

The Last Glacial Maximum Balearic Abyssal Plain Megabed revisited

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2 <u>Antonio Cattaneo^{1*}</u>, Shray Badhani^{1,2} Cristina Caradonna³, Massimo Bellucci^{2,3}, Estelle Leroux¹, Nathalie Babonneau², Sébastien Garziglia¹, Jeffrey Poort⁴, Grigorii 3 4 G. Akhmanov⁵, Germain Bayon¹, Bernard Dennielou¹, Gwenael Jouet¹, Sebastien 5 Migeon⁶, Marina Rabineau² Laurence Droz² & Michael Clare⁷ 6 7 8 ¹IFREMER, Géosciences Marines, Plouzané, France ²UMR 6538 Géosciences Océan, Université de Brest, France 9 ³Università di Trieste, Italy 10 ⁴ UMR 7193 ISTeP. Sorbonne Université, Paris, France 11 ⁵ Lomonosov Moscow State University, Moscow, Russian Federation 12 13 ⁶ UMR7329, GEOAZUR, Valbonne, France 14 ⁷ National Oceanography Centre, University of Southampton, United Kingdom *Corresponding author (e-mail: antonio.cattaneo@ifremer.fr) 15 16 Abstract: Megabeds are thick sedimentary layers extending over thousands square 17 18 kilometres in deep sea basins and are thought to result from large slope failures 19 triggered by major external events. Such deposits have been found in at least three 20 areas of the Mediterranean Sea. Although their discovery dates back to the early 21 1980s, many questions remain, concerning their initiation, source area, extent, and 22 the nature of their emplacement. One of the largest previously documented 23 megabeds was emplaced during the Last Glacial Maximum across the Balearic 24 Abyssal Plain with a thickness of 8-10 m in water depths of up to 2800 m. 25 New 3.5 kHz sub-bottom profiles and sediment cores provide greater constraint on 26 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 27 28 gradual pinch-out to the West and an abrupt eastward termination against the 29 Sardinia steep margin. The megabed presents both in seismic profiles and in 30 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 31 oriented NNE-SSW allowing renewed discussions about sources and trigger of the 32 33 megabed.

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35 **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 some of the largest mass movements documented worldwide; often in excess of 100 41 km³ (Fildes, 2013 and references therein). The term megaturbidite indicates a 42 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 basinwide extent (Bouma, 1987). In this study we use the term 'megabed', because 46 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 genetically linked deposits (e.g. Campos et al., 2013). The reason to study 54 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 inhibited a clear interpretation of the associated sedimentary processes at the origin 57 of these anomalously large event deposits. Secondly, they may be diagnostic of 58 59 major catastrophic events within a basin and around the adjacent as their triggering has been attributed to major external events, including large earthquakes and 60 tsunamis, or may themselves have triggered tsunamis (e.g., Talling et al., 2014). The 61 62 emplacement of such a megabed could impact important deep-sea benthic communities as a result of widespread and rapid burial of the seafloor over hundreds 63 64 of square kilometres, as well as the prolonged (>>months) effects of turbid waters during the settling of suspended fine sediments. Following the 12 January 2010 Haiti 65 66 Mw 7.0 earthquake, a 600-m thick nepheloid layer took two months to settle after the initial event (McHugh et al., 2011). 67

As megatubeds typically form widespread, low-relief deposits that blanket broad basin topography, their identification from seafloor data is challenging. As a result, their identification is usually based on the recognition of extensive acoustically transparent layers in sub-bottom profiles: a diagnostic echo-facies signature that 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 impact of the Santorini volcanic eruption (3500 BP; Cita et al., 1984) and finally linked 80 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 megabeds. 86

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 Abyssal Plain (BAP) megabed, the largest megabed in the Mediterranean, is a 95 perfect example of a puzzling deposit. While its age is well constrained by multiple 96 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 with an estimated volume of 500-600 km³ has no obvious source, especially given 100 101 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

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

- Sub-bottom seismic profiles are an important data set for near-surface structural and 114 115 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 homogeneite part.
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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 largest abyssal plain of the Mediterranean with an area of about 77,000 km² and may 135 be identified by the 2800-m isobath (Rothwell et al., 1998, 2000). It is surrounded by 136 137 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 than 50 km along Corsica, Sardinia and north Africa (Rothwell et al., 1998;
Hoogakker et al., 2004; Zuniga et al., 2007). Sources for turbidity currents have been
documented from several of these continental margins and include earthquake
triggered events associated with tsunami waves, such as the 2003 Boumerdès event
(Cattaneo et al., 2012).

The most striking morphological feature of the BAP is the presence of a thick 146 147 Messinian evaporite layer and salt walls and diapirs at the seafloor (Stanley et al., 1974). Another key feature of the BAP is a thick layer identified in the abyssal plain 148 149 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 five dates on top of the megabed following Reimer et al. (2013) and obtained a 2-164 165 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.

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168 **3. Data and methods**

169 **3.1 Sub-bottom profiles**

All sub-bottom available data within the interest area were integrated in a single Kingdom database for interpretation. This includes in particular the newly acquired data during the WestMedFlux survey (Poort and Loucazeau, 2016; Poort and Gorini, 2018; **Figs 2-5**), but also the datasets from the PROGRES (Droz., 2003) and SARDINIA (Aslanian and Olivet, 2006) campaigns. Some profiles from AM-MED (Rabineau et al., 2013) survey were also integrated. Successive processing steps were applied onboard consisting of correlation (signal compression), correction of the spherical divergence, compensation of the ship movements (pitch, roll and heave), calculation of the location of the source and receptors, and correction for the delay. Imports of sub-bottom data in Kingdom were applied in amplitude, and envelope was computed for each segy file. Locations of cores were also loaded into the database to be correlated with the seismic data (**Tab. 1**).

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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 reported by Rothwell et al. (1998) recalibrated by Dennielou et al. 2019). Grey 190 191 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).

Sediment core WMF2-KF11 is positioned on seismic profile WMF2016-AT006 by adopting a velocity of 1529 m s⁻¹ based on an averaged value of the Multi Sensor Core Logger data (P-wave velocity) measured on the whole core (**Fig. 6**). Radiocarbon dates on core WMF2-KF11 were obtained by AMS at Beta Analytic 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

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

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212 **4. Results**

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

constrasting details of megabed termination from two opposite sides of the abyssal
 plain. Profile WMF2018-AT141A (Fig. 3a) shows the pinch-out of the BAP megabed
 towards the west, beyond an area with salt domes: the lateral termination of the

megabed seems to be at offset 15000, but it actually goes further west (offset 1000 in 243 244 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 as flat-lying within each basin where they deposit with abrupt terminations against the 250 251 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 comformable in the majority 255 of the seismic lines analised (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 area comprised within a dashed blue line in Figure 4c, as localised erosional 261 262 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

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

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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 velocity of 1529 m s⁻¹ based on MSCL data (Fig. 6c), the core is projected on the 302 303 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 homogeneite.

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

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

The megabed likely represents a ponded megaturbidite resulting from steady longlived turbidity current as suggested in the existing literature (e.g., Rothwell et al., 1998, 2000; Clare et al., 2014). Planar laminae formed as a result of grain flow at the turbidity current head. The rest of the flow settled out due to low density turbulent 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 megabed. In the grey shaded area, a sediment layer stands out in photos for its 324 325 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 seimic 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**).

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

334 A marked change in both density and Vp 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 (Su) which decrease abruptly below 2.28 m (Fig. 339 9). Comparisons with the trends generally exhibited by normally consolidated 340 sediments (Su= 0.2 σ 'v or 0.3 σ 'v; e.g., Garziglia et al., 2010) can be reconciled with YSR values to indicate that below 2.28 m the sediment is under-consolidated. 341

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5. Discussion

5.1 Overall distribution of the BAP megaturbidite and inferences on sources

The BAP megabed is reported in the literature as extending in the BAP identified by 345 the isobath 2800 m over a surface of 60,000 km² for a volume of 500 km³ (Rothwell 346 et al., 1998), and, successively, over a surface of 77,000 km² for a volume of 600 347 km³ (Rothwell et al., 1998; Hoogakker et al., 2004). We find, thanks to the 348 identification of a distal correlative of the megabed to the West (Fig. 8), that the 349 350 megabed extends further 200 km along the central Algerian basin (Fig. 1, dashed lines). The resulting extent would thus become of up to 90,000-100,000 km², while 351 352 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).

Beyond its considerable size, the importance of the information coming from the 354 355 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 contrasting style of megabed terminations with a gradual pinch-out towards the West 360 361 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 on zircon analysis (Fildes et al., 2010) to African provenance (Thomas et al., 2010) or 368 369 again African based on a series of argumentations including paleogeographic reconstructions. The case of the BAP megabed could be theoretically simpler, 370 371 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 the support of future geochemical investigations. 376

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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 (Eggenhuisen et al., 2011), the evidence of seismic reflector truncations and in 386 387 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.

Finally, the homogenite shows peculiar physical and geotechnical properties, in particular the consolidation state (underconsolidated). The megabed appears to be composed of sediment which remained under-consolidated since its deposition. 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

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

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

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

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

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

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

southern Balearic margin or a composite source from several margins cannot bediscarded at the present state of knowledge.

- Further work on geochemistry of the sediment cores could help identify the source areas and possible triggering mechanisms that influenced the deposition of the Western Mediterranean megabed, and enhance the understanding of geohazard in the Mediterranean region.
- 453

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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 continuous black line represent the indicative areal coverage of the BAP 647 megaturbidite as proposed by Rothwell et al. (1998; 2000). White boxes show the 648 649 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.

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653 Fia. 2. Sub-Bottom Profiles from campaigns WestMedFlux (2016) and 654 WestMedFlux2 (2018) with images of the BAP megaturbidite identifiable as an acoustically transparent layer. (a) Profile WMF2016-AT010 shows the acoustically 655 656 transparent unit of the BAP megaturbidite less thant 10 m below the seafloor with gentle folds following the geometry of underlying strata and a gradual pinch-out of the 657 658 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 black box is the location of zoomed image of Figure 3a. (c) Profile WMF2016-AT 660 661 shows towards the east, in the central part of the basin, the presence of faults 662 displacing the megaturbidite.

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

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

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

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

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

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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://igsn.org/BFBGX-86346); PSM-KS23: 704 http://igsn.org/BFBGX-86348; PSM-KS27 : http://igsn.org/BFBGX-86352.

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Fig. 9 S Physical and geotechnical parameters measured on core WMF2-KF11. From left to right: Density form Multi Sensor Core Logger (MSCL, black line) and from water content on discrete samples (blue dots); P-wave velocity from MSCL (black line) and discrete measurements on half core via celerimeter (blue dots); Derived parameters from oedometric tests Yield Stress Ratios (YSR) and Recompression, Compression and Swelling Indices; Undrained shear strength (Su) measured by Vane test in the half core: normally consolidated sediment would fall within the black and red lines. Note the abrupt change of several parameters at 2.28 mbsf. The grey shadow correspond to the depth of the homogeneite part of the BAP megabed (2.28-4.50 mbsf), whereas in yellow is the silty/sandy portion of the megabed sampled by the core.