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1 Holocene turbidites record earthquake supercycles at slow  
2 rate plate boundary

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15 **ABSTRACT**

16 Ongoing evidence for earthquake clustering calls upon records of numerous  
17 earthquake cycles to improve seismic hazard assessment, especially where recurrence  
18 times overstep historical records. We show that most turbidites emplaced at the Africa-  
19 Eurasia plate boundary off west Algeria over the past ~8 k.y. correlate across sites fed by  
20 independent sedimentary sources, requiring a regional trigger. Correlation with  
21 paleoseismic data inland and ground motion predictions support that M ~7 earthquakes  
22 have caused them. The bimodal distribution of paleo-events supports the concepts of

23 earthquake supercycles and rupture synchronization between nearby faults: thirteen  
24 paleo-earthquakes underpin clusters of 3–6 events with recurrence intervals of ~300–600  
25 yr, separated by periods of quiescence of ~1.6 k.y. without major events on other faults  
26 over the study area. This implies broad phases of strain loading alternating with phases of  
27 strain release. Our results suggest that fault slip rates are time-dependent and call upon  
28 revising conventional seismic hazard models.

## 29 INTRODUCTION

30 Earthquake time series reveal that rupture occurrence depends on the history of  
31 the causative fault, but also of adjacent ones (Stein, 1999; Scholz, 2010). Two main  
32 limitations however exist in outcrop study of faults: the scarce access to faults and the  
33 short time span of earthquake time series. Chronostratigraphy of earthquake-triggered  
34 turbidites provides insightful paleoquake records in subduction zones (Goldfinger et al.,  
35 2003) and helps overcoming these limitations.

36 Turbidite paleoseismology relies on the fact that significant seafloor shaking  
37 during large earthquakes promotes multiple and widespread turbidity currents, depositing  
38 greater sediment volumes (Goldfinger et al., 2003 and references therein) than those  
39 triggered by climatic events (Einsele et al., 1996). A widespread synchronous trigger is a  
40 key assumption for reconstructing paleo-earthquake records. Synchronicity is established  
41 by counting, dating and correlating deposits in independent channels (Goldfinger et al.,  
42 2003), basins (Gràcia et al., 2010) or sedimentary systems (Pouderoux et al., 2014).

43 Turbidite stratigraphy is a powerful tool to characterize the complex and  
44 multiscale seismic behavior of megathrusts and to evidence supercycles and superquakes  
45 (Goldfinger et al., 2013). However, the behavior of slow-rate plate boundaries has

46 received little attention despite high seismic risks and patchy knowledge of full seismic  
47 cycles. We aim to reconstruct thousand-year-long time-series of paleoquakes that  
48 triggered large turbidity flows in a low seismicity rate setting, and highlight the cycling of  
49 earthquakes at a slow convergence plate boundary.

## 50 REGIONAL SETTING

51 The Algerian margin is located at the diffuse boundary of the African plate  
52 converging at 3–6 mm yr<sup>-1</sup> toward Eurasia (Stich et al., 2006). The 1954 M<sub>s</sub> 6.7  
53 Orléansville earthquake and the 2003 M<sub>w</sub> 6.8 Boumerdes earthquake triggered  
54 widespread turbidity flows documented by submarine cable breaks (Heezen and Ewing,  
55 1955; Cattaneo et al., 2012), supporting a turbidite paleoseismology approach. The area  
56 of the Orléansville and El Asnam earthquakes (Fig. 1) is a ~150-km-long margin segment  
57 where strain is located inland along northeast-southwest strike-slip faults and landward-  
58 verging thrusts and folds (Beldjoudi et al., 2011). The main active tectonic feature is the  
59 El Asnam Fault System (EAFS) forming a complex set of deep ramps connecting  
60 laterally, followed upwards by fault-propagation folds (Avouac et al., 1992). The 1954  
61 M<sub>s</sub> 6.7 Orléansville earthquake likely occurred along the deepest ramp without breaking  
62 the surface. In contrast, the 1980 M<sub>s</sub> 7.3 El Asnam earthquake ruptured a ~30-km-long  
63 frontal scarp (Meghraoui et al., 1988). The El Asnam earthquake did not trigger  
64 widespread turbidity currents, since no submarine cable broke offshore, except a single  
65 cable ~200 km eastward (El Robrini et al., 1985). From available surface faulting  
66 (Beldjoudi et al., 2011) and historical seismicity (Boughacha et al., 2004), whether other  
67 faults than the EAFS can produce M > 6.5 earthquakes in this part of Algeria is unclear.  
68 Offshore El Asnam, the eastern continental slope is 3–4° steep, dominated by the Kramis

69 fan, fed by the Kramis and Khadra canyons (Fig. 1). The canyons are obliquely oriented  
70 (N170 and N090) and build an asymmetric 800-m-high levee (Babonneau et al., 2012).  
71 Westward and eastward, the slope is steeper (up to  $\sim 16^\circ$ ) and shows numerous slump  
72 scars and gullies. No large active faults are observed offshore.

## 73 **METHODS**

### 74 **Scientific Rationale**

75 To infer the seismic trigger of turbidites, we test their synchronicity in three cores  
76 collected in two independent sedimentary systems (Fig. 1; Fig. DR1 in the GSA Data  
77 Repository<sup>1</sup>). Core site KMDJ07 (2630 m below sea level, mbsl) is fed by turbidity flows  
78 coming from the Kramis turbidite system, whereas core KMDJ08 (2631 mbsl) samples  
79 the margin toe and collects only turbidity currents originated from the overhanging slope.  
80 To avoid any local or climatically triggered turbidites (flood, hyperpycnal flow) that  
81 usually depict short runouts (Einsele et al., 1996), we collected core PSMKS19 (2626  
82 mbsl) in the distal part of the Kramis fan (Fig. 1). As it is close to a A.D. 1954 cable  
83 break, it stands on the path of the earthquake-triggered turbidity currents. We then  
84 compare our record with the paleoseismic one on the El Asnam fault scarp (Meghraoui et  
85 al., 1988).

86 Combined effects of lower sea level before ca. 8 ka and wetter conditions in the  
87 Maghreb from the Bølling-Allerød stage (14.7–12.7 ka BP) to ca. 8 k.y. B.P. (Barcena et  
88 al., 2001) favored the connection between river mouths and canyons, and the formation  
89 of hyperpycnal flows able to reach the coring sites. We thus limited our investigation to  
90 the past  $\sim 8$  k.y. when the sea level was high and climate was drier and more stable, a  
91 period less favorable to the climatic triggering of large turbidity flows.

92 **Sediment Analyses and Dating**

93 We measure gamma density, porosity and magnetic susceptibility each centimeter  
94 on the cores. We split them for description, photography, X-Ray imagery, magnetic  
95 susceptibility, and laser granulometry. Finally, we measure composition of major  
96 elements by X-Ray fluorescence (XRF) (Fig. 2; Figs. DR2 and DR3). Dating turbidites  
97 requires calculating the hemipelagic accumulation rate between successive  $^{14}\text{C}$  ages dated  
98 on planktonic foraminifers (Fig. DR4) by subtracting all turbidites. We calibrate the  
99 radiocarbon dates, built age/depth models, and thus calculate the age of each turbidite  
100 (OxCal software; Figs. DR5–DR7). We choose an interpolation parameter allowing  
101 heterogeneous sediment deposition to account for possible erosion at the base of each  
102 turbidite that we cannot quantify.

103 **RESULTS AND INTERPRETATIONS**

104 The three cores KMDJ07, KMDJ08, and PSM-KS19 show alternating light-to-  
105 dark olive beige, poorly sorted bioclastic silty clay, interpreted as background  
106 hemipelagic deposits, and dark olive gray to olive beds with a sharp, sometimes erosive  
107 silty base and a fining-upward grain-size trend. These beds are interpreted as  
108 instantaneous turbiditic deposits (Fig. 2; Figs. DR1–DR3). The top of turbidites is  
109 determined by the analysis of several proxies. In Northern Algeria, the watersheds are  
110 mainly calcareous, resulting into relatively low contrasts in carbonated content between  
111 turbidites tails and hemipelagites based on Ca/Fe ratios (biogenic vs detrital fluxes) (Fig.  
112 2b). This limits the use of variation in magnetic susceptibility, density or geochemical  
113 composition often used for accurate identification of turbidites (Goldfinger et al., 2003;  
114 Gràcia et al., 2010). Moreover, sediment sorting (Fig. 2c) reveals normally graded

115 turbidites with a coarse base (up to 1000  $\mu\text{m}$ ) fining upwards to silts and clays. The grain  
116 size distribution supports well-sorted deposits. Contrastingly, most hemipelagites are  
117 unsorted and show a plateau for grain size comprised between  $\sim 30$  and  $>300$   $\mu\text{m}$   
118 associated to biogenic particles (Fig. 2c). This criterion appears more reliable for  
119 discriminating turbidites from hemipelagites when the compositional contrast is low  
120 (Ratzov et al., 2010). Where discrimination remains uncertain (e.g., sediment mixing by  
121 bioturbation), we consider the interval as an uncertainty included in the age model (Fig.  
122 2; Figs. DR2 and DR3).

123 Turbidites may be stacked without intervening hemipelagites in proximal cores  
124 KMDJ07 and KMDJ08. Such stacks may reflect: (1) simultaneous slope failures during  
125 an earthquake, (2) large aftershocks or earthquakes occurring closely in space and time,  
126 (3) pulses and flow discontinuities in the turbidity current (Van Daele et al., 2013) or (4)  
127 seafloor erosion of hemipelagites by the coarse fraction of the subsequent turbidite  
128 (Goldfinger et al., 2003). Since we hardly discriminate among these scenarii, we consider  
129 a single trigger when stacks contain no hemipelagites, and multiple triggers where the  
130 presence of hemipelagites is unclear.

131 We define an event (E) as a turbidite or a stack of turbidites that either  
132 corresponds to a historical earthquake or is synchronous in at least two cores. We identify  
133 13 events based on turbidite correlation with overlapping age error bars across two or  
134 three cores (Figs. 2 and 3). Although the error bars of events may overlap, the  
135 stratigraphy of deposits allows establishing the number of events. Seven events are  
136 retrieved in all cores (E3, E5, E9, E10, E11, E12, and E13), five correlate across two

137 cores (E2 and E4 collected in the same system, E6, E7, and E8), and only two turbidites  
138 are single ones: T1 in core PSMKS19 (E1) and T10 in core KMDJ07 (Fig. 2a).

139 Ground motion prediction equations applied to our case study show that  $M > 6.5$   
140 earthquakes are required to produce a peak ground acceleration (PGA) sufficient to  
141 promote slope failures (Fig. 4; Fig. DR8). Our study should therefore trace the cycling of  
142  $M > 6.5$  earthquakes occurring approximately within the area mapped in Figure 1.

## 143 **DISCUSSION AND CONCLUSION**

### 144 **From Turbidites to Paleo-Earthquakes**

145 The greater amount of turbidites in more proximal cores (Fig. DR1) suggests that  
146 turbidites in our cores are not linked to climatic events (floods, hyperpycnal flows) that  
147 usually depict short runouts. Instead, the clear synchronicity of at least seven groups of  
148 turbidites supports a regional trigger that we interpret as coseismic. Although visible in a  
149 single core, turbidite T1 of core PSMKS19 has an error bar (0–460 yr) that includes the  
150 age of the 1954 Orléansville earthquake and is located near a cable break (Heezen and  
151 Ewing, 1955). As no large ( $M > 6.5$ ) historical events occurred in the area during the 0–  
152 460 yr time span (Boughacha et al., 2004), T1 likely corresponds to the 1954 earthquake.  
153 The lack of events E1 in cores KMDJ07 and KMDJ08, and E2 in core KMDJ07, likely  
154 results from the loss of the uppermost deposits in the piston corer. Conversely, the lack of  
155 turbidites coeval with T10 in Core KMDJ07 cannot be caused by sampling limitations.  
156 Because T10 occurs ~500 yr after the previous earthquake, the slope was most likely  
157 reloaded with sediments, thus the lack of coeval record in other cores supports that T10 is  
158 local and not triggered by a large earthquake.



159           The strongest argument to interpret the turbidites as coseismic is their correlation  
160 with independent paleoseismic data inland (Sumner et al., 2013), here, the El Asnam fault  
161 scarp, the greatest fault in the area. At least eight out of nine paleoquakes are coeval with  
162 the submarine record within their error bars (all events except E7, Fig. 3). This clear  
163 correlation suggests that ruptures on the El Asnam fault triggered these turbidites.  
164 However, other faults in the area may have triggered the turbidites in case they ruptured  
165 almost synchronously (i.e., within few decades) with the El Asnam paleoquakes. Indeed,  
166 although the error bar of Event E1 overlaps both 1954 and 1980 earthquakes, only the  
167 first one triggered turbidity flows in the area (Heezen and Ewing, 1955). Sediment prone  
168 to failure was probably flushed during the earlier earthquake, thus lowering the  
169 probability of a subsequent failure. Similarly, the slight asynchrony of Event E7 with the  
170 El Asnam paleo-earthquake (<100 yr) may result from bursts of activity on nearby faults.  
171 Therefore, it is impossible to assign a turbidite to a specific fault segment, and the  
172 number of large earthquakes may exceed the number of turbidites found (i.e., a single  
173 turbidite may hide multiple earthquakes). Still, the nine ruptures identified on the El  
174 Asnam fault scarp remarkably match the nine widespread turbidites deposited within very  
175 short time spans. Turbidites triggered by earthquakes from active faults located in other  
176 regions (e.g., the Iberian margin) have no chance to reach our area, given (1) the large  
177 distance (>250 km) of our coring sites to canyons and major faults of Iberia (Gràcia et al.,  
178 2006), and (2) the depth of coring, significantly less than the deepest basin floor  
179 (Babonneau et al., 2012).

## 180 **Earthquake Recurrences and Supercycles**

181 Although the turbidite record is incomplete for earthquakes occurring closely in  
182 time (a few decades), the 13 paleo-events identified define three clusters of seismicity  
183 (Fig. 3): C1 (4 events in  $1800 \pm 250$  yr), C2 (3 events in  $850 \pm 260$  yr), and C3 (6 events  
184 in  $1650 \pm 400$  yr). The distribution is bimodal: the 3 clusters depict mean Recurrence  
185 Intervals (RI) of  $0.3 \pm 0.2$  (C3),  $0.4 \pm 0.2$  (C2), and  $0.6 \pm 0.4$  ka (C1) and are separated by  
186 two Quiescence periods Q1 and Q2 of  $1625 \pm 490$  yr and  $1575 \pm 580$  yr, respectively  
187 (Fig. 3). This distribution suggests 3–4 k.y.-long patterns including clusters of 3 to 6  
188 events and periods without major events inbetween. This variability in earthquake  
189 recurrence is akin to the concept of “supercycles” suggested in subduction zones  
190 (Goldfinger et al., 2013). Interestingly, similar quiescence periods are found in the  
191 southwest Iberian margin (Gràcia et al., 2010) and in central Italy (Benedetti et al., 2013),  
192 where slip rates are low. This concept supports alternation of broad phases of strain  
193 loading and shorter phases of strain release and implies that fault slip rates are time  
194 dependent (Friedrich et al., 2003; Benedetti et al., 2013). Note also that the mean RI in  
195 clusters rises progressively (C3: 305 yr; C2: 430 yr; C1: 580 yr; Fig. 3), suggesting that  
196 strain rates may change through time.

### 197 **Earthquake Synchrony**

198 Fault interactions have proved to promote or delay fault activity by stress transfer,  
199 sometimes leading to synchronization between fault segments (Scholz, 2010). If slope  
200 sediments are prone to failure, turbidites record the activity of any neighboring fault able  
201 to cause earthquakes strong enough to trigger turbidity currents (Fig. 4). The  
202 cluster/quiescence pattern found here supports the idea that the seismogenic segments  
203 (EAFS and other large faults in the area) are in synchrony, at least at the scale of the

204 study region ( $\sim 100 \times 100$  km, Fig. 1). Knowledge of long-term cycling in the rupture  
205 pattern (here, two complete supercycles; Fig. 3) is important since it reveals phases of  
206 strain release and loading, therefore a given elapsed time after a clustering period would  
207 not necessarily mean a higher hazard. This result thus modifies the probability models of  
208 earthquake recurrence (Gomberg et al., 2005) and helps improve seismic hazard  
209 assessments.

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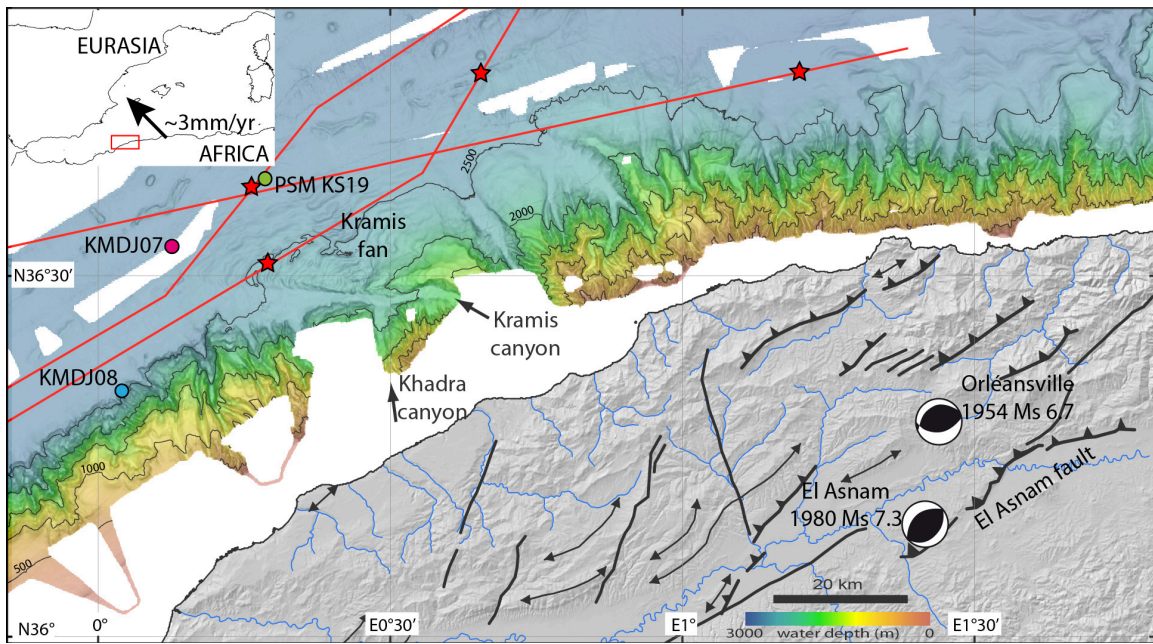
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309

310 **FIGURE CAPTIONS**

311 Figure 1. Morphostructural map of the northwestern Algerian margin. Capsule: Arrow is  
312 the Africa/Eurasia convergence inferred from GPS (Stich et al., 2006). Map: Black lines  
313 onland are the active fault network, double arrows are folds (Beldjoudi et al., 2011).  
314 Focal mechanisms of the 1954 and 1980 earthquakes are from Avouac et al. (1992).  
315 Offshore, isobaths represent 500 m. Red lines are submarine cables, stars are the breaks  
316 after the 1954 earthquake (after Heezen and Ewing, 1955). Color circles are sedimentary  
317 cores used in this study.

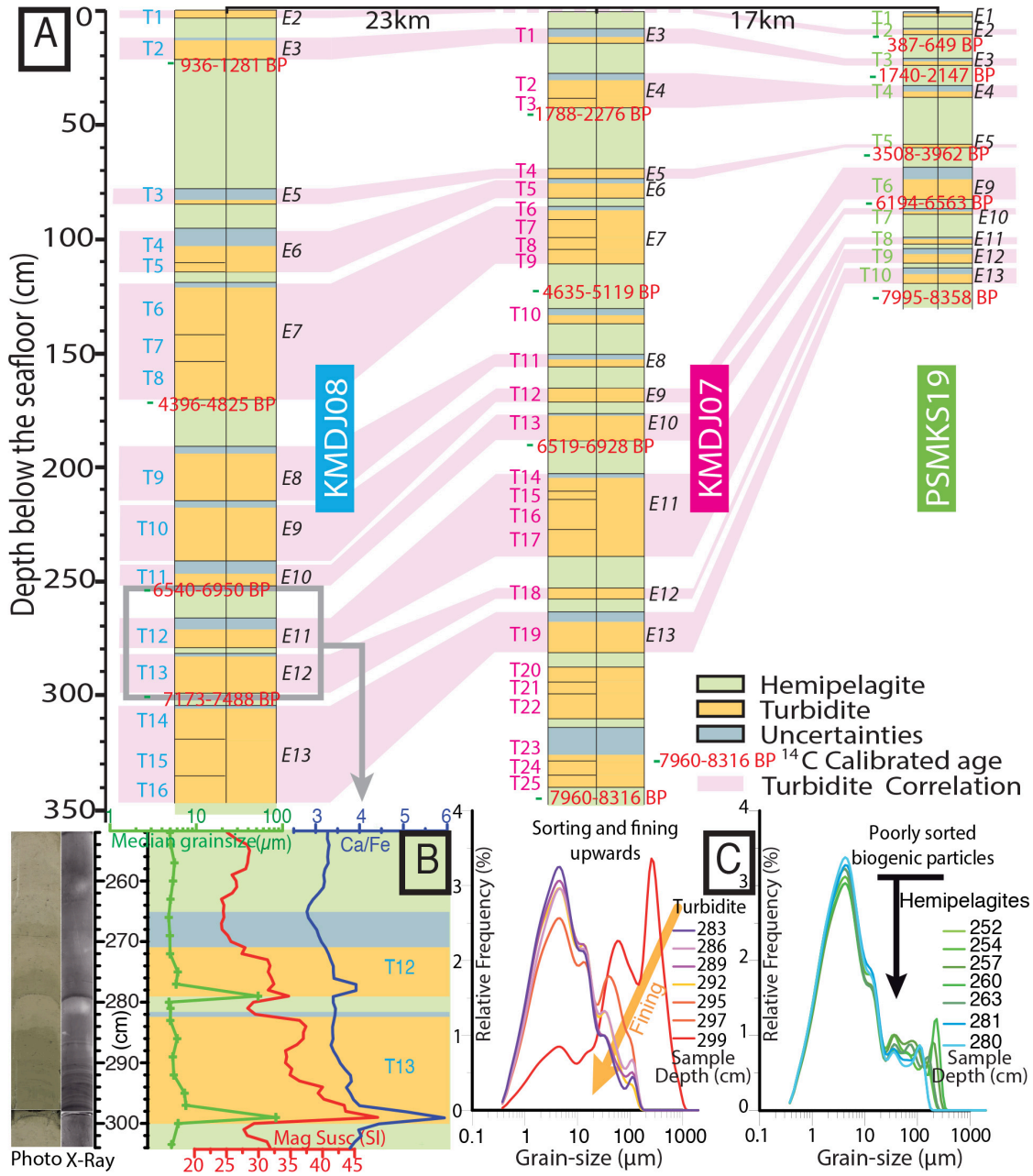
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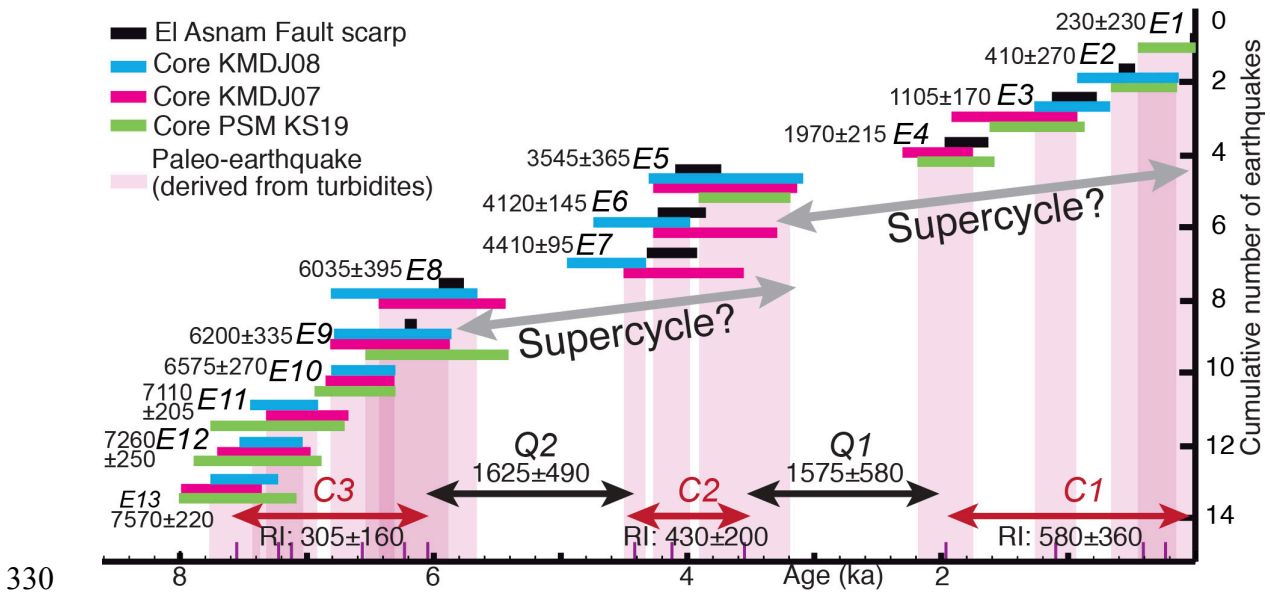


320 Figure 2. Synthetic logs of the cores used for turbidite correlations depicting  
 321 interpretation from turbidite in each core (Tx) to widespread events (Ex) where the  
 322 turbidites are correlated across numerous cores. Gray layer outlines the uncertainties on  
 323 identifying the precise turbidites boundaries. Deposits are discriminated based on Photo,  
 324 X-ray pictures, magnetic susceptibility, density, XRF (B), and sediment sorting (C).



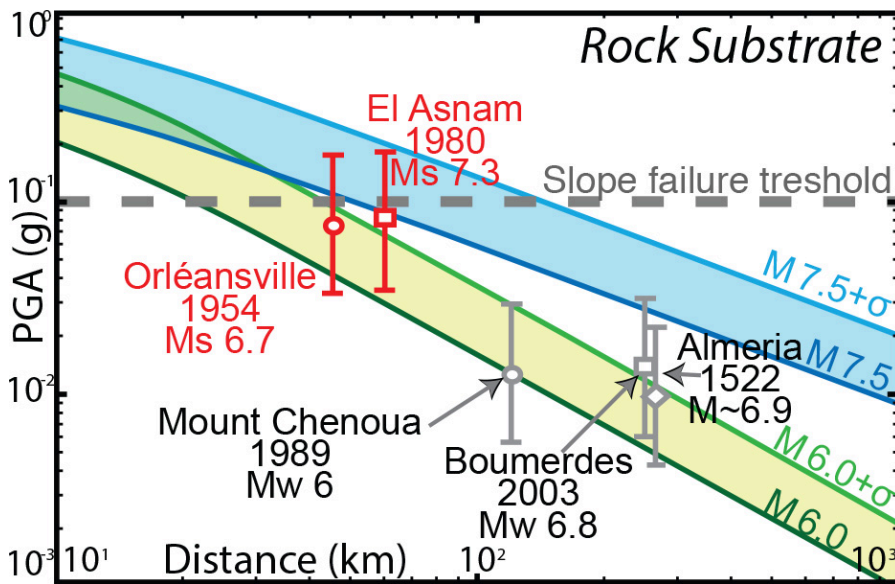
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326 Figure 3. Correlations between ages of events recorded in each core (color lines) and the  
327 paleoquake chronology reconstructed across the El Asnam fault (Meghraoui et al., 1988).  
328 Purple stripes outline the intersection of the error bars of turbidite ages, thus the  
329 probability age of earthquake triggering.



330  
331

332 Figure 4. Mean Peak Ground Acceleration (PGA) predicted for historical earthquakes,  
333 felt in the area of submarine canyon heads where sediment turbidity flows likely  
334 originate. PGA is calculated with empirical equations (Akkar and Bommer, 2010) for  
335 rock sites. Color stripes outline the PGA caused by  $M_w 6.0 \pm \sigma$  and  $M_w 7.5 \pm \sigma$   
336 earthquakes (Fig. DR8 [see footnote 1] for further details). Geotechnical analyses of the  
337 sediment cover show that slope should fail at 0.1 g PGA.



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340 <sup>1</sup>GSA Data Repository item 2015xxx, xxxxxxxx, is available online at  
341 [www.geosociety.org/pubs/ft2014.htm](http://www.geosociety.org/pubs/ft2014.htm), or on request from [editing@geosociety.org](mailto:editing@geosociety.org) or  
342 Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

**DR1:** Detailed bathymetric map of the study area, sites of all the cores initially available for the paleoseismic investigation and synthetic lithologic logs of the cores. On the map, yellow circles show the location of cores, red stars are the locations of cable breaks after the 1954 M<sub>s</sub>6.7 Orléansville earthquake. On the lithologic logs, the red rectangles show the core sections used in the study. Sedimentological analyses are detailed in SM2.

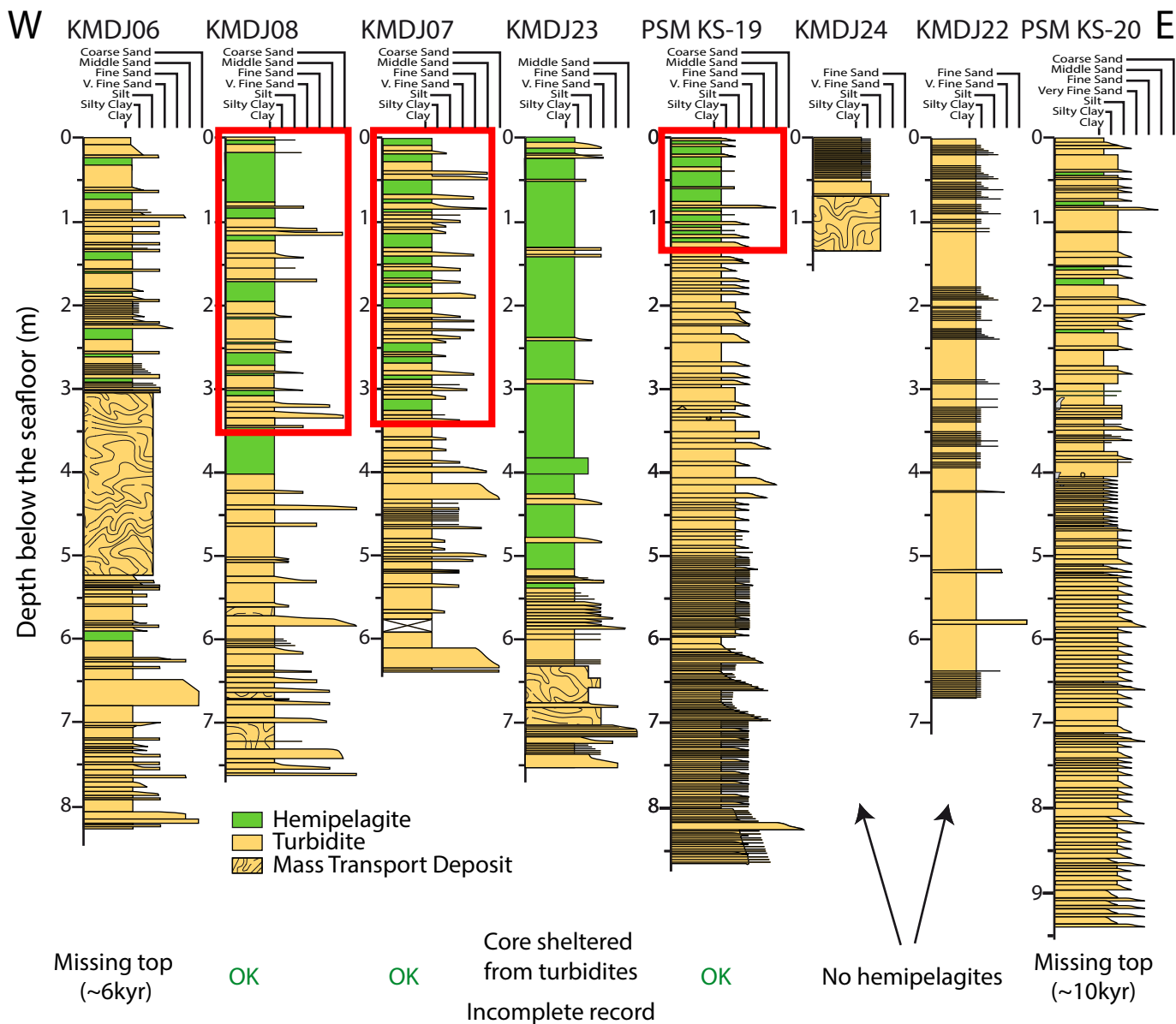
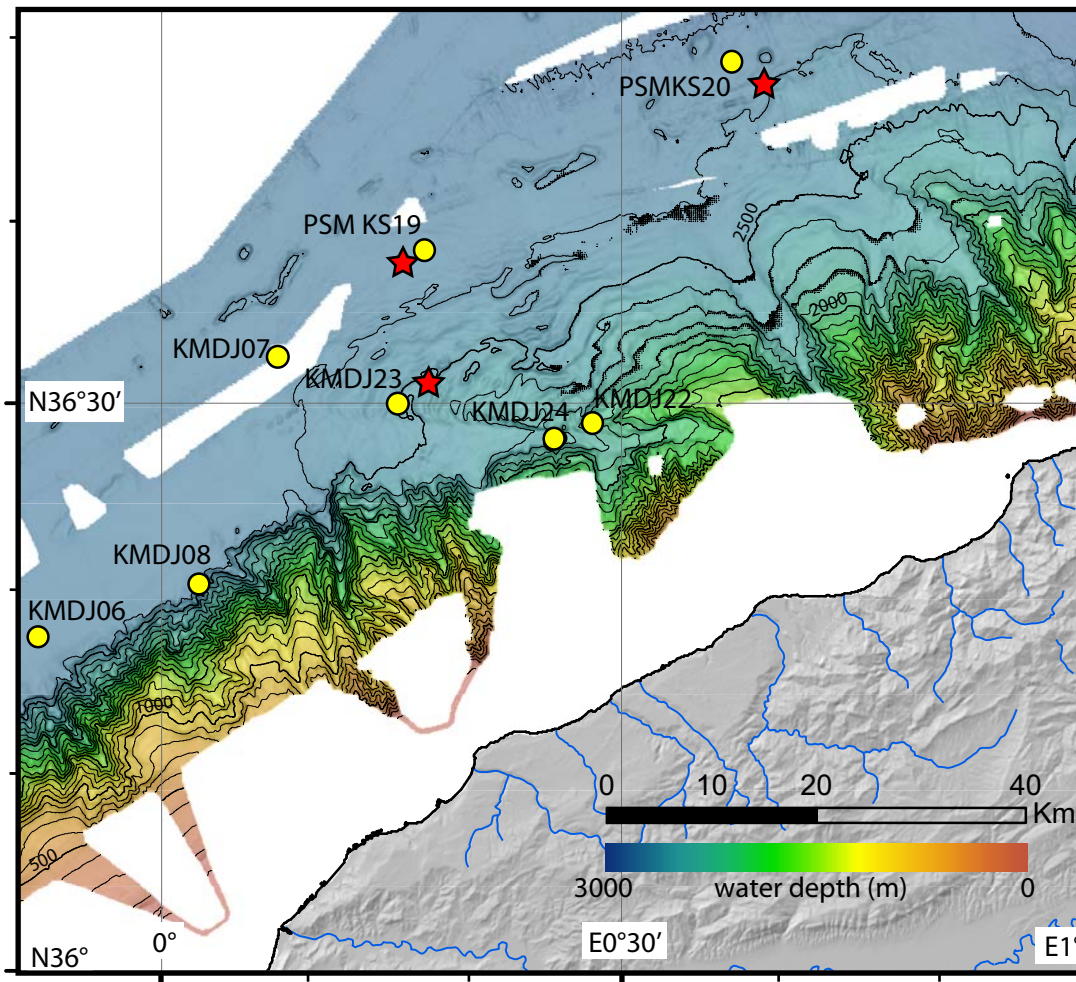
The coring strategy was established in order to (1) collect turbidites originated from independent sedimentary system to test synchronicity and infer a regional trigger of turbidites, (2) obtain a record with amounts of datable hemipelagic deposits between turbidites, (3) avoid climatically triggered turbidites, and (4) collect turbidites associated at least to the 1954 Earthquake, thus located close to the cable breaks,

This figure shows encountered issues while establishing a coring strategy for a turbidite paleoseismology investigation:

A) No datable hemipelagic deposits: For example, cores KMDJ24 and KMDJ22 did not contain any intervening hemipelagites between turbidites thus discarding dating possibilities. Indeed, these two cores are most probably too axially located compared to the sediment transport axis. Turbidity currents at these sites are too energetic, thus eroding any intervening deposits. Moreover, these two cores are also likely too proximally located, contain much more turbidites than the distal cores, and probably record flood- or storm-triggered turbidites. More generally, all the cores contain a greater amount of turbidites without intervening hemipelagites during the Last Glacial Maximum and the sea-level rise, and probably record climatic events. We therefore discarded cores KMDJ22, KMDJ24, and the periods before ~8ka on all the other cores.

B) Incomplete turbidite record: Core KMDJ23 was collected on a levee of the channel in order to avoid basal erosion by turbidity currents and climatically-driven turbidites. Unfortunately, turbidites in this core are scarce, very fine grained and difficult to identify. The core most likely contains an incomplete turbidite record and was discarded for detailed investigation.

C) Missing core tops: Loss of the uppermost deposits may occur with a piston corer as exemplified by cores KMDJ06 and PSMKS20. Although located in independent sedimentary systems and showing a good alternation of turbidites and hemipelagites, <sup>14</sup>C datings near the top of the cores show that ~6kyr and ~10kyr are missing respectively. We therefore discarded these two cores.

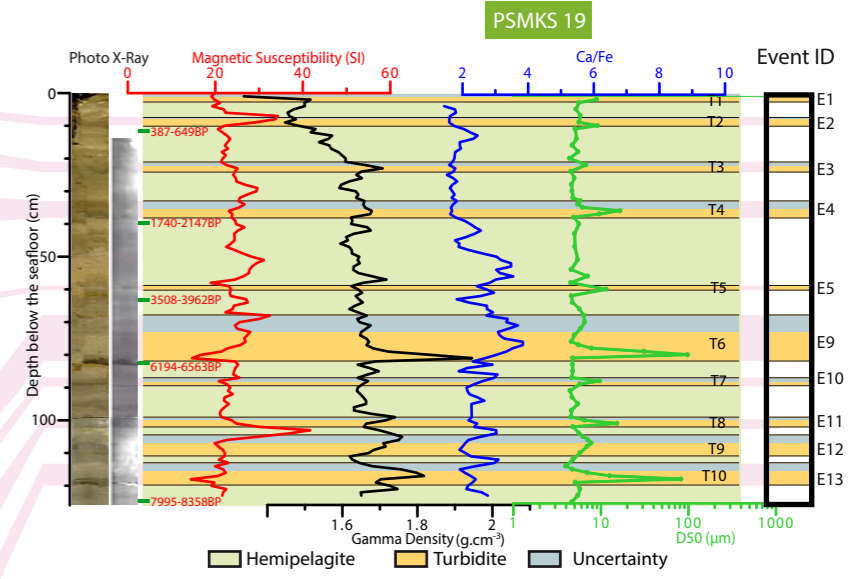
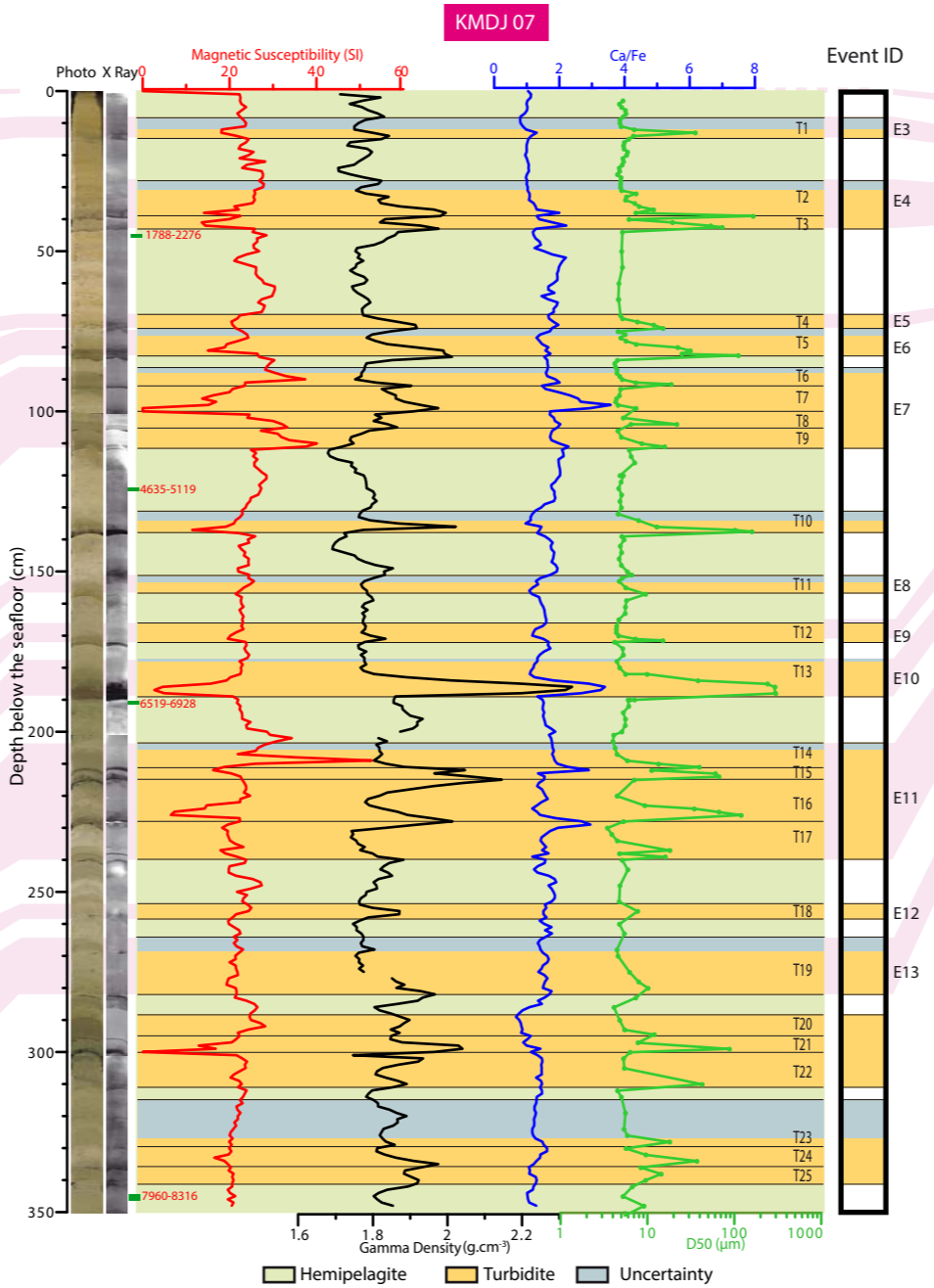
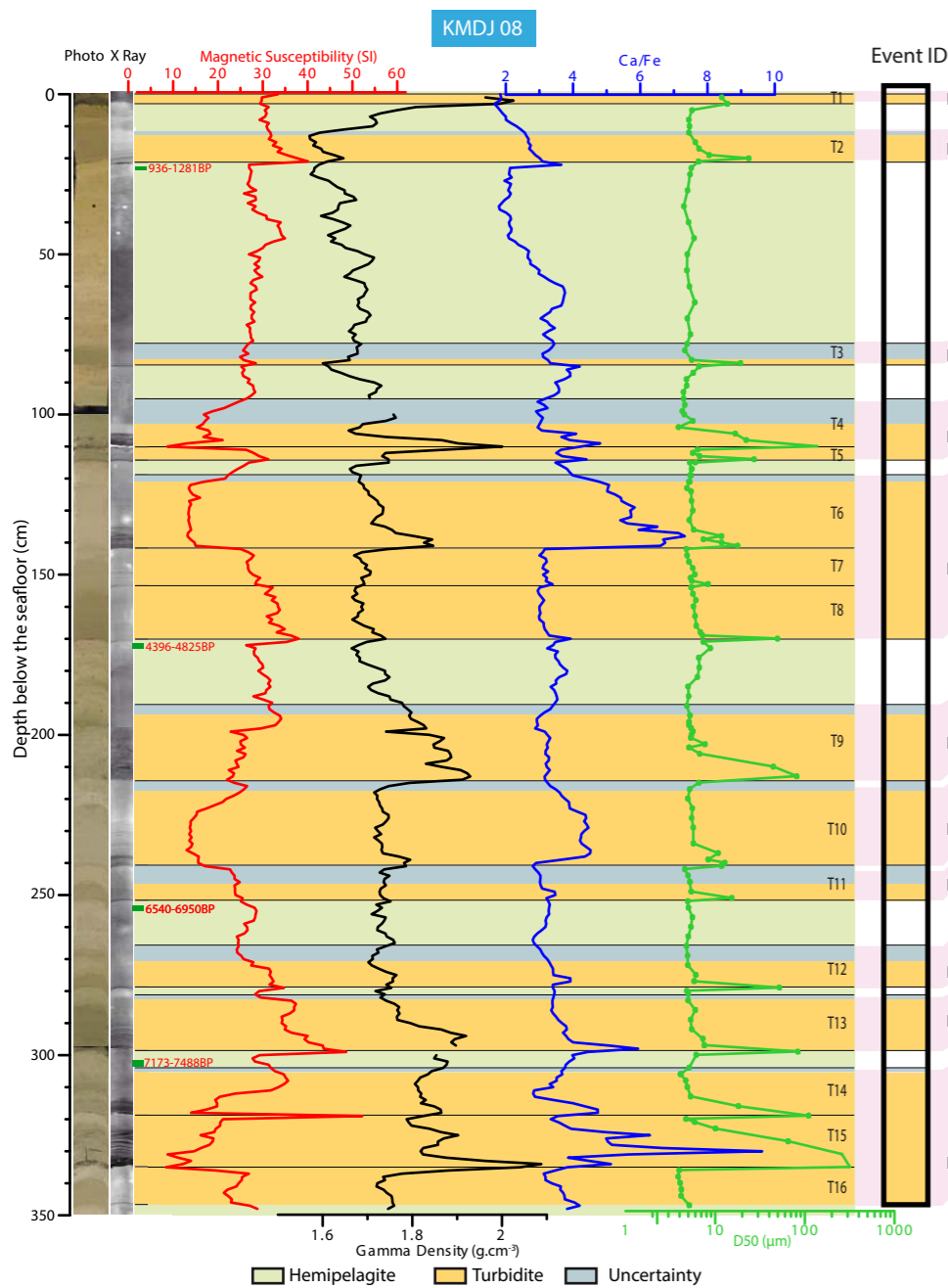


**DR2:** Detailed view of cores KMDJ08, KMDJ07, and PSMKS19. Turbidites and hemipelagites were discriminated based on visual description, X-Ray photography, Magnetic Susceptibility, Gamma Density, Ca/Fe ratios, and granulometry.

X Ray photography was performed using the SCOPIX system at the University of Bordeaux I (Migeon et al., 1999); Magnetic Susceptibility was performed using a hand operating, high resolution, BARTINGTON surface sensor with 10s acquisitions; Gamma Density was performed on unopened cores with a GEOTEK Multi Sensor Core Logger; Semi-quantitative major elements composition was performed using a X-Ray Fluorescence Core Scanner. All these analyses were acquired at a step of 1cm. Finally, granulometry was acquired using a COULTER LS230 Laser Granulometer, at a step ranging between one and five centimeters depending on the homogeneity of deposits.

We outlined the portions where uncertainties on the discrimination of deposits remain, such as within bioturbated sediment.

The correlation from site to site was based on the age of each turbidite or stack of turbidites. Please refer to SM3 to SM6 for details on <sup>14</sup>C datings and establishment of age models.



**DR3:** Detailed grain-size histograms of all the analyses performed on cores KMDJ08, KMDJ07, and PSMKS19. Analyses were performed at 1 to 5 cm intervals depending on the variation of sedimentary facies. Each sample was collected with a 0.5 cm-large spatula, and analysed with a COULTER LS230 Laser Diffraction Particle Size Analyser. Facies and grain-size were interpreted using multiple proxies: visual identification, Xray radiography, gamma density, magnetic susceptibility, and XRF (SM2).

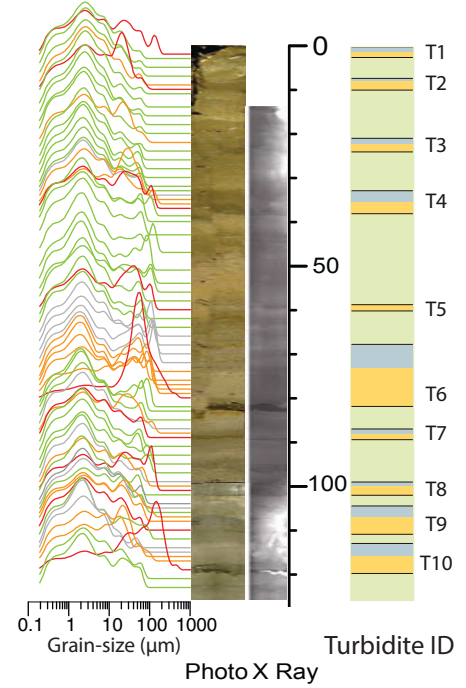
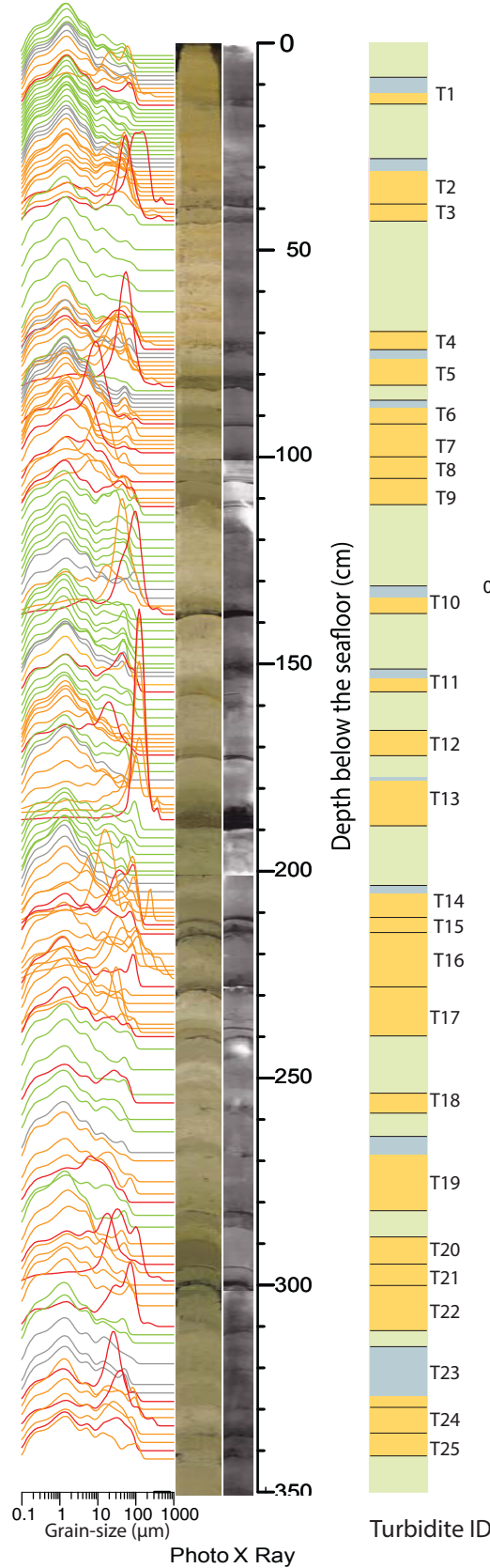
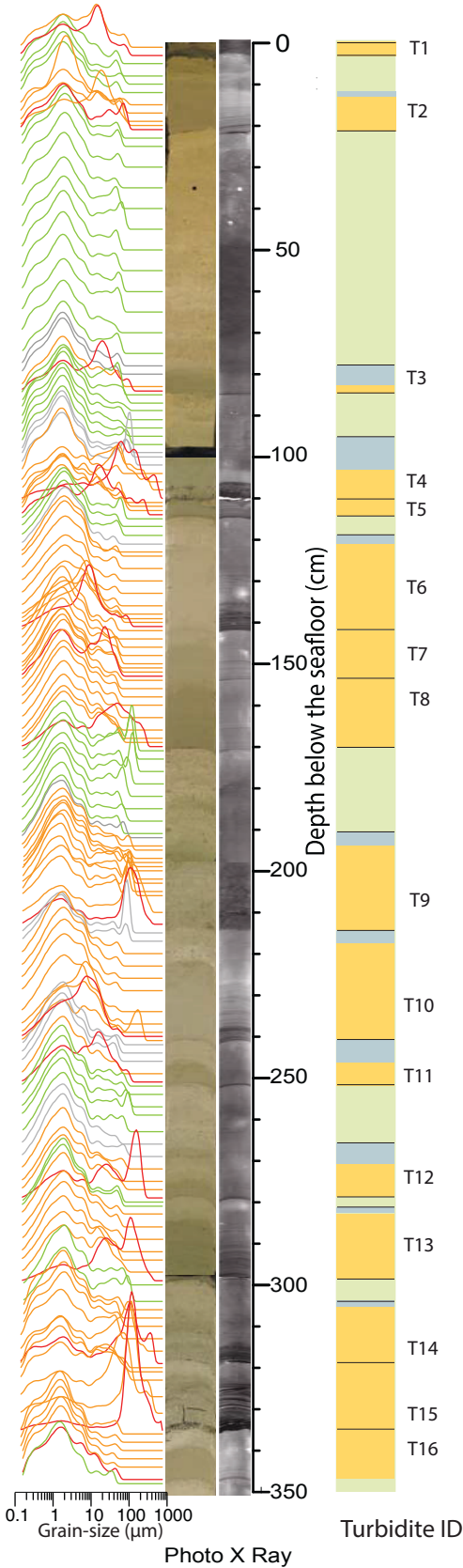
These analyses aim to accurately point the boundaries between hemipelagites and turbidites (see main text for details). As the difference between turbidite tails and hemipelagites may not be obvious, we systematically performed a serie of measurement from base to top of turbidite to infer the subtle evolution of grainsize during fining upwards, and pointed out where the grainsize signature changed. The hemipelagic deposit aver usually less sorted in these cores, characterized by a plateau in grainsize for ~30-300 $\mu$ m (see main text). However, hemipelagites properties may vary, and where sorting was less obvious, the interpretation was helped by the other proxies. We considered unclear intervals as uncertainties.



KMDJ08

KMDJ07

PSMKS19



Facies interpretation

- Hemipelagite
- Turbidite
- Uncertainties

Grain-size analyses

- Hemipelagite
- Turbidite
- Base of turbidite
- Uncertainties

**DR4:** Radiocarbon dates used to construct the age model. We performed radiocarbon dating using 13 samples of 1 to 2 cm-thick slices of hemipelagic sediment. We handpicked >10mg of >150 $\mu$ m-diameter foraminifers per date. We preferentially used species *Globigerinoides Ruber* and *Globigerinoides Sacculifer* because they are common species living in shallow waters (0-50m), and completed with *Globigerinoides Bulloides* (0-200m) or mixed planktonic foraminifers to reach 10mg when needed. <sup>14</sup>C AMS dating were then processed at the CAIS Lab (University of Georgia – Sample codes UGAMS) or at the French national facility ARTEMIS (sample codes SacA). To obtain accurate dating, we calibrated the radiocarbon ages with the OxCal software (Ramsey, 2008) using the Marine09 curve. In the Western Mediterranean sea offshore Algeria, as marine radiocarbon reservoir may vary a lot (Reimer and McCormac, 2002), we used a standard  $\Delta R=0$  value, and an extreme  $\Delta R=161\pm 40$ yr measured offshore Algeria (Reimer and McCormac, 2002), then considered the whole age interval as an uncertainty bar  $\Delta R=101\pm 100$ yr.

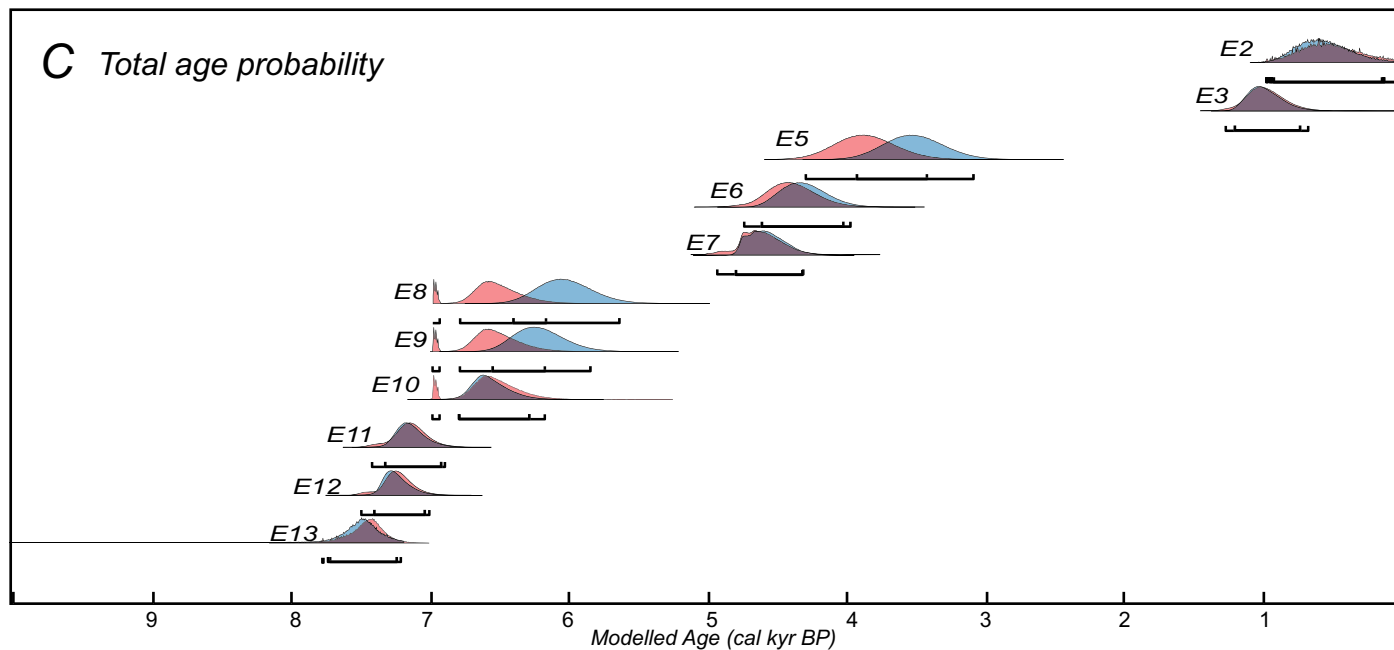
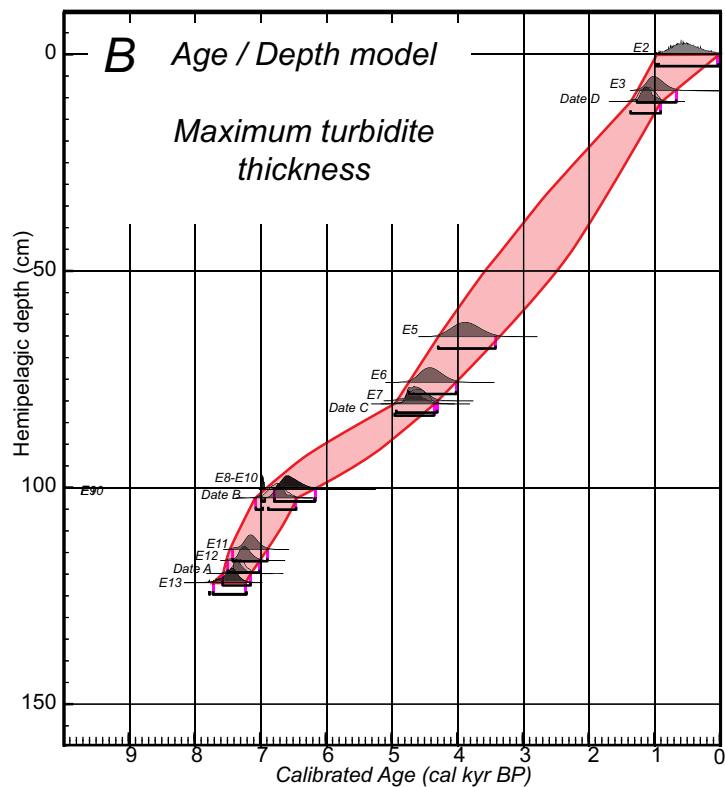
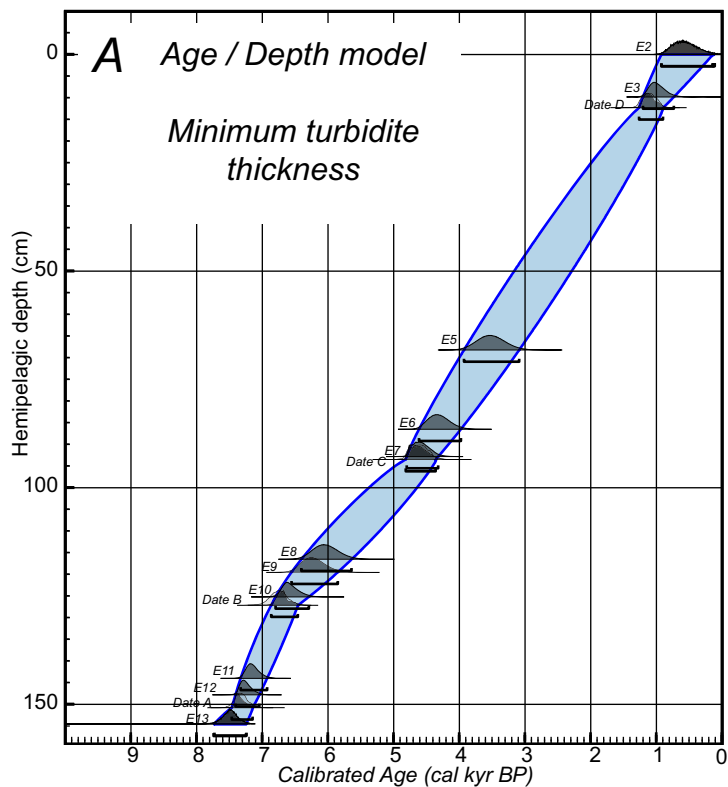
Core	Lat (dec °)	Lon (dec °)	Water depth (m)	Core length (m)	AMS Lab reference	Depth in the core (cm)	Foraminifer species	Radiocarbon age (yr ± 1σ)	Calibrated age (cal yr BP / 2σ)
KMDJ08	36.3362	0.0462	2631	7.65	UGAMS 9291	23	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	1660 ± 25	936-1281
					UGAMS 9292	171	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	4540 ± 25	4396-4825
					UGAMS 9293	253	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	6390 ± 25	6540-6950
					UGAMS 9294	303	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	6910 ± 25	7173-7488
KMDJ07	36.5403	0.1267	2630	6.68	UGAMS 8785	45	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	2590 ± 25	1788-2276
					SacA 29350	124-125	<i>G. ruber</i> , <i>G. sacculifer</i>	4745 ± 30	4635-5119
					UGAMS 8786	190	Mixed Planctonic Foraminifers	6370 ± 25	6516-6928
					UGAMS 8788	345	Mixed Planctonic Foraminifers	7770 ± 25	7960-8316
PSM									
KS19	36.6340	0.2863	2626	8.65	UGAMS 8782	11	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	1020 ± 25	387-649
					UGAMS 8783	39	<i>G. ruber</i> , <i>G. sacculifer</i> , <i>G. bulloides</i>	2430 ± 25	1740-2147
					SacA 29351	63-64	<i>G. ruber</i> , <i>G. sacculifer</i>	3885 ± 30	3508-3962
					SacA 21669	82	<i>G. ruber</i> , <i>G. sacculifer</i>	6045 ± 30	6194-6563
					UGAMS 8784	127	Mixed Planctonic Foraminifers	7820 ± 25	7995-8358

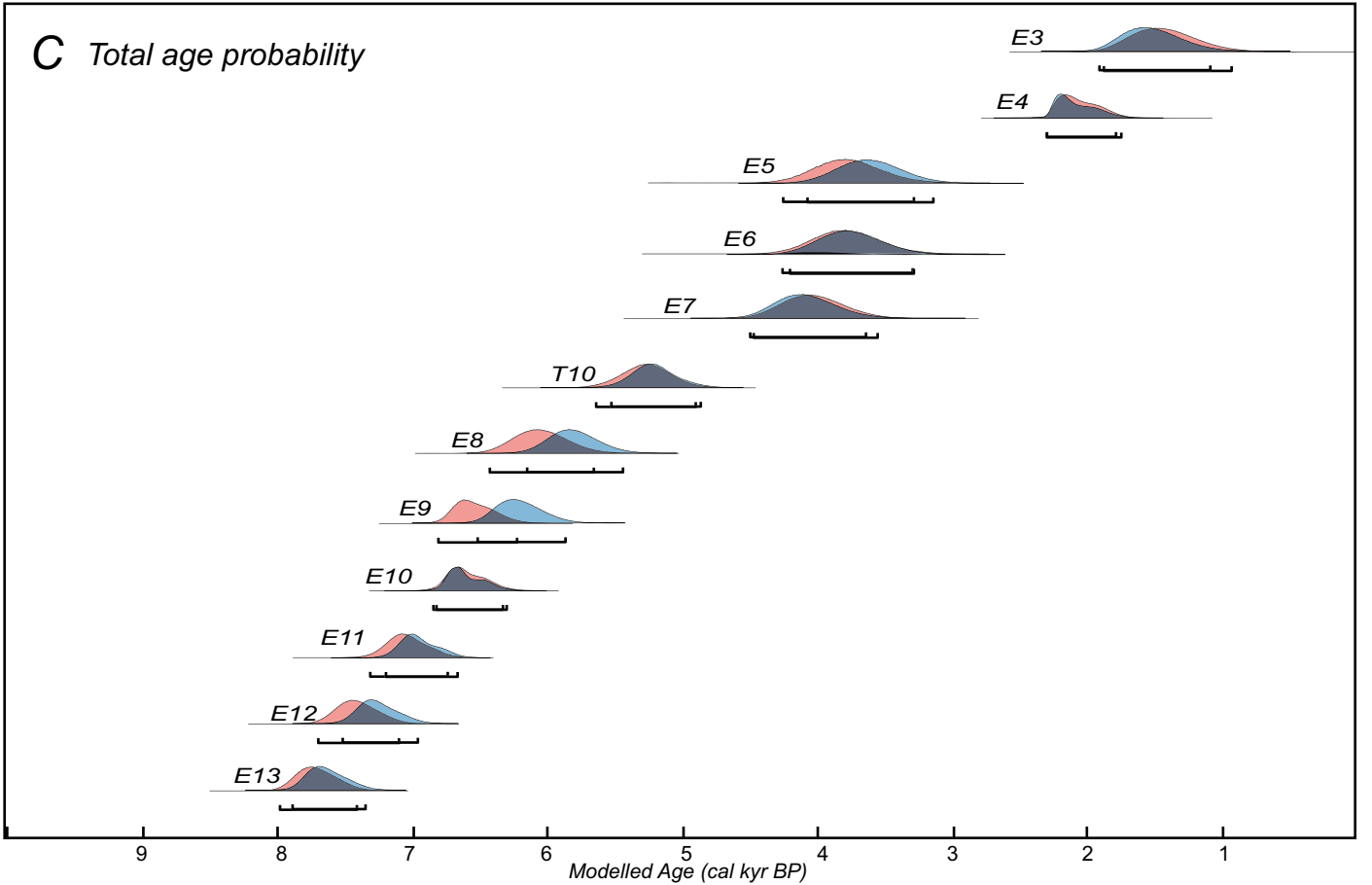
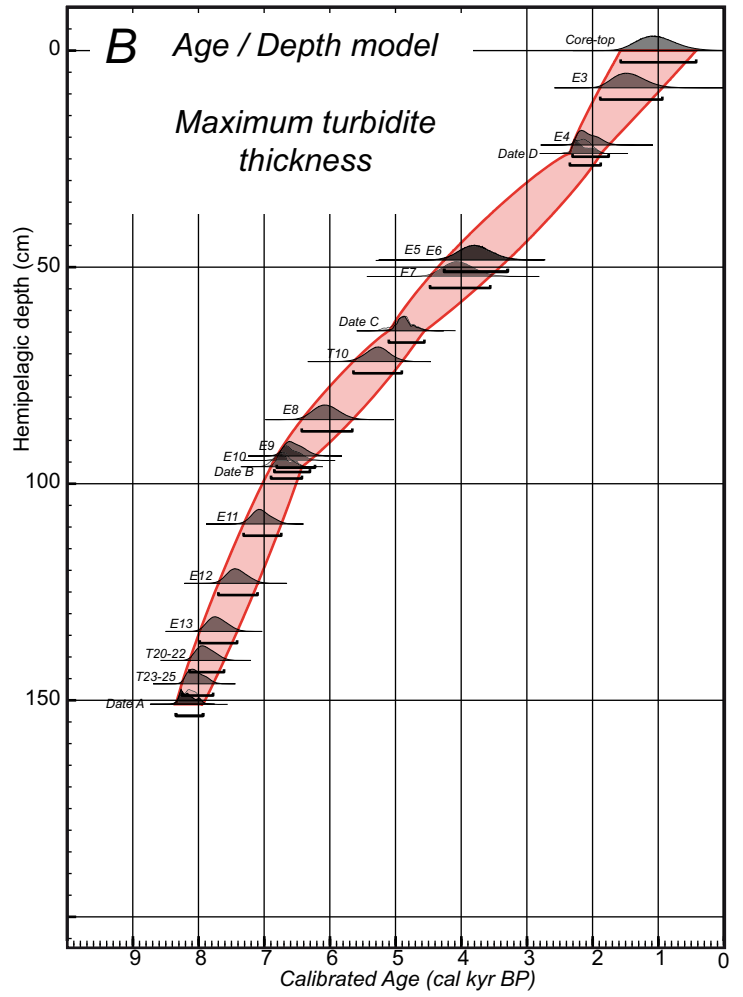
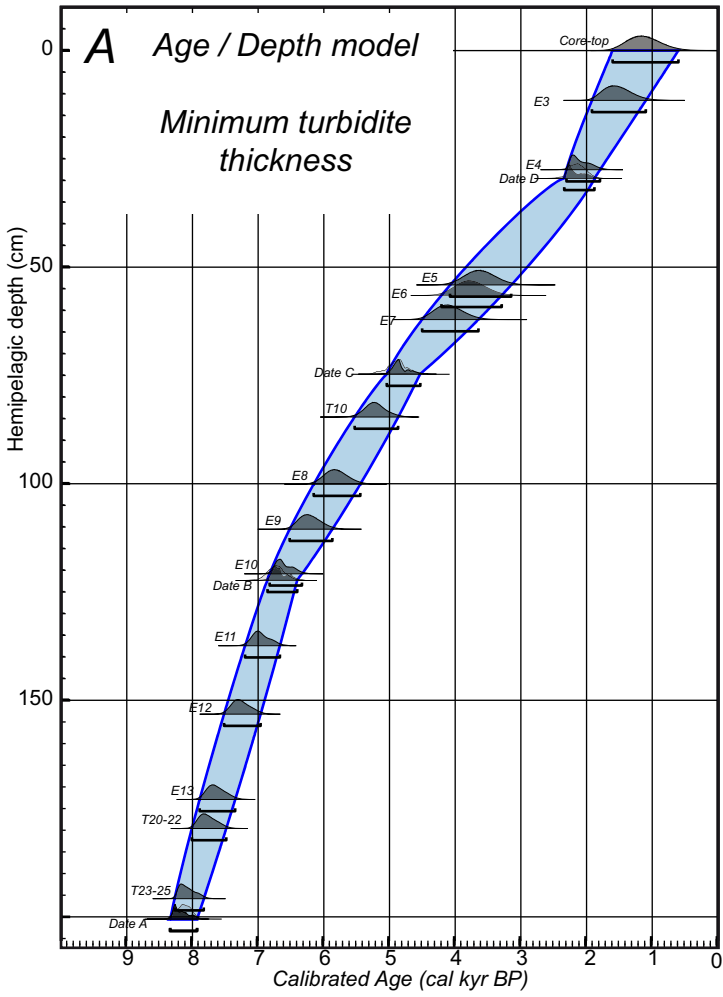
**DR5-DR7:** Age / Depth models used to calculate the age of each turbidite / event in cores KMDJ08, KMDJ07, and PSMKS19.

Because each turbidite is located few to tens centimeters away from dated hemipelagic samples, it is necessary to interpolate / extrapolate the time span of each intervening hemipelagic interval. We used a Bayesian model of deposition *P\_sequence* implemented in the OxCal software (Ramsey, 2008). The program considers hemipelagic sedimentation as a random process, and takes into account variation in the sedimentation rates. Thus, uncertainties increase with distance from calibrated age samples. The *k* value determines the regularity of sedimentation rates: a high value (1 or more) considers an almost homogeneous deposition. Erosion is observed at the base of numerous turbidites, and we cannot quantify it. We therefore intentionally chose a low value of *k* (0.1) in order to reflect high variability of sedimentation rates and account for basal erosion.

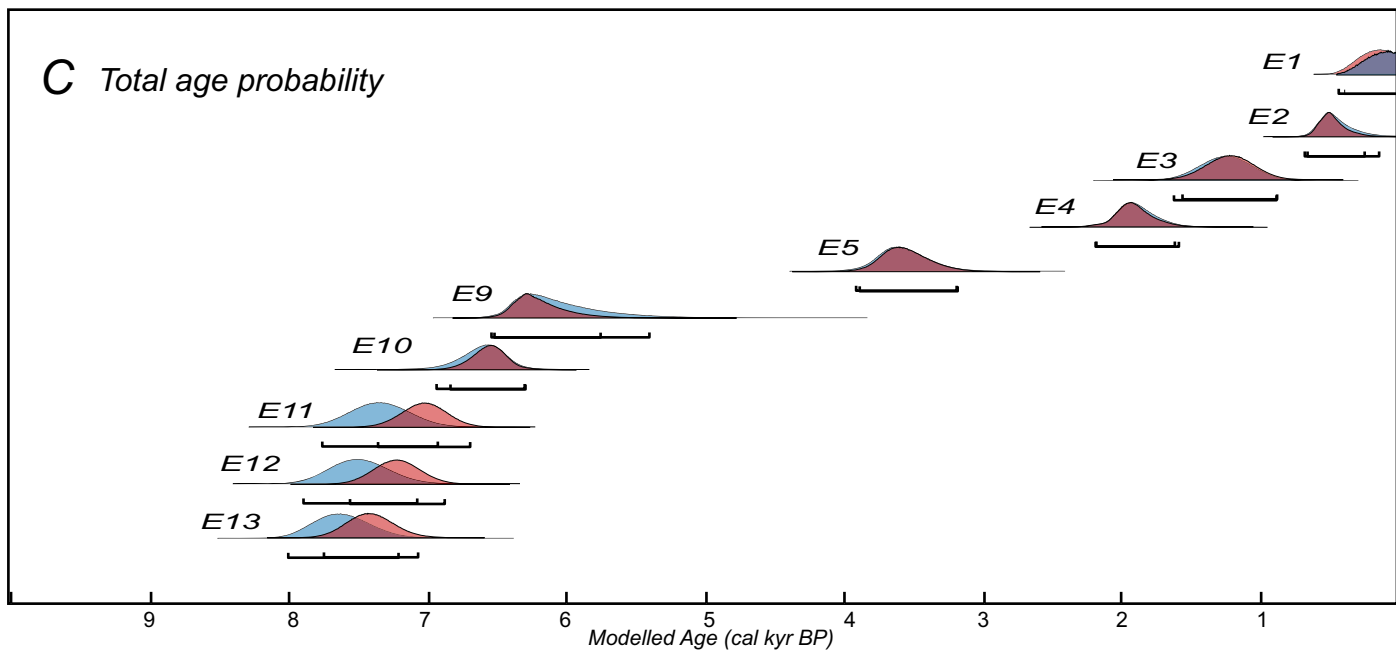
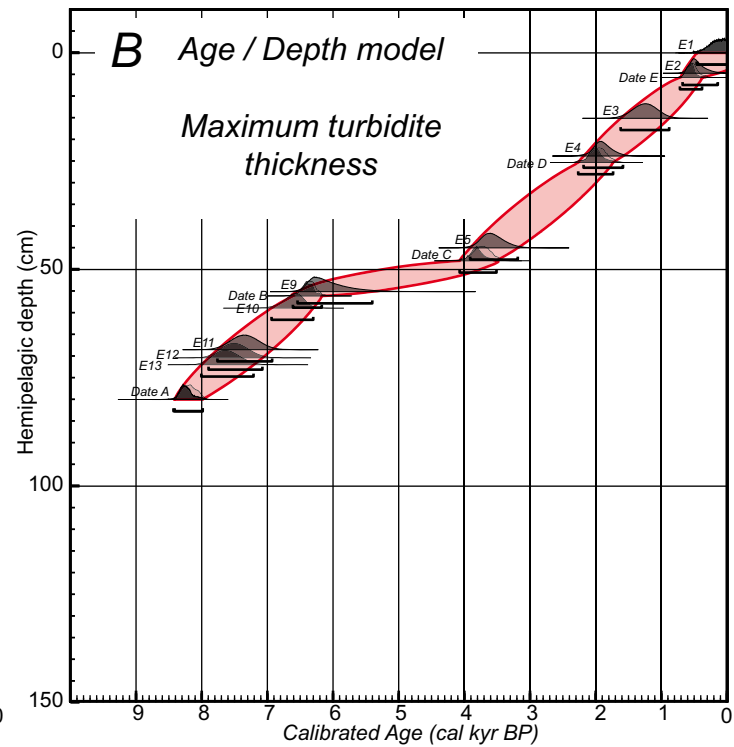
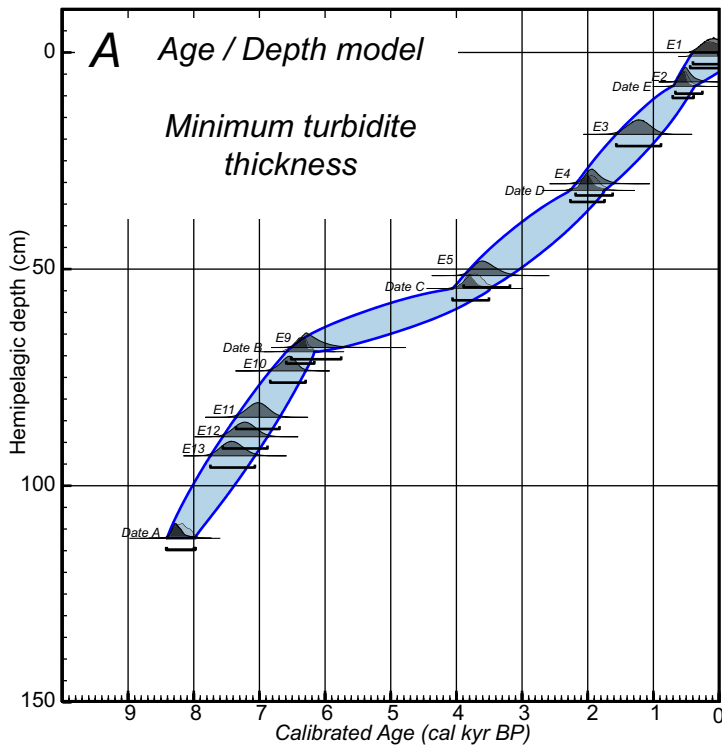
For each core, we computed two age/depth models: **(A)** considering minimum turbidite thickness were uncertainties on the boundary between hemipelagites existed, and **(B)** considering maximum turbidite thickness. As the modeled turbidite age distribution could differ between the two models we considered the sum of the distributions as an error bar for each turbidite **(C)**. The bars below each age distribution corresponds to 2 sigma.

# KMDJ08





# PSMKS19



**DR8:** Peak ground acceleration ( $PGA \pm \sigma$ ) predicted for historical earthquakes using Akkar and Bommer (2010) empirical equations for rock sites and strike-slip earthquakes. The x axis corresponds to the closest distance between the fault activated during the earthquake and the area of submarine canyon heads where sediment turbidity currents likely originate. Color stripes outline mean PGA values and mean  $PGA + \sigma$  predicted for Mw 6.0 and Mw 7.5 earthquakes (Fig. DR8 for further details). The line at  $PGA = 0.1$  g depicts the limit above which the slope could fail. Historical earthquakes include: 1522 M~6.9 Almeria (Martinez-Solares and Mezcua, 2002), 1954 Ms6.7 Orléansville (McKenzie, 1972), 1980 Ms7.3 El Asnam (Deschamps et al., 1982), 1989 Mw6.0 Mont Chenoua (Bounif et al, 2003), and 2003 Mw6.8 Boumerdes (Bounif et al., 2004)

According to geotechnical analyses performed on the sediment cover of the Algerian continental slope, slope failures should occur at PGA values larger than 0.1g/0.2g (Dan et al., 2009). Given the distance of the site from the faults, historically, only the 1954 Ms6.7 Orléansville and 1980 Ms7.3 El Asnam, were able to trigger slope failure. However, cable break record proves that only the first did, supporting that the slope was flushed and not enough sediment prone to failure was deposited between the two earthquakes. The 2003 Mw6.8 Boumerdes and 1522 M~6.9 Almeria earthquakes, although of large magnitude are located too far from the studied area, whereas the 1989 Mw6.0 Mont Chenoua earthquake, although coastal had a too low magnitude.

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