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1 The Valanginian Weissert Event on the south Tethyan margin: a dynamic paleoceanographic
2 evolution based on the study of calcareous nannofossils

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15 **Highlights:**

- 16 • Paleoceanographic reconstruction around the Weissert Event in the southern Tethys
- 17 • High surface-water fertility and nannofossil production during the Weissert Event
- 18 • Major impact of sea-level and river clastic input on the nannofossil community
- 19 • Sea level fall caused the nannoconid decline before the Weissert Event
- 20 • Nannoconid recovery was associated with high surface-water fertility

21 **ABSTRACT:**

22 Paleoceanographic conditions across the Valanginian Weissert oceanic anoxic event
23 were reconstructed for the first time on the central Moroccan margin from a quantitative-based
24 calcareous nannofossil study. Two onshore successions in the Essaouira-Agadir Basin and one
25 offshore from DSDP Hole 416A were studied, providing a proximal-distal transect on the
26 central Moroccan margin. The paleoceanographic conditions were reconstructed in an accurate
27 chronostratigraphic framework. The sedimentary evolution of the Essaouira-Agadir Basin
28 shows that sea-level variations controlled the paleogeographic context, clastic input, and
29 nutrient availability. A thick photic zone and mesotrophic conditions favored the development
30 of a diverse nannofossil community before the Weissert Event in the early Valanginian. In all
31 studied successions, a collapse of the nannofossil community was recorded during the onset of
32 the Weissert Event at the early-late Valanginian transition, and was caused by a major sea-level
33 fall. The nannofossil community gradually recovered and reached its highest nannofossil
34 production associated with high surface-water fertility during the Weissert Event in the late
35 Valanginian. This eutrophication is coeval with the high and stable $\delta^{13}\text{C}_{\text{carb}}$ values of the carbon-
36 isotope positive shift. After the Weissert Event, surface-water fertility and nannofossil
37 production decreased but remained higher than during the early Valanginian. Additionally, the
38 nannoconid decline started in the early Valanginian and was linked to a low sea-level. Their
39 recovery in the early late Valanginian occurred during conditions of high sea-level and of high
40 surface-water fertility. The central Moroccan margin is integrated into a global
41 paleoceanographic reconstruction.

42 **Keywords:** Carbon isotope excursion; Central Moroccan margin; Biostratigraphy;
43 Sedimentary evolution; Surface-water fertility

44 **1. Introduction**

45 The Valanginian stage (137.7 – 132.6 Ma; Gale et al., 2020) records the first positive
46 carbon-isotope excursion (CIE) of the Early Cretaceous (Lini et al., 1992; Weissert and Erba,
47 2004), termed the Weissert oceanic anoxic event or the Weissert Event (Erba et al., 2004; Kujau
48 et al., 2012). The amplitude of the CIE ranges between 1.5–2 ‰ in bulk marine carbonate rock
49 and 1.5–3 ‰ in marine organic matter (Lini et al., 1992; Hennig et al., 1999; McArthur et al.,
50 2007; Charbonnier et al., 2013). In addition, the positive CIE was recognized in terrestrial fossil
51 plants with a magnitude of ~4 ‰, implying a perturbation of both the oceanic and atmospheric
52 Earth systems (Gröcke et al., 2005; Nunn et al., 2010). Martinez et al. (2015) identified three
53 phases for the CIE, a first phase of rapid $\delta^{13}\text{C}_{\text{carb}}$ increase with a duration of 0.60 myr, a second
54 phase of stable $\delta^{13}\text{C}_{\text{carb}}$ values lasting 1.48 myr, and a final phase of smooth decrease in $\delta^{13}\text{C}_{\text{carb}}$
55 values lasting 3.77 myr and extending to the early-late Hauterivian boundary. The onset of the
56 positive CIE was observed just below the early-late Valanginian boundary (Duchamp-Alphonse
57 et al., 2007; McArthur et al., 2007; Gréselle et al., 2011; Martinez et al., 2015). In the Tethyan
58 Realm, the positive CIE was dated from the late NK3A calcareous nannofossil Subzone and
59 extends to the NC4A calcareous nannofossil Subzone in some localities (Lini et al., 1992;
60 Sprovieri et al., 2006; Duchamp-Alphonse et al., 2007; Bornemann and Mutterlose, 2008;
61 Charbonnier et al., 2013; Aguado et al., 2018). Calibrated with ammonite biostratigraphy, the
62 onset of the positive CIE was identified in the lower part of the *Karakaschiceras inostranzewi*
63 Standard Zone (uppermost early Valanginian) and the highest values occur during the
64 *Saynoceras verrucosum* Standard Zone (lowermost late Valanginian; McArthur et al., 2007;
65 Gréselle et al., 2011; Martinez et al., 2015; Aguado et al., 2018). The aforementioned zones
66 follow the standard ammonite zonation that is suitable for the Mediterranean Province of the
67 Mediterranean-Caucasian Subrealm (Tethyan Realm; Reboulet et al., 2018). In addition to the
68 Tethyan Realm, records of the positive CIE extend to a wide range of geographic locations that

69 include the Atlantic Ocean (Brenneke, 1978; Cotillon and Rio, 1984), the northwestern Pacific
70 Ocean (Bartolini, 2003), the Boreal Realm (Price and Mutterlose, 2004; Meissner et al., 2015;
71 Morales et al., 2015), and the southern Hemisphere (Aguirre-Urreta et al., 2008; Gómez-Dacal
72 et al., 2018).

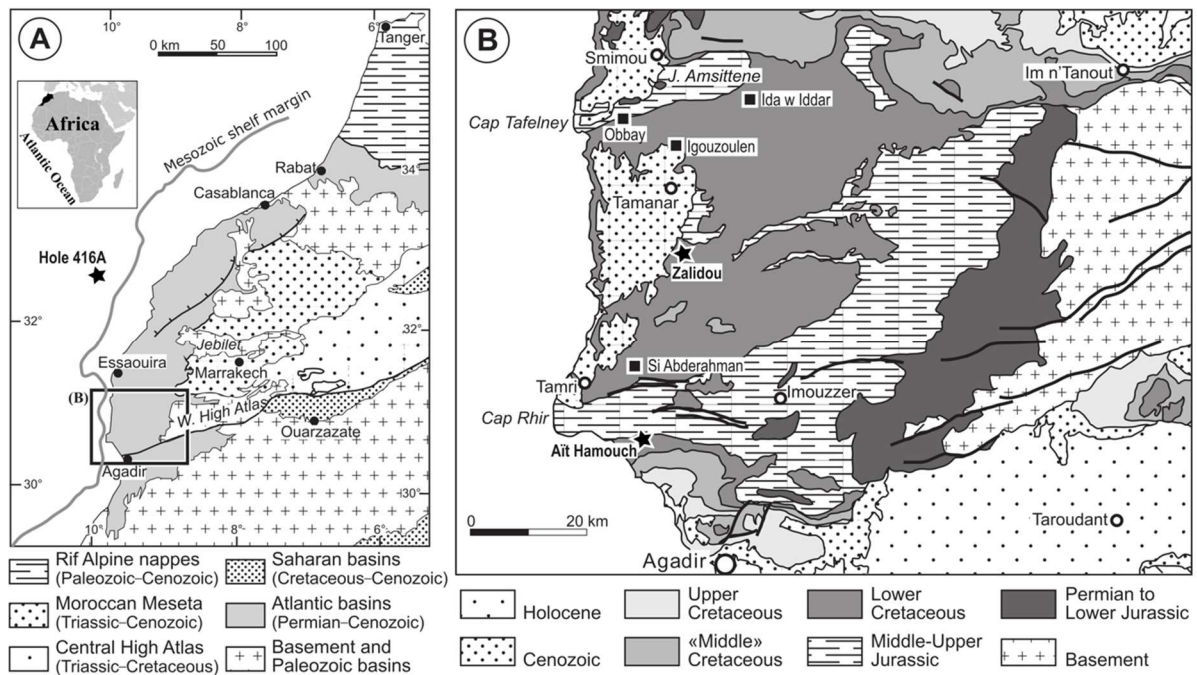
73 The positive CIE has been associated with a global increase in marine surface-water
74 primary productivity (Erba et al., 2004). During the Valanginian, calcareous nannofossils and
75 dinoflagellates were the major marine planktonic primary producers (Bown et al., 2004).
76 Several studies on calcareous nannofossil assemblages have shown enhanced surface-water
77 trophic conditions occurring before and during the Weissert Event, inferred from increasing
78 abundances of high-fertility taxa such as *Biscutum*, *Discorhabdus*, *Diazomatolithus*, and small
79 *Zeugrhabdotus* spp. (Tethyan Realm: Bersezio et al., 2002; Erba and Tremolada, 2004;
80 Duchamp-Alphonse et al., 2007; Mattioli et al., 2014; Atlantic Ocean: Bornemann and
81 Mutterlose, 2008; Kessels et al., 2006; Pacific Ocean: Lozar and Tremolada, 2003; and Boreal
82 Realm: Williams and Bralower, 1995; Melinte and Mutterlose, 2001; Kessels et al., 2006).
83 Nevertheless, paleoceanographic reconstructions based on calcareous nannofossils from the
84 south Tethyan margin have not been documented yet, such that it needs to be further
85 investigated. The causes of the increase in marine primary productivity differ in coastal and
86 distal pelagic settings. Eutrophication in the coastal settings is hypothesized to have been caused
87 by a greenhouse climate, intensification of the hydrological cycle, and consequently higher
88 weathering rates and detrital input (Lini et al., 1992). Climate reconstructions demonstrated
89 intensified hydrolyzing conditions culminating around the early-late Valanginian transition
90 observed from clay mineral distributions (Duchamp-Alphonse et al., 2011; Charbonnier et al.,
91 2020) and spore-pollen ratios (Kujau et al., 2013). Eutrophication in pelagic settings could be
92 explained by the introduction of limiting bio-metals from hydrothermal vents during the break-
93 up of Gondwana (Lini et al., 1992; Weissert et al., 1998; Erba et al., 2004). Sea-level changes

94 might have also influenced the fertilization of the ocean. (1) Enhanced continental runoff
95 increases nutrient fluxes to the proximal parts of the ocean (gradual fertilization) during low
96 sea level. (2) An increase in nutrients within the outer shelf realm may be linked to upwelling
97 (sharp fertilization) during high sea level. In the late Valanginian, a global sea-level rise was
98 documented after an all-time minimum of the Early Cretaceous occurred in the mid-
99 Valanginian (Haq, 2014). The different hypotheses that could cause the fertilization of the
100 ocean need to be tested for the Weissert positive CIE. A biocalcification crisis in both platform
101 and pelagic settings has been inferred from carbonate platform drowning around the early-late
102 Valanginian (Weissert et al., 1998; Wortmann and Weissert, 2000; Föllmi et al., 2006), and a
103 nannoconid decline predating the positive CIE has been identified (Channell et al., 1993;
104 Bersezio et al., 2002; Erba and Tremolada, 2004; Gréselle et al., 2011; Barbarin et al., 2012).

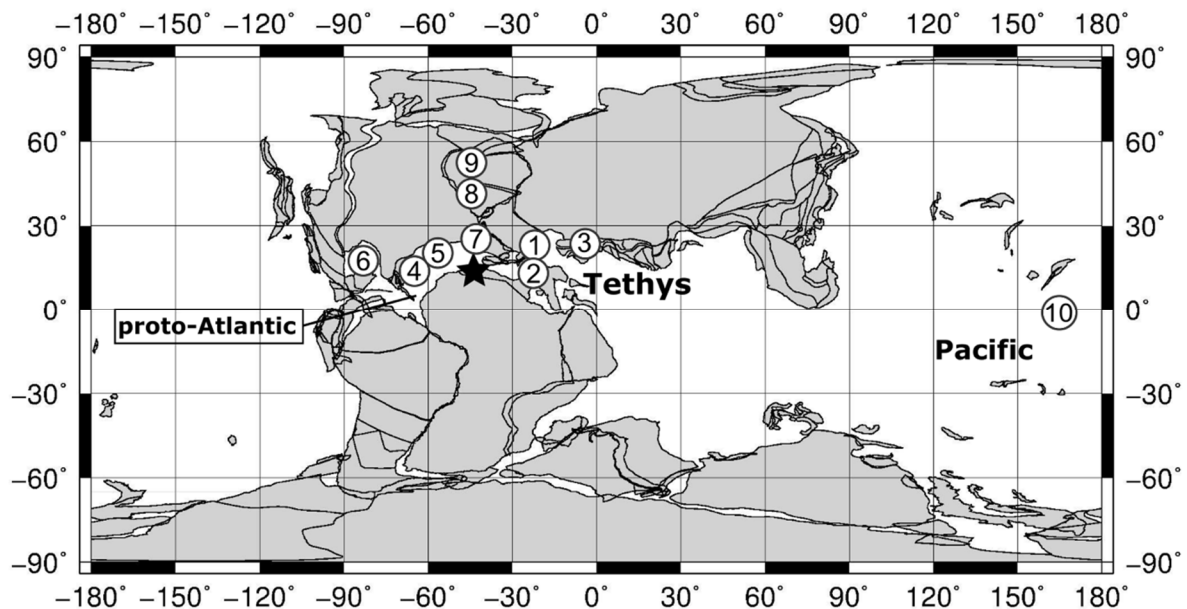
105 This study aims to reconstruct the paleoceanographic conditions around the Weissert
106 Event on the central Moroccan margin, which was located on the south Tethyan margin during
107 the Cretaceous. Calcareous nannofossil abundances and accumulation rates together with their
108 assemblages were used to quantify changes in surface-water nannofossil production and fertility
109 conditions. Nannofossil samples were collected from three geological successions located on a
110 proximal-distal transect: two onshore sections (Zalidou and Aït Hamouch belonging to the
111 Essaouira-Agadir Basin, EAB) and an offshore DSDP Hole 416A (east Atlantic Ocean). The
112 paleogeographic context of the onshore sections was defined from a sedimentological analysis
113 done at the scale of the EAB. The time framework was based on ammonite (only for the onshore
114 sections) and calcareous nannofossil biostratigraphy, and carbon-isotope stratigraphy. The
115 transect allowed to better constrain the variations of continental nutrient flux, upwellings that
116 were present on the NW African margin during the Early Cretaceous due to active trade winds
117 considering atmospheric circulation models from Price et al. (1995) and Poulsen et al. (1998),
118 and calcareous nannofossil production.

119 **2. Geological setting**

120 The Essaouira-Agadir Basin (EAB) is located in southwest Morocco and corresponds
121 to the westernmost part of the High Atlas fold belt, bounded by 9°55' to 9°20' W and 30°30' to
122 31°05' N. The basin is bordered to the north by the Jebilet Massif and Doukkala Plateau
123 (Paleozoic basements), to the south by the plain of Souss (Neogene basin), and to the east by
124 the High Atlas (Fig. 1). The EAB presently constitutes part of the Atlantic passive margin which
125 is considered one of the oldest existing passive margins (Stets and Wurster, 1982; Sahabi et al.,
126 2004). The EAB extends offshore until the western limit of the continental margin (Frizon de
127 Lamotte et al., 2008). During the Cretaceous, the central Moroccan margin which includes the
128 EAB occupied a paleogeographic location on the south Tethyan margin, between paleo-
129 latitudes ~ 15°N and ~ 22°N (Fig. 2). Until the opening of the South Atlantic (Valanginian) and
130 its connection with the Central Atlantic (early Albian), the Tethys Ocean included what is
131 presently the Central Atlantic. Therefore, the geological evolution of the Atlantic-Tethyan
132 passive margin controlled the development of the EAB (Ellouz et al., 2003). Two sections in
133 the EAB, namely Zalidou and Aït Hamouch, were selected for the study of calcareous
134 nannofossils. The Zalidou section is located 45 km north of Agadir (30°54'23"N; 9°39'48"W;
135 Fig. 1B), whereas the Aït Hamouch section is located ~25 km NNW of Agadir (30°36'54"N;
136 9°42'14"W). The Aït Hamouch section is composed of two adjacent sections, only 0.6 km apart
137 from each other. The primary section, denoted "AH", was not accessible in its middle part
138 (between 32 and 42 m). Accordingly, the nearby "ATH" section was studied and correlated
139 using ammonite biostratigraphy and sedimentological discontinuities. Moreover, calcareous
140 nannofossils were studied in the offshore succession DSDP Leg 50 Hole 416A (Fig. 1A).
141 Additional sections were used in this paper to improve the precision of the ammonite
142 biostratigraphy and the sedimentological framework (Fig. 1B), although these sections will not
143 be discussed in detail herein as this is beyond the scope of this paper.



144
 145 Fig. 1. Location of the study area in SW Morocco, modified from Ouajhain et al. (2009). (A)
 146 Location of the central Moroccan margin including the Essaouira-Agadir Basin and DSDP Hole
 147 416A (not to scale). Approximate location of the Mesozoic shelf margin from Tari and Jabour
 148 (2013). (B) Geological sketch including the location of the sections used in this study (square
 149 shape). The successions studied for their calcareous nannofossil assemblages (Zalidou, Aït
 150 Hamouch, and Hole 416A) are identified in "bold" font and by a "star" sign.



151
 152 Fig. 2. Paleogeographic map of the Valanginian (136 Ma) showing the location of the central
 153 Moroccan margin (star shape). The "white circles" correspond to the location of
 154 basins/successions where calcareous nannofossils of the Weissert Event were investigated:
 155 Tethyan Realm, (1) Vocontian Basin (France) (Duchamp-Alphonse et al., 2007, 2014; Gréselle
 156 et al., 2011; Barbarin et al., 2012; Mattioli et al., 2014), (2) Lombardy Basin (Italy) (Bersezio
 157 et al., 2002; Erba and Tremolada, 2004), and (3) Moesian Platform (south and east Carpathians-
 158 Romania) (Melinte and Mutterlose, 2001); western and central Atlantic, (4) DSDP 534A (Blake

159 Bahama basin, NE Florida) and (5) DSDP 603B (east Florida) (Bornemann and Mutterlose,
160 2008), and (6) DSDP 535 (SE Gulf of Mexico) (Kessels et al., 2006); Boreal Realm, (7) ODP
161 638 (NW Iberian Peninsula) (Kessels et al., 2006), (8) BGS 81/43 (southern North Sea Basin,
162 east England) (Williams and Bralower, 1995; Kessels et al., 2006), and (9) east Greenland Basin
163 (NE Greenland) (Pauly et al., 2012); western Pacific, (10) ODP 1149B (Nadezhda Basin)
164 (Lozar and Tremolada, 2003). Construction from <http://www.odsn.de> (made from the datafiles
165 of Hay et al. (1999)).

166 **2.1 Ammonite zonal framework for the late Berriasian-early Hauterivian interval of the** 167 **EAB**

168 The systematic revision and identification of ammonites sampled at Zalidou and Aït
169 Hamouch sections are being prepared as a separate paper and were part of a chapter in Shmeit's
170 PhD thesis (2021), in which paleontological comments and ranges of ammonite taxa are
171 provided. The standard ammonite zonation for the Mediterranean Province (Tethyan Realm,
172 Reboulet et al., 2018) is applied here. Only two regional units are added, namely *Neocomites*
173 *subtenuis* and *Busnardoites campylotoxus* local subzones, to make more accessible the
174 comparisons with previous works made in this Moroccan area by Wippich (2001, 2003) and
175 Ettachfini (2004). The ammonite (sub-)zones are interval (sub-)zones defined by the first
176 appearance datum (FAD) of two successive ammonite-indices. Hereafter will be used the
177 following abbreviations: standard zone = StZ, standard subzone = StSz, and local subzone =
178 LSz.

179 The base of the *Thurmanniceras pertransiens* StZ, and therefore the lower boundary of
180 the Valanginian, is placed by the FAD of the index-species (Kenjo et al., 2021). As it is
181 relatively rare at Zalidou and Aït Hamouch, the base of the zone can be placed at the first records
182 of *Neocomites premolicus* (Ettachfini, 2004; Reboulet et al., 2018). Due to the rarity of the
183 index-species, the base of the *N. neocomiensiformis* StZ is identified at Zalidou and Aït
184 Hamouch sections by the first occurrence (FO) of *Neocomites subtenuis*, as its appearance is
185 contemporaneous with that of *N. neocomiensiformis* in SE Spain (Company and Tavera, 2015).
186 Above the *N. subtenuis* LSz, the upper part of the *N. neocomiensiformis* StZ is characterized by

187 the *Busnardoites campylotoxus* LSz, for which the base is placed at the FO of its relatively
188 abundant index-species at Zalidou and Aït Hamouch. The base of the *Karakaschiceras*
189 *inostranzewi* StZ is placed at the FO of its index species. In both sections, *Saynoceras*
190 *verrucosum*, index species of the *S. verrucosum* StZ, was not found. Other ammonite markers
191 of the basal part of this zone, as *Valanginites ventrotuberculatus*, were also not observed.
192 Consequently, at Zalidou, the base of the *S. verrucosum* StZ, and so the base of the late
193 Valanginian, are placed at the FO of *Karakaschiceras pronecostatum* that is the index-species
194 of the second subzone of the *S. verrucosum* StZ. At Aït Hamouch, very few specimens of some
195 taxa that could be restricted to the *S. verrucosum* StZ are recorded in a single layer (AH89) with
196 the FO of *Neocomites peregrinus* allowing to identify the base of the *N. peregrinus* Stz. Thus,
197 the ammonite assemblage could be interpreted as a result of a condensed lithology. In this layer,
198 there are also few doubtful specimens of *K. inostranzewi*?; their preservation could indicate
199 that they have been reworked. At Zalidou, *N. peregrinus* was also observed allowing to place
200 the base of the zone. In this section, the *Olcostephanus nicklesi* StSz is identified by the
201 occurrence of the genus *Himantoceras* (see Reboulet, 1996). The *O. nicklesi* StSz is not
202 recognized at Aït Hamouch. The base of the *Criosarasinella furcillata* StZ and that of the
203 *Tescheniceras callidiscum* StSz are identified in both sections. The base of the *Acanthodiscus*
204 *radiatus* StZ, and thus the base of the Hauterivian (see Mutterlose et al., 2020), are placed at
205 the FO of *Breistrofferella castellanensis* and that of *Acanthodiscus radiatus* at Zalidou and Aït
206 Hamouch, respectively.

207 **2.2 DSDP Hole 416A**

208 DSDP Leg 50 Hole 416A was drilled ~180 km NW of Essaouira (32°50'10.7"N;
209 10°48'03.6"W) at a water depth of 4201 m in the eastern Atlantic (Fig. Supp. 1). The Berriasian
210 to Hauterivian sediments consist of a turbidite succession deposited in a lowermost continental
211 rise environment (Lancelot et al., 1980). The Valanginian interval was identified onboard from

212 cores 48 to 14, between –1540 and –1222 meters below seafloor (mbsf) (Čepek and Gartner,
213 1980; Sliter, 1980). The detailed lithology of Hole 416A was described by Lancelot et al.
214 (1980). Briefly, the Berriasian and early Valanginian were assigned to lithological unit VII
215 (from –1624 to –1430 mbsf, cores 57 to 37), characterized by alternating siliciclastic and
216 carbonate turbidites. The lithology displays quartz-rich siltstone and mudstone cycles
217 alternating with hard micritic and calpionellid-rich limestones. A prominent change in lithology
218 above –1430 mbsf characterizes the shift to the overlying lithological unit VI (from to –1430
219 to –880 mbsf, cores 36 to 7). This change is identified by an abrupt decrease in carbonate
220 deposition and a subsequent increase in terrigenous input, with siliciclastic terrigenous
221 turbidites replacing the calcareous turbidites. The lithology change was regarded as a classical
222 example of the mid-Valanginian platform drowning (Schlager, 1980). Lithological unit VI
223 spans the rest of the Valanginian and builds up to the Hauterivian (Lancelot et al., 1980;
224 Schlager, 1980). The lithology shows graded calcareous and siliciclastic cycles, from siltstone
225 or fine sandstone to mudstone.

226 **3. Materials and methods**

227 The onshore successions (Zalidou and Aït Hamouch) span the late Berriasian to early
228 Hauterivian covering the entire Valanginian. The offshore DSDP Leg 50 Hole 416A spans the
229 Valanginian stage (Čepek and Gartner, 1980). Samples for calcareous nannofossils, calcium
230 carbonate content, and carbon-isotope analyses were collected from different lithologies
231 (except sandstones). The sampling interval was on average 0.3 m in Zalidou, 0.5 m in Aït
232 Hamouch, and 5 m in Hole 416A. Both macrofossils and nannofossil smear slides are curated
233 at the Collections de Géologie de l'Observatoire des Sciences de l'Univers de Grenoble
234 (OSUG), with an appropriate UJF-ID number. "OSUG-COLLECTIONS" is a database of
235 rocks, minerals, and fossils (<https://web.collections.osug.fr>, OSUG, UGA; doi:10.5072/OSUG-
236 COLLECTIONS.all).

237 **3.1 Sedimentological analysis**

238 Sedimentological analysis was based on sections located in the southern and central
239 parts of the EAB (Fig. 1B). Observations were made both in the field and under microscope.
240 All sedimentary features (lithology, peculiar surfaces, sedimentary figures, faunal content, and
241 bioturbation) were observed and recorded in the field. Limestone beds, mainly in the lower
242 Valanginian series, were also sampled for microfacies analysis. We used the classification
243 defined by Dunham (1962).

244 **3.2 Calcareous nannofossils**

245 Biostratigraphic and paleoenvironmental analyses of the Zalidou and Aït Hamouch
246 sections were based on 85 and 54 samples (Supplementary Table), respectively, from
247 calcareous claystone to limestone. For Hole 416A, 44 samples were investigated.

248 Smear slides were prepared using a random settling technique developed by Beaufort et
249 al. (2014) and modified by Menini et al. (2019). Only 17 samples from the Aït Hamouch “AH
250 section” were prepared using the random settling technique of Geisen et al. (1999) (see
251 Supplementary Table). Both techniques allow the determination of the nannofossil absolute
252 abundance (nannofossils/gram of rock) using the equations presented in the Supplementary
253 Table. A comparison between both techniques for absolute abundance quantification has not
254 been done yet. Studies comparing other slide preparation techniques have shown that
255 nannofossil proportions can be reliably determined regardless of the technique (Bordiga et al.,
256 2015; Lupi et al., 2016).

257 Nannofossils were observed using a polarizing light microscope (Leica “DM2500 P”)
258 at 1000x magnification. Five hundred specimens per slide, both coccoliths and nannoliths, were
259 generally counted in a variable number of fields of view (a mean of 52 for Zalidou, 80 for Aït
260 Hamouch, and 39 for DSDP Hole 416A). All nannofossils with at least more than half of the
261 specimen preserved were counted. In few samples (4 from Zalidou and 3 from Aït Hamouch),

262 characterized by low abundance of nannofossils (approx. 1–2 specimens/4 fields of view), ~
263 350–400 specimens were counted (Supplementary Table). In addition, two longitudinal random
264 transverses (200 fields of view per transverse) were scanned after each counting for rare species
265 that could be of biostratigraphic importance. To improve the biostratigraphic schemes whenever
266 needed, scanning ~8–12 random longitudinal transverses was done on additional samples not
267 counted (5 from Zalidou, 1 from Aït Hamouch, and 11 from Hole 416A).

268 The taxonomic frameworks of Perch-Nielsen (1985), Bown and Young (1998), and
269 Nannotax3 (Young et al., 2017) were followed. For nannoconids, the work of Deres and
270 Achéritéguy (1980) was followed. The calcareous nannofossil zonation applied to the
271 investigated sections were the NC and NK zones of Bralower (1987) and Bralower et al. (1989,
272 1995), modified from Roth (1978). This zonation scheme was selected because of its
273 applicability to low-latitude Tethyan continental margins and Atlantic oceanic settings
274 (Bralower et al., 1995; Bown, 2005; Bornemann and Mutterlose, 2008). The biostratigraphic
275 scheme (CC zones and subzones) of Sissingh (1977), modified by Perch-Nielsen (1979, 1985)
276 and Applegate and Bergen (1988), was also applied to the studied sections because it allows
277 subdividing the early Valanginian. This zonal scheme uses taxa with cosmopolitan distribution
278 and Tethyan affinities, and it relies on the first occurrence (FO) of *Eiffelithus* taxa (*E. windii*
279 and *E. striatus*) for subzone divisions during the Valanginian stage.

280 Nannofossil preservation was evaluated following the classes defined by Roth and
281 Thierstein (1972) and modified by Roth (1983). Nannofossil absolute abundances are
282 controlled by the nannoplankton biomass, preservation, and sedimentation rate. Nannofossil
283 accumulation rates (nannofossils/m²/yr) were calculated to cancel the sedimentation rate effect
284 (see formula in Supplementary Table). The duration of the different phases of the positive CIE
285 from Martinez et al. (2015) were used to determine the sedimentation rates in the studied
286 sections. These authors provided an improved age model for the Valanginian-Hauterivian

287 boundary using astrochronology, and acquired absolute age durations for the different phases
288 of the positive CIE. The $\delta^{13}\text{C}_{\text{carb}}$ values and the ammonite zonation of the onshore sections
289 (Zalidou and Aït Hamouch) were correlated with those of Martinez et al. (2015).

290 For each nannofossil taxon (or group of combined taxa) the absolute abundance (AA),
291 the relative abundance (RA), and the accumulation rate (AR, only for the Zalidou and Aït
292 Hamouch sections) were calculated. In addition, the nannofossil total absolute abundance
293 (NTAA) and the nannofossil total accumulation rate (NTAR, for Zalidou and Aït Hamouch
294 sections) were calculated, corresponding to the entire nannofossil assemblage. To consider the
295 inherent counting uncertainty, binomial proportion confidence intervals for relative abundances
296 were computed based on the ‘exact’ Clopper–Pearson method using the PAST software
297 (Hammer et al., 2001; Suchéras-Marx et al., 2019). Additionally, diversity indices were
298 calculated. *Nannoconus* spp. were excluded from the calculation of sample diversity indices,
299 absolute/relative abundances, and accumulation rates of other taxa because of their uncertain
300 biological affinity (Aubry et al., 2005). The counting and the different calculation formulae are
301 given in the Supplementary Table.

302 **3.3 Calcimetry and carbon isotopes**

303 The calcium carbonate content was measured on 117 and 56 bulk rock samples from
304 Zalidou and Aït Hamouch sections, respectively (Supplementary Table). For Aït Hamouch,
305 analyses were done on samples from the “AH” section. Additionally, 88 samples from DSDP
306 Hole 416A were measured (Supplementary Table). The CaCO_3 content was determined using
307 the carbonate bomb technique (Müller and Gastner, 1971). For the calculation of the calcium
308 carbonate percentage, see Appendix A in Peybernes et al. (2013).

309 Carbon stable isotope analysis was performed on the same samples as for the calcium
310 carbonate content at the stable isotope laboratories of the Institute of Earth Surface Dynamics
311 of the University of Lausanne, using a Thermo Fisher Scientific Gas Bench II carbonate

312 preparation device connected to a Delta Plus XL isotope ratio mass spectrometer. The CO₂
313 extraction was done at 70°C. The carbon stable isotope ratios were reported in the delta (δ)
314 notation as the per mil (‰) relative to the Vienna Pee Dee belemnite standard (VPDB), where
315 $\delta = (R_{\text{sample}} - R_{\text{standard}})/R_{\text{standard}}$ and $R = {}^{13}\text{C}/{}^{12}\text{C}$. The $\delta^{13}\text{C}_{\text{carb}}$ values were standardized relative
316 to the international VPDB scale by calibration of the reference gases and working standards
317 with international reference materials NBS 18 (carbonatite, $\delta^{13}\text{C} = -5.01$ ‰) and NBS 19
318 (limestone, $\delta^{13}\text{C} = +1.95$ ‰). Analytical uncertainty (1 sigma), monitored by replicate analyses
319 of the international calcite standard NBS 19 and the laboratory standard Carrara Marble ($\delta^{13}\text{C}$
320 $= +2.05$ ‰) was not greater than ± 0.05 ‰ for $\delta^{13}\text{C}$.

321 **4. Results**

322 **4.1 Summary of the Valanginian sedimentary evolution**

323 Geological sections indicated in “bold” font hereafter, correspond to sections that have
324 been investigated for calcareous nannofossils in the present study. Detailed analysis allowed
325 the identification of several sequences. Three main stages can be recognized in the Valanginian
326 sedimentary evolution of the EAB.

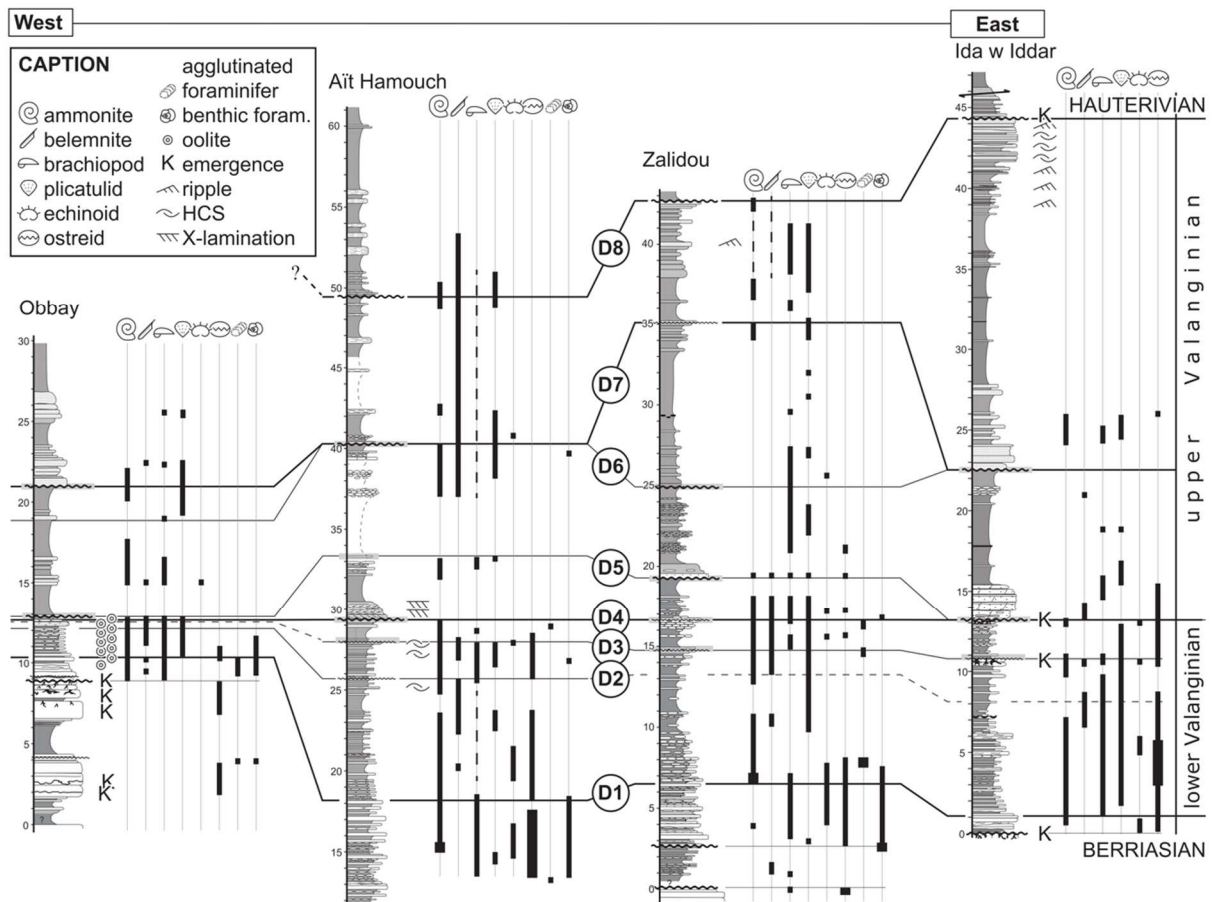
327 1. The top of the Berriasian carbonate shelf is marked by a karstified surface in the
328 northern sections. The overlying lower Valanginian succession (8-15 m) is dominated by
329 marlstone and thin limestone beds (Fig. 3). It shows a thinning-upward, then thickening-upward
330 trend. In the thinning-upward lower part, ammonites, belemnites, plicatulids, and brachiopods
331 dominate. They are also associated with ostreids, *Trichites* sp., pectinids, and with sea-urchins
332 at the base (Fig. 3). Microfacies show mudstone to wackestone textures containing mainly
333 echinoids, bivalves, and agglutinated foraminifers. The fauna indicates an outer shelf
334 depositional environment that represents the maximum depositional depth for the early
335 Valanginian period. In the upper part of the lower Valanginian succession, limestone beds are
336 more abundant and sandstone beds appear in the south (**Aït Hamouch**). The macrofauna is

337 composed of ammonites, belemnites, brachiopods, oysters, and plicatulids, with subordinate
338 regular and irregular sea-urchins, crinoids, serpulids, and locally corals and bone fragments
339 (Fig. 3). Compared with the lower part, this assemblage indicates a shallower depositional
340 depth. Microfacies analysis reveals wackestone textures containing agglutinated foraminifers,
341 brachiopods, echinoids, and benthic foraminifers. Several discontinuities (erosion, karsted
342 surfaces) indicate the existence of three or four depositional sequences, and support a marked
343 shallowing-upward trend that culminated in the late early Valanginian. The Obbay section
344 exhibits a very reduced lower Valanginian succession (3 m), mainly made of limestone beds
345 alternating with thin marlstone interbeds (Fig. 3). Limestones show a wackestone texture
346 containing abundant phosphate-rich glauconitic oolites and are frequently capped by iron-rich
347 hardgrounds. The causes of condensation of this series are discussed in section 5.1.

348 2. The lower part of the upper Valanginian series (5-15 m) is mainly made of marlstone,
349 thin limestone beds, sandy marlstone, and sandy limestone. The sandy beds are more abundant
350 to the north and east (Fig. 3). The succession shows a thinning-upward trend, locally overlain
351 by a thickening-upward series, interrupted by a major erosion period (D7) that removed one
352 depositional sequence in many sections (Fig. 3). It contains an outer shelf to hemipelagic
353 macrofauna (ammonites, belemnites, brachiopods, and plicatulids), although small bivalves and
354 wood fragments are locally found. The upper Valanginian succession is interpreted as a
355 transgressive-regressive sequence, the top of which is frequently eroded. The maximum
356 depositional depth reached a rather deep outer shelf environment during the “middle” late
357 Valanginian.

358 3. The uppermost Valanginian series (8-22 m) is mainly composed of marlstone, thin
359 limestone beds, sandy limestone to the south, and of sandy marlstone and calcareous sandstone
360 to the north. The succession exhibits an overall thinning-, then thickening-upward trend. The
361 macrofauna is dominated by ammonites, belemnites, brachiopods, plicatulids, and serpulids,

362 locally associated with gastropods and wood fragments. To the north and east of the basin, the
 363 uppermost Valanginian deposits are made of sandstone (**Zalidou**) locally showing current
 364 ripples, Hummocky Cross Stratification (HCS), and low angle lamination (Ida w Iddar) (Fig.
 365 3), interpreted as foreshore deposits. This succession is thus interpreted as a transgressive-
 366 regressive sequence reaching an outer shelf environment to the south. The thick overlying
 367 Hauterivian marlstone represent a new, major sea level rise (Ferry et al., 2007).



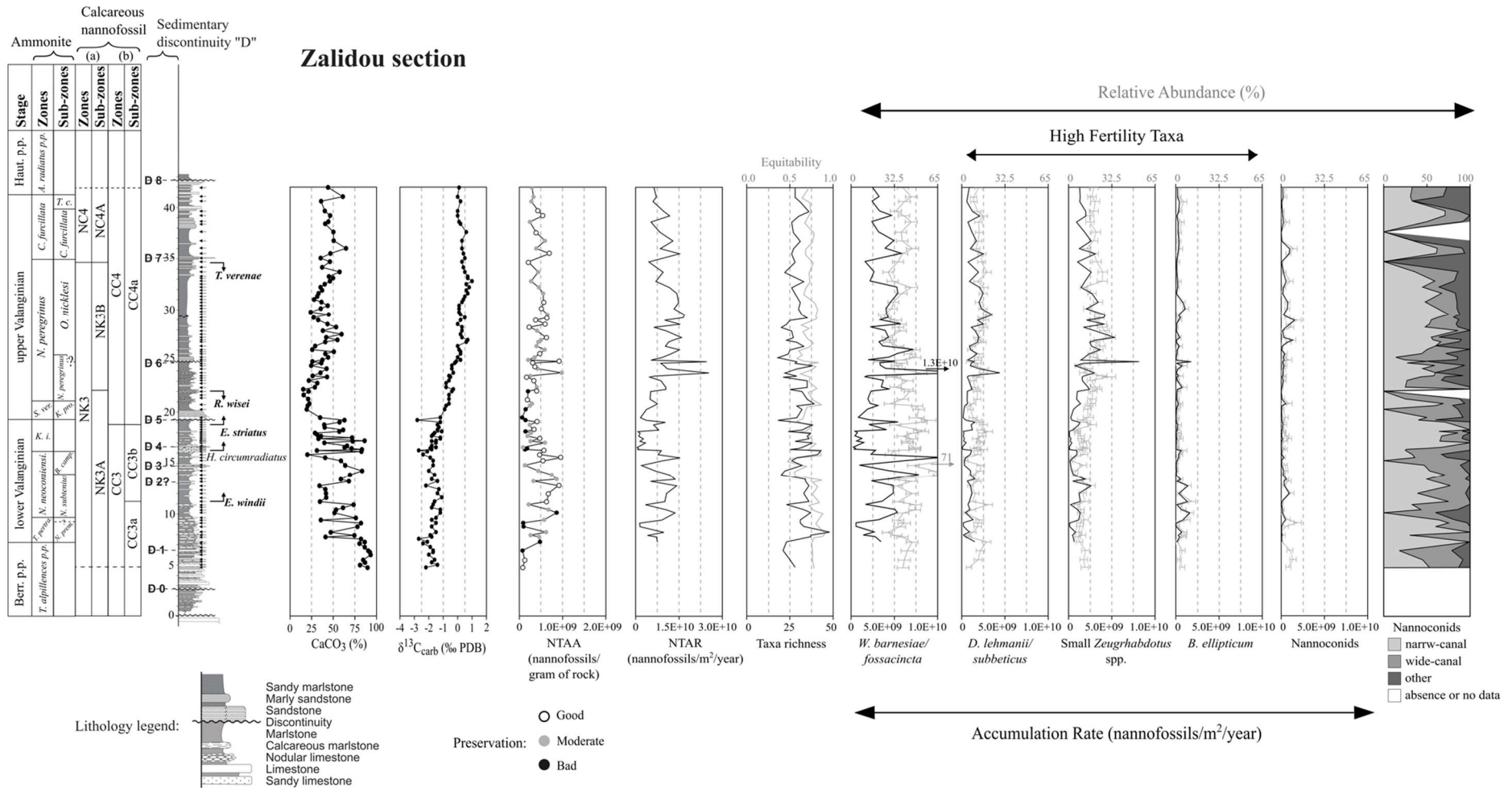
368
 369 Fig. 3. Main sedimentary features, faunal assemblages, and discontinuities (D1 to D8) of some
 370 Valanginian sections in the Essaouira-Agadir Basin. Location of sections is shown in Fig. 1B.

371 **4.2 Calcareous nanofossil biostratigraphy**

372 The identified biozones of Bralower et al. (1995) and Sissingh (1977) are illustrated for
 373 the Zalidou section (Fig. 4), Ait Hamouch section (Fig. 5), and Hole 416A (Fig. 6). Secondary
 374 nanofossil bioevents were also observed (Figs. 4-6). Nanofossil zonal and subzonal markers
 375 are illustrated in Figure 7.

376 A gradual size transition was observed between *Eiffelithus windii* and *E. striatus*
377 (Applegate and Bergen, 1988; Bralower et al., 1989; Bown and Concheyro, 2004), making a
378 proper differentiation difficult. Coccoliths with the length of their long-axes greater than 6.0
379 μm and with a relatively wide central area (almost 2/3 or greater of coccolith length) were
380 identified in this study as *E. striatus* (Fig. 7).

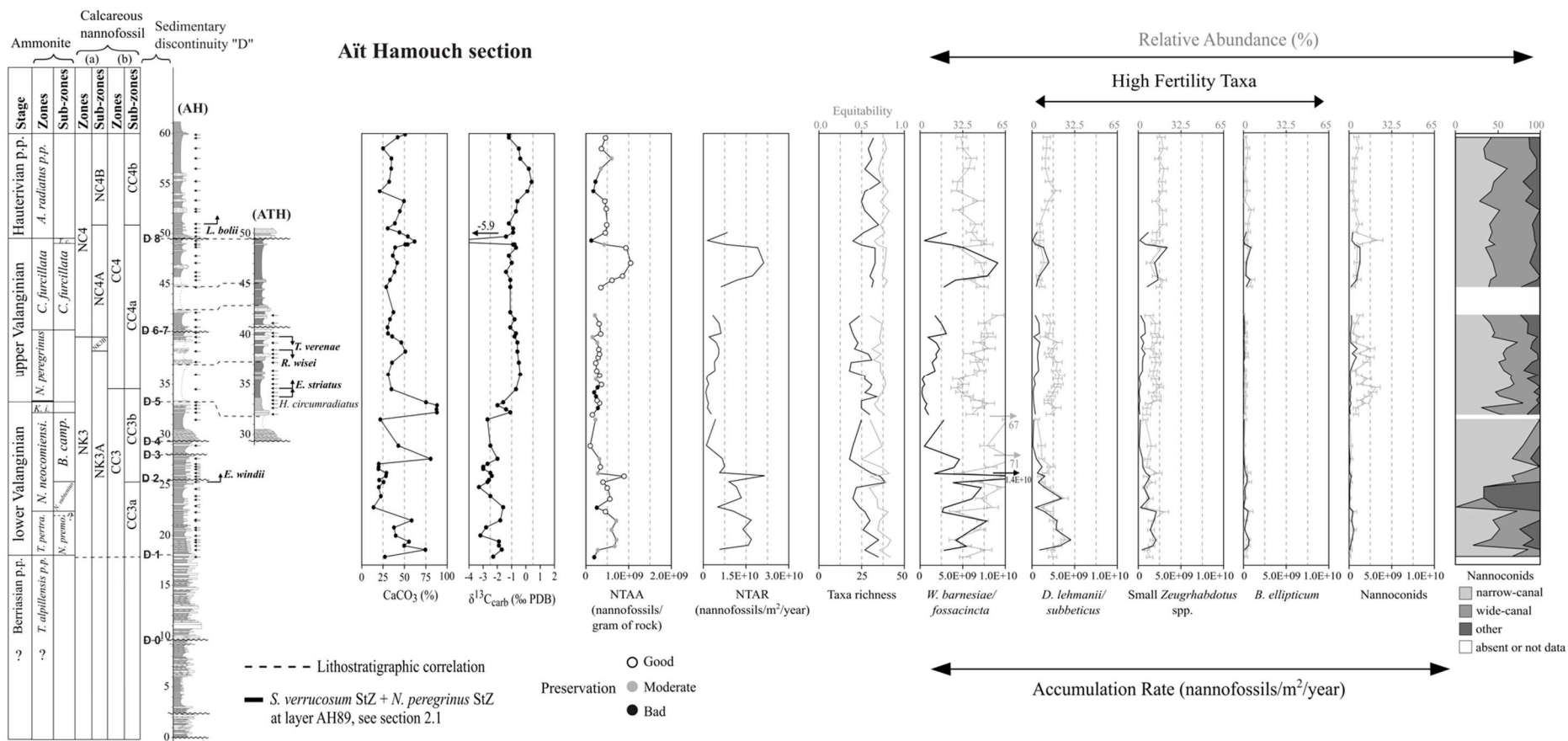
381 Additionally, a new calcareous nannofossil biostratigraphy is proposed for Hole 416A.
382 Čeppek and Gartner (1980) dated the interval between cores 48-1 and 7-1 (~ -1530 to -1000
383 mbsf) to the early Valanginian-late Hauterivian based on calcareous nannofossil
384 biostratigraphy. The LO of *R. wisei* was observed in this study in core 11-4 (-1200 mbsf; Fig.
385 6). In the Zalidou and Aït Hamouch sections, the LO of *R. wisei* was observed in the early late
386 Valanginian (lower and upper *N. peregrinus* StZ in Zalidou and Aït Hamouch, respectively;
387 Figs. 4, 5). Also, our results demonstrate that the Valanginian stage extends to core 9-3 (-1122
388 mbsf) based on the LO of *T. verenae* (top NK3B Subzone). In the onshore sections, the top of
389 the NK3B Subzone ends in the late Valanginian (uppermost *N. peregrinus* StSz). The LO of *T.*
390 *verenae* was also observed at a similar stratigraphic interval both in the Vocontian Basin
391 (Duchamp-Alphonse et al., 2007; Gréselle et al. 2011) and in the Subbetic Basin (Aguado et al.
392 2018). Therefore, we can assume that the top of the studied interval at Hole 416A records the
393 late Valanginian, but not the latest Valanginian.



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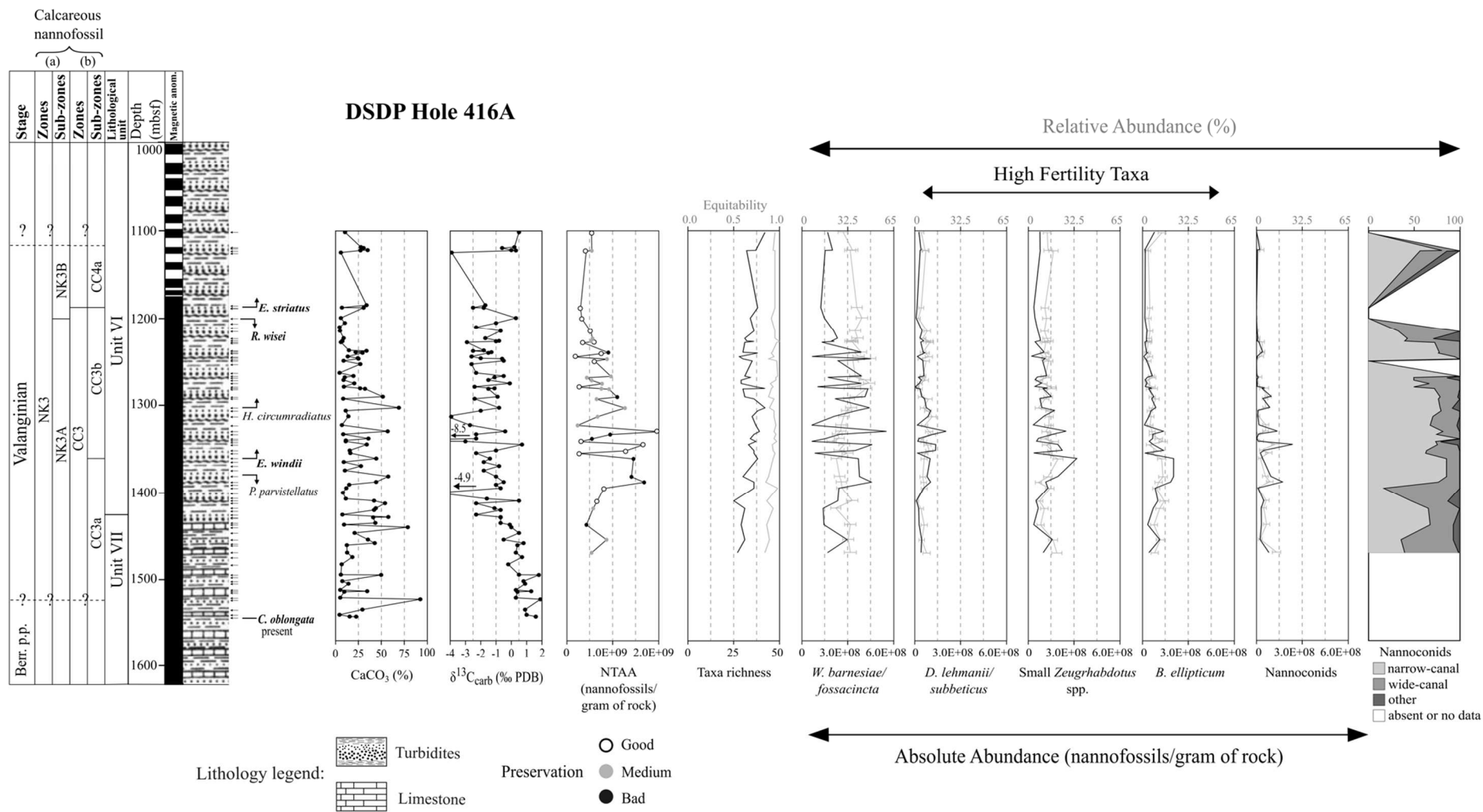
Fig. 4. Calcareous nannofossil and geochemical results in the Zalidou section. Sample locations are indicated by the arrow signs. The recognized stages are plotted with, the ammonite biostratigraphy (zones/subzones) following the ammonite standard zonation of the Mediterranean Province from Reboulet et al. (2018), calcareous nannofossil biostratigraphy (zones/subzones) following the (a) NC and NK zonation of Bralower et al. (1989, 1995) and (b) CC zonation of Sissingh (1977) modified by Applegate and Bergen (1988), sedimentary discontinuities (D0 to D8), and lithology. Calcareous nannofossil first and last occurrences are included; taxa indicated in "bold" font are used in the biostratigraphic schemes (a)

400 and (b), and those in "normal" font correspond to the secondary bioevents. Binomial proportion confidence intervals are included for the nannofossil
 401 relative abundances using the 'exact' Clopper–Pearson method. The proportion of narrow- and wide-canal nannoconids within the nannoconid
 402 population are also shown, "other" nannoconids include specimens whose central-canal was not recognizable. Abbreviations: Berr., Berriasian;
 403 Haut., Hauterivian; *T. pertra.*, *T. pertransiens*; *N. prem.*, *N. premolicus*; *N. neocomiensi.*, *N. neocomiensiformis*; *B. camp.*, *B. campylotoxus*; *K. i.*,
 404 *K. inostranzewi*; *S. ver.*, *S. verrucosum*; *K. pro.*, *K. pronecostatum*; *T. c.*, *Tescheniceras callidiscum*; NTAA, nannofossil total absolute abundance
 405 and NTAR, nannofossil total accumulation rate.

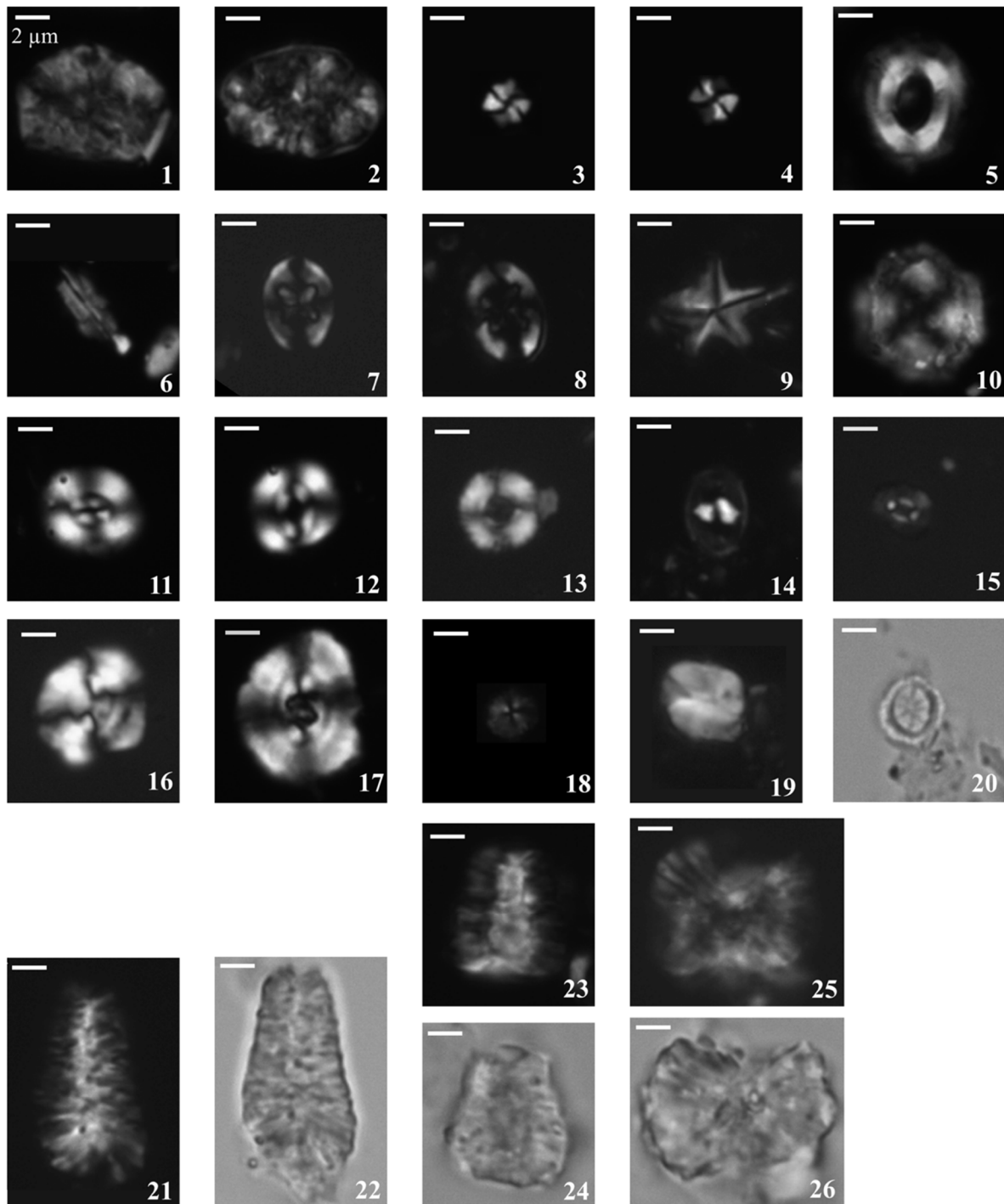


406

407 Fig. 5. Calcareous nannofossil and geochemical results in the Ait Hamouch section, same caption and lithology legend as for Fig. 4. Calcareous
 408 nannofossil results from “AH” section are separated from “ATH” section (see section 2).



410 Fig. 6. Calcareous nannofossil and geochemical results in the DSDP Hole 416A. Sample locations are indicated by the arrow signs. The recognized
411 stage is plotted with, the calcareous nannofossil biostratigraphy (zones/subzones) following the (a) NC and NK zonation of Bralower et al. (1989,
412 1995) and (b) CC zonation of Sissingh (1977) modified by Applegate and Bergen (1988), and lithology. Calcareous nannofossil first and last
413 occurrences are included; taxa indicated in "bold" font are used in the biostratigraphic schemes (a) and (b), and those in "normal" font correspond
414 to the secondary bioevents. Binomial proportion confidence intervals are included for the nannofossil relative abundances using the 'exact'
415 Clopper–Pearson method. The proportion of narrow- and wide-canal nannoconids within the nannoconid population are also shown, "other"
416 nannoconids include specimens whose central-canal was not recognizable. Abbreviations: Berr., Berriasian; magnetic anom., magnetic anomalies;
417 and NTAA, nannofossil total absolute abundance.



418
 419 Fig. 7. Photomicrographs of the selected nannofossil species (XPL: cross-polarized light; PPL:
 420 plane-polarized light). 1, *Calcicalathina oblongata*, side view, XPL, sample Za43c; 2,
 421 *Calcicalathina oblongata*, top view, XPL, sample Za49b; 3, *Rucinolithus wisei*, XPL, sample
 422 Za27a; 4, *Rucinolithus wisei*, XPL, sample Za27a, same specimen rotated $\sim 90^\circ$; 5, *Tubodiscus*
 423 *verenae*, XPL, sample 416A 21R2w 103-104; 6, *Lithraphidites bollii*, XPL, sample AH112a;
 424 7, *Eiffellithus windii*, XPL, sample 416A 10R2w 144-145; 8, *Eiffellithus striatus*, XPL, sample
 425 Za53a; 9, *Polycostella parvistellatus*, XPL, sample 416A 49R1w 124-125; 10, *Haqius*
 426 *circumradiatus*, XPL, sample ATH2d; 11, *Watznaueria barnesiae*, XPL, sample Za28a; 12,
 427 *Watznaueria fossacincta*, XPL, sample Za39a; 13, *Diazomatolithus lehmanii*, XPL, sample
 428 Za32b; 14, *Zeugrhabdotus erectus*, XPL, sample 416A 9R3w 135-136; 15, *Biscutum ellipticum*,
 429 XPL, sample Za32a; 16, *Watznaueria biporta*, XPL, sample Za32a; 17, *Watznaueria*
 430 *britannica*, XPL, sample Za39c; 18, *Discorhabdus ignotus*, XPL, sample Za39d; 19, *Assipetra*

431 *infracretacea*, XPL, sample Za32a; 20, *Rotelapillus crenulatus*, PPL, sample 416A 47R1w 76-
432 77; 21, *N. steinmannii subsp. steinmannii*, XPL, sample ATH2h; 22, *N. steinmannii subsp.*
433 *steinmannii*, PPL, sample ATH2h, same specimen; 23, *N. kamptneri subsp. minor*, XPL, sample
434 ATH2f; 24, *N. kamptneri subsp. minor*, PPL, sample ATH2f, same specimen; 25, *N. globulus*
435 *subsp. globulus*, XPL, sample ATH2f; 26, *N. globulus subsp. globulus*, PPL, sample ATH2f,
436 same specimen.

437 **4.3 Calcareous nannofossil assemblages**

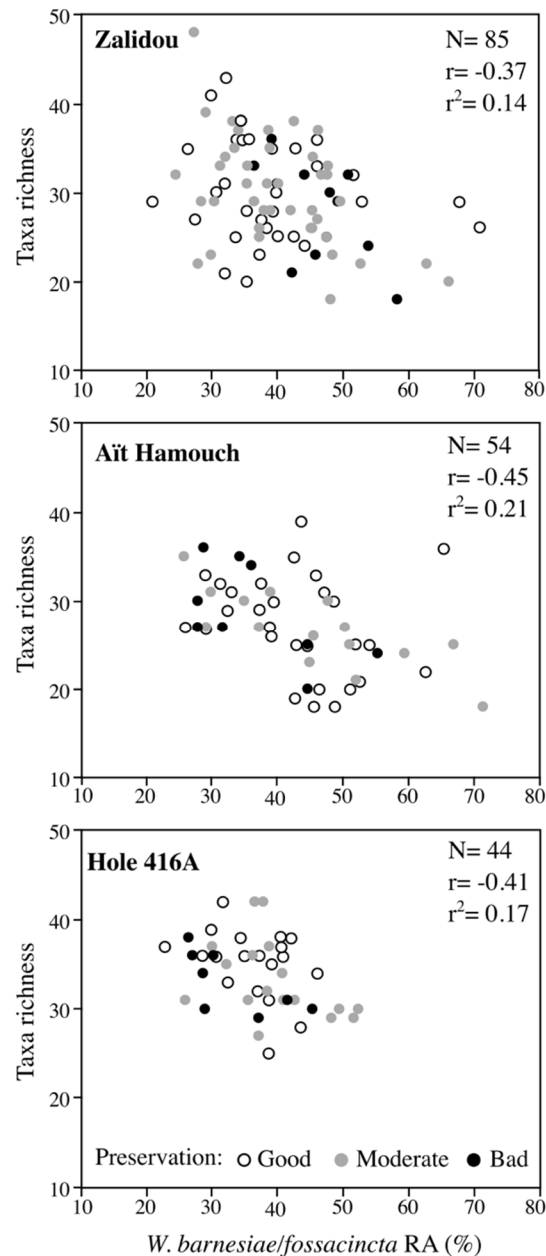
438 The majority of studied samples show good to moderate preservation of calcareous
439 nannofossils with minor dissolution and recrystallization (Fig. 8). Note that the delicate
440 structures of coccoliths are still visible. Highly dissolved and recrystallized coccoliths were
441 limited to 14–18 % of all the samples.

442 Following the abundance classes defined by Erba and Quadrio (1987), calcareous
443 nannofossils are common (10–20 specimens per field of view) in the majority of the studied
444 samples. The calcareous nannofossil assemblage is dominated by eight and nine groups of taxa
445 in the onshore and offshore successions, respectively, illustrated in Figure 7. Altogether, they
446 constitute on average 81 % of the total assemblage at Zalidou, 88 % at Aït Hamouch, and 79 %
447 at Hole 416A. They are: *Watznaueria barnesiae/fossacincta*, *Diazomatolithus*
448 *lehmanii/subbeticus*, small *Zeugrhabdotus* spp., *Biscutum ellipticum*, nannoconids, and to a
449 lesser extent *Discorhabdus ignotus*, other *Watznaueria* species (*W. biporta* and *W. britannica*),
450 and *Assipetra infracretacea*. *Rotelapillus crenulatus* are negligible in both onshore sections,
451 but not at Hole 416A. The reader is referred to the Supplementary Table for more details.

452 In this study, *Diazomatolithus lehmanii* and *Diazomatolithus subbeticus* were combined
453 since they are considered as morphological variants (Grün and Allemann, 1975). The small
454 *Zeugrhabdotus* spp. in this study correspond to *Zeugrhabdotus* with long axis $\leq 5 \mu\text{m}$ combined
455 with *Zeugrhabdotus erectus*. Finally, *W. barnesiae* and *W. fossacincta* were merged since they
456 are considered to be morphological variants (Bornemann and Mutterlose, 2006).

457 The nannoconid group is mainly represented in all studied successions by three taxa, *N.*
458 *steinmannii* corresponding to narrow-canal, and *N. kamptneri* and *N. globulus* both

459 corresponding to wide-canal (see Supplementary Table). These three taxa constitute on average
460 ~80 % of the total nannoconid population in both onshore sections and ~94 % at Hole 416A.
461 Additionally, *N. steinmannii* is the dominant taxon within the total nannoconid population in
462 all three successions (see Supplementary Table).



463
464 Fig. 8. Plot of *W. barnesiaefossacincta* relative abundance (RA, %) and taxa richness in
465 Zalidou, Aït Hamouch, and Hole 416A samples. Preservation classes follow the classes defined
466 by Roth and Thierstein (1972) and modified by Roth (1983). N is the total number of samples,
467 r and r² are the correlation coefficients.

468 4.3.1 Calcareous nannofossil absolute abundance and accumulation rate

469 Four and three intervals with different sedimentation rates were identified throughout
470 the Valanginian stage in Zalidou and Aït Hamouch, respectively (see Supplementary Table).
471 Thus, allowing the calculation of the nannofossil total accumulation rate (NTAR,
472 nannofossils/m²/year). It was not possible to calculate sedimentation rates, and then NTAR, for
473 Hole 416A because the large scatter in $\delta^{13}\text{C}_{\text{carb}}$ (Fig. 6) hindered identifying possible correlation
474 points with the $\delta^{13}\text{C}_{\text{carb}}$ curve from Martinez et al. (2015).

475 The average nannofossil total absolute abundance (NTAA, nannofossils/gram of rock)
476 is higher offshore compared to onshore, and the average NTAR is higher at Zalidou than at Aït
477 Hamouch (Figs 4-6, see also Supplementary Table). In both Zalidou and Aït Hamouch
478 successions (Figs. 4, 5), the NTAR is high in the early Valanginian. Afterwards, NTAR
479 decreases and minimal values are recorded around the early-late Valanginian transition (*K.*
480 *inostranzewi* to *S. verrucosum* StZ, upper NK3A and upper CC3b subzones). Upwards, in the
481 late Valanginian, NTAR gradually increases in both successions. It reaches maximal values
482 within the *N. peregrinus* StZ at Zalidou (Fig. 4), followed by a slight decrease during the rest
483 of the succession. At Aït Hamouch, NTAR values higher than that of the early Valanginian are
484 recorded within the *C. furcillata* StZ (Fig. 5). In both successions, NTAR reflects an
485 amplification of NTAA with very similar trends (Figs. 4, 5), which implies that the
486 sedimentation rate does not significantly affect the NTAA. At Hole 416A, NTAA is low in the
487 lower NK3A and CC3a subzones, and increases during the mid-NK3A and upper CC3a to lower
488 CC3b subzones (Fig. 6). Thereafter, the NTAA gradually decreases to minimal values in the
489 NK3B and the CC3b-CC4a subzones transition.

490 In this study, only the taxa that presented significant variations in all studied successions
491 are considered (Figs. 4-6). Thereby, the following groups are not described: other *Watznaueria*
492 species (*W. biporta* and *W. britannica*), *A. infracretacea*, *D. ignotus*, and *R. crenulatus*. For
493 Zalidou and Aït Hamouch sections, the absolute abundance (AA, nannofossils/gram of rock) of

494 nannofossil taxa are shown in Figs. Supp. 2 and 3, respectively (see also Supplementary Table).
495 The average accumulation rate (AR, nannofossils/m²/year) of each considered nannofossil
496 taxon is generally higher at Zalidou (Fig. 4) compared to Aït Hamouch (Fig. 5), except for
497 nannoconids their average AR is higher at Aït Hamouch than at Zalidou (Supplementary Table).

498 The AR of nannofossil taxa in the onshore sections generally decreases during the *B.*
499 *campylotoxus* LSz and *K. inostranzewi* StZ (NK3A and lower CC3b subzones), earlier than the
500 decrease of NTAR. Their AA in Hole 416A decreases during the same calcareous nannofossil
501 subzones. Notably, the reductions in the NTAR and the AR of taxa are observed earlier in Aït
502 Hamouch (*B. campylotoxus* LSz) with respect to Zalidou (*K. inostranzewi* StZ). During the rest
503 of the successions, the AR or AA of nannofossil taxa generally follow the same trend as that of
504 the NTAR or NTAA, respectively (Figs 4-6).

505 **4.3.2 Calcareous nannofossil diversity indices and relative abundances**

506 Taxa richness and equitability are plotted for Zalidou (Fig. 4), Aït Hamouch (Fig. 5),
507 and Hole 416A (Fig. 6). The offshore succession is characterized by higher nannofossil
508 diversity indices compared to those of the onshore sections. At Zalidou (Fig. 4), the taxa
509 richness shows a long-trend decrease from the early to late Valanginian. The equitability is
510 highest in the early Valanginian. At Aït Hamouch (Fig. 5), the taxa richness decreases to lowest
511 values in the late early Valanginian and in the early late Valanginian. The lowest equitability
512 values are recorded in the late early Valanginian. At Hole 416A (Fig. 6), both taxa richness and
513 equitability increase during the lower NK3A and CC3a to lower CC3b subzones. Upwards, the
514 equitability remains high in the rest of the Valanginian, whereas the richness decreases.

515 At Zalidou (Fig. 4), the RA of *W. barnesiae/fossacincta* is high in the early Valanginian
516 and around the early-late Valanginian transition, then it decreases during the early late
517 Valanginian. At Aït Hamouch (Fig. 5), its RA increases during the late early Valanginian and
518 during the late Valanginian. The RA of *D. lehmanii/subbeticus* increases at Zalidou in the late

519 Valanginian and remains high upsection. Whereas, its RA at Aït Hamouch decreases in the late
520 early Valanginian, followed by a re-increase in the early late Valanginian. In both onshore
521 sections, the RA of small *Zeugrhabdotus* spp. increases to highest values in the late
522 Valanginian. The RA of *B. ellipticum* decreases in both onshore sections to minimal values
523 from the late early Valanginian. Its RA re-increases only at Aït Hamouch in the late
524 Valanginian. The RA of nannoconids declines to minimal values in Zalidou (Fig. 4) from the
525 late early Valanginian to the early late Valanginian. Whereas, at Aït Hamouch (Fig. 5), the RA
526 of nannoconids is low in the early Valanginian and increases to maximal values in the early late
527 Valanginian. Change in the proportion of narrow-canal nannoconids within nannoconid
528 population is observed at Aït Hamouch. Their proportion is high from the early Valanginian to
529 the early late Valanginian compared with the rest of the Valanginian (Fig. 5).

530 At Hole 416A (Fig. 6), the RA of *W. barnesiaefossacincta* increases during the upper
531 NK3A and CC3b subzones. The RA of *D. lehmanii/subbeticus* is relatively stable throughout
532 the Valanginian. The RA of small *Zeugrhabdotus* spp. increases during the upper NK3A and
533 CC3b subzones. The RA of *B. ellipticum* decreases during the same biozones. The RA of
534 nannoconids decreases in the upper NK3A to NK3B and upper CC3b to CC4a subzones. The
535 proportion of narrow-canal nannoconids within the nannoconid population is generally lower
536 in the lower NK3A and CC3a subzones compared with the rest of the succession.

537 **4.4 Calcium carbonate content and carbon isotopes**

538 The CaCO₃ (%) contents range between 15 – 93 (avg. 49 %) at Zalidou, 14 – 88 (avg.
539 41 %) at Aït Hamouch, and 4 – 92 (avg. 23 %) at Hole 416A. At both onshore sections (Figs.
540 4-5), the highest CaCO₃ content is recorded in the early Valanginian. At Zalidou, the decrease
541 in CaCO₃ content is concomitant with a lithological change to more clastic-rich marlstone-
542 limestone beds. At Hole 416A (Fig. 6), the CaCO₃ content decreases and exhibits fewer

543 fluctuations in the upper NK3A to NK3B and upper CC3b to CC4a subzones, compared with
544 down-section.

545 The $\delta^{13}\text{C}_{\text{carb}}$ values range between -2.8 and $+1$ (avg. -0.8 ‰) at Zalidou, -3.3 and $+0.4$
546 (avg. -1.5 ‰) at Aït Hamouch, and between -4.9 and $+1.9$ (avg. -1.0 ‰) at Hole 416A. At
547 Zalidou (Fig. 4), the $\delta^{13}\text{C}_{\text{carb}}$ increases from -2.4 ‰ to $+1$ ‰ between the latest early
548 Valanginian (*K. inostranzewi* StZ, upper NK3A, and upper CC3b subzones) and the latest
549 Valanginian (upper *O. nicklesi* StSz, upper NK3B, and upper CC4a subzones). At Aït Hamouch
550 (Fig. 5), the $\delta^{13}\text{C}_{\text{carb}}$ increases from ~ -2.5 ‰ to ~ -0.4 ‰ between the latest early Valanginian
551 (*K. inostranzewi* StZ, upper NK3A, and upper CC3b subzones) and the early late Valanginian
552 (lower *N. peregrinus* StZ, upper NK3A, and lower CC4a subzones). Accordingly, the carbon-
553 isotope positive shift is of magnitude 3.7 ‰ and 2.3 ‰ at Zalidou and Aït Hamouch,
554 respectively. Then, the $\delta^{13}\text{C}_{\text{carb}}$ smoothly decreases in the rest of the late Valanginian in both,
555 Zalidou ($\sim +0.1$ ‰) and Aït Hamouch (~ -1.1 ‰). At Hole 416A, the $\delta^{13}\text{C}_{\text{carb}}$ does not show
556 any positive shift (Fig. 6).

557 **5. Interpretation**

558 **5.1 Sedimentary paleoenvironment**

559 Except in the lower Valanginian condensed strata of the Obbay section, we did not
560 observe oolites in the limestone beds. This indicates a rather low energy depositional
561 environment in the EAB during most of the Valanginian. As a matter of fact, since trade winds
562 blew to the west, and because the EAB is located on the western coast of Africa, it was little
563 affected by intense tropical storms. These storms may have been generated in the Atlantic
564 Ocean, but were pushed to the west by the trade winds and to the north by the Coriolis force
565 (see Trabucho-Alexandre et al., 2011; Pohl et al., 2019; Jaillard et al., 2021). Therefore, the
566 EAB can be considered to have been a low energy ramp gently sloping toward the ocean.
567 However, the numerous oolites observed on the Obbay swell (Fig. 3) indicate that the

568 shallowest part of the water column was moderately agitated, at least in the early Valanginian.
569 Actually, in the sandstone and sandy limestone beds of late early and late Valanginian age,
570 ripples and scarce trough cross beds indicate a moderate wave activity, while planar parallel
571 laminations suggest tidal processes. Also, the occurrence of thin-bedded HCS in shallow marine
572 beds suggests the occurrence of storms of low intensity. During the late early Valanginian and
573 late Valanginian, the moderate hydrodynamic activity of the surficial part of the water column
574 also accounted for the occurrence of sandstone or sandy limestone beds above the surfaces
575 interpreted as sequence boundaries (Fig. 3). This may be due to the erosion occurring during
576 low sea-level periods, which removed the shale particles and cleared up quartz grains from the
577 sediments. The quartz grains were then deposited as sandy beds during the subsequent
578 transgression.

579 The scarcity of corals and algae, the abundance of agglutinated foraminifers, and the
580 presence of bryozoans in the calcareous beds (mainly early Valanginian) suggest temperate to
581 cold sea water temperatures. Because of the activity of trade winds, the EAB was probably
582 subjected to upwellings (Price et al., 1995; Poulsen et al., 1998). Oceanic upwellings may
583 explain both the cold to temperate waters, and the common occurrence of phosphate in shallow
584 deposited beds.

585 The abundance of ostreids and plicatulids throughout the section suggests mesotrophic
586 conditions, while the presence of agglutinated foraminifers in the early Valanginian suggests,
587 additionally, an oxygen depletion at that time (e.g., Kuhnt et al., 1996; Reolid et al., 2008;
588 Kender and Kaminski, 2017). This interpretation is supported by the abundance of pyrite in the
589 lower Valanginian marlstone of the southern sections. Oxygen depletion, however, must have
590 been mild or sporadic since echinoids are common at that time. Mesotrophic conditions were
591 most likely related to the terrigenous influx of fine-grained clastic particles, more abundant
592 toward the north and east (Fig. 9). This is supported by the sporadic occurrence of wood and

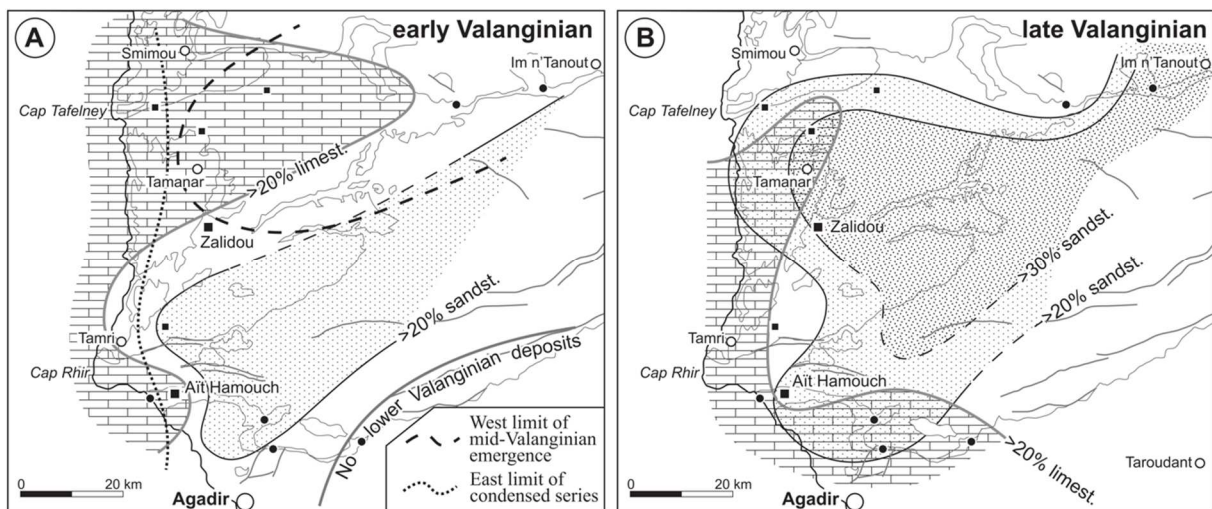
593 leaf fragments (Zalidou) in Valanginian deposits. Actually, a combination of high terrigenous
594 supply, temperate to cold temperature, and the presence of upwellings favors the development
595 of heterozoan carbonate systems (Michel et al., 2018).

596 **5.2 Paleogeography**

597 In the early Valanginian, the northern sections were marked by open marine, oyster-rich
598 shallow carbonate shelf facies exhibiting several karstified surfaces. Whereas, the southern ones
599 presented distal facies marked by thick marlstone intervals, abundant cephalopods, and the lack
600 of emergence evidence (Fig. 9). During the late Valanginian, the northern sections recorded the
601 progradation of a clastic sedimentary system (Fig. 9), which indicates that the clastic supply
602 proceeded from the Central High Atlas (Ferry et al., 2007). Clastic supply was interrupted by a
603 significant erosion period (D7, Figs. 3, 9), likely related to an emergence episode. Furthermore,
604 the uppermost Valanginian deposits end up with foreshore deposits and are capped by an
605 emergence surface to the northeast (Ida w Iddar). Conversely, the coeval sediments in Zalidou
606 bear cephalopods and plicatulids, and end up with a submarine erosional surface to the
607 southwest (Aït Hamouch). The south-westward sloping topography is supported by the onlap
608 of the lower upper Valanginian sequence to the north or northeast (Fig. 3). Although sandstone
609 prograded in the northern part of the basin during the late Valanginian, the southernmost section
610 (Aït Hamouch) displays sandy layers in the late early to earliest late Valanginian (Fig. 9). This
611 suggests that the course of rivers that supplied quartz grains to the EAB was changing through
612 time.

613 In the Obbay section, the lower Valanginian succession is very condensed (Fig. 3). Two
614 explanations may be proposed. First, the presence of strong upwelling currents in the early
615 Valanginian (Price et al., 1995; Poulsen et al., 1998) could have accounted both for the
616 condensation and the abundance of phosphate and glauconite (Föllmi, 1996; Puhfal and Groat,
617 2017). Second, incipient movements of the Amsittene diapir (e.g., Tari and Jabour, 2013) or

618 compressional tectonics in Early Cretaceous times (Bertotti et al., 2012; Fernández-Blanco et
 619 al., 2020) may have locally uplifted this area. If so, the area became a shallow swell reaching
 620 the Fair-Weather Wave Base, on which a high energy regime caused condensation. A
 621 combination of both upwelling and uplift is likely. The fact that condensation disappears during
 622 the late Valanginian sea level rise suggests that either, upwelling currents were less active, or
 623 more probably, their activity was distributed and mitigated in the thicker water column.



624 Fig. 9. Paleogeographic sketch of the Essaouira-Agadir Basin showing the distribution of
 625 sandstone and limestone in the (A) lower Valanginian and the (B) upper Valanginian deposits.
 626 Reconstruction based on data from this study (black squares) and from Ferry et al. (2007) (black
 627 dots).
 628

629 5.3 Preservation of a calcareous nannofossil primary signal

630 The relative abundance (RA) of the solution-resistant *W. barnesiaefossacincta* taxa is
 631 used as an indication of the preservation state. Roth and Krumbach (1986) suggested that
 632 relative abundances of *W. barnesiaefossacincta* > 40 % indicate high degree of diagenesis and dissolution,
 633 while Williams and Bralower (1995) suggested that even higher proportions (> 70 %) indicate
 634 assemblage alteration. In the studied samples, the RA of *W. barnesiaefossacincta* is on average
 635 41 % at Zalidou, 43 % at Ait Hamouch, and 37 % at Hole 416A. Additionally, RA ranges of
 636 *W. barnesiaefossacincta* in this study are not very different from those recorded in other basins:
 637 ~50 – 90 % in Lombardian and Belluno Basins-northern Italy (Erba and Tremolada, 2004); 48
 638 – 78 % in the Vocontian Basin, SE France (Reboulet et al., 2003); 18 – 77 % in DSDP Site 535,

639 Gulf of Mexico (Kessels et al., 2006); and 22 – 59 % in DSDP Hole 603B, northern Atlantic
640 (Bornemann and Mutterlose, 2008). Also, *W. barnesiaefossacincta* dominate the assemblage
641 in the Subbetic Domain (SE Spain) although no quantification was done (Aguado et al., 2018).
642 Most of these studies come from sections having experienced low levels of diagenesis,
643 supporting that the dominance of *W. barnesiaefossacincta* is not a local effect.

644 The correlation between the RA of *W. barnesiaefossacincta* and the taxa richness was
645 tested in all the studied successions (Fig. 8). Despite the fact that a negative correlation can be
646 suspected ($r = -0.37$, $p_{\text{uncorr.}} = 0.0005$, $n = 85$ in Zalidou; $r = -0.45$, $p_{\text{uncorr.}} = 0.0006$, $n = 54$ in Aït
647 Hamouch; and $r = -0.41$, $p_{\text{uncorr.}} = 0.005$, $n = 44$ in Hole 416A), the preservation classes show that
648 samples with strong dissolution and recrystallization do not necessarily correspond to high
649 proportions of *W. barnesiaefossacincta* (Fig. 8). These samples are homogeneously distributed
650 for any given proportion of *W. barnesiaefossacincta*. Moreover, some samples with good and
651 moderate preservation present a high percentage (> 40 %) of *W. barnesiaefossacincta*, which
652 implies that the high proportions of *W. barnesiaefossacincta* can also be part of the original
653 calcareous nannofossil assemblage during the Valanginian.

654 Thereby, based on all aforementioned evidence, we assume that the nannofossil
655 assemblages of both the Essaouira-Agadir Basin and the DSDP Hole 416A are slightly affected
656 by diagenetic alteration but still hold a primary signal that can be used for the paleoceanographic
657 reconstruction.

658 **5.4 Time succession in calcareous nannofossil assemblages**

659 The nannofossil total accumulation rate (NTAR) and nannofossil total absolute
660 abundances (NTAA) along with the accumulation rate (AR), absolute abundance (AA), and
661 relative abundance (RA) of the major calcareous nannofossil taxa demonstrate variations from
662 the early to late Valanginian. This, associated with the sedimentology results, will allow the
663 reconstruction of the paleoceanographic conditions on the central Moroccan margin and to

664 better constrain the evolution of paleoceanographic conditions around the Weissert Event. As
 665 the late Berriasian *p.p.* was only recognized at Zalidou and the early Hauterivian *p.p.* was only
 666 recognized at Aït Hamouch, the discussion will be focused on paleoceanographic conditions
 667 during the Valanginian.

668 For the paleoceanographic reconstruction, the NTAR (and NTAA for Hole 416A) is
 669 used as a proxy to estimate the nannofossil production. The accumulation rates and abundances
 670 (absolute and relative) of the selected nannofossil taxa are used as a proxy for surface-water
 671 fertility levels. The ecological affinity of calcareous nannofossil taxa used for this purpose,
 672 along with the associated literature, are summarized in Table 1.

673 Table 1. Main ecological affinity of the calcareous nannofossil taxa used for paleoceanographic
 674 reconstruction, following the specified literature. 1. Bersezio et al. (2002); 2. Bornemann et al.
 675 (2003); 3. Coccioni et al. (1992); 4. Crux (1989); 5. Erba (1992); 6. Erba et al. (1992); 7. Erba
 676 (1994); 8. Elson and Bralower (2005); 9. Giraud et al. (2003); 10. Herrle (2002); 11. Herrle et
 677 al. (2003); 12. Lees (2002); 13. Lees et al. (2005); 14. Mattioli et al. (2014); 15. Mutterlose
 678 (1991); 16. Mutterlose (1992a); 17. Mutterlose (1992b); 18. Mutterlose and Kessels (2000); 19.
 679 Mutterlose et al. (2003); 20. Mutterlose et al. (2005); 21. Noël et al. (1987); 22. Pauly et al.
 680 (2012); 23. Pittet and Mattioli (2002); 24. Premoli Silvá et al. (1989); 25. Roth (1981); 26. Roth
 681 (1989); 27. Roth and Bowdler (1981); 28. Roth and Krumbach (1986); 29. Street and Bown
 682 (2000); 30. Thierstein (1980); 31. Tremolada et al. (2006); 32. Watkins (1989); 33. Williams
 683 and Bralower (1995).

Taxa	Fertility of surface waters	Ecological strategy	Paleoceanography
<i>B. constans</i>	eutrophic ^{5, 18, 19, 24, 25, 26, 27, 28, 29, 32, 33} meso-eutrophic ⁸	low diversified assemblages ¹⁸ eurytopic ¹⁷	upwelling ^{5, 18, 24, 25, 26, 27, 28} shelf surface-waters ^{21, 29}
<i>B. ellipticum</i>	eutrophic ^{9, 27} meso-eutrophic ¹⁶	r-selected ¹⁸	upwelling ^{6, 12, 30}
<i>D. lehmanii</i>	eutrophic ^{1, 4, 14, 20, 31, 33}		transgressive intervals ⁴ upwelling ³³
<i>D. subbeticus</i> nannoconids	eutrophic ¹⁴ oligotrophic ^{1, 2, 3, 7, 11, 18} meso-oligotrophic ²²	r-selected ²⁹	distal environments ¹⁴ neritic ^{10, 25, 27, 28, 29} lower photic zone ^{2, 7}
<i>W. barnesiae</i>	oligotrophic ^{8, 10, 11, 26, 28, 30, 31, 32} mesotrophic ²³ eurytopic ¹⁴	eurytopic ^{13, 15, 21, 29} r-selected ^{12, 23, 30}	oceanic setting ²⁷
<i>W. barnesiae/fossacincta</i> <i>Z. erectus</i>	eutrophic ^{5, 9, 10, 11, 24, 25, 26, 27, 28, 29, 32, 33} more eutrophic than <i>B. constans</i> ⁶	eurytopic ¹³ r-selected ^{6, 12, 23} low diversified assemblages ¹⁸	upwelling ^{5, 24, 25, 26, 27, 28} shelf-surface water ¹⁸
Small <i>Zeugrhabdotus</i> spp.	eutrophic ^{6, 32}		

684 *B. ellipticum* is considered as a morphotype of *B. constans* (Bornemann and Mutterlose, 2006)

685 **5.4.1 The Zalidou section**

686 During the early Valanginian (*N. premolicus* StSz to upper *B. campylotoxus* LSz, NK3A
687 and upper CC3a to lower CC3b calcareous nannofossil subzones), except for small fluctuations
688 the nannofossil production did not vary and was relatively high (Fig. 4). During the *N.*
689 *premoliticus* StSz and *N. subtenuis* LSz (lower NK3A and CC3a to lower CC3b subzones),
690 favorable surface-water conditions allowed the development of the nannofossil community as
691 suggested by the highest diversity indices. Additionally, local mesotrophic conditions are
692 suggested by the abundant high-fertility taxa. Afterwards, a decoupling between NTAR,
693 diversity indices, AR, and RA of the selected taxa is recorded. In the *B. campylotoxus* LSz
694 (within the NK3A and CC3b subzones), surface-water conditions became less favorable,
695 leading to a decrease in the AR of all nannofossil taxa and in the diversity. Only the eurytopic
696 *W. barnesiaeffossacincta* remained high during this time interval, and the nannofossil
697 production was maintained (Fig. 4).

698 In the latest early Valanginian (*K. inostranzewi* StZ, upper NK3A and upper CC3b
699 subzones), the nannofossil production collapsed as supported by both, minimal NTAR and
700 minimal AR of all nannofossil taxa (Fig. 4). Excluding poor preservation, this collapse could
701 be explained by major paleoenvironmental changes.

702 Afterwards, in the late Valanginian (*S. verrucosum* to upper *O. nicklesi* StSz, upper
703 NK3A to NK3B and uppermost CC3b to lower CC4a subzones), the nannofossil production
704 gradually increased, supported by the re-increasing NTAR and AR of all nannofossil taxa (Fig.
705 4). The end of this recovery phase was marked by a high nannofossil production and meso-
706 eutrophic conditions. The meso-eutrophic conditions are interpreted from the important
707 increase in the small *Zeugrhabdotus* spp. during the late Valanginian (upper *N. peregrinus* and
708 upper *O. nicklesi* StSz, NK3B and CC4a subzones). This time interval was also characterized
709 by the recovery of nannoconids (Fig. 4).

710 Lastly, in the remaining late Valanginian, the nannofossil production slightly decreased
711 with similar magnitudes as those observed in the early Valanginian. However, despite a
712 decrease in surface-water fertility, the fertility remained higher with respect to the early
713 Valanginian as supported by the higher RA of the small *Zeugrhabdotus* spp. (Fig. 4).

714 **5.4.2 The Aït Hamouch section**

715 During the early Valanginian (*N. premolicus* StSz to *N. subtenuis* LSz, lower NK3A
716 and CC3a to lowermost CC3b calcareous nannofossil subzones), the nannofossil production
717 was high with values higher compared to the Zalidou section (Figs. 4, 5). A decoupling between
718 NTAR, diversity indices, AR, and RA of the selected nannofossil taxa is also observed (Fig. 5).
719 During the *N. premolicus* StSz (lower NK3A and CC3a subzones), mesotrophic conditions in
720 surface waters and a thick photic zone allowed a diverse calcareous nannofossil community to
721 flourish. Also, these conditions allowed the development of benthic carbonate producers, such
722 as agglutinated foraminifers, ostreids, and plicatulids (see section 4.1). Afterwards, during the
723 *N. subtenuis* LSz, the surface-water conditions became less favorable for both high-fertility taxa
724 and nannoconids. As at Zalidou, the eurytopic *W. barnesiaefossacincta* remained high during
725 this time interval and nannofossil production was maintained (Fig. 5).

726 During the late early Valanginian (*B. campylotoxus* LSz to *K. inostranzewi* StZ, NK3A
727 and CC3b subzones), the nannofossil production gradually declined and collapsed (Fig. 5).
728 Excluding poor preservation, the trigger of the collapse can be also explained by major
729 paleoenvironmental changes. Decline in the nannofossil production is suggested from the
730 drastic decrease in accumulation rate and abundance of the dominant taxa, *W.*
731 *barnesiaefossacincta*. Nannofossil production remained low during the early late Valanginian
732 (lower *N. peregrinus* StZ, upper NK3A Subzone and CC3a-CC3b subzones transition; Fig. 5).
733 Decreasing percentages of *W. barnesiaefossacincta* within the nannofossil assemblage explain

734 that all other taxa show increasing percentages (in particular nannoconids) despite decreasing
735 AR.

736 Afterwards, in the late Valanginian (upper *N. peregrinus* to *C. furcillata* StZ, upper
737 NK3A to NC4A and CC4a subzones), the nannofossil production first recovered before
738 reaching higher magnitudes than that of the early Valanginian (Fig. 5). This is attested by the
739 increasing NTAR, and AR of all taxa. In parallel, enhanced surface-water trophic levels are
740 demonstrated by the increasing abundances of both *D. lehmanii/subbeticus* and small
741 *Zeugrhabdotus* spp.. The nannoconid AR is maximal, and is associated with decreasing
742 proportion of narrow-canal forms (Fig. 5). Lastly, in the latest Valanginian (*T. callidiscum* StSz,
743 uppermost NC4A and CC4a subzones), the nannofossil production and trophic levels decreased
744 to magnitudes slightly lower than that of the early Valanginian.

745 **5.4.3 DSDP Hole 416A**

746 The lower NK3A and CC3a calcareous nannofossil subzones are characterized by an
747 increase in the nannofossil production, as suggested by both increasing NTAA and abundances
748 of meso-eutrophic taxa (Fig. 6). Marine conditions were also favorable for the development of
749 nannoconids, as their absolute abundance is higher compared with both onshore sections (Fig.
750 6, and Figs. Supp. 2-3). In addition, the nannoconids were mainly represented by narrow-canal
751 forms with the large dominance of *N. steinmannii* (Fig. 6). The assumption that narrow-canal
752 *Nannoconus* inhabited the deep photic zone under stratified waters and a deep nutricline (Erba,
753 2004, 1994) has been challenged by Mattioli et al. (2014), who showed that *N. steinmannii*
754 could have affinity for destratified surface waters. Hole 416A is characterized by turbiditic
755 sequences and low calcium carbonate contents within the Valanginian sediments. The repeated
756 input of clastic material would prevent the stratification of the water column.

757 Upsection, in the upper NK3A-NK3B and CC3b-CC4a subzones, the NTAA and AA
758 of all taxa decrease (Fig. 6). Reduced surface-water fertility during this time interval is shown

759 by the decreasing relative abundance of high-fertility taxa. Nannoconids decline slightly after
760 the fertility decreased in the uppermost NK3A and upper CC3b subzones. These are interpreted
761 as unfavorable surface-water conditions, similar to those observed in the onshore Essaouira-
762 Agadir Basin.

763 The onset of the nannofossil production recovery, similar to that of NTAR observed
764 onshore, seems to occur in the topmost samples (Fig. 6). However, the recovery phase itself as
765 recorded in the onshore settings seems to be missing at Hole 416A.

766 **5.5 The carbon isotope record and identifying the Weissert Event**

767 At Zalidou, we identify the Weissert Event from the base of the carbon-isotope (CI)
768 positive shift (16.25 m) until the climax (32.8 m; Fig. 10), following the formal definition of
769 Erba et al. (2004). The CI positive shift is observed from the lower part of the *K. inostranzewi*
770 StZ to the upper part of the *O. nicklesi* StSz (upper NK3A to upper NK3B and upper CC3b to
771 upper CC4a calcareous nannofossil subzones). The top of the Weissert Event is recorded just
772 below the LO of the nannofossil biomarker *T. verena*.

773 At Aït Hamouch, the *S. verrucosum* StZ and the *O. nicklesi* StSz are not recognized (see
774 section 2.1). Additionally, the *N. peregrinus* StZ is reduced (~7 m) compared with Zalidou (~14
775 m). This can be also observed from the reduced NK3B calcareous nannofossil Subzone in Aït
776 Hamouch (1.5 m) compared with Zalidou (12.5 m; Fig. 10). Moreover, the smooth increase in
777 $\delta^{13}\text{C}_{\text{carb}}$ within the CI positive shift is suspected to be missing from Aït Hamouch. This phase
778 is observed during the *O. nicklesi* StSz in Zalidou (Fig. 10). Thereby, considering both the
779 biostratigraphy of ammonites and calcareous nannofossils along with the chemostratigraphy
780 from carbon-isotope analysis, it is highly possible that part of the late Valanginian could be
781 missing from Aït Hamouch. Furthermore, the paleoceanographic reconstruction from
782 calcareous nannofossils at Zalidou showed a collapse in nannofossil production just after the
783 onset of the identified Weissert Event interval (*K. inostranzewi* StZ; Fig. 10). The collapse was

784 followed by an increase in both nannofossil production and surface-water fertility, and then by
785 slightly decreasing nannofossil production and fertility during the rest of the Weissert Event
786 interval. Using all the above-mentioned information, the Weissert Event interval at Ait
787 Hamouch is cautiously identified from 32.2 to 39.2 m (Fig. 10). This identified Weissert Event
788 interval starts just before the nannofossil production collapse, and terminates when both
789 nannofossil production and surface-water fertility recover and prior to the LO of *T. verenae*.
790 The LO of *T. verenae* demonstrates that it is a reliable event.

791 At Hole 416A, the measured $\delta^{13}\text{C}_{\text{carb}}$ values do not show any positive shift (Fig. 6).
792 Wortmann and Weissert (2000) measured $\delta^{13}\text{C}_{\text{org}}$ in samples from Hole 416A and identified a
793 $\delta^{13}\text{C}_{\text{org}}$ positive excursion from -1420 to -1300 mbsf, which is not recognized in this study (Fig.
794 6). In both onshore sections, the base of the Weissert Event is roughly near to the FO of *H.*
795 *circumradiatus*, although we acknowledge its occurrence is very sporadic. Therefore, we
796 tentatively consider the interval corresponding to the Weissert Event from -1303 to -1122 mbsf
797 in Hole 416A (Fig. 10). Its base is after the onset of the decline in nannofossil production and
798 surface-water fertility, similar to the observation from the onshore sections. The explanation
799 for the absence of a CI positive shift at Hole 416A is unclear. The supposed positive shift might
800 have been diluted by the highly reworked material and terrigenous supply, or concealed by the
801 graded turbidite cycles and/or by the high sedimentation rates known for this interval (Lancelot
802 et al., 1980; Schlager, 1980). Indeed, the Valanginian sediments at Hole 416A are more than
803 400 m thick (Lancelot et al., 1980). Furthermore, the carbonate sediments in all studied
804 successions, including Hole 416A, generally present a similar order of magnitude to the $\delta^{13}\text{C}_{\text{carb}}$
805 values (~ -1.0 ‰).

806 In the Essaouira-Agadir Basin (EAB), the calibration of the Weissert Event with
807 calcareous nannofossils allows the assignment of the CI positive shift to the upper NK3A-upper
808 NK3B subzones (upper CC3b to “middle” CC4a). The base of the Event is close to the FO of

809 *H. circumradiatus*, whereas its end coincides roughly with the LO of *T. verenae* (Fig. 10). The
810 Zalidou section is the most appropriate section to study the Weissert Event in the EAB.
811 Although sedimentological discontinuities and related hiatuses are present, it is the most
812 complete section and well dated by ammonite and nannofossil biostratigraphy (Fig. 10). The
813 $\delta^{13}\text{C}_{\text{carb}}$ clearly shows a carbon-isotope positive shift similar to that observed elsewhere.

814 **5.6 Basin-wide paleoceanographic reconstruction**

815 In the EAB, a high calcareous nannofossil production and mesotrophic surface-water
816 conditions occurred in the early Valanginian before the Weissert Event interval. This time-
817 interval was also characterized by a low energy depositional environment and a mild oxygen-
818 depletion (see section 5.1), which could infer stratification of the water-column. However, some
819 differences existed between the different settings due to their respective paleogeographic
820 location (Fig. 9). The nannofossil production was higher at Aït Hamouch with respect to
821 Zalidou in the early Valanginian (Fig. 10). Aït Hamouch was more distal from the shoreline
822 with respect to Zalidou (see section 5.2; Fig. 9). Consequently, the greater depth of deposition
823 at Aït Hamouch and its location farther from the coastline allowed the development of a large
824 and diverse nannofossil community in a thicker photic zone. Also, trophic levels in surface
825 waters were higher at Aït Hamouch than at Zalidou (Fig. 10). Nutrient input in the EAB was
826 generally maintained from both, clastic river input and oceanic upwelling (see sections 5.1 and
827 5.2). During the early Valanginian, the northern part of the EAB (Zalidou section) was less
828 influenced by clastic river influx with respect to the southern part (Aït Hamouch; see Fig. 9).
829 Moreover, Aït Hamouch was potentially fed by nutrients from the nearby upwelling system
830 observed in the Obbay section. Although, the highest nannofossil production was in Hole 416A,
831 being offshore with the thickest photic zone (Fig. 6, and Figs. Supp. 2-3). Fertility levels
832 decreased prior to the Weissert Event interval in the late early Valanginian in all successions
833 (Fig. 10). Nonetheless, a high nannofossil production was maintained by the eurytopic *W.*

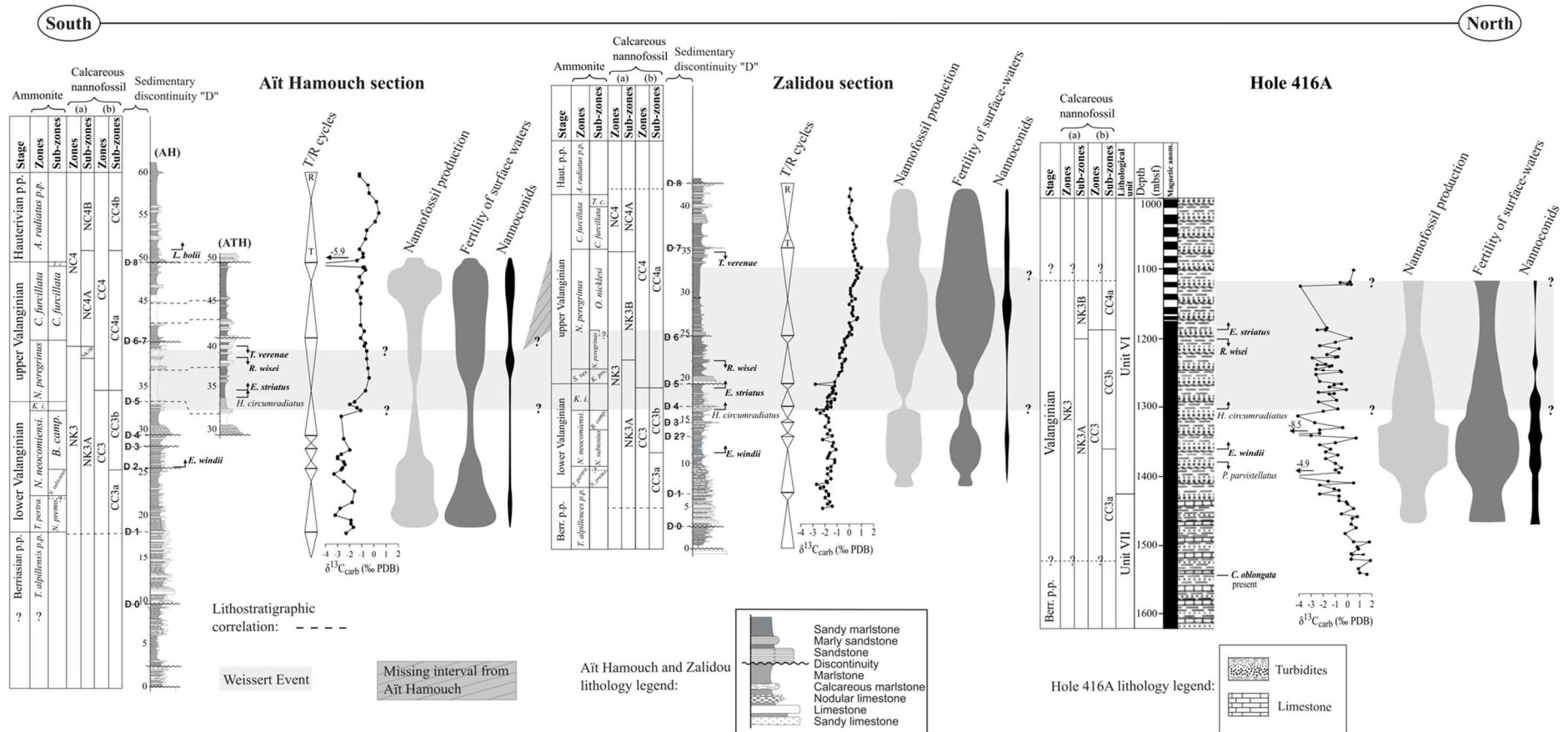
834 *barnesiae/fossacincta*. The fertility decrease was probably related to a major sea level fall
835 recorded on the central Moroccan margin, and culminated with the expression of the D4 and
836 D5 sedimentary discontinuities (Figs. 3, 10). The sea level fall first impacted the nannofossil
837 community of the distal Ait Hamouch section with the possible ocean-ward migration of the
838 upwelling system away from this site, which should have consequently reduced nutrient input.
839 At the same time, storm deposits and coarse clastic input are recorded at Ait Hamouch (section
840 5.1). Additionally, more turbid surface-water due to riverine-clastic input must have favored
841 the proliferation of the eurytopic *W. barnesiae/fossacincta*. Afterwards, the entire nannofossil
842 community collapsed at the onset of the Weissert Event and in its lower part, around the early-
843 late Valanginian transition (Fig. 10). Offshore, in Hole 416A, the onset of the surface-water
844 fertility decline (upper NK3A and CC3b subzones) and the later collapse of the nannofossil
845 community (NK3B and CC3b-CC4a subzones) seem to have occurred slightly later than in the
846 EAB (Fig. 10). We similarly relate these changes to the maximum drop of sea level expressed
847 by the D4 and D5 discontinuities in the EAB. The collapse is observed later in the distal Hole
848 416A possibly due to the hiatuses related to emergences observed on the platform which are
849 not recorded in a deep setting. The nannofossil production gradually recovered during the
850 Weissert Event in the early late Valanginian and was associated with a rising sea-level (section
851 4.1, Fig. 10). Higher riverine clastic input is recorded in the north (Zalidou) with respect to the
852 south (Ait Hamouch; see Fig. 9). High input of clastics and associated nutrients could explain
853 the early recovery at Zalidou in the nannofossil production and in the abundance of high fertility
854 taxa. At Ait Hamouch, the recovery occurred later, and can be explained by the nutrient input
855 that started arriving from the upwelling system. Maximal nannofossil production along with
856 eutrophic surface-waters are recorded only at Zalidou during the upper part of the Weissert
857 Event interval in the late Valanginian (upper *N. peregrinus* to upper *O. nicklesi* ammonite StSz,
858 NK3B and lower CC4a subzones; Fig. 10). Eutrophic surface-waters occurred during maximal

859 flooding and continuous continental influx (section 5.1, Fig. 10). Lastly, a decrease in both the
860 nannofossil production and surface-water fertility occurred after the Weissert Event interval in
861 the rest of the late Valanginian (Fig. 10). Although, trophic levels were higher compared with
862 the early Valanginian. An abrupt increase in the nannofossil production and surface water
863 fertility is observed only at Aït Hamouch during the late Valanginian (*C. furcillata* StZ, NC4A
864 and upper CC4a subzones) after the Weissert Event. At this time, the depositional environment
865 in Aït Hamouch corresponded to an outer shelf (Fig. 9), possibly with a thick photic zone for
866 the nannofossils to flourish. Whereas, the depositional environment in Zalidou corresponded to
867 a clastic shelf with higher turbidity responsible for a reduced photic zone.

868 The nannoconids in the EAB and Hole 416A, mainly represented by *N. steinmannii*
869 (narrow-canal form), generally show a distal-to-proximal gradient with highest abundances in
870 Hole 416A followed by Aït Hamouch and Zalidou, successively. Also, the nannoconids were
871 “thriving” during periods of relatively high fertility in surface-waters in all studied successions
872 (Fig. 10). Initially, this is observed in the early Valanginian onshore (*N. premolicus* StSz to
873 lowermost *N. subtenuis* StSz in Aït Hamouch and *N. subtenuis* LSz in Zalidou section, lower
874 NK3A and CC3a subzones) and in the lower part of the Valanginian interval offshore. Then, a
875 nannoconid decline is recorded onshore in the early Valanginian (*N. neocomiensiformis* to
876 lower *N. peregrinus* StZ, NK3A to lower NK3B subzones, CC3b to lower CC4a subzones),
877 earlier in the southernmost section Aït Hamouch (Fig. 10). Offshore, in Hole 416A, the decline
878 occurred slightly later in the uppermost NK3A to lower NK3B and upper CC3b to lower CC4a
879 subzones. On the central Moroccan margin, this decline can be explained by the drop of sea-
880 level that negatively impacted the entire nannofossil community. A fall of sea-level reduces the
881 size of the photic zone (thickness and geographic extent), and can thus explain the observed
882 decrease within the nannoconid population. DSDP Hole 416A was impacted later due to its
883 distal setting and thicker photic zone. Afterwards, the nannoconids recovered in the late

884 Valanginian (upper *N. peregrinus* StZ, NK3A-NK3B and lower CC4a subzones) during the
885 Weissert Event interval. The nannoconids recovery occurred during periods of relatively high
886 surface-water fertility in all studied successions (Fig. 10). These time-intervals were
887 characterized by a high sea-level, which allowed the development of a thicker photic-zone and
888 consequently various habitats to be occupied. Moreover, during the late early and late
889 Valanginian, the occurrence of thin-bedded HCS restricted to shallow marine beds suggests the
890 occurrence of storms of low intensity (section 5.1). This could suggest the absence of
891 stratification in the water-column.

892 Different positions within the photic zone were proposed for narrow- and wide-canal
893 *Nannoconus* (Table 1). At Ait Hamouch, the proportion of narrow-canal forms (mainly *N.*
894 *steinmannii*) within the nannoconid population reached its highest value during the sea-level
895 fall interval and coincided with maximum clastic input (Fig. 5). Afterwards, although the clastic
896 input was reduced, the proportion of narrow-canal forms within the nannoconid population
897 decreased all along the succession. Then, as shown for Hole 416A, high abundance of *N.*
898 *steinmannii* was not associated with a stratified water column but occurred during high clastic
899 input (see section 5.4.3). This implies a shallow nutricline. Our results confirm the assumption
900 of Mattioli et al. (2014) suggesting that *N. steinmannii* inhabited de-stratified surface waters.



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Fig. 10. Synthesis of the paleoceanographic conditions on the central Moroccan margin. Gray shading refers to the Weissert Event interval, for more details see section 5.5. Striped-correlation refers to a possible missing interval in Ait Hamouch (section 5.5). Simplified schemes of nannofossil production, fertility, and nannoconids abundance are comparable between Zalidou and Ait Hamouch since they are based on the accumulation rate results. Whereas, those of Hole 416A are based on the absolute abundance results. Also added are the transgression (T) – regression (R) cycles (sections 5.1 and 5.2).

907 **5.7 Integrating the central Moroccan margin in a global paleoceanographic**
908 **reconstruction**

909 In order to globally reconstruct the fertility in surface-waters during the Weissert Event,
910 the paleoceanographic conditions (reconstructed from calcareous nannofossil data) of the
911 central Moroccan margin are compared with those of other basins. All of the considered studies
912 used the following taxa (small *Zeugrhabdotus* spp., *B. ellipticum*, *D. ignotus*, and *D. lehmanii*)
913 as indicators of high surface-water fertility.

914 In the early Valanginian, high surface-water fertility was suggested in the western
915 Atlantic in DSDP 535 (Gulf of Mexico; Kessels et al., 2006). In the western and northern
916 Atlantic (DSDP 534A/603B), Bornemann and Mutterlose (2008) suggested that surface-water
917 productivity was already increasing from the Berriasian-Valanginian boundary prior to the
918 Weissert Event. Whereas, in the Tethys (Vocontian Basin, SE France), generally oligotrophic
919 conditions were recorded in the earliest Valanginian (lowermost NK3 Zone). These
920 oligotrophic conditions were followed by more mesotrophic surface-waters prior to the
921 Weissert Event in the early Valanginian (lower NK3 Zone; Duchamp-Alphonse et al., 2007).
922 In the EAB, and in Hole 416A, the nannofossil production and surface-water fertility were
923 relatively high in the early Valanginian (*N. premolicus* StSz to *N. subtenuis* LSz, lower NK3
924 and lower CC3 subzones).

925 At the early-late Valanginian transition and/or during the incipient Weissert Event,
926 increasing surface-water fertility was observed in several basins. In the Pacific (Site 1149B)
927 and Tethys oceans (Lombardian Basin, northern Italy), higher fertility and primary productivity
928 was demonstrated in the upper NK3 Zone to the NC4A Subzone (Erba et al., 2004; Erba and
929 Tremolada, 2004). In the Vocontian Basin (SE France), increasing calcareous nannofossil
930 fluxes resulted from an increase in surface-water fertility during the Weissert Event, with
931 highest values recorded within the lower NK3B calcareous nannofossil Subzone (upper *B.*

932 *Campylotoxus* to lower *S. verrucosum* ammonite zones; Gréselle et al., 2011; Mattioli et al.,
933 2014). In the western and northern Atlantic (DSDP 534A and 603B), a further increase in
934 surface-water primary productivity was observed during the NK3A Subzone and just prior to
935 the carbon-isotope excursion (Bornemann and Mutterlose, 2008). Also, in the western Atlantic
936 (DSDP 535), Kessels et al. (2006) interpreted higher surface-water fertility in the early late
937 Valanginian. The central Moroccan margin complements these previous records, and similarly
938 demonstrates increasing surface-water fertility and nannofossil production during the Weissert
939 Event on the south Tethyan margin.

940 In the rest of the late Valanginian, during the end or after the Weissert Event, surface-
941 water fertility was observed to globally decrease. In the western Atlantic (DSDP 535), trophic
942 conditions decreased in the late Valanginian (Kessels et al., 2006). In the northern Tethys, a
943 decrease in surface-water fertility was observed in the Lombardian Basin (northern Italy),
944 during the NC4A Subzone when $\delta^{13}\text{C}_{\text{carb}}$ is decreasing (Erba and Tremolada, 2004). In the
945 Vocontian Basin (SE France), a decrease in both nannofossil fluxes and fertility indicators was
946 observed from the upper part of the Weissert Event (*N. peregrinus* Zone and upper NK3-lower
947 NC4 subzones; Gréselle et al., 2011; Mattioli et al., 2014). Nonetheless, in the Lower Saxony
948 Basin (northern Germany) surface-water fertility increased during the latest Valanginian
949 (Möller et al., 2020). In the EAB, surface-water fertility and nannofossil production decreased
950 at the top of the Weissert Event and after it, as seen in the most complete section of Zalidou.
951 Although, the fertility remained higher than in the early Valanginian. In the Aït Hamouch
952 section, an abrupt increase in surface-water fertility and nannofossil production related to a
953 thick photic zone in an outer shelf setting was observed in the latest Valanginian (upper *C.*
954 *furcillata* StZ, NC4A and upper CC4a subzones).

955 However, in other studied basins, marine surface-water fertility was stable during the
956 Valanginian. In the northern-central Atlantic (DSDP 638, NW Spain), high surface-water

957 fertility was observed throughout the Valanginian (Kessels et al., 2006). Further north in NE
958 Greenland, which was a gateway between the Arctic Ocean and the northern Tethys,
959 oligotrophic conditions were observed during the Valanginian (Pauly et al., 2012). In the eastern
960 Tethys (south and east Carpathians), generally oligotrophic surface-waters were observed
961 during the Berriasian-Valanginian interval, supported by stable nannofossil diversity and
962 abundance (Melinte and Mutterlose, 2001). From the available data, the eastern and
963 northernmost Tethys seem to have been characterized by unchanging paleoceanographic
964 conditions during the Valanginian. This might have been linked to the physiographic
965 characteristics of these basins and the associated atmospheric/oceanic circulation currents (see
966 Price et al., 1995; Poulsen et al., 1998).

967 **5.8 The nannoconid decline**

968 The decrease in the nannoconid abundances is known as the “Nannoconid decline”, and
969 is globally recorded to start before the Valanginian positive CIE and spans the Weissert Event
970 (Channell et al., 1993; Bersezio et al., 2002; Erba and Tremolada, 2004; Pauly et al., 2012;
971 Möller et al., 2015). In the western Atlantic, the decrease in the nannoconid abundances was
972 observed from the NK3A to NC4A calcareous nannofossil subzones (DSDP 534A; Bornemann
973 and Mutterlose, 2008). In the Vocontian Basin (SE France), a more complicated decline was
974 observed, such that a first decline was recorded from the NK3A to lower NK3B calcareous
975 nannofossil subzones. This was followed by a brief recovery, then by another decline from the
976 upper NK3B Subzone to NC4 Zone (Barbarin et al., 2012). On the central Moroccan margin,
977 the nannoconid decline similarly started prior to the CI positive-shift. It is generally recorded
978 from the NK3A to lower NK3B subzones (CC3b to lower CC4a subzones). Several authors
979 interpreted the decline to be due to enhanced continental-clastic influx and increased
980 nannofossil primary productivity, and possibly under higher oceanic $p\text{CO}_2$ levels (Erba and
981 Tremolada, 2004; Barbarin et al., 2012; Duchamp-Alphonse et al., 2014). Increasing surface-

982 water fertility induces the breakdown of the water-column stratification, and then the decrease
983 in the nannoconid population. Various authors proposed that the distribution of narrow-canal
984 *versus* intermediate and wide-canal *Nannoconus* is controlled by fluctuations in nutricline
985 dynamics. In particular, a nutricline rise from the lower to the upper photic zone would lead to
986 the decrease in the narrow-canal forms, these forms are interpreted as deep-dwellers under
987 stratified waters (Erba, 1994, 2004; Duchamp-Alphonse et al., 2014). Since different habitats
988 within the photic zone seem plausible for the big calcifying nannoconids, a deep-dwelling
989 behavior for *N. steinmannii* can be challenged in this study (see section 5.6) confirming the
990 hypothesis of Mattioli et al. (2014). Furthermore, in the Vocontian Basin, high proportions of
991 narrow-canal forms (mainly represented by *N. steinmannii*) correlate with high coccolith
992 abundance (NK3B to lower NC4A calcareous nannofossil subzones; Angles section; Duchamp-
993 Alphonse et al., 2007, 2014). In addition, the highest proportion of narrow-canal nannoconids
994 are recorded within the Weissert Event in the composite section of Vergol/La Charce, when the
995 values of nannofossil fluxes are the highest (Gréselle et al., 2011; Barbarin et al., 2012). On the
996 central Moroccan margin, the nannoconid decline was probably caused by a sea-level fall that
997 gave rise to higher turbidity in the surface-waters. Higher turbidity probably attenuated light
998 penetration, reducing the photic zone and the development of the total nannoconid population.
999 However, enhanced clastic input and associated nutrients led to a shallow nutricline that did not
1000 particularly impact *N. steinmannii*.

1001 Moreover, the nannoconid recovery was observed to coincide with the high $\delta^{13}\text{C}_{\text{carb}}$
1002 values in the Tethys (Vocontian Basin, France) and in the western and northern Atlantic (DSDP
1003 534A and 603B; Erba and Tremolada, 2004; Bornemann and Mutterlose, 2008; Barbarin et al.,
1004 2012). This agrees with observations in the EAB, since nannoconids recover during the
1005 Weissert Event when the $\delta^{13}\text{C}_{\text{carb}}$ is high and under conditions of both, high nannofossil

1006 production and surface-water fertility. This suggests that nannoconids do not particularly
1007 disfavor such surface-water conditions.

1008 **6. Conclusions**

1009 The quantitative analyses of calcareous nannofossil assemblages from two onshore
1010 sections belonging to the Essaouira-Agadir Basin (SW Morocco) and one offshore succession
1011 (DSDP Hole 416A, east Atlantic Ocean) allowed to reconstruct the paleoceanographic
1012 conditions on a proximal-distal transect across the Valanginian Weissert Event. This
1013 reconstruction was done in a well-constrained ammonite (for onshore sections only) and
1014 nannofossil biostratigraphic and chemostratigraphic (carbon-isotopes) framework, along with
1015 a detailed sedimentological characterization.

1016 The Weissert Event interval is identified in the onshore sections from the
1017 *Karakaschiceras inostranzewi* to upper *Neocomites peregrinus* Standard Zone (StZ) or from
1018 the upper NK3A to upper NK3B, and upper CC3b to “middle” CC4a calcareous nannofossil
1019 subzones. The Valanginian stage demonstrated variations in surface-water fertility and
1020 nannofossil production. A general paleoceanographic scheme is developed: (1) mesotrophic
1021 and favorable surface-water conditions for the nannofossil community prevailed before the
1022 Weissert Event time interval in the early Valanginian. (2) Surface-water fertility levels
1023 decreased prior to the Weissert Event interval, and a high nannofossil production was
1024 maintained by the eurytopic *Watznaueria barnesiaefossacincta*. (3) A collapse of the
1025 nannofossil community during the onset of the Weissert Event interval at the early-late
1026 Valanginian transition was caused by a major sea-level fall. (4) A recovery followed in the early
1027 late Valanginian linked to the rising sea-level. (5) The recovery was followed by maximal
1028 nannofossil production associated with high surface-water fertility, recorded in the northern
1029 section during the upper part of the Weissert Event interval in the late Valanginian; or in the
1030 southern section after the Weissert Event interval in the latest Valanginian. Finally, (6) a

1031 decrease in both surface-water fertility and nannofossil production occurred after the Weissert
1032 Event interval, although they remained high compared with the early Valanginian. Moreover,
1033 the “nannoconid decline” occurred from the early Valanginian to the early late Valanginian.
1034 The nannoconid recovery occurred during conditions of high sea-level and high surface-water
1035 fertility.

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