detrital and supplied by the  
444 Garonne and Dordogne rivers. These two rivers are responsible for 70% and 18%,  
445 respectively, of the supply of detrital clay minerals to the estuary funnel respectively  
446 (Latouche, 1971; Parra et al., 1998). The seasonal position of the turbidity-maximum zone  
447 (TMZ) seems to be a major factor controlling the amount of clay, the clay-mineral  
448 assemblage, and the coated-grain distribution, in the intertidal zone of the estuary (Virolle et  
449 al., 2019a).

450 The incorporation of clay particles in the heterolithic point-bar deposits seems to be mostly  
451 related to hydrodynamic variations (seasonal variations in river discharge associated with  
452 seasonal TMZ position and tidal-current cycles), rather than mechanical infiltration or

453 bioturbation processes, as bioturbation is rarely observed and no significant variations in  
454 clay content are observed in near-surface sediments (Virolle et al., 2019a). If these  
455 postdepositional (mechanical infiltration or bioturbation) processes occurred, they are minor  
456 and do not overprint the distribution of detrital-clay grain coats in surface sediments or in  
457 the vertical facies associations of the point bar.

458 Diatom biofilms extensively cover the chute channel, especially during the summer (Virolle  
459 et al., 2019a). These biofilms produce abundant exopolymeric substances (EPSs), especially  
460 on the surface of the chute channel (facies F3, Virolle et al., 2019a). The role of EPSs in  
461 binding detrital clay to sand grains has been discussed in several modern estuarine studies  
462 (Shchepetkina et al., 2017, 2018; Jones, 2017; Wooldridge et al., 2017a; Virolle et al., 2019a).  
463 EPSs produced by biofilms observed in the chute channel, could be resuspended during a  
464 semidiurnal cycle (Underwood and Kromkamp, 1999) and transported in suspension, finally  
465 interacting with sand grains and clay particles on the surface of the point bar. This  
466 interaction could result in the formation of clay-coated sand grains in the zone of deposition  
467 of facies F2 (Fig. 12). Aggregates of detrital-clay grain coats in facies (F1), are observed only  
468 in depressions or hollows of detrital grains. As these grains are transported by rolling during  
469 periods of strong currents or flood events, these coats would be expected to be preserved  
470 only in depressions. It also supposes that these coats are probably inherited, preserved, and  
471 formed in another location of the point bar or facies before being incorporated in facies (F2  
472 or F3) after sediment transport. Verhagen et al. (2020) demonstrated experimentally that  
473 clay coats can be preserved during sediment transport in turbulent flows of about  $50 \text{ cm}\cdot\text{s}^{-1}$ .  
474 This velocity is reached during all tidal cycles in the point bar and corresponds to the  
475 formation of dunes in Facies F1. The high clay fraction (> 30% in sandy beds) in the muddy  
476 facies of core Bo-2016-W (muddy chute-channel facies) could be due to the *in situ*

477 production of EPS and clay entrapment by diatom biofilms (Figs 6A, B, 12; Virolle et al.,  
478 2019a). The presence of the chute channel and the mud-rich F3 facies appears to be a key  
479 point required for the production of biofilms and on the coated grains in the point bars. The  
480 chute channel traps both mud and clay (a favorable location for biofilm development), and  
481 thus appears to play an important role in binding clay to sand grains in the point bar.

482

#### 483 *Clay-Coat Composition and Mineralogy in a Modern Point Bar*

484 The detrital-clay grain coats observed in cores are consistent with those reported in surface  
485 sediments, in the intertidal zone of the heterolithic point bar (Virolle et al., 2019a). Infrared  
486 measurements (at a very tight sampling step) provide rapid and continuous information  
487 about the clay content of the core (Fig. 8). Overall, they confirm the relative stability of clay  
488 mineralogy with depth. A focus on certain adsorption bands, such as the water band (at  
489 about 1900 nm) or the bands characteristic of aluminous phases (at 2200 and 2253 nm)  
490 reveals local accumulations of smectite or mica (Fig. 8). Locally, in core Bo-2016-W, each  
491 band exhibits a slightly increasing trend coupled with stronger fluctuations with depth  
492 (between 4 and 6 m deep) (Fig. 8). Since the clay content does not particularly increase  
493 downward, this could be due to the overall increase in the mica content. Petrographically,  
494 similar textures are observed (ridged, aggregated, or bridged textures) at all core depths.  
495 XRD analyses confirm a homogeneous clay-mineral composition in the tidal bar: (1) illite  
496 represents on average 9 wt.% of the total sediment and 45% of the clay content; (2) smectite  
497 represents on average 7 wt.% of the total sediment and 34% of the clay content; (3) chlorite  
498 represents on average 1.8 wt.% of the total sediment and 9% of the clay content; and (4)  
499 kaolinite represents on average 2.4 wt.% of the total sediment and 12% of clay content.  
500 Occasional silt-size quartz, carbonates, and pyrite are also observed embedded in detrital-

501 clay grain coats (Fig. 3G). The clay assemblage and the associated minerals are comparable  
502 to those reported from the Plassac tidal bar, which is located 30 km downstream in the  
503 Gironde inner estuary funnel (Virolle et al., 2019a, 2020). In contrast, the clay-mineral  
504 assemblage differs from the Richard tidal bar, which is located 70 km downstream in the  
505 Gironde outer estuary funnel. The Richard tidal-bar sediments contain less smectite (3 wt.%)  
506 and more illite (16 wt.%) (Virolle et al., 2019a, 2020).

507 In the alluvial plain of the Ravenglass estuary, the average clay content of 15% is slightly  
508 lower (Griffiths et al., 2019) than the 20% clay content found in the Bordeaux north point bar  
509 (20%). The majority of sand grain surfaces of the Ravenglass estuarine channels are covered  
510 by clay coats, with coat coverage greater than 30% (Griffiths et al., 2018, 2019a). The main  
511 difference in the clay-mineral assemblage is the absence of smectite (Griffiths et al., 2018,  
512 2019a), with illite being the main clay mineral in 1–6 wt.% of the samples and representing  
513 60% of the clay content. As in the Bordeaux North point bar, only minor amounts of kaolinite  
514 and illite (0.01–3%) were found, confirming that the Garonne estuarine channel is more  
515 turbid than the Ravenglass estuary (Griffiths et al., 2019).

516

#### 517 *Reservoir Implications*

518 Authigenic chlorite coats have been recognized to play a significant role in preserving  
519 porosity in sandstones around the world (Pittman and Lumsden, 1968; Thomson, 1979;  
520 Ehrenberg, 1993; Bloch et al., 2002; Anjos et al., 2003; Taylor et al., 2010; Ajdukiewicz and  
521 Larese, 2012; Sun et al., 2014; Huggett et al., 2015; Saiag et al., 2016; Virolle et al., 2019b;  
522 Worden et al., 2020). Sandstones where at least 60-80% of the grains were coated (Virolle et  
523 al., 2019b; Worden et al., 2020) and/or at least 80% of quartz surfaces are covered by clay  
524 coats (Lander and Walderhaug, 1999; Taylor et al., 2010; Stricker et al., 2016) have been

525 found to have the best reservoir quality. Numerical models for quartz cementation suggest  
526 that complete grain coats are needed to preserve porosity in deep, high-temperature (> 70-  
527 80 deg C) reservoirs (Bloch et al., 2002; Lander et al., 2008). Modern studies have found that  
528 from 2 to 10% chlorite is needed to fully coat quartz grains (Virolle et al., 2019b; Worden et  
529 al., 2020). At all scales, in the Garonne Bordeaux North heterolithic point bar, the facies with  
530 the least mud baffles were found to be the sand-dominated facies (F1 and F2) (Figs. 3, 4, 6;  
531 Table 2). On average, in these two facies, medium-grained sandstone (mean grain size of 292  
532  $\mu\text{m}$ ) were typically composed of 30% clay-coated grains, with about 5-15% of the quartz  
533 grain surfaces covered in clay, a chlorite clay content of about 2%, and a total clay fraction of  
534 20 wt.% (Tables 1, 2, Figs. 4, 12). The clay fraction of Facies F3 was typically higher (25%) and  
535 contained a higher amount of coated grains (32%) (Table 2, Fig. 8). Those values are  
536 significantly lower the 60-80% values and 80% quartz surface coverage proposed in the  
537 literature for chloritized reservoirs (Lander and Walderhaug, 1999; Taylor et al., 2010;  
538 Stricker et al., 2016; Virolle et al., 2019b; Worden et al., 2020). This difference is mainly due  
539 to the diagenetic process of recrystallization from detrital-clay coats to authigenic chlorite. It  
540 has been proposed that authigenic grain-coating chlorite, especially Fe-rich chlorite, does  
541 not form directly from solution by precipitation during eogenesis (Beaufort et al., 2015) but  
542 through a complex chloritization processes that involves the formation of an Fe-rich clay-  
543 mineral precursor, such as berthierine (Hornibrook and Longstaffe, 1996; Beaufort et al.,  
544 2015; Virolle et al., 2019b; Worden et al., 2020). During the chloritization process, the  
545 detrital-clay coatings initially covering 30% of the sand grains and 5-15% of the quartz grain  
546 surfaces are homogeneously redistributed around grains. After chloritization, it is likely that  
547 the percentage of coated grains in the sediment increases from 30% initially to more than  
548 80%. It is also likely that the coat coverage (coat surface) around the detrital quartz grains

549 increases from an initial 5-15% to > 80%, almost complete coat coverage. From a diagenetic  
550 perspective, the detrital-clay grain coats composed of kaolinite, illite, smectite, and chlorite  
551 found in the Bordeaux North heterolithic point bar might evolve into chlorite coatings during  
552 eogenesis and burial diagenesis, and the initiation of chloritization actually begins with the  
553 formation of an early clay-mineral precursors, such as berthierine (Gould et al., 2010;  
554 Beaufort et al., 2015; Worden et al., 2020) that eventually with increasing temperature and  
555 pressure evolve into chlorite grain coats that inhibit the development of quartz cement and  
556 thus preserve deep-reservoir quality. Facies F1 and F2 have the best reservoir potential if  
557 deeply buried (more 2.5 km). We consider that the initial coated-grain content (about 30%)  
558 and initial clay-fraction content of the sediment (on average lower than 20 wt.%) could be  
559 conducive to the preservation of a porosity network (Fig. 12). In the interbedded sands of  
560 facies F3, 20-35% of clays could potentially stop development of quartz overgrowths and  
561 minimize porosity loss during burial diagenesis. However, it is likely that higher clay contents  
562 favor the development of pore-filling clay, rather than fine clay coatings, thus resulting in the  
563 loss of porosity during burial. Lastly, this study found that the mud-rich facies F3 and the  
564 chute channel facies are favorable to the development of biofilms and may play an  
565 important role in the binding of clay to sand grains in the heterolithic point bar.

566 Comparisons between modern analogues (such as the Garonne estuarine heterolithic point  
567 bars) and deeply buried reservoirs are key to improving predications of reservoir quality in  
568 deeply buried estuarine heterolithic point-bar reservoirs (Martinius et al., 2005) by providing  
569 critical information on the initial conditions necessary for the crystallization of chlorites  
570 during burial (Byrne et al., 2011; Shchepetkina et al., 2016b, 2018; Wooldridge et al., 2017b,  
571 2019a; Dowey et al., 2017; Griffiths et al., 2019b, 2019a; Virolle et al., 2019a, 2020; Worden  
572 et al., 2020). The next step will be to fully understand the conditions of incipient

573 chloritization in shallow buried sediments (temperature, depth, pressure, chemical  
574 conditions), especially the role of iron reduction in promoting the development of chlorite  
575 precursors (such as berthierine)

576

577

## CONCLUSION

578 (1)  $^{14}\text{C}$  dating suggests that the Bordeaux North point bar has settled over the last 300  
579 years.  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  chronologies highlight that the sedimentation rate in the chute  
580 channel is about  $2\text{ cm}\cdot\text{y}^{-1}$ .  $^{14}\text{C}$  ages suggesting that the average vertical sedimentation  
581 rate ranged from  $1.5$  to  $3.6\text{ cm}\cdot\text{y}^{-1}$  in the point bar. Radiometric ages ( $^{14}\text{C}$ ,  $^{137}\text{Cs}$ , and  
582  $^{210}\text{Pb}$ ), coupled with historical data found that the point bar has migrated laterally,  
583 approximately 200 m to the northeast since 1820, suggesting a lateral migration rate  
584 of  $1\text{ m}\cdot\text{y}^{-1}$ .

585 (2) The Garonne point bar is composed of three main facies: (1) sandy gravels; (2)  
586 heterolithic, medium-grained sand dunes; and (3) heterolithic, fine-grained sand  
587 beds and mud drapes. Sands are classified as lithic arkoses to feldspathic litharenites.  
588 The coated-grain content, coat coverage, or the mineralogy of the coats and  
589 distribution is not controlled by facies.

590 (3) Clay coats were observed in the entire vertical sequence of a heterolithic point bars  
591 in the modern Gironde estuarine channel (at depths down to almost 7 m). The clay  
592 assemblage is composed on average of (1) 9% illite, (2) 7% smectite, (3) 2% chlorite,  
593 and (4) 2% kaolinite. Detrital-clay grain coats, generally less than 1 mm thick (10 to  
594 several hundred  $\mu\text{m}$ ), were observed on fine- to-medium-grained sands (average  
595 grain size *ca.*  $223\ \mu\text{m}$ ). In the chute channel facies, EPSs produced by diatoms were  
596 identified that may interact directly with detrital grains. In the suspended particulate

597 matter of the tidal channel, EPSs could play a key role in binding clay particles around  
598 sand grains during the saltation or rolling of sand grains.

599 (4) On average, 31% of detrital sand grains are coated, covering 5 to 15% of the total  
600 grain surface area. These early coatings could initiate chloritization during burial  
601 diagenesis, by transforming into clay precursors (such as berthierine), thus promoting  
602 the preservation of reservoir quality by inhibiting quartz overgrowths.

603

604

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622

## 623 FIGURES

624

625 **Figure 1:** A) Simplified facies map of the Gironde estuary. B) Bathymetric map showing the  
626 location of the Bordeaux North point bar. C) Google Earth aerial view of the point bar. Yellow  
627 stars indicate the location of the cores sampled in this study: Bo-2016-W, Latitude (°N):  
628 44.895911, Longitude (°E): -0.540475; Bo-2017-C, Latitude (°N): 44.896000, Longitude (°E): -  
629 0.539836; Bo-2016-E, Latitude (°N): 44.896086, Longitude (°E): -0.539217. The Bordeaux  
630 dock core was described in Jouanneau et al. (1999).

631 **Figure 2:** Left: Stratigraphic column showing principal facies of the Bordeaux North  
632 heterolithic point bar. Middle: Field photographs showing facies in the intertidal zone of the  
633 point bar. Right: Representative core photographs from the three main facies (F1, F2 and  
634 F3).

635 **Figure 3:** A) quartz-feldspar-lithic (QFL) ternary diagram (after Folk, (1974) showing the  
636 framework composition of Bordeaux North point-bar samples. B) Thin-section  
637 photomicrograph of mud drape and sand bed (BORNW-P4, 127 cm, F3). C) Thin-section  
638 photomicrograph showing clay-coatings bridges (br.), aggregates (agg.), and clay drapes (dr.)  
639 [arrows] around detrital framework grains (BORNW-P17, 590 cm, F3). D) Thin-section  
640 photomicrograph of clay-coated detrital grains showing clay-coatings bridges (br.),  
641 aggregates (agg.), and clay drapes (dr.) [arrows] (BORNW-P17, 590 cm, F3). E) Thin-section  
642 photomicrograph showing clay-coated framework grains in sand dunes, showing clay-  
643 coatings bridges (br.), aggregates (agg.), and clay drapes (dr.) [arrows] (BORN2C-P3, 84 cm,

644 F2). F) SEM image showing clay coatings on a quartz grain from sandy gravel facies [yellow  
645 box indicates location of G] (BORNE-P14, 438 cm, F1 facies). G) Close-up view of the clay  
646 coat displayed in Part F. The clay coatings are mainly composed of detrital clay minerals and  
647 occasional silt-size grains and authigenic pyrite [+ marks location of EDS spot analysis]. H)  
648 EDS spectrum of a clay coat on detrital quartz seen in Part G, Spots 1 consists primarily of  
649 detrital clay; KEY: Qz = quartz; Li = lithoclast; Fd = feldspar; W = wood debris. See Figure 4 for  
650 the location of the thin sections.

651 **Figure 4:** E-W stratigraphic cross section across the Bordeaux North point bar showing the  
652 three cores analyzed in this study: Bo-2016-W; Bo-2017-C and Bo-2016-E with associated  
653 ages. pMC: percent modern carbon (modern age).

654 **Figure 5:** A) Vertical profiles showing  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  activities along core Bo-2016-W. This  
655 part of the core corresponds to facies F3 of the chute channel (see Fig. 4). B) Core  
656 photograph of facies F3 and ages obtained after data processing. C) Time (horizontal-axis) vs.  
657 depth (vertical-axis) plot constructed using  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  activities.

658 **Figure 6:** A) Thin-section microphotographs showing diatoms embedded in detrital-clay grain  
659 coats in facies F3 from the Bordeaux North point bar (BORNW-P5, 179 cm). B) SEM image  
660 showing diatom embedded in detrital-clay grain coats in facies F2 from the Bordeaux North  
661 point bar (BORN2C-P3, 84 cm). C, D, E) Cryo-SEM images of sediment sample from the  
662 Bordeaux North point bar (depth 25 cm). C) Low-magnification SEM view of quartz sand  
663 grain coated with an EPS-clay complex. D) Composite EDS spectra of the two analyzed spots  
664 marked with + in Part E. Spot 1 [black line] confirms detrital quartz grain host. Spot 2  
665 appears to be an aluminous phyllosilicate (clay-mineral signature). E) SEM close-up view of  
666 Part C showing the alveolar network formed by EPS intermixed with patchy clay platelets.  
667 See Figure 4 for the location of samples BORNW-P5 and BORN2C-P3.

668 **Figure 7:** Histograms showing average grain-coat content per facies divided into coat  
669 coverage classes. The sum of the coat coverage classes gives the total coated-grain content  
670 for each facies.

671 **Figure 8:** Summary core logs showing evolution with depth of mean grain size, percentage of  
672 < 2  $\mu\text{m}$  particles, and relative fraction of clay minerals, coated-grain content, and FTIR  
673 measurements for the three cores from the Bordeaux North point bar.

674 **Figure 9:** Plots representing the mean proportions in % of A) coated-grain content (from  
675 image analysis), B) clay-fraction content (weighted percentage of clay fraction from total  
676 volume), C) smectite (from XRD analysis), D) illite (from XRD analysis), E) kaolinite (from XRD  
677 analysis), and F) chlorite (from XRD analysis) in each facies. Above each histogram is the  
678 number of samples analyzed.

679 **Figure 10:** X-Ray diffractograms of the < 2  $\mu\text{m}$  fraction showing dominant clay minerals  
680 (BORNW-11, depth: 281 cm). See Fig. 4 for the location of this sample.

681 **Figure 11:** Aerial photographs showing lateral bank accretion from 1820–1866 to present of  
682 the Bordeaux North point bar (Source: IGN maps, <https://remonterletemps.ign.fr>).

683 **Figure 12:** A) Synthetic diagram of the heterolithic point-bar deposits at macro- (core) and  
684 micro- (thin-section) scales. The core drawing illustrates the heterolithic vertical facies  
685 association, while the thin-section documents how the clay coats are distributed. B) Cartoon  
686 summarizing how detrital-clay coatings may form on a heterolithic point bar. C) Table  
687 showing the average clay values, total clay, and grain-coat coverage by facies. KEY: EPS:  
688 exopolymeric substances.

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## REFERENCES

691

- 692 Aagaard, P., Jahren, J.S., Harstad, A.O., Nilsen, O., and Ramm, M., 2000, Formation of grain-  
693 coating chlorite in sandstones. Laboratory synthesized vs. natural occurrences: *Clay*  
694 *Minerals*, v. 35, p. 261–269, doi:10.1180/000985500546639.
- 695 Ajdukiewicz, J.M., and Larese, R.E., 2012, How clay grain coats inhibit quartz cement and  
696 preserve porosity in deeply buried sandstones: Observations and experiments:  
697 *American Association of Petroleum Geologists, Bulletin*, v. 96, p. 2091–2119,  
698 doi:10.1306/02211211075.
- 699 Allen, G.P., 1991, Sedimentary processes and facies in the Gironde estuary: a recent model  
700 for macrotidal estuarine systems, *in* Smith, D.G., Zaitlin, B.A., Reinson, G.E., and  
701 Rahmani, R.A. eds., *Clastic Tidal Sedimentology, Recognition Criteria and Facies*  
702 *Models*, v. Memoir 16, p. 29–39.
- 703 Allen, G.P., and Posamentier, H.W., 1993, Sequence Stratigraphy and Facies Model of an  
704 Incised Valley Fill: The Gironde Estuary, France: *Journal of Sedimentary Petrology*,  
705 v. 63, doi:10.1306/D4267B09-2B26-11D7-8648000102C1865D.
- 706 Anjos, S.M.C., De Ros, L.F., and Silva, C.M.A., 2003, Chlorite Authigenesis and Porosity  
707 Preservation in the Upper Cretaceous Marine Sandstones of the Santos Basin,  
708 Offshore Eastern Brazil, *in* Worden, R.H. and Morad, S. eds., *Clay Mineral Cements*  
709 *in Sandstones*, Oxford, UK, Blackwell Publishing Ltd., p. 289–316,  
710 doi:10.1002/9781444304336.ch13.
- 711 Appleby, P.G., Nolan, P.J., Gifford, D.W., Godfrey, M.J., Oldfield, F., Anderson, N.J., and  
712 Battarbee, R.W., 1986, <sup>210</sup>Pb dating by low background gamma counting:  
713 *Hydrobiologia*, v. 143, p. 21–27, doi:10.1007/BF00026640.
- 714 Appleby, P.G., Richardson, N., and Nolan, P.J., 1992, Self-absorption corrections for well-  
715 type germanium detectors: *Nuclear Instruments and Methods in Physics Research*  
716 *Section B: Beam Interactions with Materials and Atoms*, v. 71, p. 228–233,  
717 doi:10.1016/0168-583X(92)95328-O.
- 718 Beaufort, D., Rigault, C., Billon, S., Billault, V., Inoue, A., Inoue, S., and Patrier, P., 2015,  
719 Chlorite and chloritization processes through mixed-layer mineral series in low-  
720 temperature geological systems – a review: *Clay Minerals*, v. 50, p. 497–523,  
721 doi:10.1180/claymin.2015.050.4.06.
- 722 Billy, J., Chaumillon, E., Féliès, H., and Poirier, C., 2012, Tidal and fluvial controls on the  
723 morphological evolution of a lobate estuarine tidal bar: The Plassac Tidal Bar in the  
724 Gironde Estuary (France): *Geomorphology*, v. 169–170, p. 86–97,  
725 doi:10.1016/j.geomorph.2012.04.015.
- 726 Bloch, S., Lander, R.H., and Bonnell, L., 2002, Anomalously high porosity and permeability  
727 in deeply buried sandstone reservoirs: Origin and predictability: *American Association*  
728 *of Petroleum Geologists, Bulletin*, v. 86, p. 301–328.
- 729 Blong, R.J., and Gillespie, R., 1978, Fluvially transported charcoal gives erroneous <sup>14</sup>C ages  
730 for recent deposits: *Nature*, v. 271, p. 739–741.
- 731 Boersma, J.R., and Terwindt, J.H.J., 1981, Neap–spring tide sequences of intertidal shoal  
732 deposits in a mesotidal estuary: *Sedimentology*, v. 28, p. 151–170.

- 733 Braissant, O., Decho, A.W., Dupraz, C., Glunk, C., Przekop, K.M., and Visscher, P.T., 2007,  
734 Exopolymeric substances of sulfate-reducing bacteria: Interactions with calcium at  
735 alkaline pH and implication for formation of carbonate minerals: *Geobiology*, v. 5, p.  
736 401–411, doi:10.1111/j.1472-4669.2007.00117.x.
- 737 Byrne, G.M., Worden, R.H., Hodgson, D.M., Polya, D.A., Lythgoe, P.R., Barrie, C.D., and  
738 Boyce, A.J., 2011, Understanding the fate of iron in a modern temperate estuary:  
739 Leirárvogur, Iceland: *Applied Geochemistry*, v. 26, p. S16–S19,  
740 doi:10.1016/j.apgeochem.2011.03.018.
- 741 Castaing, P., and Allen, G.P., 1981, Mechanisms controlling seaward escape of suspended  
742 sediment from the Gironde: A macrotidal estuary in France: *Marine Geology*, v. 40, p.  
743 101–118, doi:10.1016/0025-3227(81)90045-1.
- 744 Chaumillon, E., Féliès, H., Billy, J., Breilh, J.-F., and Richetti, H., 2013, Tidal and fluvial  
745 controls on the internal architecture and sedimentary facies of a lobate estuarine tidal  
746 bar (The Plassac Tidal Bar in the Gironde Estuary, France): *Marine Geology*, v. 346,  
747 p. 58–72, doi:10.1016/j.margeo.2013.07.017.
- 748 Cosma, M., Ghinassi, M., D’Alpaos, A., Roner, M., Finotello, A., Tommasini, L., and Gatto,  
749 R., 2019, Point-bar brink and channel thalweg trajectories depicting interaction  
750 between vertical and lateral shifts of microtidal channels in the Venice Lagoon (Italy):  
751 *Geomorphology*, v. 342, p. 37–50, doi:10.1016/j.geomorph.2019.06.009.
- 752 Coynel, A., Schafer, J., Hurtrez, J., Dumas, J., Etcheber, H., and Blanc, G., 2004, Sampling  
753 frequency and accuracy of SPM flux estimates in two contrasted drainage basins:  
754 *Science of The Total Environment*, v. 330, p. 233–247,  
755 doi:10.1016/j.scitotenv.2004.04.003.
- 756 D’Alpaos, A., Ghinassi, M., Finotello, A., Brivio, L., Bellucci, L.G., and Marani, M., 2017,  
757 Tidal meander migration and dynamics: A case study from the Venice Lagoon:  
758 *Marine and Petroleum Geology*, v. 87, p. 80–90,  
759 doi:10.1016/j.marpetgeo.2017.04.012.
- 760 De Mowbray, T., and Visser, M.J., 1984, Reactivation surfaces in subtidal channel deposits,  
761 Oosterschelde, Southwest Netherlands: *Journal of Sedimentary Petrology*, v. 54, p.  
762 811–824.
- 763 De Resseguier, A., 1983, A portable coring device for use in the intertidal environment:  
764 *Marine Geology*, v. 52, p. M19–M23, doi:10.1016/0025-3227(83)90015-4.
- 765 Decho, A.W., 2000, Microbial biofilms in intertidal systems: an overview: *Continental Shelf*  
766 *Research*, v. 20, p. 1257–1273, doi:10.1016/S0278-4343(00)00022-4.
- 767 Donnici, S., Madricardo, F., and Serandrei-Barbero, R., 2017, Sedimentation rate and lateral  
768 migration of tidal channels in the Lagoon of Venice (Northern Italy): *Estuarine,*  
769 *Coastal and Shelf Science*, v. 198, p. 354–366, doi:10.1016/j.ecss.2017.02.016.
- 770 Dowey, P.J., Worden, R.H., Utley, J., and Hodgson, D.M., 2017, Sedimentary controls on  
771 modern sand grain coat formation: *Sedimentary Geology*, v. 353, p. 46–63,  
772 doi:10.1016/j.sedgeo.2017.03.001.

- 773 Duteil, T., Bourillot, R., Grégoire, B., Virolle, M., Brigaud, B., Nouet, J., Braissant, O.,  
774 Portier, E., Féliès, H., Patrier, P., Gontier, E., Svahn, I., and Visscher, P.T., 2020,  
775 Experimental formation of clay-coated sand grains using diatom biofilm exopolymers:  
776 *Geology*, v. 48, p. 1012–1017, doi:10.1130/G47418.1.
- 777 Ehrenberg, S.N., 1993, Preservation of anomalously high porosity in deeply buried sandstones  
778 by grain-coating chlorite: examples from the Norwegian continental shelf: *American*  
779 *Association of Petroleum Geologists, Bulletin*, v. 77, p. 1260–1286.
- 780 Ely, L.L., Webb, R.H., and Enzel, Y., 1992, Accuracy of post-bomb  $^{137}\text{Cs}$  and  $^{14}\text{C}$  in dating  
781 fluvial deposits: *Quaternary Research*, v. 38, p. 196–204, doi:10.1016/0033-  
782 5894(92)90056-O.
- 783 Etcheber, H., Schmidt, S., Sottolichio, A., Maneux, E., Chabaux, G., Escalier, J.-M.,  
784 Wennekes, H., Derriennic, H., Schmeltz, M., Quémener, L., Repecaud, M., Woerther,  
785 P., and Castaing, P., 2011, Monitoring water quality in estuarine environments:  
786 lessons from the MAGEST monitoring program in the Gironde fluvial-estuarine  
787 system: *Hydrology and Earth System Sciences*, v. 15, p. 831–840, doi:10.5194/hess-  
788 15-831-2011.
- 789 Evrard, O., Chaboche, P.-A., Ramon, R., Foucher, A., and Laceby, J.P., 2020, A global  
790 review of sediment source fingerprinting research incorporating fallout radiocesium  
791 ( $^{137}\text{Cs}$ ): *Geomorphology*, v. 362, p. 107103, doi:10.1016/j.geomorph.2020.107103.
- 792 Féliès, H., Resseguier, A.D., and Tastet, J., 1999, Intertidal clay-drape couplets (Gironde  
793 estuary, France): *Sedimentology*, v. 46, p. 1–15, doi:10.1046/j.1365-  
794 3091.1999.00196.x.
- 795 Féliès, H., and Tastet, J.-P., 1998, Facies and architecture of an estuarine tidal bar (the  
796 Trompeloup bar, Gironde Estuary, SW France): *Marine Geology*, v. 150, p. 149–169,  
797 doi:10.1016/S0025-3227(98)00059-0.
- 798 Finotello, A., Lanzoni, S., Ghinassi, M., Marani, M., Rinaldo, A., and D’Alpaos, A., 2018,  
799 Field migration rates of tidal meanders recapitulate fluvial morphodynamics:  
800 *Proceedings of the National Academy of Sciences*, v. 115, p. 1463–1468,  
801 doi:10.1073/pnas.1711330115.
- 802 Folk, R.L., 1974, *Petrology of Sedimentary Rocks*: Austin, Texas, Hemphill Publishing  
803 Company, v. 182, 184 p.
- 804 Ghinassi, M., D’alpaos, A., Gasparotto, A., Carniello, L., Brivio, L., Finotello, A., Roner, M.,  
805 Franceschinis, E., Realdon, N., Howes, N., and Cantelli, A., 2018, Morphodynamic  
806 evolution and stratal architecture of translating tidal point bars: Inferences from the  
807 northern Venice Lagoon (Italy) (J. Howell, Ed.): *Sedimentology*, v. 65, p. 1354–1377,  
808 doi:10.1111/sed.12425.
- 809 Gould, K., Pe-Piper, G., and Piper, D.J.W., 2010, Relationship of diagenetic chlorite rims to  
810 depositional facies in Lower Cretaceous reservoir sandstones of the Scotian Basin:  
811 *Sedimentology*, v. 57, p. 587–610, doi:10.1111/j.1365-3091.2009.01106.x.
- 812 Griffiths, J., Worden, R.H., Wooldridge, L.J., Utley, J.E.P., and Duller, R.A., 2019a,  
813 Compositional variation in modern estuarine sands: Predicting major controls on

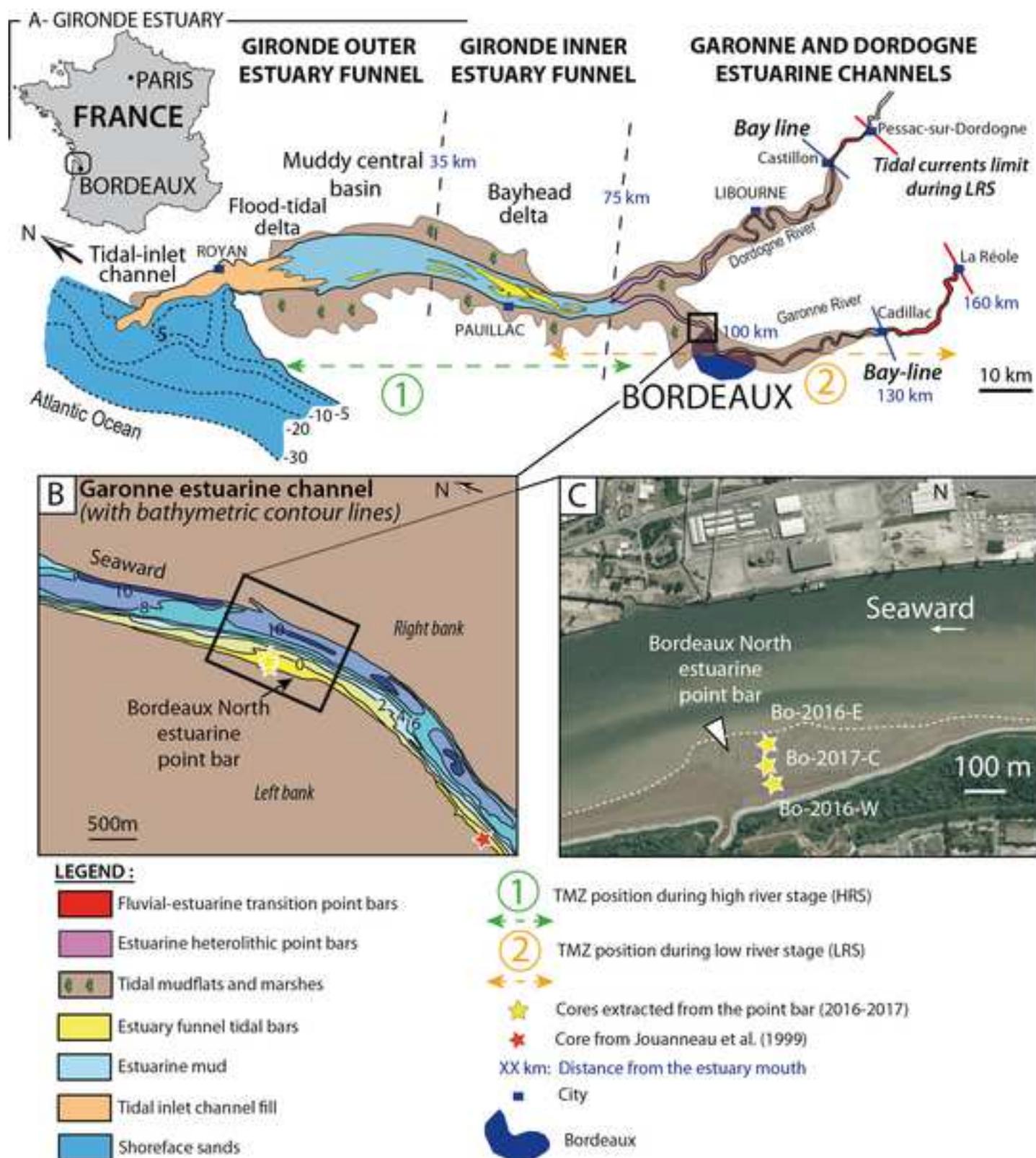
- 814 sandstone reservoir quality: American Association of Petroleum Geologists, Bulletin,  
815 v. 103, p. 797–833, doi:10.1306/09181818025.
- 816 Griffiths, J., Worden, R.H., Wooldridge, L.J., Utley, J.E.P., and Duller, R.A., 2018, Detrital  
817 Clay Coats, Clay Minerals, and Pyrite: A Modern Shallow-Core Analogue For  
818 Ancient and Deeply Buried Estuarine Sandstones: Journal of Sedimentary Research, v.  
819 88, p. 1205–1237, doi:10.2110/jsr.2018.56.
- 820 Griffiths, J., Worden, R.H., Wooldridge, L.J., Utley, J.E.P., Duller, R.A., and Edge, R.L.,  
821 2019b, Estuarine clay mineral distribution: Modern analogue for ancient sandstone  
822 reservoir quality prediction: Sedimentology, v. 66, p. 2011–2047,  
823 doi:10.1111/sed.12571.
- 824 Grim, R.E., 1942, Modern Concepts of Clay Materials: The Journal of Geology, v. 50, p.  
825 225–275, doi:10.1086/625050.
- 826 Grousset, F.E., Jouanneau, J.M., Castaing, P., Lavaux, G., and Latouche, C., 1999, A 70 year  
827 Record of Contamination from Industrial Activity Along the Garonne River and its  
828 Tributaries (SW France): Estuarine, Coastal and Shelf Science, v. 48, p. 401–414,  
829 doi:10.1006/ecss.1998.0435.
- 830 Haile, B.G., Hellevang, H., Aagaard, P., and Jahren, J., 2015, Experimental nucleation and  
831 growth of smectite and chlorite coatings on clean feldspar and quartz grain surfaces:  
832 Marine and Petroleum Geology, v. 68, p. 664–674,  
833 doi:10.1016/j.marpetgeo.2015.02.006.
- 834 Hornibrook, E.R.C., and Longstaffe, F.J., 1996, Berthierine from the Lower Cretaceous  
835 Clearwater Formation, Alberta, Canada: Clays and Clay Minerals, v. 44, p. 1–21,  
836 doi:10.1346/CCMN.1996.0440101.
- 837 Huggett, J.M., Burley, S.D., Longstaffe, F.J., Saha, S., and Oates, M.J., 2015, The nature and  
838 origin of authigenic chlorite and related cements in Oligo-Miocene reservoir  
839 Sandstones, Tapti Gas Fields, Surat Depression, Offshore Western India: Journal of  
840 Petroleum Geology, v. 38, p. 383–409, doi:10.1111/jpg.12618.
- 841 Jalón-Rojas, I., Schmidt, S., and Sottolichio, A., 2015, Turbidity in the fluvial Gironde  
842 Estuary (southwest France) based on 10-year continuous monitoring: sensitivity to  
843 hydrological conditions: Hydrology and Earth System Sciences, v. 19, p. 2805–2819,  
844 doi:10.5194/hess-19-2805-2015.
- 845 Jones, S., 2017, Goo, glue, and grain binding: Importance of biofilms for diagenesis in  
846 sandstones: Geology, v. 45, p. 959–960, doi:10.1130/focus102017.1.
- 847 Jordan, D.W., and Pryor, W.A., 1992, Hierarchical Levels of Heterogeneity in a Mississippi  
848 River Meander Belt and Application to Reservoir Systems: Geologic Note (1):  
849 American Association of Petroleum Geologists, Bulletin, v. 76,  
850 doi:10.1306/BDF8A6A-1718-11D7-8645000102C1865D.
- 851 Jouanneau, J.-M., Castaing, P., Grousset, F., Buat-Ménard, P., and Pedemay, P., 1999,  
852 Enregistrement sédimentaire et chronologie ( $^{137}\text{Cs}$ ) d'une contamination en cadmium  
853 dans l'estuaire de la Gironde (France): Comptes Rendus de l'Académie des Sciences -  
854 Series IIA - Earth and Planetary Science, v. 329, p. 265–270, doi:10.1016/S1251-

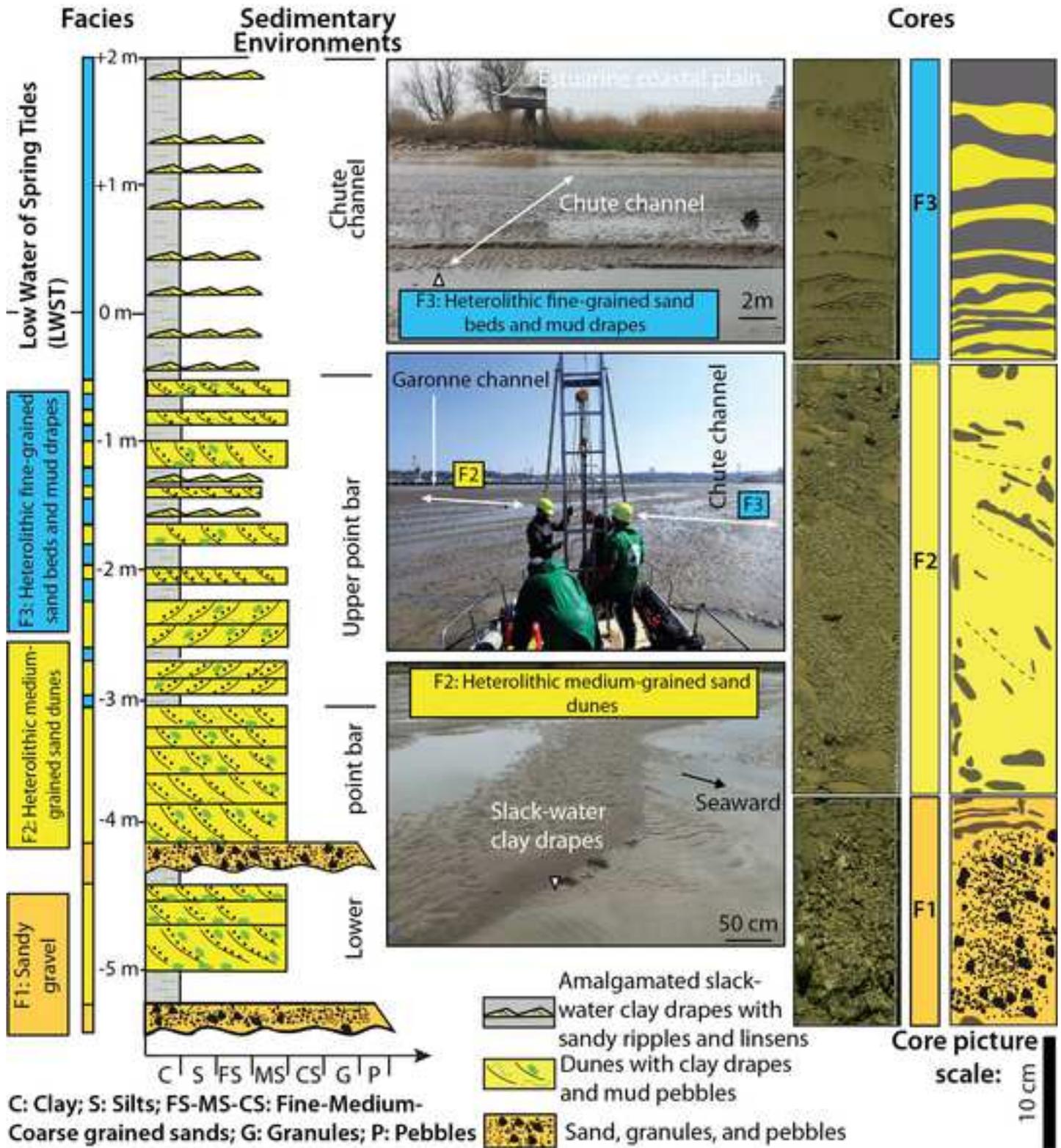
- 855 8050(99)80245-6.
- 856 Kocheil, R.C., and Baker, V., 1988, Paleoflood analysis using slackwater deposits, *in* Baker,  
857 V., Kocheil, R.C., and Patton, P.C. eds., *Flood Geomorphology*, Wiley-Interscience, p.  
858 357–376.
- 859 La Croix, A.D., Dashtgard, S.E., Gingras, M.K., Hauck, T.E., and MacEachern, J.A., 2015,  
860 Bioturbation trends across the freshwater to brackish-water transition in rivers:  
861 Palaeogeography, Palaeoclimatology, Palaeoecology, v. 440, p. 66–77,  
862 doi:10.1016/j.palaeo.2015.08.030.
- 863 La Croix, A.D., Dashtgard, S.E., and MacEachern, J.A., 2019, Using a modern analogue to  
864 interpret depositional position in ancient fluvial-tidal channels: Example from the  
865 McMurray Formation, Canada: *Geoscience Frontiers*, v. 10, p. 2219–2238,  
866 doi:10.1016/j.gsf.2019.03.008.
- 867 Lander, R.H., Larese, R.E., and Bonnell, L.M., 2008, Toward more accurate quartz cement  
868 models: The importance of euhedral versus noneuhedral growth rates: *American*  
869 *Association of Petroleum Geologists, Bulletin*, v. 92, p. 1537–1563,  
870 doi:10.1306/07160808037.
- 871 Lander, R.H., and Walderhaug, O., 1999, Predicting Porosity through Simulating Sandstone  
872 Compaction and Quartz Cementation: *American Association of Petroleum Geologists,*  
873 *Bulletin*, v. 83, p. 433–449, doi:10.1306/00AA9BC4-1730-11D7-  
874 8645000102C1865D.
- 875 Latouche, C., 1971, Les argiles des bassins alluvionnaires aquitains et des dépendances  
876 océaniques: contribution à l'étude d'un environnement [Thèse de doctorat, Université  
877 de Bordeaux]: Institut de Geologie du Bassin d'Aquitaine, 415 p.
- 878 Long, A., and Rippeteau, B., 1974, Testing Contemporaneity and Averaging Radiocarbon  
879 Dates: *American Antiquity*, v. 39, p. 205–215, doi:10.2307/279583.
- 880 Malarkey, J., Baas, J.H., Hope, J.A., Aspden, R.J., Parsons, D.R., Peakall, J., Paterson, D.M.,  
881 Schindler, R.J., Ye, L., Lichtman, I.D., Bass, S.J., Davies, A.G., Manning, A.J., and  
882 Thorne, P.D., 2015, The pervasive role of biological cohesion in bedform  
883 development: *Nature Communications*, v. 6, p. 6257, doi:10.1038/ncomms7257.
- 884 Martinius, A.W., Ringrose, P.S., Brostrøm, C., Elfenbein, C., Næss, A., and Ringås, J.E.,  
885 2005, Reservoir challenges of heterolithic tidal sandstone reservoirs in the Halten  
886 Terrace, mid-Norway: *Petroleum Geoscience*, v. 11, p. 3–16, doi:10.1144/1354-  
887 079304-629.
- 888 Monna, F., Dominik, J., Loizeau, J.-Luc., Pardos, M., and Arpagaus, P., 1999, Origin and  
889 Evolution of Pb in Sediments of Lake Geneva (Switzerland–France). Establishing a  
890 Stable Pb Record: *Environmental Science & Technology*, v. 33, p. 2850–2857,  
891 doi:10.1021/es9902468.
- 892 Musial, G., Reynaud, J.-Y., Gingras, M.K., Féliès, H., Labourdette, R., and Parize, O., 2012,  
893 Subsurface and outcrop characterization of large tidally influenced point bars of the  
894 Cretaceous McMurray Formation (Alberta, Canada): *Sedimentary Geology*, v. 279, p.  
895 156–172, doi:10.1016/j.sedgeo.2011.04.020.

- 896 Pace, A., Bourillot, R., Bouton, A., Vennin, E., Braissant, O., Dupraz, C., Duteil, T.,  
897 Bundeleva, I., Patrier, P., Galaup, S., Yokoyama, Y., Franceschi, M., Virgone, A., and  
898 Visscher, P.T., 2018, Formation of stromatolite lamina at the interface of oxygenic-  
899 anoxygenic photosynthesis: *Geobiology*, v. 16, p. 378–398, doi:10.1111/gbi.12281.
- 900 Parra, M., Trouky, H., Jouanneau, J.-M., Grousset, F., Latouche, C., and Castaing, P., 1998,  
901 Étude isotopique (Sr-Nd) de l'origine des dépôts fins holocènes du littoral atlantique  
902 (S-O France): *Oceanologica Acta*, v. 21, p. 631–644, doi:10.1016/S0399-  
903 1784(99)80022-X.
- 904 Petschick, R., 2002, MacDiff 4.2.6 - Manual: 61 p., [http://www.geol-pal.uni-](http://www.geol-pal.uni-frankfurt.de/Staff/Homepages/Petschick/PDFs/MacDiff%20Manual%20E.pdf)  
905 [frankfurt.de/Staff/Homepages/Petschick/PDFs/MacDiff%20Manual%20E.pdf](http://www.geol-pal.uni-frankfurt.de/Staff/Homepages/Petschick/PDFs/MacDiff%20Manual%20E.pdf).
- 906 Pittman, E.D., and Lumsden, D.N., 1968, Relationship between chlorite coatings on quartz  
907 grains and porosity, Spiro Sand, Oklahoma: *Journal of Sedimentary Petrology*, v. 38,  
908 p. 668–670, doi:10.1306/74D71A28-2B21-11D7-8648000102C1865D.
- 909 Pourchet, M., Pinglot, J.F., and Mélières, M.A., 1989, Cesium 137 and lead 210 in alpine lake  
910 sediments: Measurements and modeling of mixing processes: *Journal of Geophysical*  
911 *Research*, v. 94, p. 12761–12770, doi:10.1029/JC094iC09p12761.
- 912 Pranter, M.J., Ellison, A.I., Cole, R.D., and Patterson, P.E., 2007, Analysis and modeling of  
913 intermediate-scale reservoir heterogeneity based on a fluvial point-bar outcrop analog,  
914 Williams Fork Formation, Piceance Basin, Colorado: *American Association of*  
915 *Petroleum Geologists, Bulletin*, v. 91, p. 1025–1051, doi:10.1306/02010706102.
- 916 Roduit, N., 2007, JMicroVision: un logiciel d'analyse d'images pétrographiques polyvalent:  
917 Section de Sciences de la Terre, Université de Genève, 116 p., 10.13097/archive-  
918 ouverte/unige:468.
- 919 Saïag, J., Brigaud, B., Portier, É., Desaubliaux, G., Bucherie, A., Miska, S., and Pagel, M.,  
920 2016, Sedimentological control on the diagenesis and reservoir quality of tidal  
921 sandstones of the Upper Cape Hay Formation (Permian, Bonaparte Basin, Australia):  
922 *Marine and Petroleum Geology*, v. 77, p. 597–624,  
923 doi:10.1016/j.marpetgeo.2016.07.002.
- 924 Sarkar, S., Banerjee, S., Eriksson, P.G., and Catuneanu, O., 2005, Microbial mat control on  
925 siliciclastic Precambrian sequence stratigraphic architecture: Examples from India:  
926 *Sedimentary Geology*, v. 176, p. 195–209, doi:10.1016/j.sedgeo.2004.12.012.
- 927 Shchepetkina, A., Gingras, M.K., and Pemberton, S.G., 2018, Modern observations of  
928 floccule ripples: Petitcodiac River estuary, New Brunswick, Canada: *Sedimentology*,  
929 v. 65, p. 582–596, doi:10.1111/sed.12393.
- 930 Shchepetkina, A., Gingras, M.K., and Pemberton, S.G., 2016a, Sedimentology and ichnology  
931 of the fluvial reach to inner estuary of the Ogeechee River estuary, Georgia, USA:  
932 *Sedimentary Geology*, v. 342, p. 202–217, doi:10.1016/j.sedgeo.2016.07.005.
- 933 Shchepetkina, A., Gingras, M.K., Zonneveld, J.-P., and Pemberton, S.G., 2016b, Sedimentary  
934 fabrics of the macrotidal, mud-dominated, inner estuary to fluvio-tidal transition zone,  
935 Petitcodiac River estuary, New Brunswick, Canada: *Sedimentary Geology*, v. 333, p.  
936 147–163, doi:10.1016/j.sedgeo.2015.12.015.

- 937 Shchepetkina, A., Gingras, M.K., Zonneveld, J.-P., and Pemberton, S.G., 2017, Silt- and  
938 Bioclastic-Rich Floes and Their Relationship to Sedimentary Structures: Modern  
939 Observations from the Petitcodiac River Estuary: *Estuaries and Coasts*, v. 40, p. 947–  
940 966, doi:10.1007/s12237-016-0186-x.
- 941 Smith, D.J., and Underwood, G.J.C., 1998, Exopolymer production by intertidal epipellic  
942 diatoms: *Limnology and Oceanography*, v. 43, p. 1578–1591,  
943 doi:10.4319/lo.1998.43.7.1578.
- 944 Sottolichio, A., Castaing, P., Etcheber, H., Maneux, E., Schmeltz, M., and Schmidt, S., 2011,  
945 Observations of suspended sediment dynamics in a highly turbid macrotidal estuary,  
946 derived from continuous monitoring: *Journal of Coastal Research*, v. 64, p. 1579–  
947 1583.
- 948 Stoodley, P., Cargo, R., Rupp, C.J., Wilson, S., and Klapper, I., 2002, Biofilm material  
949 properties as related to shear-induced deformation and detachment phenomena:  
950 *Journal of Industrial Microbiology and Biotechnology*, v. 29, p. 361–367,  
951 doi:10.1038/sj.jim.7000282.
- 952 Stricker, S., Jones, S.J., Sathar, S., Bowen, L., and Oxtoby, N., 2016, Exceptional reservoir  
953 quality in HPHT reservoir settings: Examples from the Skagerrak Formation of the  
954 Heron Cluster, North Sea, UK: *Marine and Petroleum Geology*, v. 77, p. 198–215,  
955 doi:10.1016/j.marpetgeo.2016.02.003.
- 956 Sun, Z.-X., Sun, Z.-L., Yao, J., Wu, M.-L., Liu, J.-R., Dou, Z., and Pei, C., 2014, Porosity  
957 preservation due to authigenic chlorite coatings in deeply buried Upper Triassic  
958 Xujiahe Formation Sandstones, Sichuan Basin, Western China: *Journal of Petroleum  
959 Geology*, v. 37, p. 251–267, doi:10.1111/jpg.12582.
- 960 Taylor, T.R., Giles, M.R., Hathon, L.A., Diggs, T.N., Braunsdorf, N.R., Birbiglia, G.V.,  
961 Kittridge, M.G., Macaulay, C.I., and Espejo, I.S., 2010, Sandstone diagenesis and  
962 reservoir quality prediction: Models, myths, and reality: *American Association of  
963 Petroleum Geologists, Bulletin*, v. 94, p. 1093–1132, doi:10.1306/04211009123.
- 964 Thomson, A., 1979, Preservation of porosity in the deep Woodbine/Tuscaloosa Trend,  
965 Louisiana, *in Gulf Coast Association of Geological Societies Transactions*, San  
966 Antonio, Texas, 29th Annual Meeting, v. 29, p. 396–403.
- 967 Underwood, G.C., and Kromkamp, J., 1999, Primary production by phytoplankton and  
968 microphytobenthos in estuaries: *Advances in ecological research*, v. 29, p. 93–153.
- 969 Verhagen, I.T.E., Crisóstomo-Figueroa, A., Utley, J.E.P., and Worden, R.H., 2020, Abrasion  
970 of detrital grain-coating clays during sediment transport: Implications for diagenetic  
971 clay coats: *Sedimentary Geology*, p. 105653, doi:10.1016/j.sedgeo.2020.105653.
- 972 Virolle, M., Brigaud, B., Bourillot, R., Féliès, H., Portier, E., Duteil, T., Nouet, J., Patrier, P.,  
973 and Beaufort, D., 2019a, Detrital clay grain coats in estuarine clastic deposits: origin  
974 and spatial distribution within a modern sedimentary system, the Gironde Estuary  
975 (south-west France): *Sedimentology*, v. 66, p. 859–894, doi:10.1111/sed.12520.
- 976 Virolle, M., Brigaud, B., Luby, S., Portier, E., Féliès, H., Bourillot, R., Patrier, P., and  
977 Beaufort, D., 2019b, Influence of sedimentation and detrital clay grain coats on

- 978 chloritized sandstone reservoir qualities: Insights from comparisons between ancient  
979 tidal heterolithic sandstones and a modern estuarine system: *Marine and Petroleum*  
980 *Geology*, v. 107, p. 163–184, doi:10.1016/j.marpetgeo.2019.05.010.
- 981 Virolle, M., Féliès, H., Brigaud, B., Bourillot, R., Portier, E., Patrier, P., Beaufort, D., Jalon-  
982 Rojas, I., Derriennic, H., and Miska, S., 2020, Facies associations, detrital clay grain  
983 coats and mineralogical characterization of the Gironde estuary tidal bars: A modern  
984 analogue for deeply buried estuarine sandstone reservoirs: *Marine and Petroleum*  
985 *Geology*, p. 104225, doi:https://doi.org/10.1016/j.marpetgeo.2020.104225.
- 986 Visser, M.J., 1980, Neap-spring cycles reflected in Holocene subtidal large-scale bedform  
987 deposits: a preliminary note: *Geology*, v. 8, p. 543–546.
- 988 Webb, R.H., O'Connor, J.E., and Baker, V., 1988, Paleohydrologic reconstruction of flood  
989 frequency on the Escalante River, south-central Utah, *in* Baker, V., Kochel, R.C., and  
990 Patton, P.C. eds., *Flood Geomorphology*, Wiley-Interscience, p. 403–418.
- 991 Williams, H.F.L., and Hamilton, T.S., 1995, Sedimentary Dynamics of an Eroding Tidal  
992 Marsh Derived from Stratigraphic Records of <sup>137</sup>Cs Fallout, Fraser Delta, British  
993 Columbia, Canada: *Journal of Coastal Research*, v. 11, p. 1145–1156.
- 994 Wooldridge, L.J., Worden, R.H., Griffiths, J., Thompson, A., and Chung, P., 2017a, Biofilm  
995 origin of clay-coated sand grains: *Geology*, v. 45, p. 875–878, doi:10.1130/G39161.1.
- 996 Wooldridge, L.J., Worden, R.H., Griffiths, J., and Utley, J.E.P., 2019a, Clay- coat diversity in  
997 marginal marine sediments: *Sedimentology*, doi:10.1111/sed.12538.
- 998 Wooldridge, L.J., Worden, R.H., Griffiths, J., and Utley, J.E.P., 2017b, Clay-Coated Sand  
999 Grains in Petroleum Reservoirs: Understanding Their Distribution Via a Modern  
1000 Analogue: *Journal of Sedimentary Research*, v. 87, p. 338–352,  
1001 doi:10.2110/jsr.2017.20.
- 1002 Wooldridge, L.J., Worden, R.H., Griffiths, J., and Utley, J.E.P., 2019b, How to Quantify  
1003 Clay-Coat Grain Coverage in Modern and Ancient Sediments: *Journal of Sedimentary*  
1004 *Research*, v. 89, p. 135–146, doi:10.2110/jsr.2019.6.
- 1005 Worden, R.H., Griffiths, J., Wooldridge, L.J., Utley, J.E.P., Lawan, A.Y., Muhammed, D.D.,  
1006 Simon, N., and Armitage, P.J., 2020, Chlorite in sandstones: *Earth-Science Reviews*,  
1007 v. 204, p. 103105, doi:10.1016/j.earscirev.2020.103105.
- 1008 Worden, R.H., and Morad, S., 2003, Clay Minerals in Sandstones: Controls on Formation,  
1009 Distribution and Evolution, *in* Worden, R.H. and Morad, S. eds., *Clay Mineral*  
1010 *Cements in Sandstones*, Oxford, UK, Blackwell Publishing Ltd., p. 3–41,  
1011 doi:10.1002/9781444304336.ch1.
- 1012





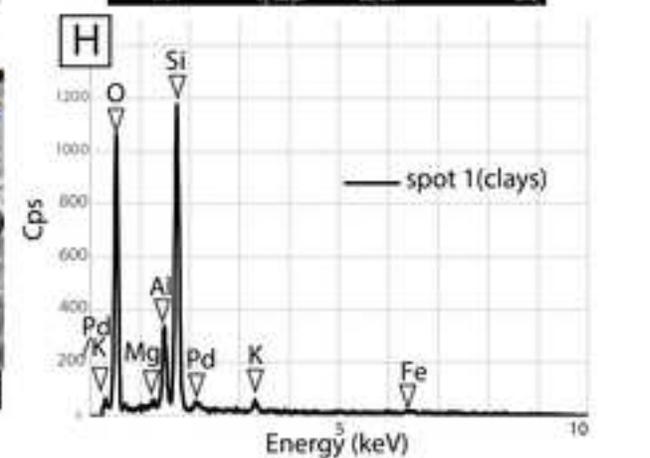
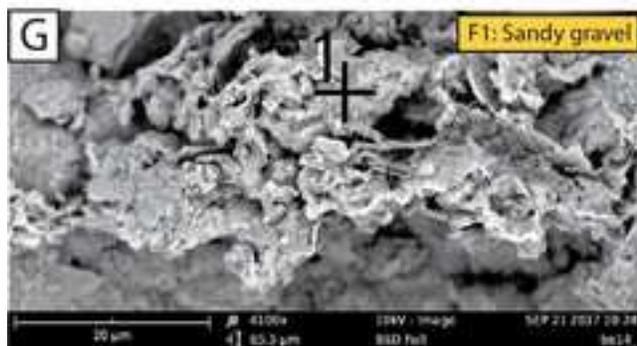
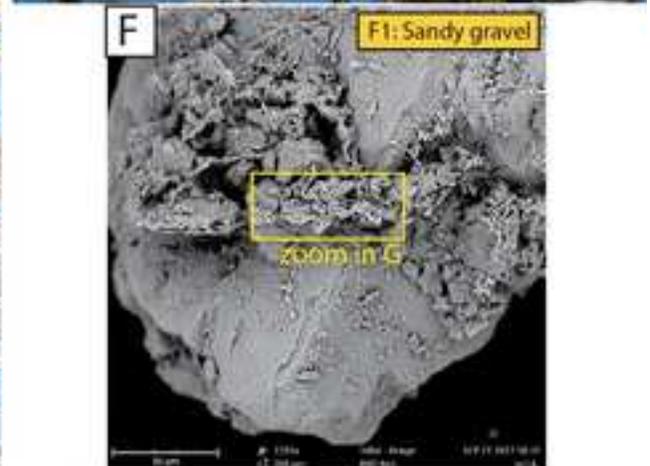
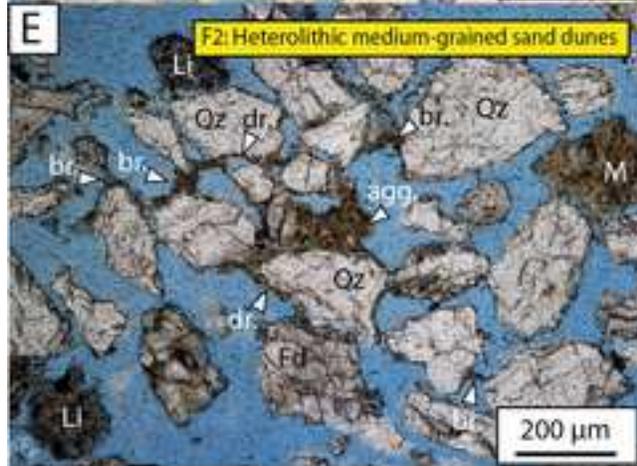
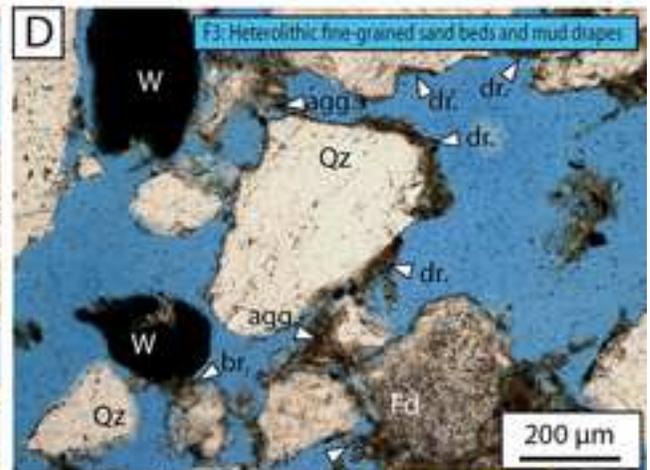
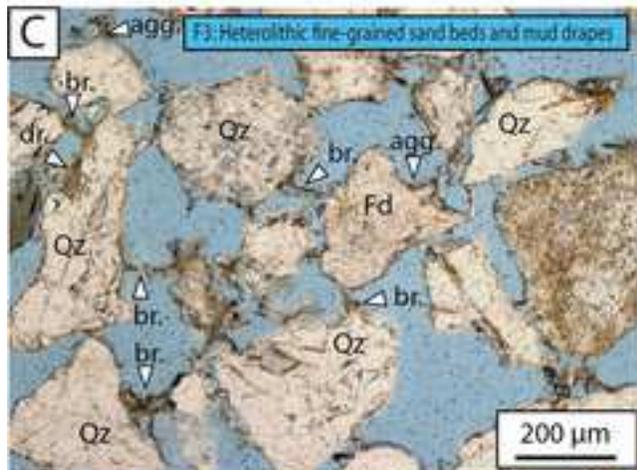
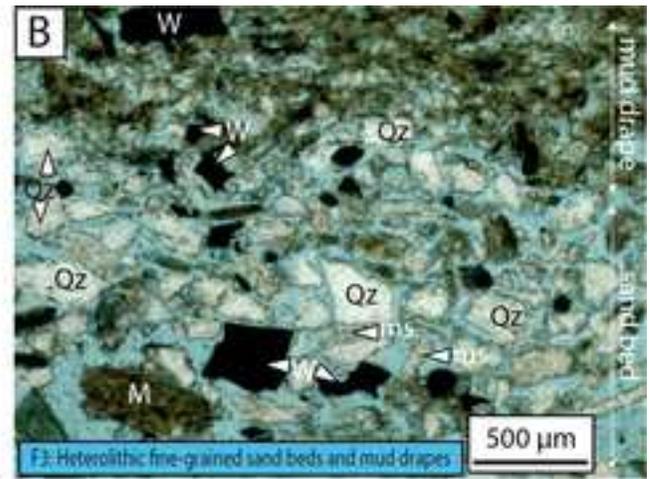
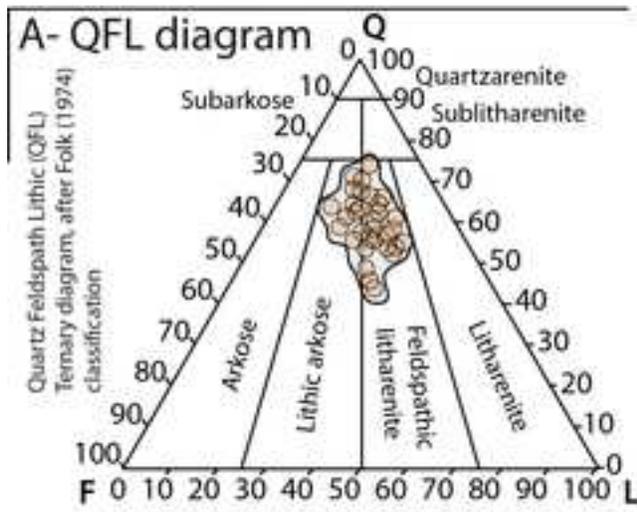
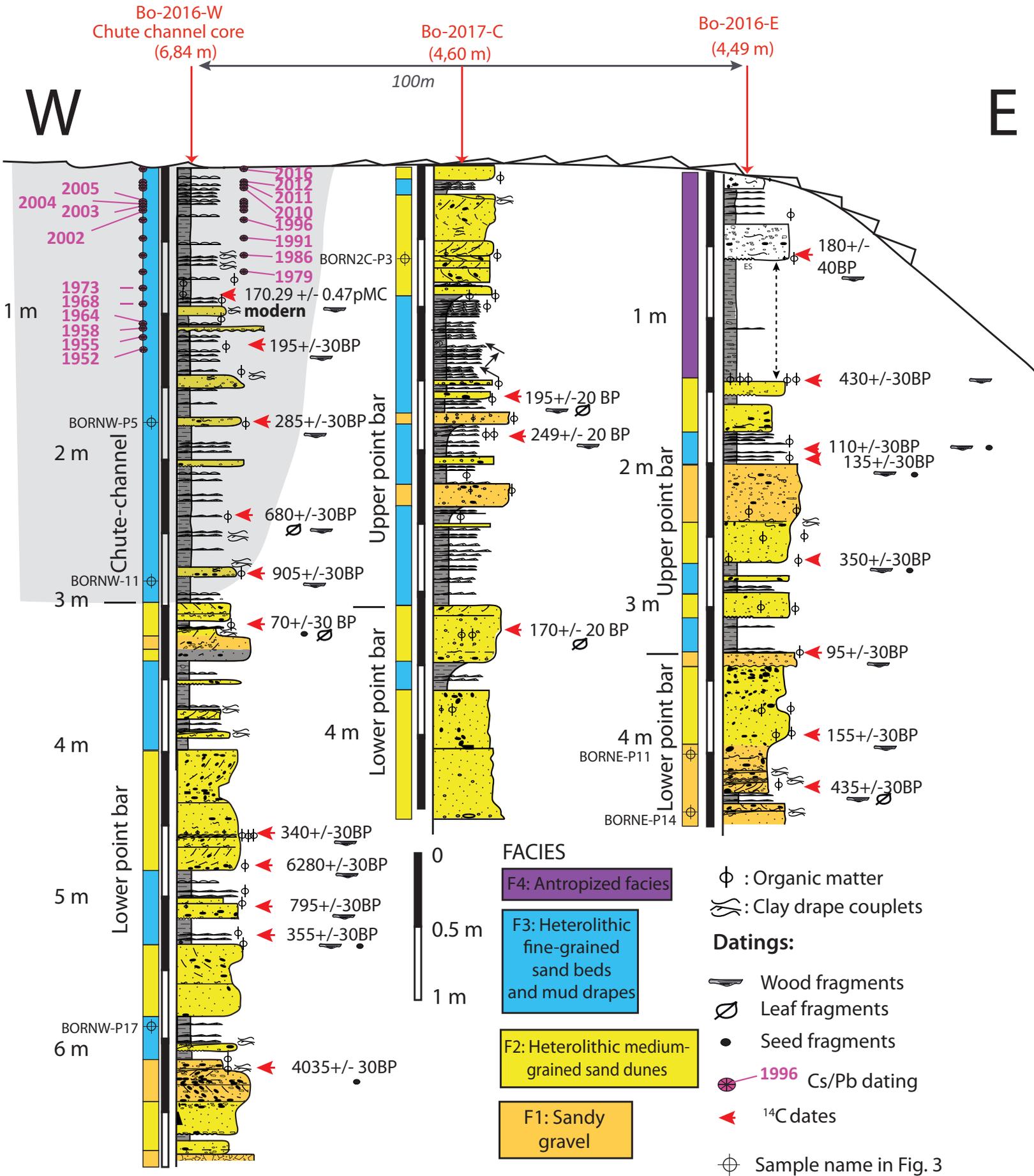
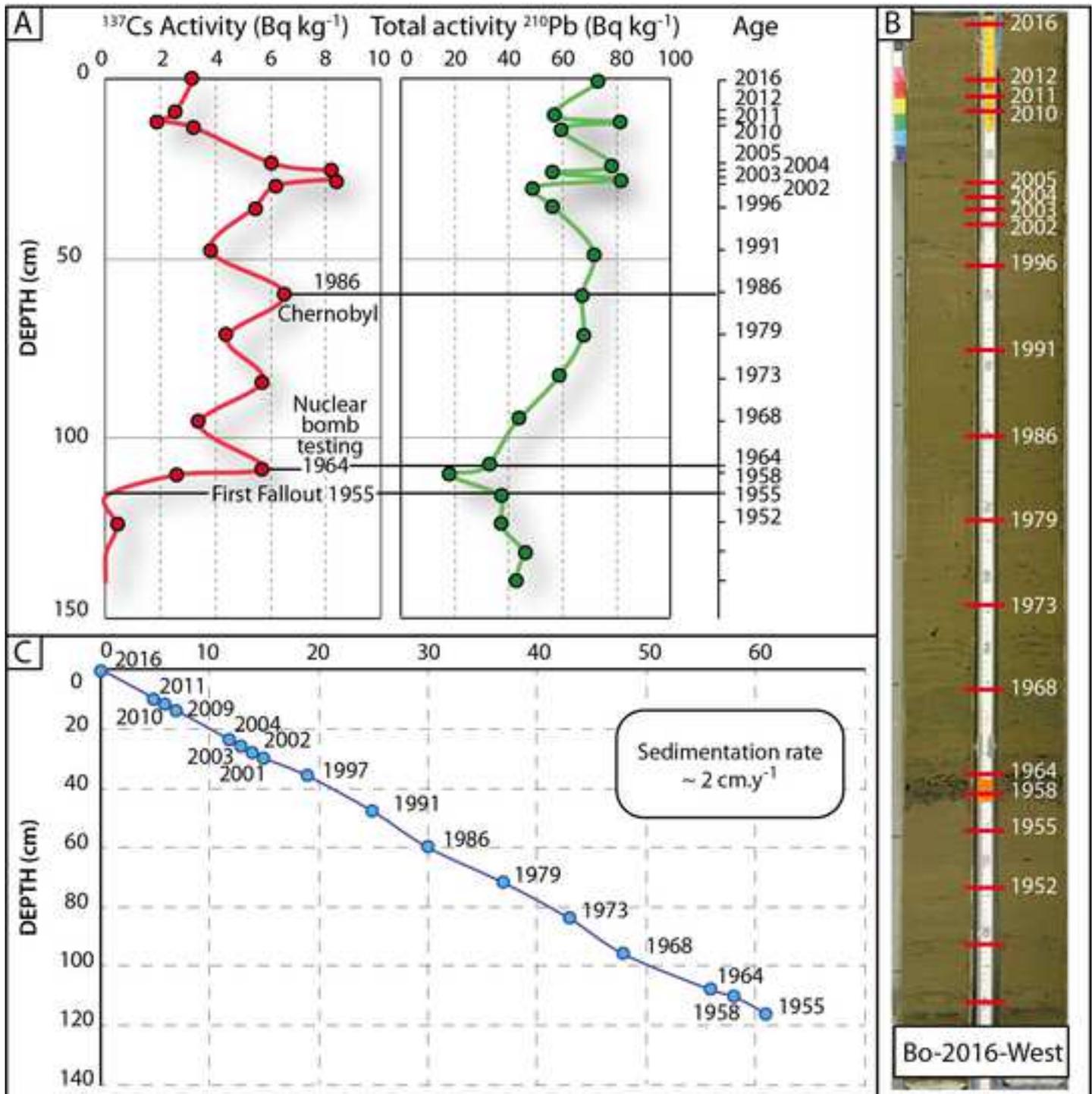
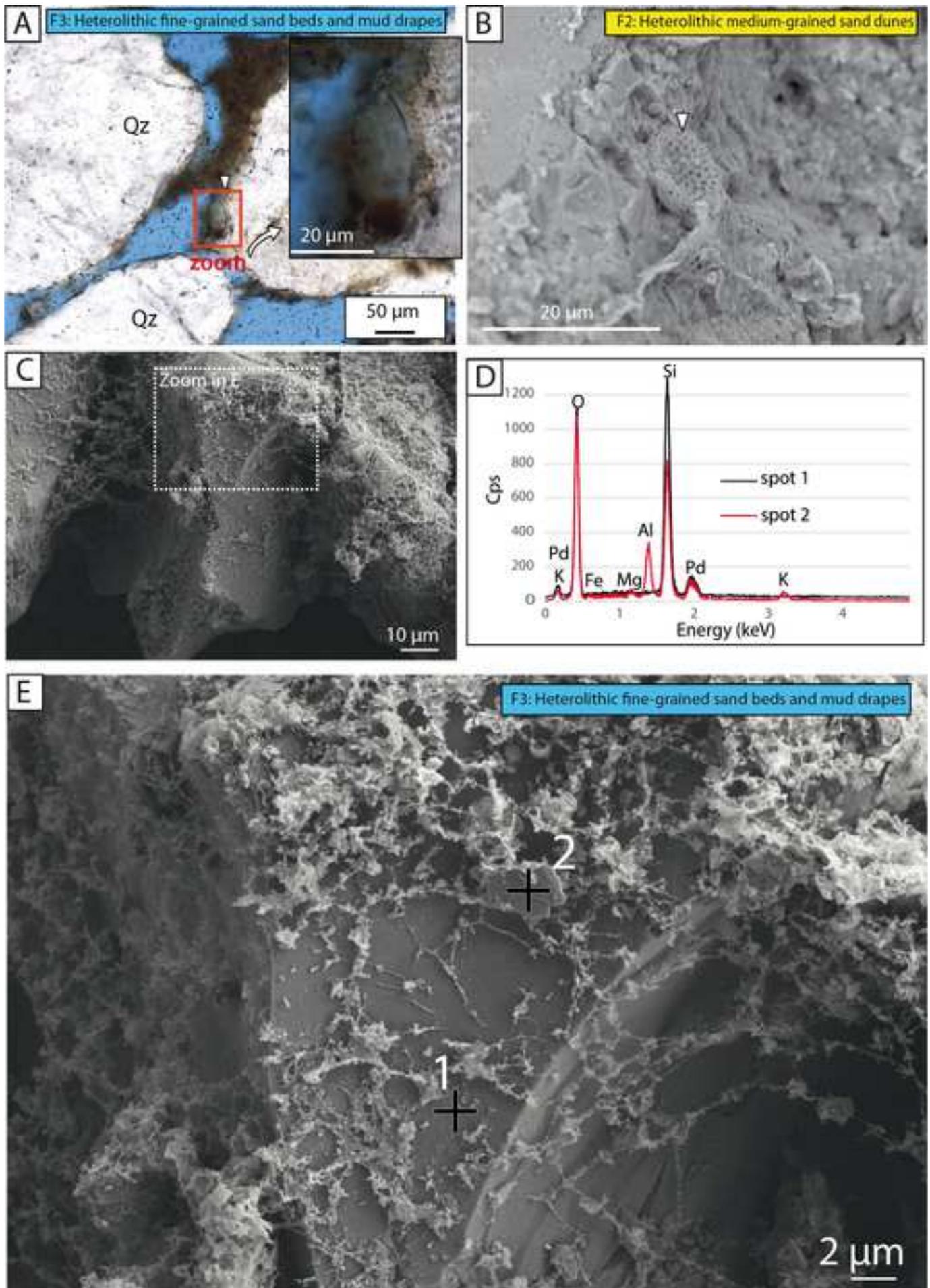


Figure 4







## BORDEAUX NORTH POINT BAR

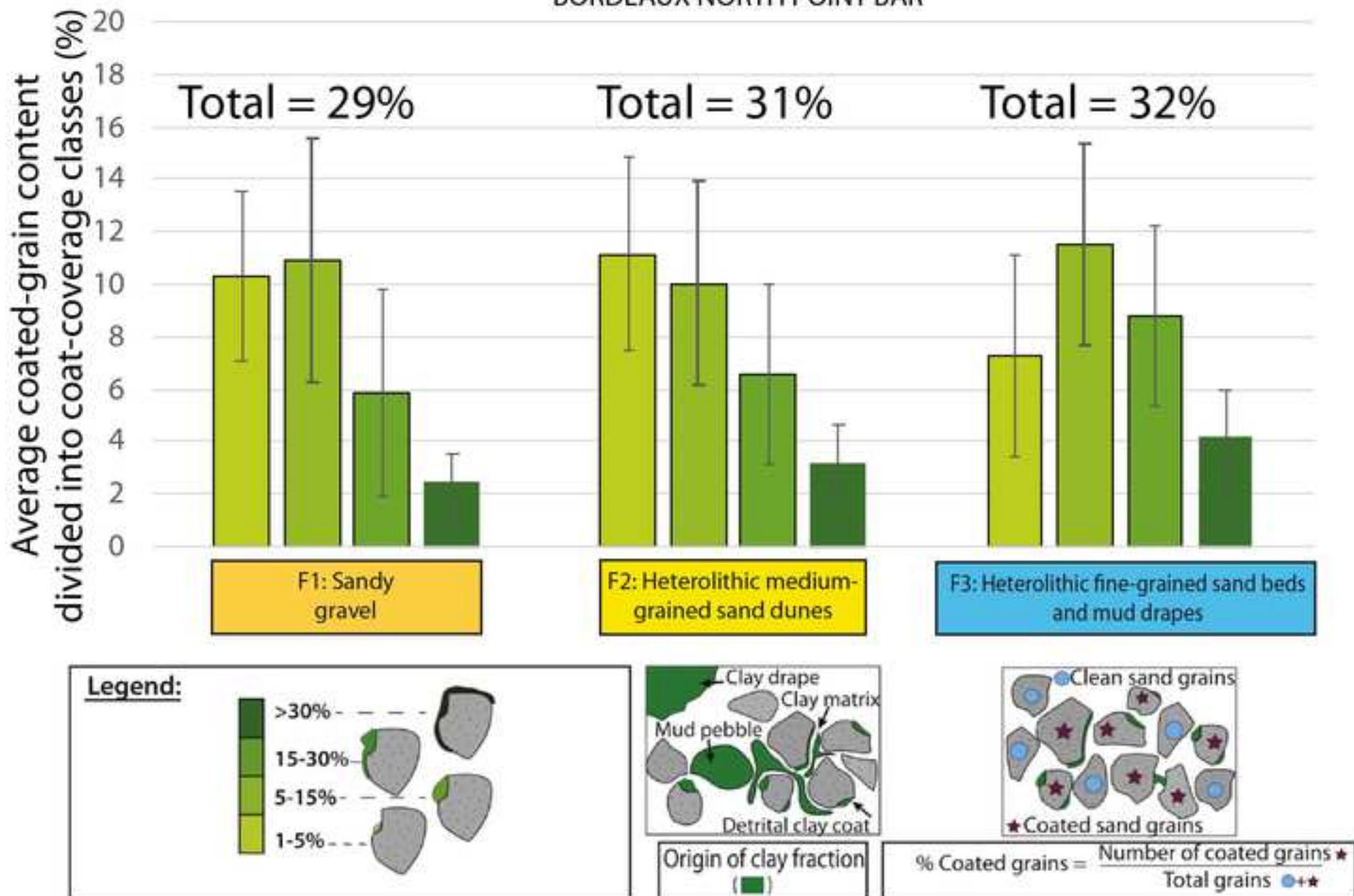
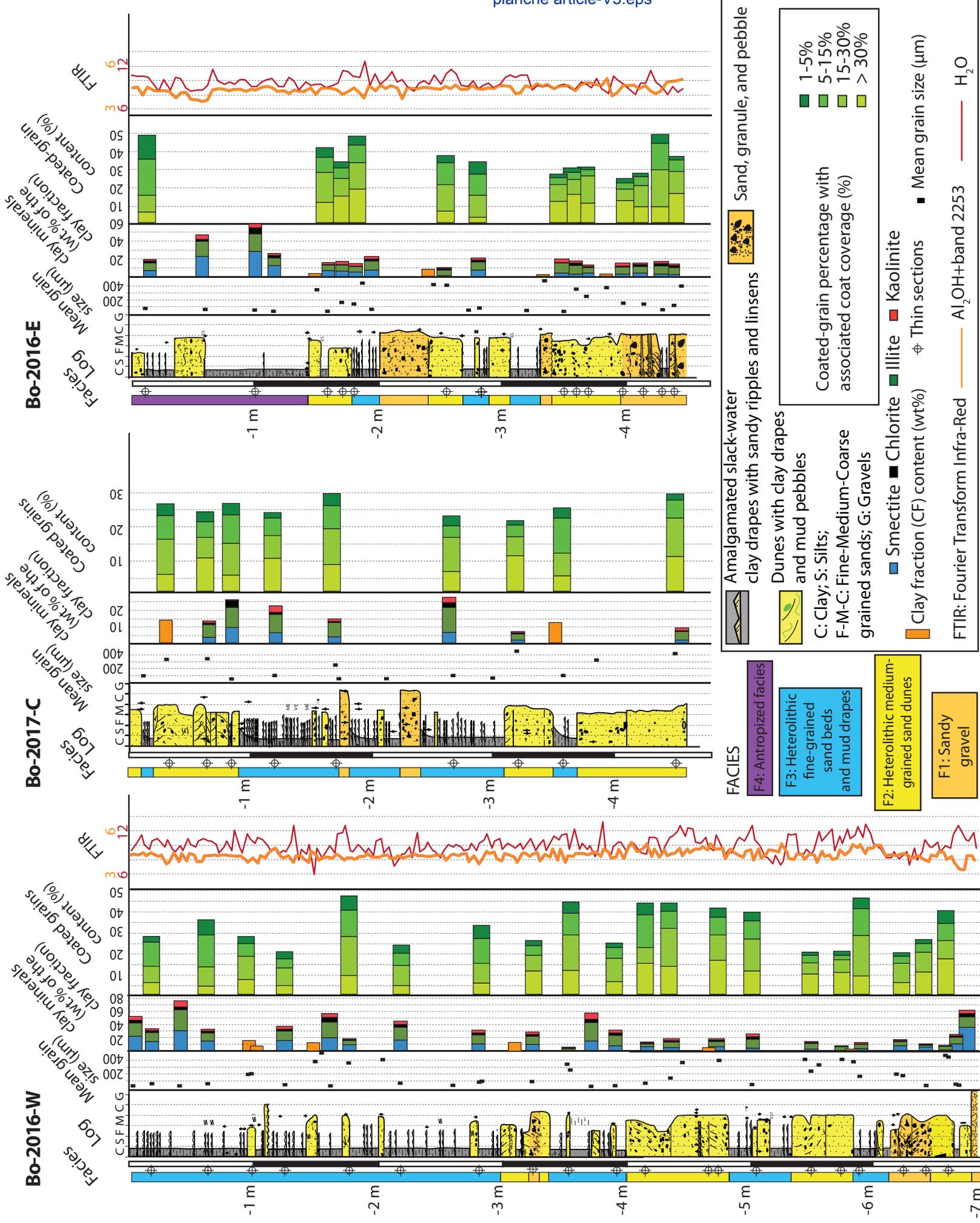
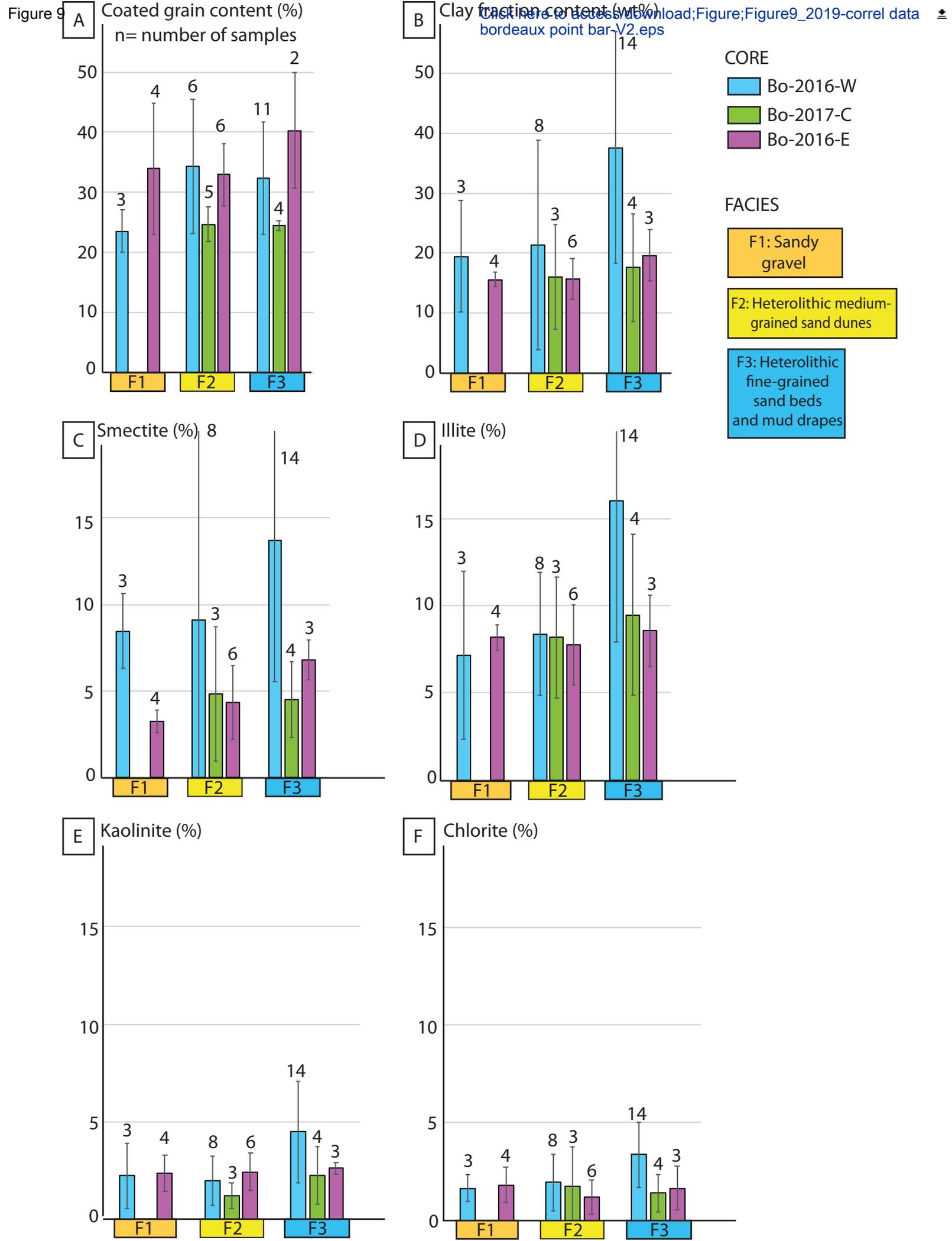
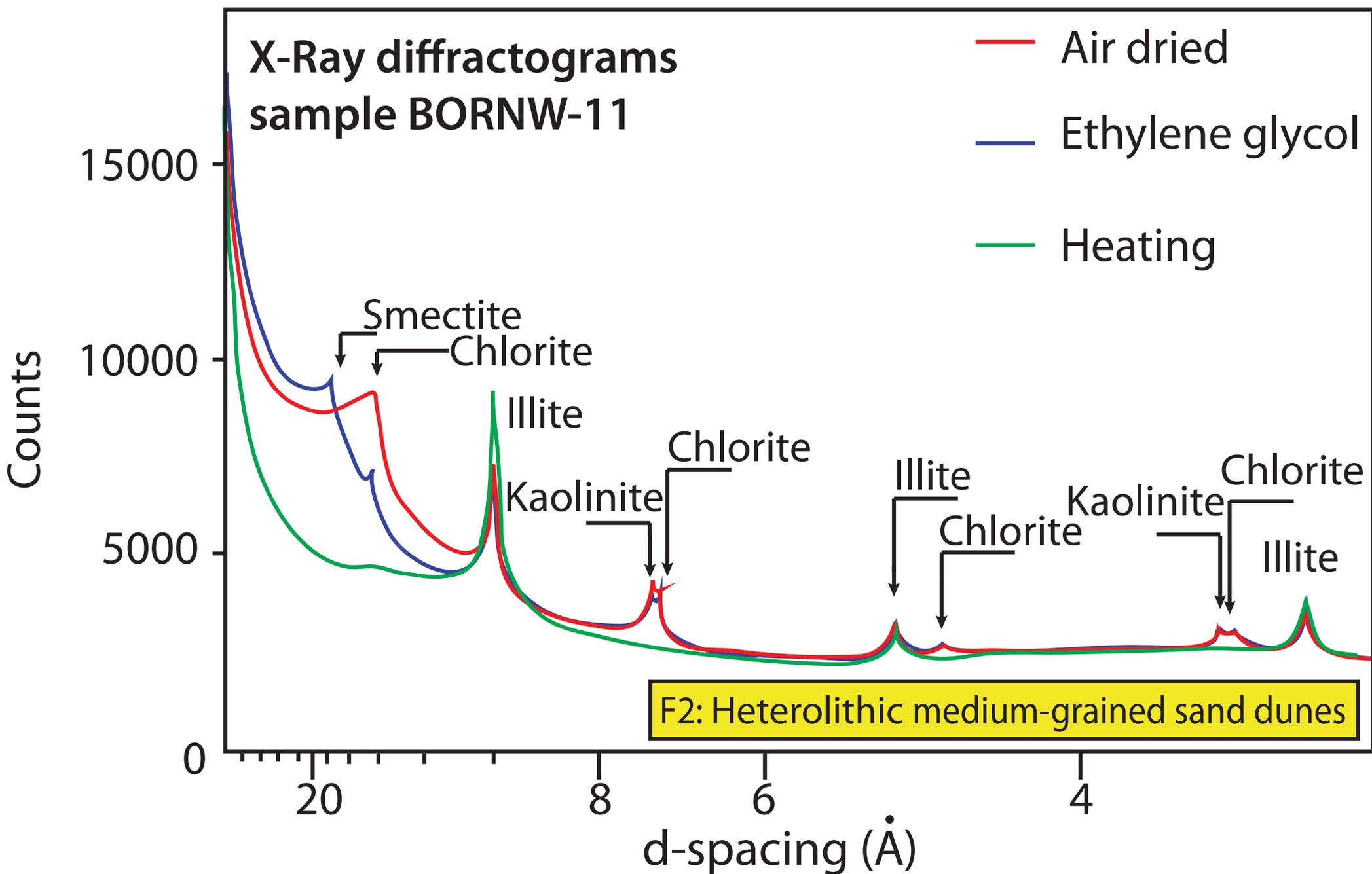
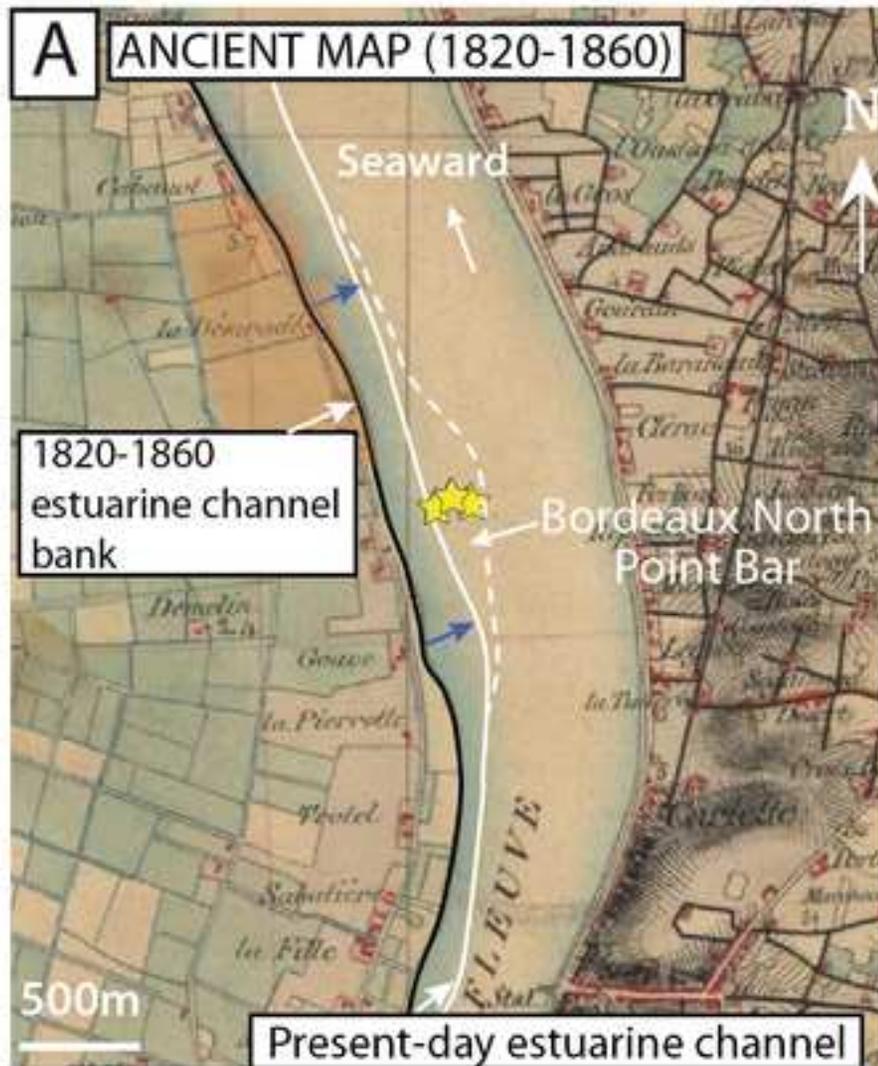


Figure 8

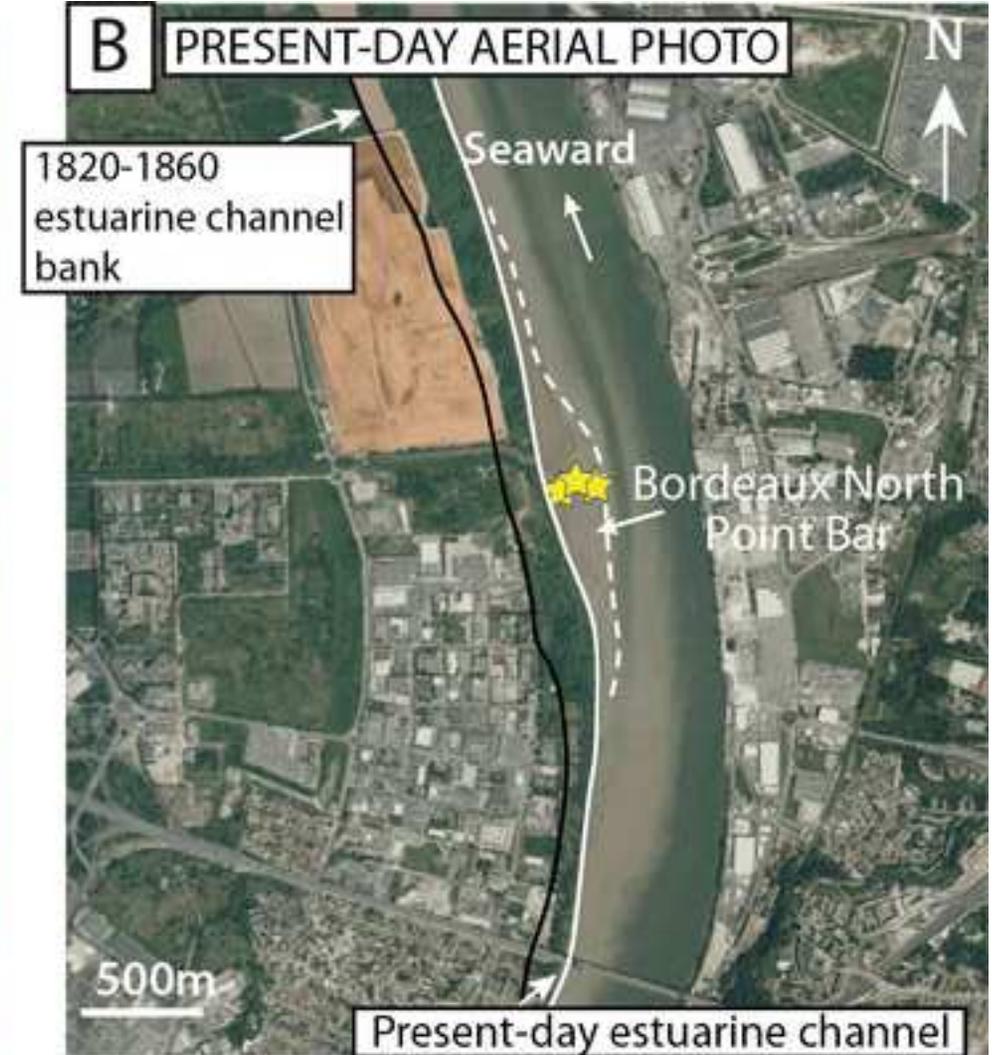




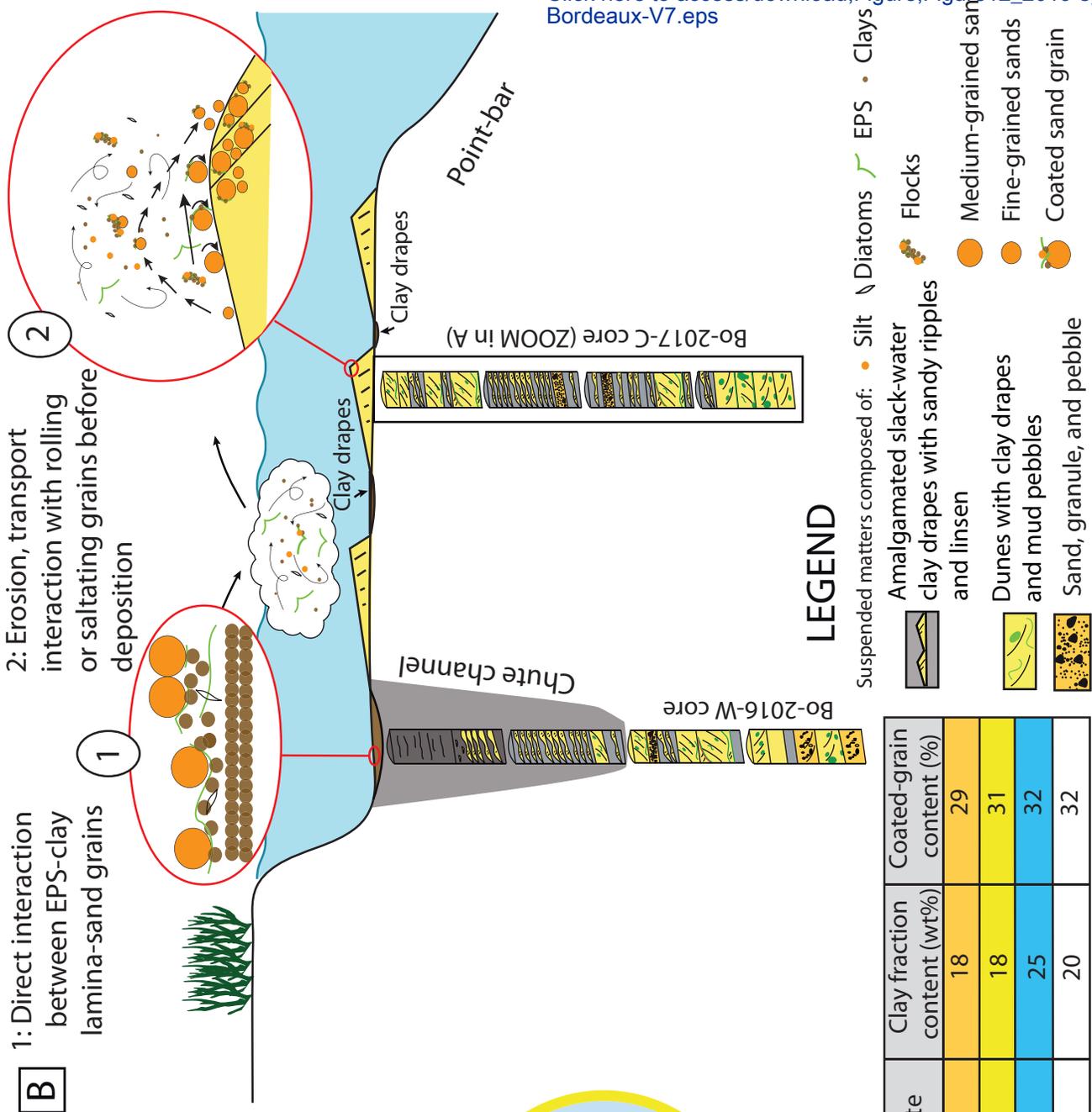




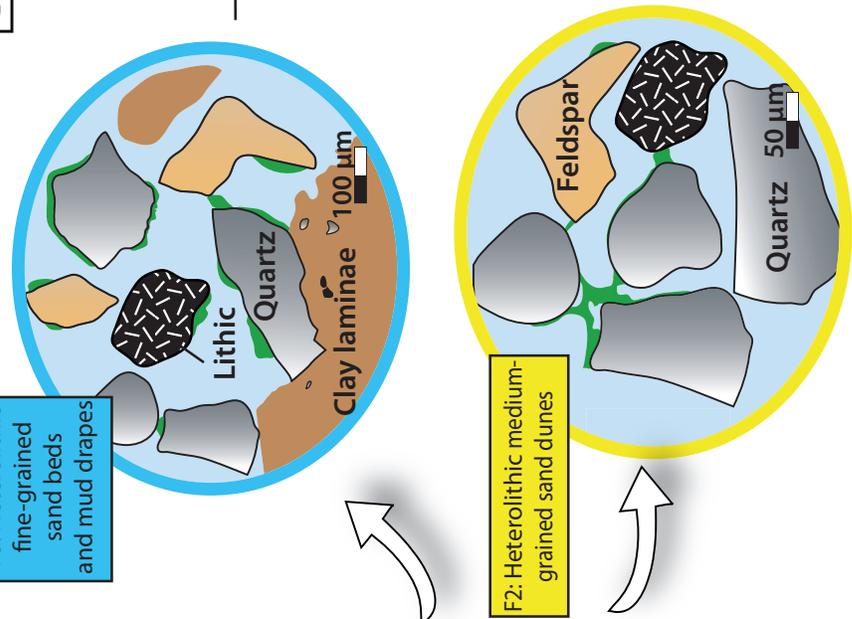
→ Lateral bank accretion  
 → from the 19th century  
 (about 200 m)



★ Studied cores

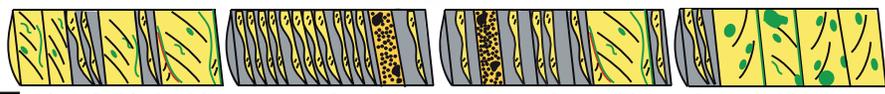


**B**



F1: Sandy gravel

**A**



**LEGEND**

- Suspended matters composed of: • Silt ∩ Diatoms ∩ EPS • Clays
- Amalgamated slack-water clay drapes with sandy ripples and linsen
  - Dunes with clay drapes and mud pebbles
  - Sand, granule, and pebble
  - Medium-grained sand
  - Fine-grained sand
  - Coated sand grain
  - Flocks

**C**

Facies	Smectite	Illite	Chlorite	Kaolinite	Clay fraction content (wt%)	Coated-grain content (%)
F1	6	8	2	2	18	29
F2	6	8	2	2	18	31
F3	8	11	2	3	25	32
Total	7	9	2	2	20	32

Facies number	Facies name	Facies description	Texture	Thickness	Set thickness	Location in the bar
F1	Sandy gravel	Coarse-grained sands, pebbles, gravels with no sedimentary structures. It contains shells and shell fragments and mud clasts, wood, seed, or leaf debris.	Mean grain size: 209 $\mu\text{m}$ . Grains are mostly subrounded and poorly sorted	At least centimeter thick, decimeter thick	/	Lower part
F2	Heterolithic medium-grained sand dunes	Sands with 5–30% clayey interbeds Small- to medium-size sand-rich dunes with few coarse mud pebbles on foresets and bottomsets or with thin clay drapes on foresets and bottomsets. Mud pebbles subrounded to subangular. Bottomsets are sometimes composed of thick individual horizontal clay drapes or thick amalgamated clay drapes. Some counter reactivation surfaces and clay drapes couplets are preserved. No bioturbation	Mean grain size: 266 $\mu\text{m}$ . Grains are subrounded to subangular and moderately well sorted to poorly sorted	Decimeter to meter thick	Mean thickness of 12 cm	Lower part
F3	Heterolithic fine-grained sand beds and mud drapes	Clays with 10–30% sand interbeds Centimeter-to-decimeter-thick mud layers or centimetre-thick clay drapes alternating with sandy ripples, sandy to silty linsens, and rare small sand dunes with clay drapes on foresets and bottomsets. Mud layers may sometimes correspond to stacked amalgamated clay drapes. Neap-spring cycle may be recorded in this facies with millimetric alternations of thinly-bedded fine-grained silty linsen to centimeter-thick ripples with amalgamated clay drapes. Rare bioturbation observed ( <i>Planolites</i> sp.?)	Mean grain size: 138 $\mu\text{m}$ . Grains are subrounded to subangular and moderately well sorted	Decimeter to meter thick		Upper part
F4	Admixed and anthropized sand and mud facies	Mud-dominated facies composed of a mix of highly disturbed and anthropized sand and mud with many elements left by humans such as pieces of brick or shipyard bolts. Coarse-grained sand sometimes mixed within mud	Mean grain size: 69 $\mu\text{m}$	Meter thick	/	

Table 1

Facies	Grain composition - JmicroVision Image analysis on thin sections							Coated-grain content and coat coverage classes (percentage of the outer surface coated) - JmicroVision Image analysis on thin sections					Clay-fraction content - relative weight percentage of the clay fraction of homogenized sediment	Compositions of the clay fraction (< 2 $\mu$ m) - X-ray diffraction (XRD)			
	Quartz (%)	Feldspars (%)	Lithic grains (%)	Carbonates (%)	Clays (%)	Macroporosity (%)	Micas (%)	1-5%	5-15%	15-30%	> 30%	Total coated grains (%)		Clay-fraction content (wt%)	% Smectite	% Illite	% Chlorite
F1	38	10	14	5	15	13	5	10	11	6	2	29	18	6	8	2	2
F2	39	12	14	2	13	14	5	11	10	7	3	31	18	6	8	2	2
F3	34	10	14	3	23	13	5	7	12	9	4	32	25	8	11	2	3
<b>Total/Mean</b>	37	11	14	3	17	13	5	10	11	7	3	31	20	7	9	2	2

Table 2

Depth		<sup>210</sup> Pb						<sup>137</sup> Cs	
cm	g cm <sup>-2</sup>	Total		Unsupported		Supported		Bq kg <sup>-1</sup>	±
		Bq kg <sup>-1</sup>	±	Bq kg <sup>-1</sup>	±	Bq kg <sup>-1</sup>	±		
0.5	0.5	74.2	6	38.2	6.2	36	1.4	3.2	0.7
10	9.8	56.8	3.8	18	3.9	38.8	0.9	2.5	0.5
12	12.2	81.3	5.6	5.8	5.8	75.5	1.5	1.9	0.7
14	14.3	59.7	3.5	17.2	3.6	42.5	0.8	3.2	0.4
24	25.3	78.3	6.3	25.6	6.5	52.7	1.5	6.1	0.8
26	27.1	56.6	4.8	12	4.9	44.6	1.2	8.2	0.8
28	28.8	81.7	7	32.5	7.2	49.2	1.6	8.4	0.9
30	30.6	49.7	5.5	10.6	5.6	39.1	1.3	6.2	0.7
36	37.8	57.3	5.6	11.8	5.8	45.5	1.3	5.4	0.9
48	50	71.4	6.9	22.8	7.1	48.6	1.7	3.8	0.8
60	60.8	67.2	6.8	22.9	7	44.3	1.7	6.5	1.1
72	74.9	67.2	5.9	22.5	6	44.7	1.4	4.4	0.8
84	86.6	57.1	5.8	8.7	6	48.4	1.5	5.7	0.9
96	98.6	42.1	4.5	5.3	4.6	36.7	1.1	3.4	0.7
108	114	31.2	3.8	-0.7	3.9	31.9	0.9	5.7	0.6
110	117.2	17.9	2.3	1.5	2.4	16.3	0.6	2.6	0.4
116	123.3	36.9	4.2	0.4	4.3	36.5	1.1	0	0
124	131.3	37	5.1	-2.2	5.3	39.3	1.3	0.4	0.8
132	141.3	45.8	4.2	8	4.3	37.8	1	0	0
140	150.8	42.7	3.9	5.5	4	37.2	0.9	0	0
234	277.6	42.9	4.1	3.9	4.2	39	1	0.4	0.5

## CLAY MINERALOGY X-RAY DIFFRACTOMETER

Sample		Facies	% Clay	% Smectite	% Illite
<b>CORE Bo-2016-West</b>					
Bdx-West-GR-1	100 cm	F3			
Bdx-West-GR-2	148 cm	F3			
Bdx-West-GR-3	205 cm	F3			
Bdx-West-GR-4	283 cm	F3			
Bdx-West-GR-5	310 cm	F2			
Bdx-West-GR-6	357 cm	F3			
Bdx-West-GR-7	445 cm	F2			
Bdx-West-GR-8	475 cm	F2			
Bdx-West-GR-9	545 cm	F2			
Bdx-West-GR-10	585 cm	F2			
Bdx-West-GR-11	623 cm	F1			
Bdx-West-GR-12	660 cm	F2			
BORNW-01	2 cm	F3	53	23	20
BORNW-02	18 cm	F3	34	15	14
BORNW-03	41 cm	F3	77	32	32
BORNW-04	63 cm	F3	34	15	12
BORNW-05	97 cm	F3			
BORNW-06	127 cm	F3	38	16	15
BORNW-07	161 cm	F3	57	21	24
BORNW-08	179 cm	F3	19	10	7
BORNW-09	218 cm	F3	46	17	20
BORNW-10	260 cm	F3			
BORNW-11	281 cm	F3	32	11	14
BORNW-12	323 cm	F1	29	11	12
BORNW-13	359 cm	F3	6	1	3
BORNW-14	371 cm	F3	58	15	28
BORNW-15	390 cm	F3	32	8	16
BORNW-16	415 cm	F2	14	7	5
BORNW-17	435 cm	F2	19	5	9
BORNW-18	471 cm	F2	19	6	8
BORNW-19	504 cm	F3	26	5	14
BORNW-20	550 cm	F2	15	3	8
BORNW-21	575 cm	F2	8	1	5
BORNW-22	590 cm	F3	13	4	7
BORNW-23	625 cm	F1	18	9	6
BORNW-24	645 cm	F1	11	6	3
BORNW-25	661 cm	F2	9	2	6
BORNW-26	666 cm	F2	25	11	10
BORNW-27	675 cm	F2	62	37	16
<b>CORE Bo-2017-Center</b>					
BORN2C-GR-1	31 cm	F2			
BORN2C-GR-2	64 cm	F2			
BORN2C-GR-3	170 cm	F3			

BORN2C-GR-4	320 cm	F2			
BORN2C-GR-5	385 cm	F2			
BORN2C-GR-6	450 cm	F2			
BORNC-01	11 cm	F3			
BORN2C-02	84 cm	F2	13	4	7
BORN2C-03	90 cm	F2	26	9	12
BORN2C-04	120 cm	F3	22	6	11
BORN2C-05	170 cm	F3	14	4	8
BORN2C-06	267 cm	F3	27	6	15
BORN2C-07	320 cm	F3	7	2	4
BORN2C-08	450 cm	F2	9	2	5
<b>CORE Bo-2016-East</b>					
Bdx-est-GR-1	150 cm	F2			
Bdx-est-GR-2	185 cm	F3			
Bdx-est-GR-3	245 cm	F1			
Bdx-est-GR-4	335 cm	F1			
Bdx-est-GR-5	385 cm	F2			
Bdx-est-GR-6	444 cm	F1			
BORNE-01	11 cm	F4	20	7	8
BORNE-02	58 cm	F4	47	23	17
BORNE-03	100 cm	F4	60	28	20
BORNE-04	115 cm	F4	26	13	8
BORNE-05	160 cm	F2	16	7	6
BORNE-06	170 cm	F2	17	7	7
BORNE-07	180 cm	F3	15	5	6
BORNE-08	195 cm	F3	23	8	10
BORNE-09	255 cm	F2	10	1	6
BORNE-10	273 cm	F3			
BORNE-11	281 cm	F3	21	7	9
BORNE-12	320 cm	F3			
BORNE-13	350 cm	F2	20	4	11
BORNE-14	360 cm	F2	18	3	10
BORNE-15	368 cm	F2	13	4	6
BORNE-16	400 cm	F1	16	3	8
BORNE-17	415 cm	F1	15	4	8
BORNE-18	430 cm	F1	17	3	9
BORNE-19	438 cm	F1	14	3	8

IMAGE ANALYSIS ON THIN SECTION			Quartz	Feldspars	Lithic

**CORE Bo-2016-West**

BORNW1-P-1	18 cm	F3	26	12	10
BORNW1-P-2	63 cm	F3	30	11	14
BORNW1-P-3	97 cm	F3	34	12	19
BORNW1-P-4	127 cm	F3	21	11	14
BORNW1-P-5	179 cm	F3	40	11	15

BORNW1-P-6	218 cm	F3	25	7	10
BORNW1-P-7	281 cm	F3	32	8	11
BORNW1-P-8	323 cm	F1	33	9	10
BORNW1-P-9	359 cm	F3	37	11	21
BORNW1-P-10	390 cm	F3	29	9	14
BORNW1-P-11	415 cm	F2	33	15	19
BORNW1-P-12	435 cm	F2	33	17	21
BORNW1-P-13	471 cm	F2	42	15	8
BORNW1-P-14	504 cm	F3	41	8	10
BORNW1-P-15	550 cm	F2	46	9	15
BORNW1-P-16	575 cm	F2	43	13	12
BORNW1-P-17	590 cm	F3	40	15	12
BORNW1-P-18	625 cm	F1	42	9	8
BORNW1-P-19	645 cm	F1	40	9	24
BORNW1-P-20	661 cm	F2	48	11	11
<b>CORE Bo-2017-Center</b>					
BORN2C-P1	31 cm	F2	37	13	15
BORN2C-P2	64 cm	F2	42	10	15
BORN2C-P3	84 cm	F2	34	10	10
BORN2C-P4	120 cm	F3	29	9	15
BORN2C-P5	170 cm	F3	40	12	13
BORN2C-P6	267 cm	F3	34	9	10
BORN2C-P7	320 cm	F2	44	16	13
BORN2C-P8	358 cm	F3	36	7	14
BORN2C-P9	450 cm	F2	41	17	13
<b>CORE Bo-2016-East</b>					
BORNE1-P-1	100 cm	F4	41	11	12
BORNE1-P-3	160 cm	F2	35	13	17
BORNE1-P-4	170 cm	F2	39	7	14
BORNE1-P-5	180 cm	F3	49	7	12
BORNE1-P-6	255 cm	F2	42	10	11
BORNE1-P-7	281 cm	F3	36	8	18
BORNE1-P-8	350 cm	F2	32	10	14
BORNE1-P-9	360 cm	F2	35	7	16
BORNE1-P-10	368 cm	F2	42	12	12
BORNE1-P-11	400 cm	F1	35	10	9
BORNE1-P-12	415 cm	F1	45	9	10
BORNE1-P-13	430 cm	F1	38	14	17
BORNE1-P-14	438 cm	F1	35	11	20

% Chlorite	% Kaolinite	mean grain size
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		201
		394
		411
		98
		349
		325
		370
		397
		408
		383
		192
		461
4	6	38
3	3	74
4	9	36
3	3	76
		199
3	4	52
7	6	35
2	1	365
4	5	74
		47
3	4	93
2	4	92
1	1	270
5	9	35
3	5	38
1	2	78
2	3	138
2	2	74
4	4	51
2	1	244
1	1	402
1	2	161
2	2	179
1	1	41
1	1	443
2	2	47
5	4	31
		334
		346
		248

		462
		342
		422
		101
1	1	56
4	1	102
1	4	71
1	1	56
3	3	105
1	1	74
0	2	91
		342
		447
		427
		492
		379
		399
2	2	89
2	5	75
7	5	61
3	2	50
1	2	43
0	3	168
0	3	126
3	3	68
2	1	414
		57
2	2	85
		51
1	4	49
3	2	360
1	2	253
1	4	159
2	2	142
3	2	56
2	2	120

	CaCO3	Clays	Porosity	Others	Coated grains		
					1-5%	5-15%	15-30%
2	32	16	3	6	8	11	
2	33	7	4	4	9	15	
5	14	12	5	7	11	6	
4	37	10	3	4	8	4	
0	17	11	5	9	18	12	

2	46	7	4	4	10	6
2	31	14	3	5	9	12
2	29	13	3	11	7	4
3	6	17	5	11	17	10
4	31	6	7	6	11	5
1	9	19	4	15	7	16
0	13	12	4	13	18	8
1	18	13	3	16	12	8
3	26	8	4	11	15	9
1	10	16	2	10	5	4
2	8	16	5	10	6	2
1	12	13	7	9	19	13
3	17	14	7	5	9	3
3	8	9	7	10	9	4
3	9	11	6	17	8	8
3	12	15	5	5	10	7
3	10	15	5	10	6	5
2	25	15	4	5	9	8
4	22	17	4	10	7	5
5	14	13	4	8	10	7
1	27	16	3	6	10	3
1	7	15	4	10	6	3
4	17	16	6	4	7	10
1	8	14	6	10	11	5
2	18	13	4	6	9	20
3	15	12	4	11	16	8
2	17	14	8	15	9	6
1	15	13	4	18	15	10
4	10	19	4	6	15	12
1	10	20	7	3	12	12
4	19	15	7	12	9	4
3	14	17	7	15	8	4
6	13	9	5	11	15	4
8	15	18	5	12	6	4
5	14	12	4	9	12	5
2	14	9	5	9	20	15
8	8	13	5	16	12	6

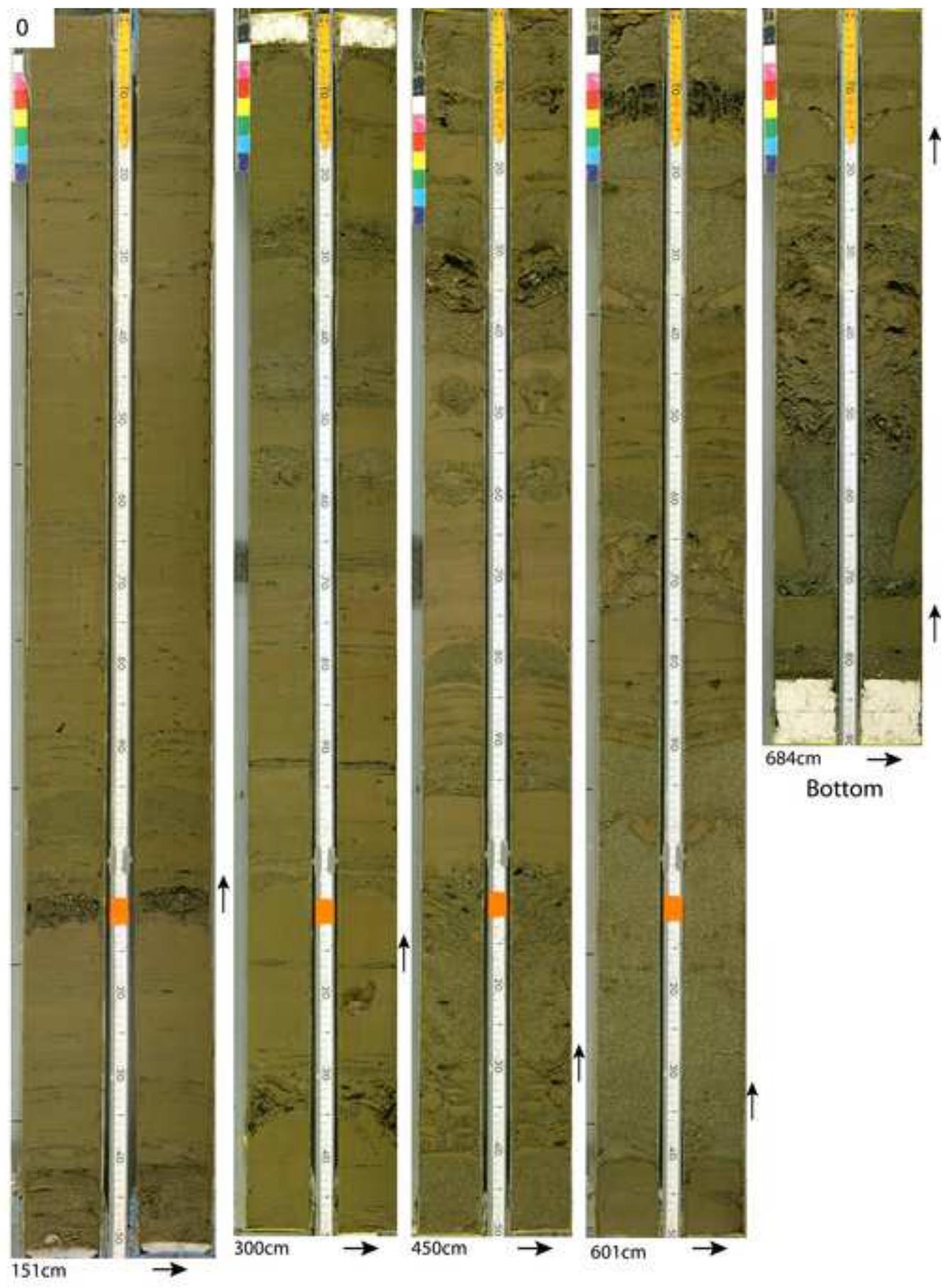


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> 30%	Total coated grain content
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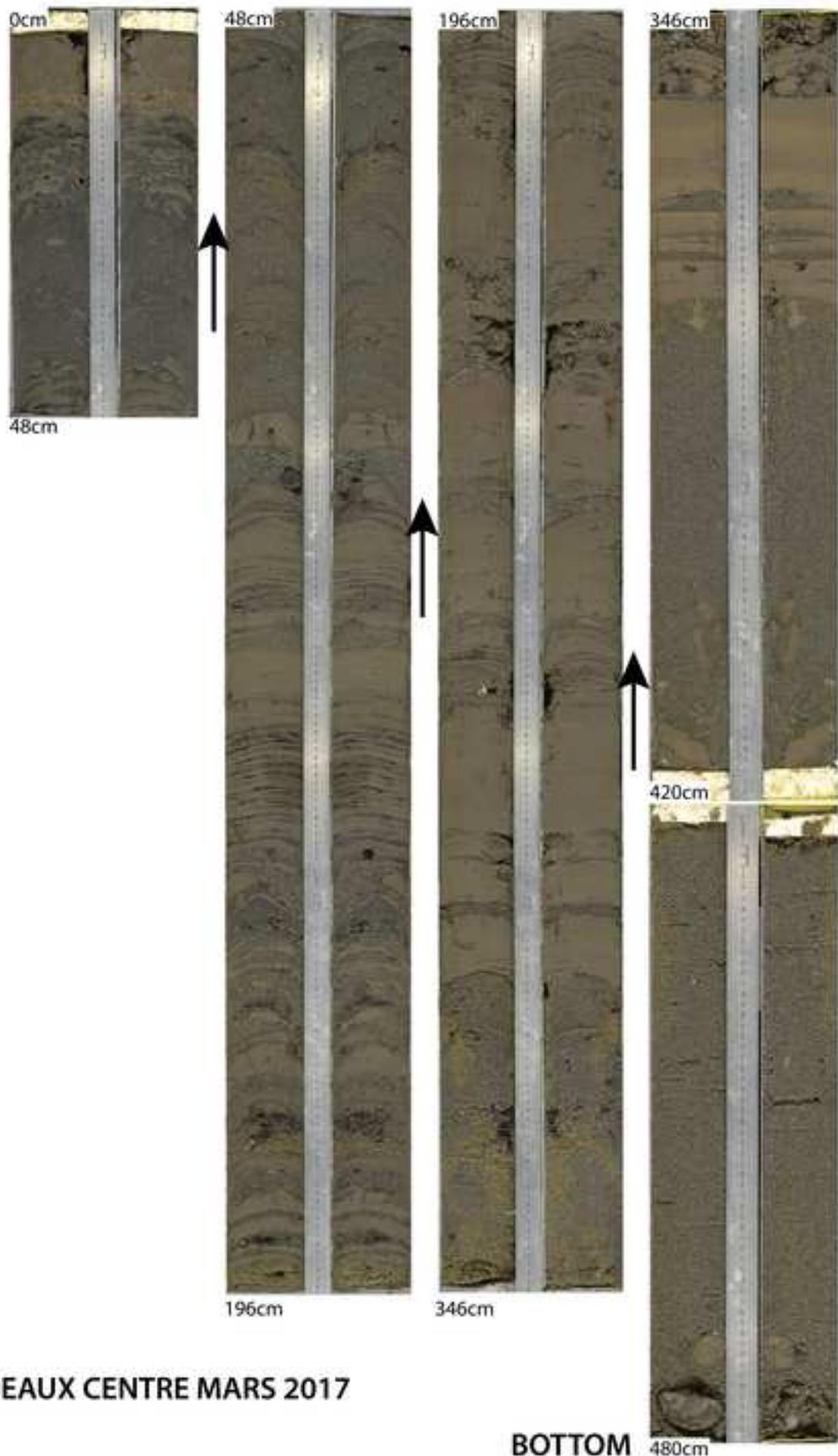
2	27
7	35
3	27
3	20
7	46

4	23
6	32
2	25
5	43
2	24
5	43
4	43
4	40
4	39
1	20
2	20
5	45
2	19
2	26
6	39
3	25
3	23
3	26
2	23
3	29
3	22
1	21
3	24
2	28
13	48
5	41
3	33
5	47
4	36
7	33
2	26
3	30
1	30
2	24
2	27
5	48
2	36



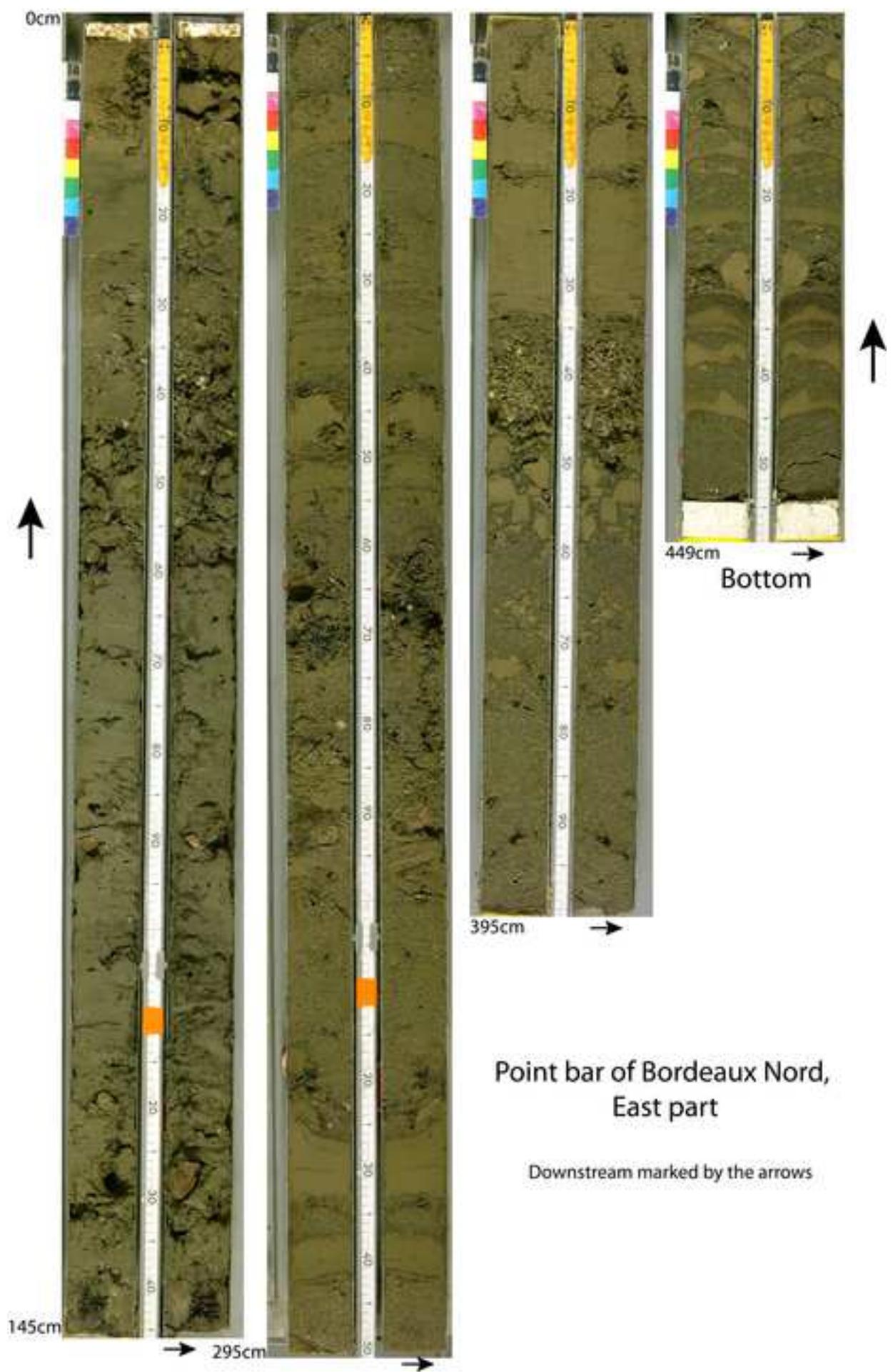
Point bar of Boreaux Nord, West part (chute channel)  
Downstream marked by the arrows

TOP



BORDEAUX CENTRE MARS 2017

BOTTOM



Point bar of Bordeaux Nord,  
East part

Downstream marked by the arrows

