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The Last Glacial Maximum Balearic Abyssal Plain Megabed revisited

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Abstract: Megabeds are thick sedimentary layers extending over thousands square kilometres in deep sea basins and are thought to result from large slope failures triggered by major external events. Such deposits have been found in at least three areas of the Mediterranean Sea. Although their discovery dates back to the early 1980s, many questions remain, concerning their initiation, source area, extent, and the nature of their emplacement. One of the largest previously documented megabeds was emplaced during the Last Glacial Maximum across the Balearic Abyssal Plain with a thickness of 8-10 m in water depths of up to 2800 m.

New 3.5 kHz sub-bottom profiles and sediment cores provide greater constraint on the lateral variability of the megabed and allow to map it beyond previous estimates, with a revised areal extent up to 90,000-100,000 km². Megabed terminations show gradual pinch-out to the West and an abrupt eastward termination against the Sardinia steep margin. The megabed presents both in seismic profiles and in sediment cores a tripartite subdivision likely corresponding to changes in flow regimes across the basin with a central area of sandy facies and erosional base oriented NNE-SSW allowing renewed discussions about sources and trigger of the megabed.

1. Introduction

Anomalously thick (up to some 10s of m) acoustically transparent sedimentary layers known as megabeds or megaturbidites are found in at least three deep basins of the Mediterranean Sea: the Balearic Abyssal Plain (Rothwell et al., 1998); the Ionian Sea

39 (Cita and Aloisi, 2000, Hieke et al., 2003) and the Herodotus basin in the eastern
40 Mediterranean (Reeder et al. 2000). These deposits have volumes equivalent to
41 some of the largest mass movements documented worldwide; often in excess of 100
42 km³ (Fildes, 2013 and references therein). The term megaturbidite indicates a
43 turbidite (that is a fining upward sand/silt/clay bed accumulated from a waning
44 turbulent semi-laden flow; Mutti, 1992) whose thickness is larger than the average
45 surrounding turbidite beds above and below, that has a peculiar composition and
46 basinwide extent (Bouma, 1987). In this study we use the term 'megabed', because
47 the terms 'megaturbidite' and 'homogenite', though describing sedimentary facies,
48 are also genetically connoted and correspond to the HmTu couplet (e.g., Campos et
49 al., 2013). Typically, megabeds are recognized in abyssal plain settings. In some
50 cases, megabeds are capped by a thick (pluri-metric) accumulation of dominantly
51 structureless, homogeneous silty clay without microfossil content also referred to as
52 homogeneite (Kastens and Cita, 1981; Cita et al., 1984). The two deposits of
53 megaturbidites and homogenite could constitute a so called HmTu couplet of
54 genetically linked deposits (e.g. Campos et al., 2013). The reason to study
55 megabeds is twofold. Firstly, in spite of their massive appearance, scarce detailed
56 information on sedimentary structures is available in the literature, which has
57 inhibited a clear interpretation of the associated sedimentary processes at the origin
58 of these anomalously large event deposits. Secondly, they may be diagnostic of
59 major catastrophic events within a basin and around the adjacent as their triggering
60 has been attributed to major external events, including large earthquakes and
61 tsunamis, or may themselves have triggered tsunamis (e.g., Talling et al., 2014). The
62 emplacement of such a megabed could impact important deep-sea benthic
63 communities as a result of widespread and rapid burial of the seafloor over hundreds
64 of square kilometres, as well as the prolonged (>>months) effects of turbid waters
65 during the settling of suspended fine sediments. Following the 12 January 2010 Haiti
66 Mw 7.0 earthquake, a 600-m thick nepheloid layer took two months to settle after the
67 initial event (McHugh et al., 2011).

68 As megatubeds typically form widespread, low-relief deposits that blanket broad
69 basin topography, their identification from seafloor data is challenging. As a result,
70 their identification is usually based on the recognition of extensive acoustically
71 transparent layers in sub-bottom profiles: a diagnostic echo-facies signature that
72 results from the generally homogenous nature of the deposits (Damuth, 1980; Cita et

73 al., 1984). Several hypotheses have been proposed concerning their mechanisms of
74 origin all associated with catastrophic high magnitude events (e.g. volcanic activity,
75 earthquakes, tsunamis). Recent studies have proposed scenarios where multiple
76 sedimentary processes contribute to the emplacement of megabeds (e.g., Mulder et
77 al., 2009; SanPedro et al., 2017) or have resulted in the revision of previous age
78 estimates for event timing. For instance, more accurate age dating linked the Augias
79 megabed in the Ionian Sea to the large volume deposit attributed initially to the distal
80 impact of the Santorini volcanic eruption (3500 BP; Cita et al., 1984) and finally linked
81 to the large historical earthquake of 365 AD in the island of Crete (Vigliotti et al.,
82 2006; Polonia et al., 2013; SanPedro et al., 2017),), rather than the previously-
83 assumed trigger, which was inferred to be the Santorini volcanic eruption (3500 BP;
84 Cita et al., 1984). Given their prodigious volumes, it is remarkable that there are still
85 so many unanswered questions about the nature and processes related to these
86 megabeds.

87 Although the discovery of megabeds dates back to the early 1980s (Kastens and
88 Cita, 1981), there are open questions concerning megabeds about: (1) determining
89 precise recurrence times of these deposits when present in superimposed layers,
90 with important implication for the reconstruction of past catastrophic events; (2) the
91 physical and mechanical characteristics of these deposits for more strictly
92 constraining the sedimentary processes that resulted in these exceptional sediment
93 accumulation events and their impact on benthic communities; (3) the sedimentary
94 and geochemical sources of the sediment forming the megabeds. The Balearic
95 Abyssal Plain (BAP) megabed, the largest megabed in the Mediterranean, is a
96 perfect example of a puzzling deposit. While its age is well constrained by multiple
97 radiocarbon dates and biostratigraphy (Rothwell et al., 1998; Hoogakker et al., 2004),
98 the initiation processes and source areas remain far from clear; even on a regional
99 basis (Rothwell et al., 1998; 2000; Droz et al., 2006). It is remarkable that a deposit
100 with an estimated volume of 500-600 km³ has no obvious source, especially given
101 the extent of marine geological studies around the western Mediterranean in recent
102 years (e.g., Dennielou et al., 2019; Badhani et al., 2019). In order to understand the
103 hazard posed by these large sediment transport events, it is important to address
104 these uncertainties. Where did they come from? How did they initiate? What is their
105 full spatial extent? What process(es) explain their emplacement and are multiple
106 phases of activity involved? These questions are particularly important given the

107 dense coastal populations that border confined Mediterranean basins, such as the
108 Balearic Abyssal Plain, and as megabed emplacement is not a one-off event in these
109 settings. Stacked megabeds have been observed in seismic data, indicating that
110 these are recurrent events both in Quaternary sediment (e.g. in the Ionian abyssal
111 plain, Heike et al., 2002; in the Marmara Sea, Beck et al., 2007) and in ancient
112 deposits (e.g. Amy and Talling, 2006 in the Northern Apennines; Fallgatter et al.,
113 2016 in Argentina).

114 Sub-bottom seismic profiles are an important data set for near-surface structural and
115 sedimentological analysis. This is why we present a basin-wide analysis of the newly
116 available sub-bottom profile data and a comparison with, in part, already published
117 analysis of sediment cores sampling the BAP megabed. We present an extensive
118 (though not comprehensive, as the vast area of the BAP is scarcely covered by
119 geophysical surveys, see **Fig. 1**) view of the geometry, terminations, bounding
120 surfaces and internal geometries of the megabed. We also set up the first steps for a
121 match of seismic to core data to reconstruct the sedimentary processes at the origin
122 of the megabed based on integrated and complementary new evidences. The aim of
123 this study is to highlight details in the seismic images of the BAP megabed that
124 unveils aspects of the sedimentary processes at its origin and source: in particular
125 we present detailed diagnostic features of sedimentary processes including evidence
126 of localised basal erosion, considerations on the nature and internal variability of the
127 megabed indicative of possible flow transformations, and some results on the
128 mechanical properties of the homogeneous part.

129

130 **2. Background**

131 The Western Mediterranean Basin formed behind a Miocene volcanic arc with the
132 clockwise rotation of the Corsica-Sardinia block and the opening of the Provencal
133 Basin (Rehault et al., 1984). It is the youngest part of the Mediterranean formed from
134 late Oligocene to present (Mauffret et al., 2004). The Balearic abyssal plain is the
135 largest abyssal plain of the Mediterranean with an area of about 77,000 km² and may
136 be identified by the 2800-m isobath (Rothwell et al., 1998, 2000). It is surrounded by
137 continental passive continental margins of the Gulf of Lions and Ligurian Sea with the
138 Rhone and Var fans to the north, by the Algerian margin to the south, by the Balearic
139 margin and the Valencia fan to the west, and by the Sardinian-Corsican margin to the
140 east, with continental shelves variable from the 200-km wide Gulf of Lions to less

141 than 50 km along Corsica, Sardinia and north Africa (Rothwell et al., 1998;
142 Hoogakker et al., 2004; Zuniga et al., 2007). Sources for turbidity currents have been
143 documented from several of these continental margins and include earthquake
144 triggered events associated with tsunami waves, such as the 2003 Boumerdès event
145 (Cattaneo et al., 2012).

146 The most striking morphological feature of the BAP is the presence of a thick
147 Messinian evaporite layer and salt walls and diapirs at the seafloor (Stanley et al.,
148 1974). Another key feature of the BAP is a thick layer identified in the abyssal plain
149 by its acoustically transparent signature in sub-bottom profiles, called “megaturbidite”
150 (Rothwell et al., 1998), which extends over the whole extent of the abyssal plain and
151 reaches a thickness of 8–10 m in the centre of the basin (Rothwell et al., 1998,
152 2000). The longest core records of the BAP megabed are the giant Calypso piston
153 cores recovered during the campaign PALAEOFLUX in 1995 (Rothwell and Balut,
154 1995; Tab. 1). These piston cores, up to 32 m in length, were recovered along a
155 SSW-NNE transect, were located about 120 km apart from each other (**Fig. 1**), and
156 were dated to reconstruct the stratigraphic history of the accumulation that accounts
157 for up to 150 ka and is constituted about 90% of turbiditic successions and only 10%
158 of hemipelagites (Rothwell et al., 2000; 2006; Hoogakker et al., 2004; Clare et al.,
159 2014). Turbidite bases towards the northern part of the BAP are thicker and coarser
160 in grain size, indicating a more likely provenance according to Hoogakker et al.
161 (2004). The attribution of the age of the megabed is based on 10 radiocarbon ages
162 above and below the megabed in cores MD95-LC01, -LC02, -LC04, -LC05 and -
163 LC06 (Rothwell et al., 1998). Dennielou et al. (2019) performed a recalibration of the
164 five dates on top of the megabed following Reimer et al. (2013) and obtained a 2-
165 sigma age comprised between 20.3 and 20.9 ka cal BP with a median probability of
166 20.6 ka cal BP, within the Last Glacial Maximum.

167

168 **3. Data and methods**

169 **3.1 Sub-bottom profiles**

170 All sub-bottom available data within the interest area were integrated in a single
171 Kingdom database for interpretation. This includes in particular the newly acquired
172 data during the WestMedFlux survey (Poort and Loucazeau, 2016; Poort and Gorini,
173 2018; **Figs 2-5**), but also the datasets from the PROGRES (Droz., 2003) and
174 SARDINIA (Aslanian and Olivet, 2006) campaigns. Some profiles from AM-MED

175 (Rabineau et al., 2013) survey were also integrated. Successive processing steps
176 were applied onboard consisting of correlation (signal compression), correction of the
177 spherical divergence, compensation of the ship movements (pitch, roll and heave),
178 calculation of the location of the source and receptors, and correction for the delay.
179 Imports of sub-bottom data in Kingdom were applied in amplitude, and envelope was
180 computed for each segy file. Locations of cores were also loaded into the database
181 to be correlated with the seismic data (**Tab. 1**).

182

183 **3.2 Sediment cores**

184 Sediment cores reaching the top or the entire BAP megabed are summarised in
185 **Table 1**, including cores presented in the literature and in this study (**Figs. 6, 7**). In
186 most cases, the identification of the BAP megabed is based on two criteria for cores
187 in the central part of the abyssal plain; 1) the identification of a turbidite layer
188 outpacing in thickness the encasing successions of alternating hemipelagites and
189 thin bedded turbidites, and 2) the attribution to a comparable age range as that
190 reported by Rothwell et al. (1998) recalibrated by Dennielou et al. 2019). Grey
191 homogeneous mud beds identified in cores PSM-KS21 (~8.8 m bsf – below
192 seafloor), PSM-KS23 (~5 m bsf) and PSM-KS27 (~11 m bsf) are correlated to the
193 BAP megabed mainly based on age attribution (**Tab. 2**), but also on sedimentary
194 facies characters, mainly the sediment colour different from adjacent beds and the
195 homogeneous structureless texture (**Fig. 8**).

196 Sediment core WMF2-KF11 is positioned on seismic profile WMF2016-AT006 by
197 adopting a velocity of 1529 m s^{-1} based on an averaged value of the Multi Sensor
198 Core Logger data (P-wave velocity) measured on the whole core (**Fig. 6**).
199 Radiocarbon dates on core WMF2-KF11 were obtained by AMS at Beta Analytic
200 laboratory and calibrated with MARINE 13 database (Reimer et al., 2013) (**Tab. 2**).

201 Geotechnical analyses were performed on core WMF2-KF11 (**Fig. 9**). They included
202 measurements on freshly open core (water content, vane shear, P-wave velocity with
203 a celerimeter). Four oedometer tests were performed on samples from the same
204 core, two within the megabed, two in overlying sediments. Values of compressional
205 wave velocities, undrained shear strength (peak and residual) and water content
206 were measured on split sections of core WMF2-KF11 using devices and approaches
207 as reported in Miramontes et al., (2018). Four oedometer tests with incremental
208 loading were also carried out on preserved samples from the same core to determine

209 the recompression (Cr), compression (Cc) and swelling indices (Cs) as well as the
210 yield stress ratio (YSR) of sediments.

211

212 **4. Results**

213 **4.1 Expression and variability of the BAP megabed in sub-bottom profiles**

214 With the available bathymetric and seismic reflection dataset it is difficult to have an
215 exhaustive view of all the lateral variability of the BAP megabed due to the lack of
216 complete coverage of the abyssal plain. The BAP is characterised by variable
217 morphologies and structures linked to halokinesis of Messinian evaporites creating a
218 highly variable seafloor landscape. To account for such variability we present here
219 some evidence of the expression of the megabed in distinct sectors of the abyssal
220 plain, including megabed terminations (**Fig. 3**), erosion at the base of the megabed
221 (**Fig. 4**) and internal subdivisions (**Figs. 5-7**). The BAP megabed is identifiable as an
222 acoustically transparent layer all over the area outlined by a black line in **Figure 1**
223 and corresponding to the limits of this layer according to Rothwell et al. (1998, 2000),
224 that is to the isobath of 2800 m. The sub-bottom profile WMF2016-AT010 shows the
225 laterally continuous acoustically transparent unit of the BAP megabed less than 10 m
226 below the seafloor, with gentle folds following the geometry of underlying strata and a
227 gradual pinch-out of the unit towards the west (**Fig. 2a**). In sub-bottom profile
228 WMF2018-AT141A, however, the same acoustically transparent layer presents still a
229 good degree of lateral continuity, but with accentuated effect of deformation due to
230 the presence of salt domes: it is also possible to lose the lateral continuity of the layer
231 and find it beyond the highest salt domes (see **Fig. 3a** towards the west). In **Figure**
232 **2b** the sub-bottom profile WMF2016-AT shows towards the east, in the central part of
233 the basin, the presence of faults, likely linked to salt dome movements, displacing the
234 megabed of several metres either in distinct locations (**Fig.2b**, towards the west) or in
235 sets of narrowly spaced faults (**Fig. 2b**, towards the east). By appreciating the
236 geometry of the BAP megabed and that of the underlying strata, it is possible to
237 deduce that the halokinetic deformation postdates the emplacement of the megabed.
238 Another characteristic feature of sedimentary bodies, and of their expression as
239 seismic units, is the geometry of pinch-out terminations. In **Figure 3** we show two
240 contrasting details of megabed termination from two opposite sides of the abyssal
241 plain. Profile WMF2018-AT141A (**Fig. 3a**) shows the pinch-out of the BAP megabed
242 towards the west, beyond an area with salt domes: the lateral termination of the

243 megabed seems to be at offset 15000, but it actually goes further west (offset 1000 in
244 **Fig. 3a**). Towards the east, the termination of the acoustically transparent unit is
245 against the Sardinia margin, which is relatively steep with a slope angle exceeding
246 11° (Deiana et al., 2016). The termination is abrupt, passing from about 10 ms in
247 thickness to zero, masked by the hyperbolae of the Sardinian margin (**Fig. 3b, c**). In
248 this latter case the termination reminds of the first identifications of 'homogenetes' in
249 the Eastern Mediterranean by Kasten and Cita (1981), who described these deposits
250 as flat-lying within each basin where they deposit with abrupt terminations against the
251 steep basin walls. The megabed thickness in East-West direction is not thinning
252 gradually towards the West, but presents higher values towards the centre of the
253 basin (**Fig. 3b**).

254 The contact of the megabed with the underlying strata is conformable in the majority
255 of the seismic lines analysed (**Figs. 2, 6**), but, especially in the area imaged in **Figure**
256 **4** the contact is irregular. A diagnostic indicator of the processes generating turbidite
257 beds is the nature of the beds basal surfaces in being erosional. In the case of the
258 BAP megabed, we observe in some sub-bottom profiles truncation and disruption of
259 underlying strata. **Figure 4 (a, b)** presents evidence of seismic reflectors truncated
260 below the base of the megabed: we interpret these features, present mostly in the
261 area comprised within a dashed blue line in **Figure 4c**, as localised erosional
262 features. An alternative interpretation might suggest that these features have resulted
263 from fluid escape, but this is highly unlikely, because of the lack of evidence in this
264 sector of vertical anomalies in the seismic profiles that could be identified as fluid
265 escape chimneys. Other sub-bottom profiles in this central-western area of the
266 abyssal plain show similar features.

267 Far from being fully homogeneous, the dominantly acoustically transparent megabed
268 presents also a certain variability in its acoustic response. We summarise this
269 variability in three slightly differentiated seismic echo-facies (Damuth et al., 1980)
270 presented in **Figure 5**. Echo-facies I, below the top of the megabed, presents faint,
271 chaotic reflectors. Echo-facies II is dominantly transparent, but it is topped by a
272 discontinuous seismic reflector mappable in several areas where the megabed is
273 relatively thick. Finally, Echo-facies III is characterised by a discontinuous base and
274 top showing medium-amplitude discontinuous reflectors: it could occur also in
275 association with local erosional features (**Fig. 4b**). Echo-facies III is present at the
276 base of the megabed where it reaches a thickness exceeding ca. 10 ms in the central

277 area of the abyssal plain identified in **Figure 5c** by a dashed blue line. The three
278 echo-facies cannot be identified thoroughly over the entire extent of the megabed.

279

280 **4.2 Sediment character of the BAP megabed**

281 Lithology and sedimentary structures of the BAP megabed known from the literature
282 are compared with new observations on core WMF2-KF11. **Table 1** shows the
283 identification of the BAP megabed its grain size divisions and their depth in 10 cores.
284 In general, cores located within the limits identified by Rothwell et al. (1998) and
285 reaching the megabed present an overall bipartite lithology with a normally graded
286 sandy to silty base capped by a homogeneous clay unit that can be several metres
287 thick. The megabed can thus be described rather as a *HmTu* couplet, since it is
288 composed of two distinct components: a basal sandy and/or silty turbidite interval
289 and an upper interval of overall homogeneous silty mud (Campos et al., 2013; see
290 also McHugh et al. 2006).

291 Sediment core WMF2-KF11 was collected in 2848 m water depth in the central part
292 of the Balearic abyssal plain. It is 5.92 m long and presents brownish yellow silty clay
293 with foraminifera and shell fragments in the upper ca 30 cm, gradually passing to
294 alternating very thin to medium (20-cm) thick normally graded sandstones and olive
295 grey silty clays down to 2.28 mbsf (**Figs. 6b,d, 7**). The interval 0 to 2.28 m is
296 interpreted as alternating turbidites and hemipelagites. The rest of the core down to
297 5.92 mbsf is composed of homogeneous dark grey silty clay (2.28 to 4.50 mbsf), dark
298 grey clayey silt with sub-millimetric laminae (4.50 to 5.25 mbsf), and dark grey
299 structureless, possibly normally graded silt. All the interval from 2.28 to 5.92 mbsf is
300 interpreted as part of the BAP megabed including the *Hm* division (2.28-4.50 mbsf)
301 and part of the *Tu* division (*sensu* Campos et al., 2013). By using a conversion
302 velocity of 1529 m s^{-1} based on MSCL data (**Fig. 6c**), the core is projected on the
303 sub-bottom profile WMF2016-AT006 (**Fig. 6a**). It is possible to tentatively correlate
304 the three echo-facies to sedimentary facies: echo-facies I would correspond to sandy
305 turbidite facies, echo-facies II to silty turbidite, and echo-facies III to homogeneousite.

306 The same tri-partition of sedimentary facies within the megabed in core WMF2-KF11
307 is visible also in core LC05 which is in the southwestern sector of the BAP (**Fig. 7**).
308 The megabed presents a sharp and irregular (eroded) base and a upper contact
309 gradational and bioturbated. Its grain size is coarse sand to clay with positive
310 grading, although negative grading may exists in the coarse fraction at the base.

311 There is an overall upward fining trend to the homogeneous mud unit at the top, with
312 slight grains size break at the transition from silt to mud. The sedimentary structures
313 include planar laminae at the base, a massive basal division which may include
314 planar intra-bed contacts, a transition into cross-bedded, climbing ripples and
315 convolute laminae.

316 The megabed likely represents a ponded megaturbidite resulting from steady long-
317 lived turbidity current as suggested in the existing literature (e.g., Rothwell et al.,
318 1998, 2000; Clare et al., 2014). Planar laminae formed as a result of grain flow at the
319 turbidity current head. The rest of the flow settled out due to low density turbulent
320 suspension and/or gel strength and/or excess pore pressure.

321 A transect of sediment cores offshore the Algerian margin (PSM3-KS21, PSM3-KS23
322 and PSM3-KS27; **Fig. 8**) fully described in Babonneau et al. (2017 ; their Fig. 7)
323 shows a homogeneous grey bed that we interpret as the distal expression of the BAP
324 megabed. In the grey shaded area, a sediment layer stands out in photos for its
325 colour different from that of other encasing turbidity layers. The age constraint above
326 and below the bed (Babonneau et al., 2017; **Tab. 2**) suggests that it is possible to
327 identify it as the distal expression of the BAP megabed. This Identification of BAP
328 megabed in distal cores goes up to 200 km beyond the pinch-out of the megabed as
329 visible in seismic lines and suggests that also other cores, such as for example cores
330 WMF-KF10 and -KF11 south of the Balearic Islands could contain the same layer
331 (**Fig. 1; Tab. 1**).

332

333 **4.3 Mechanical properties of the BAP megabed in core WMF2-KF11**

334 A marked change in both density and V_p profiles occurs at 2.28 m (**Fig. 9**). This
335 change is reflected by Yield Stress Ratios (YSR) higher than 1 above 2.28 m and
336 lower than 1 below. However, except the recompression indices, the other indices
337 determined from oedometer tests do not show a clear change; this contrasts with the
338 values of undrained shear strength (S_u) which decrease abruptly below 2.28 m (**Fig.**
339 **9**). Comparisons with the trends generally exhibited by normally consolidated
340 sediments ($S_u = 0.2 \sigma'_v$ or $0.3 \sigma'_v$; e.g., Garziglia et al., 2010) can be reconciled with
341 YSR values to indicate that below 2.28 m the sediment is under-consolidated.

342

343 **5. Discussion**

344 **5.1 Overall distribution of the BAP megaturbidite and inferences on sources**

345 The BAP megabed is reported in the literature as extending in the BAP identified by
346 the isobath 2800 m over a surface of 60,000 km² for a volume of 500 km³ (Rothwell
347 et al., 1998), and, successively, over a surface of 77,000 km² for a volume of 600
348 km³ (Rothwell et al., 1998; Hoogakker et al., 2004). We find, thanks to the
349 identification of a distal correlative of the megabed to the West (**Fig. 8**), that the
350 megabed extends further 200 km along the central Algerian basin (**Fig. 1**, dashed
351 lines). The resulting extent would thus become of up to 90,000-100,000 km², while
352 the total volume would not be much affected by this extension because of the limited
353 thickness of this part of the megabed (< 1 m; **Fig. 8**).

354 Beyond its considerable size, the importance of the information coming from the
355 analysis of the BAP megabed consist in its exceptional state of preservation and
356 basinwide extent. The BAP megabed has preserved much detail that is missing in
357 many other more ancient settings, but unfortunately the extent of the dataset is
358 limited and uneven. Core data (**Tab. 1**) show that the distribution of the megabed
359 thickness has a maximum in the deepest central part of the BAP (core LC04). The
360 contrasting style of megabed terminations with a gradual pinch-out towards the West
361 and an abrupt termination with more important thickness to the East could be related
362 to the distance from the source, but also to an enhanced effect of ponding, or, rather,
363 possibly oblique reflection against the steep Sardinia margin (*sensu* Kneller et al.,
364 1991).

365 As in the case of several ancient megabeds in outcrops, the provenance problem
366 cannot be simply solved by a single argument. The sediment provenance of the
367 Oligocene Numidian megabed is debated and attributed to European sources based
368 on zircon analysis (Fildes et al., 2010) to African provenance (Thomas et al., 2010) or
369 again African based on a series of argumentations including paleogeographic
370 reconstructions. The case of the BAP megabed could be theoretically simpler,
371 because paleogeography during the Last Glacial Maximum can be inferred with a
372 higher degree of certitude than Oligocene and basically corresponds to the present
373 one with a sea level lowered of about 120 m during the Last Glacial Maximum (**Fig.**
374 **7c** modified from Clare et al., 2014). Nevertheless, we agree that the solution is not
375 easy and several independent lines of evidence have to be explored, possibly with
376 the support of future geochemical investigations.

377

378 **5.2 Internal structure of BAP megabed and inferred sedimentary processes**

379 Hoogakker et al. (2004) and Rothwell et al. (2006) found that over the last 130 kyr
380 over 90% of the sediment accumulation in the BAP was composed of turbidites and
381 that the overall amount of erosion was negligible, allowing a rather continuous record
382 of hemipelagites. By analysing in detail Sub-Bottom profiles, we found that the base
383 of the BAP megabed could be in part an exception to this general rule, and we think
384 that this fact could be interesting for sedimentary processes reconstructions. Even if
385 the interpretation of erosional base of turbidite beds is far from being straightforward
386 (Eggenhuisen et al., 2011), the evidence of seismic reflector truncations and in
387 particular the location of zones of enhanced basal erosion could suggest areas of the
388 BAP impacted by stronger turbidity flows (**Fig. 4**). The location of erosion at the base
389 of the megabed is centred around the location of WMF2018-AT143A profile. The
390 distribution of the erosional areas in available profiles suggests that the area of
391 erosion is oriented along a roughly N-S or NE-SW orientation; it is possible that this
392 orientation represent a direction of axial transport of the main initial flow in the
393 deepest part of the basin.

394 The notion of turbidity currents running very long distances down to the abyssal
395 plains has been demonstrated in several cases both in recent and ancient case
396 studies (e.g., Zuffa et al., 2000; Clare et al., 2014). Zuniga et al. (2007) demonstrated
397 that turbidity currents originated from continental margins surrounding the Balearic
398 Abyssal Plain can reach the centre of the basin during sea level highstands as the
399 present one. An implication in the long distance of a turbiditic flow is the series of flow
400 transformations that could occur along the turbidity flow path (Talling, 2013; Fallgatter
401 et al., 2016). The tripartite structure of the megabed found in seismic profiles and in
402 sediment cores might reflect flow transformations, even if, given the scarce spatial
403 coverage of the data it is difficult to reconstruct a continuous scenario of flow
404 evolution. We agree with former interpretations of sediment cores (e.g., Rothwell et
405 al., 2000; Clare et al., 2014) considering the megabed as a single event and we think
406 that the presence/absence of tripartition in echo-facies could be due to changes in
407 flow velocity possibly linked to seafloor irregularities such as the presence of salt
408 domes and related faults.

409 Finally, the homogenite shows peculiar physical and geotechnical properties, in
410 particular the consolidation state (underconsolidated). The megabed appears to be
411 composed of sediment which remained under-consolidated since its deposition.
412 Water incorporation during the flow may explain the under-consolidated state of the

413 sediments during tens of years after rapid deposition. However, since burial has
414 ensued over the last ca. 20 kyr, one might expect this characteristic signature to have
415 been erased upon consolidation unless the transport and depositional process gave
416 the deposit an atypical structure (combination of particle arrangement and bounding).
417 This underconsolidation could be suggestive of extremely rapid and water-saturated
418 deposition of the megabed with the clay on top acting as a sealer and could further
419 support the hypothesis of a relatively rapid accumulation from a single event. In situ
420 tests such as CPTU (cone penetration test undrained) could thus help confirm this
421 observation.

422

423 **6. Conclusions**

424

425 A large deposit sitting on the Balearic Abyssal Plain - originally mapped by using the
426 extent of acoustically transparent reflection - has been redefined (modern
427 classification) and remapped to discover that it is larger than previously thought.

428 The Balearic Plain megabed is one of the most known examples of megabeds in
429 abyssal plains and an analogue to megabeds studied in outcrop of ancient rocks. It
430 occupies the whole abyssal plain over an extent of at least 77,000 km², but up to
431 90,000-100,000 km² and with a thickness of 7-8 m in the centre of the basin and a
432 volume of 600 km³ comparable to ancient giant MTD.

433 The analysis of new data in the area allowed to present some details of its
434 geophysical appearance, in particular the presence of contrasting pinch-outs on the
435 abrupt eastern Sardinian margin, and the other sectors where the limit is asymptotal.
436 This suggests on one side that provenance is likely not from the west, and that there
437 could have been some reflected turbidite pattern against the Sardinia margin.

438 The megabed is affected by faults and halokinetic deformation (salt domes)
439 suggesting recent (post LGM) activity of tectonics based on the age of the deformed
440 megabed.

441 The internal geometry of the BAP megaturbidite presents three faint but distinctive
442 echo-facies from bottom to top: that correspond tentatively to the three sedimentary
443 faces identified in cores.

444 In some areas of the abyssal plain, the basal layer of the BAP megaturbidite shows
445 evidence of erosional truncation of underlying deposits that might indicate enhanced
446 erosion of turbiditic flows and/or proximity of sedimentary sources: an origin from the

447 southern Balearic margin or a composite source from several margins cannot be
448 discarded at the present state of knowledge.

449 Further work on geochemistry of the sediment cores could help identify the source
450 areas and possible triggering mechanisms that influenced the deposition of the
451 Western Mediterranean megabed, and enhance the understanding of geohazard in
452 the Mediterranean region.

453

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466

467

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- 641

642 **Figure captions**

643

644 **Fig. 1.** General bathymetric map of the Balearic abyssal plain (BAP) with location of
645 seismic surveys (colour lines, see the graphic legend to identify the name of the
646 cruise) and sediment cores (red dots) mentioned or presented in this study. The
647 continuous black line represent the indicative areal coverage of the BAP
648 megaturbidite as proposed by Rothwell et al. (1998; 2000). White boxes show the
649 location of seismic profiles presented in Figures 2 and 3. The dashed black line
650 shows a proposed extent of the megaturbidite based on sediment core evidence from
651 Babonneau et al. (2017) and this study.

652

653 **Fig. 2.** Sub-Bottom Profiles from campaigns WestMedFlux (2016) and
654 WestMedFlux2 (2018) with images of the BAP megaturbidite identifiable as an
655 acoustically transparent layer. (a) Profile WMF2016-AT010 shows the acoustically
656 transparent unit of the BAP megaturbidite less than 10 m below the seafloor with
657 gentle folds following the geometry of underlying strata and a gradual pinch-out of the
658 unit towards the west. (b) Profile WMF2018-AT141A presents the same feature as
659 above with accentuated effect of deformation due to the presence of salt domes. The
660 black box is the location of zoomed image of Figure 3a. (c) Profile WMF2016-AT
661 shows towards the east, in the central part of the basin, the presence of faults
662 displacing the megaturbidite.

663

664 **Fig. 3.** (a) Zoom of profile WMF2018-AT141A presented in Fig. 2 with evidence of
665 the pinch-out of the BAP megaturbidite towards the west beyond the salt domes. The
666 lateral termination of the megaturbidite seems to be at offset 15000, but it actually
667 goes further west (offset 1000 in Fig. 2b). (b) Profile WMF2016-AT013 with a view of
668 the abrupt eastward termination of the BAP megaturbidite on the steep Sardinian
669 margin testified by diffraction hyperbolae.

670

671 **Fig. 4.** SBP profile WMF2018-AT143A in a sector where the BAP megaturbidite is
672 relatively isopach by folded by salt diapirs and cut by vertical faults showing metric
673 displacement (a). The pop-up image (b) shows evidence of erosion at the base of the
674 BAP megaturbidite with apparent truncation of seismic reflectors.(c) Map with
675 location of the seismic profile.

676

677 **Fig. 5.** (a) Profile WMF2016-AT012 where the BAP megaturbidite is dissected by
678 several vertical faults. (b) The pop-up image shows three distinct echo-facies within
679 the BAP megaturbidite: I faint chaotic echo-facies, II dominantly transparent echo-
680 facies topped by a discontinuous but mappable reflector, III basal unit with a
681 discontinuous base and top showing medium-amplitude discontinuous reflectors. (c)
682 Map with location of the profile.

683

684 **Fig. 6.** (a) Portion of SBP profile WMF2016-AT006 at the site of sediment core
685 WMF2-KF11. (b, d) Core WMF2-KF11 photo. Note the 4 intervals in blue where
686 whole core samples for oedometer tests were reserved: two within the homogeneous
687 clay of the megabed, two in overlying layers characterised by alternating thin beds of
688 sand and silt with dominant hemipelagic silty clay (the latter two samples are from
689 fine grained sediment). (c) P-wave velocity log of the core showing a clear
690 identification of three lithological units.

691

692 **Fig. 7.** (a) Lithological log of sediment cores LC05 (only the upper ca. 13 m, modified
693 from Clare et al., 2014) and WMF2-KF11. Note that the majority of the sedimentary
694 succession is represented by turbidites. (b) Synthetic sedimentary structures of the
695 megabed. (c) Map modified from Clare et al. (2014) showing the possible sources of
696 the megabed.

697

698 **Fig. 8.** Transect of sediment cores PSM3-KS21, -KS23 and -KS27 offshore the
699 Algerian margin. Only the upper part of the cores is visible, see the whole correlation
700 in Babonneau et al. (2017 ; their Fig. 7). Note in the grey shaded area a sediment
701 layer standing out in photos for its colour different from that of other encasing
702 turbidity layers whose age is compatible with that of the BAP megabed (**Tab. 2**). Core
703 identifier are: PSM-KS21 (<http://igs.org/BFBGX-86346>); PSM-KS23:
704 <http://igs.org/BFBGX-86348>; PSM-KS27 : <http://igs.org/BFBGX-86352>.

705

706 **Fig. 9 S** Physical and geotechnical parameters measured on core WMF2-KF11.
707 From left to right: Density from Multi Sensor Core Logger (MSCL, black line) and
708 from water content on discrete samples (blue dots); P-wave velocity from MSCL
709 (black line) and discrete measurements on half core via celerimeter (blue dots);

710 Derived parameters from oedometric tests Yield Stress Ratios (YSR) and
711 Recompression, Compression and Swelling Indices; Undrained shear strength (Su)
712 measured by Vane test in the half core: normally consolidated sediment would fall
713 within the black and red lines. Note the abrupt change of several parameters at 2.28
714 mbsf. The grey shadow correspond to the depth of the homogeneous part of the BAP
715 megabed (2.28-4.50 mbsf), whereas in yellow is the silty/sandy portion of the
716 megabed sampled by the core.