

Manuscript Details

Manuscript number	EARTH_2018_56_R2
Title	Morphometry and elevation of the Last Interglacial tidal notches in tectonically stable coasts of the Mediterranean Sea.
Article type	Review Article

Abstract

We report detailed morphometric observations on several MIS 5.5 and a few older (MIS 11, 21, 25) fossil tidal notches shaped along carbonate coasts at 80 sites in the central Mediterranean Sea and at an additional six sites in the eastern and western Mediterranean. At each site, we performed precise measurements of the fossil tidal notch (FTN) width and depth, and of the elevation of its base relative to the base of the present tidal notch (PTN). The age of the fossil notches is obtained by correlation with biologic material associated with the notches at or very close to the site. This material was previously dated either through radiometric analysis or by its fossiliferous content. The width (i.e. the difference in elevation between base and top) of the notches ranges from 1.20 to 0.38 m, with a mean of 0.74 m. Although the FTN is always a few centimetres wider than the PTN, probably because of the lack of the biological reef coupled with a small erosional enlargement in the FTN, the broadly comparable width suggests that tide amplitude has not changed since MIS 5.5 times. This result can be extended to the MIS 11 times because of a comparable notch width, but not to the MIS 21 and 25 epochs. Although observational control of these older notches is limited, we regard this result as suggesting that changes in tide amplitude broadly occurred at the Early-Middle Pleistocene transition. The investigated MIS 5.5 notches are located in tectonically stable coasts, compared to other sectors of the central Mediterranean Sea where they are uplifted or subsided to ~100 m and over. In these stable areas, the elevation of the base of the MIS 5.5 notch ranges from 2.09 to 12.48 m, with a mean of 5.7 m. Such variability, although limited, indicates that small land movements, deriving from slow crustal processes, may have occurred in stable areas. We defined a few sectors characterized by different geologic histories, where a careful evaluation of local vertical land motion allowed the selection of the best representative elevation of the MIS 5.5 peak highstand for each sector. This elevation has been compared against glacial isostatic adjustment (GIA) predictions drawn from a suite of ice-sheet models (ICE-G5, ICE-G6 and ANICE-SELEN) that are used in combination with the same solid Earth model and mantle viscosity parameters. Results indicate that the GIA signal is not the main cause of the observed highstand variability and that other mechanisms are needed. The GIA simulations show that, even within the Mediterranean Basin, the maximum highstand is reached at different times according to the geographical location. Our work shows that, besides GIA, even in areas considered tectonically stable, additional vertical tectonic movements may occur with a magnitude that is significantly larger than the GIA.

Keywords	Fossil and Present Tidal Notches, glacial isostatic adjustment (GIA), Vertical tectonic movements
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Opposed reviewers	Alessio Rovere

Submission Files Included in this PDF

File Name [File Type]

lettera editor 2.docx [Cover Letter]

letter to editor 01.05.docx [Response to Reviewers]

annotated manuscript Antonioli et al. 19.06.docx [Revised Manuscript with Changes Marked]

ABSTRACT.docx [Abstract]

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S7.docx [Supporting File]

Submission Files Not Included in this PDF

File Name [File Type]

S2.kmz [Interactive Map Data (.kml, .kmz)]

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Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:

Data will be made available on request



ENTE PER LE NUOVE TECNOLOGIE,
L'ENERGIA E L'AMBIENTE

ENEA, Casaccia, Via Anguillarese 301, 00123 Roma, Italy

Dear Editor in chief,

the present paper we submit to Earth Science Review deals with the fossil tidal notches, carved on the carbonatic cliff of the Mediterranean Sea and attributed to the Marine Isotope Stage 5.5 (125 ka BP, Last Interglacial). When well-preserved, these notches are the most precise markers of past sea levels because they are closely linked to the local tidal range.

We provide a database for more than 80 sites, mostly located in Italy, but also including locations in the eastern and western Mediterranean Sea. All these sites are considered tectonically stable and were already studied. We gathered high-resolution morphometric observations and reviewed the geometric and elevation parameters on a regional perspective.

The elevation of the fossil tidal notch base (measured relative to the base of the present tidal notch) varies from 2 to 12 meters above the current sea level. To understand the reasons for this large variability even in areas considered tectonically stable, these numbers were compared with three different models of Glacial and hydro-isostatic adjustment (GIA), namely ICE-5G, ICE-6G and Anice-Selen.

The results show that in the Mediterranean Sea the variability of the maximum GIA elevation is of the order of 1-2.5 m. Even at sites commonly inferred to be on stable crustal sectors, the current MIS 5.5 FTN elevation is affected by low-rate, albeit significant, local or regional tectonic motions, whose mechanisms and effects are described on a case-by-case basis.

In addition, the morphometric dimension of the fossil notch (width), when compared with the present notch, allows us to speculate that tides during MIS 5.5 were the same as today. For the fossil tidal notches older than 760 ka Bp, the tide amplitudes of the Mediterranean Sea were three time higher than today (up to about 1.8 meters).

All co-authors have approved the manuscript, and agree to its submission. The manuscript has not been previously published and is not under consideration for publication elsewhere.

Sincerely yours,

Fabrizio Antonioli

A handwritten signature in black ink, appearing to read 'F. Antonioli', written in a cursive style.

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2
3 Dear Prof Kandy,
4

5 We have accepted and reported corrections requested by Reviewers 1 and 2 in text,
6 figures and tables. We have also answered to all the questions, as highlighted in this letter
7 and shown (in red) in the annotated manuscript.
8

9
10 Concerning the section on older notches that show a width that is three times that of the of
11 PTN and MIS 5.5 FTN, we agree with Rev. 2 that they are a secondary part of the
12 research, however we believe that they add an important piece of information about the
13 tide amplitude through time. Because this is a morphometric result, and the paper
14 morphometric observations have strong implications on ancient tides, we would prefer to
15 leave this section. Because of the strong correlation between the width notch, the MIS 5.5
16 and the current tide amplitude, this result implies that the tide amplitude in the
17 Mediterranean sea has significantly changed since the middle/lower Pleistocene.
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21 Reviewer 1

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25 The paper focuses on global warming and sea level change, which are topics of global
26 concern and significance. It specifically considers evidence for the MIS 5.5 sea level high-
27 stand derived from fossil tidal notches in the Mediterranean. The paper is very well
28 illustrated and is data-rich, including primary field data and secondary data. The title
29 suggests that the paper uses field-measured tidal notch data, from tectonically stable
30 coasts, as indicators of past sea levels in order to evaluate GIA model predictions but I am
31 not sure it is what it delivers (or, indeed if that is what the title really means). There is a
32 lack of clarity around the specific aim of the paper – although a number of objectives/goals
33 are specified early on there is no clear specification of the research question. It would be
34 helpful for the authors to provide a specific research question that the objectives/goals
35 address because, as it currently stands it is a little difficult to follow and to know how the
36 conclusions address the overall aim.
37
38

39 Introduction par 2 – the reader is told that there is an uncertainty of +/- 5 m in estimates of
40 MIS 5.5 highstand above psl using coral reefs but is not given the estimates – how do they
41 compare with those derived from FTN? Is it reasonable to compare them if coral reefs are
42 not common in the Mediterranean?
43

44 We think that it is reasonable to assign an error bar on the use of corals as sea level
45 markers, whose accuracy is not so clear, but was reported by Muhs et al., 2017 (cited in
46 the reference list) in a recent paper. We wanted to underline in the introduction the high
47 precision of a tidal notch as sea level marker (few centimeters) in comparison with a coral
48 (*Acrocora Palmata*, *Cervicornis*, ecc.) that lives few meters under sea level.
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52 There is a lack of clarity around the specific aim of the paper – although a number of
53 objectives/goals are specified early on there is no clear specification of the research
54 question. It would be helpful for the authors to provide a specific research question that the
55 objectives/goals address because, as it currently stands it is a little difficult to follow and to
56 know how the conclusions address the overall aim.
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62 The overall aim of the work could be made clearer – there are a list of objectives at the
63 end of the introduction but no clear over-arching research question. It is to assess the
64 validity of GIA models using evidence from FTN of known age or something else?
65
66

67 The goals of our work are the following:

68 to carry precise morphometric measurements of FTNs found along coasts in Italy and few other locations in
69 the Mediterranean Sea that are considered tectonically stable, and attributed to the MIS 5.5;

70 to link the FTNs to the closest outcrops with deposits aged to the MIS 5.5;

71 to reference the elevation and morphometry of the FTNs with respect to the modern tidal notch;

72 to make, at some of these localities, morphometric measurements of more elevated and older notches,
73 whose age is known or can be estimated, and compare them with the MIS 5.5 FTNs;

74 to map the regional variability in the elevation of the MIS 5.5 notches, and compare this variability with
75 predictions of specifically built GIA models including different ice-sheets scenarios;

76 to evaluate the residual difference between GIA-corrected elevation of notches in light of slow, mostly
77 tectonically-induced land motions.

78 we changed and inserted this phrase in the manuscript.

79 Section 2.1 par 1 – page number for quotations.

80 We added the page number (pag 81)

81 2.3 what is MIS 5e (others are all numbers) and according to whom are there over 1000
82 sites recorded with MIS 5e evidence? (reference).

83 We changed in the ms MIS 5e in MIS 5.5

84 Are Tyrrhenian sites the same as MIS 5? Final par – what does it mean to calibrate the
85 whole Mediterranean? Not clear what this par means.

86 We explained in the text the calibration of Hearty (1986) on the amino acid ratios
87 measured on mollusk shells based on U/Th or paleontologically dated MIS 5.5 deposits.

88 3. this is a little unclear. Did you measure notches at 80 sites and only in areas that are
89 considered to be tectonically stable?

90 Yes from MIS 5.5.

91 Are the additional sites also only on tectonically stable coastlines?

92 Yes, uplifted notches at 6 sites are older (Middle/Lower Pleistocene) than MIS 5.5 and
93 they are all on tectonically stable coasts since MIS 5.5 times but before are uplifting.

94 It is not clear what 'presented good morphological continuity with a certain origin' means in
95 respect of the FTN at the additional sites.

96 we modified and clarified in the ms as follows:
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121 We established that a tidal notch it is defined as continuous when it can be followed laterally for at least 50
122 meters.
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126 Page 8 'we solved the gravitationally self-consistent sea level equation (SLE)' – add some
127 explanation as to what this is and why it needs to be solved

128 We have modified the Section according to the comment from the reviewer. We have
129 added in the ms further details and information about the numerical modeling and
130 expanded the text to provide the reader with a broad and comprehensive explanation of
131 the theory of the GIA models.
132

133 Page 8 – models of GIA – if the purpose of this section is to identify potential elevations of
134 stillstands in order to see which model the FTN fit best - which is what appears to be
135 stated at the end of the section – then it would be helpful to make this clear at the start of
136 the section.
137

138 First we want to investigate the GIA contribution to the elevation of the highstand and how
139 it works. We do this for three ice-sheet models just to appreciate the variability of the
140 signal. It is what we call “sensitivity test”. How does the RSL change respond throughout
141 the Mediterranean Sea? Are there regional patterns? Are they consistent among the
142 employed ice-sheet models How are they modulated by the solid Earth response? What is
143 the contribution of the earth mantle viscosity profile?
144

145 We then attempt to find a “best” model for explaining the observations.
146
147

148 Page 9, section 4.1 – explain why you would exclude notched lower than 2.5 m and higher
149 than 10 m elevation as this is not clear.

150 It is only a statistic choice: take off maximum and minimum values. As we have specified
151 in the manuscript the result remains the same: general mean **5,75**, cutting maximum and
152 minimum values: **5,95** m.
153

154 It is also not clear what the measure correction is that has not been applied by the other
155 authors when their notch elevations are included. It that the elevation correction for the
156 presence of vermitid rim? Or something else?
157

158 We personally measured 80 sites, but we haven't personally measured 6 published sites
159 at non-Italian locations (Table 3). All this is clearly illustrated in Table 3 caption. Anyway
160 we clarified with a sentence in the text.
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167 Page 11 section 5.1 par 1 – 'This difference supports, based on a larger data set, the
168 conclusions of Antonioli et al. (2015)' – what were their conclusions? Did they find the
169 same differences in width – if so it would be better to state that.
170
171

172 In the paper Antonioli et al., 2015 in addition to the Present day tidal notch, measurements
173 on the FTN morphometry at 8 sites were published. They found that the width of FTN was
174 larger of 8 -15 cm than PTN (Table 1 of Antonioli et al., 2015). In the present paper we
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180 extend the comparison to the 80 sites and found the same result based on a more robust
181 dataset.
182
183

184
185 Section 5.1 par 4 – solution rates are extrapolated over long time periods – it would be
186 helpful to discuss some of the limitations of doing this. The implication is that the notches
187 simply retreat but this assumes parallel retreat of the rock surface. Studies have shown
188 that notches may reach a certain depth, due to differential weathering and erosion on the
189 base, back, roof and surrounding rock surfaces, and then collapse. So, the process of
190 notch retreat is episodic rather than linear and means that it may not be possible to apply
191 microerosion rates over such long time scales as is the case here.
192

193 We added a discussion about the extrapolations regarding long-term rates of
194 erosion. In particular, we discussed the lack of instrumental data older than 50 years, the
195 lack of information related to past climate changes and the probable covering by younger
196 deposits now completely lacking.
197

198 Anyway, these notches do not collapse because they are cut in hard Mesozoic limestones.
199 In general, karst landforms are formed, not collapses, that are common in soft rocks, such
200 as siltstones, claystones, etc.
201

202 Micro erosion rates are commonly used to study notch development, such as many cases
203 in the Mediterranean and in the tropics (Torunski, 1979; Moses, 2013, Furlani et al., 2011,
204 Furlani and Cucchi, 2013, etc)

205 Regarding the comment included in the pdf copy, FTNs are wider because the rim is now
206 absent. It does not mean more erosion, but it means that our measures of the FTN base
207 refers to a different point than the old rim, whose exact position we do not know. The result
208 is that FTN is larger than PTN. Hopefully, our measures refer to the unknown base of the
209 rim so the two are fully comparable, although the base of the present rim is not measured.
210

211 This is also the contribution of the “rim question” to the discussion, claimed in a comment
212 by the reviewer. Anyway, we better explained in the ms these questions reported by the
213 reviewer.
214

215
216 Section 5.3 this section is not entirely clear – were the field-measured FTN elevations
217 corrected according to their geological setting? It would be helpful to clarify what has been
218 done – perhaps in a simple table that shows exactly how the elevation data for each site
219 are adjusted and why?
220

221 We made clearer in the manuscript how we selected the 13 observations considered less
222 affected by local slow tectonic or volcanic processes. We also pointed that the processes
223 still operating in individual sectors and the resulting selection criteria were already
224 illustrated in Table 6.
225

226 Perhaps this is the uncertainty value in Table 1?
227

228 We explain the uncertain variation (in column 3 of Table 1) in the section 3.1 of ms, and
229 we have added some further clarifications in this chapter.
230

231 We underlined in the manuscript the uncertain for each kind of measurement, also, we
232 added in the manuscript the quotation of Table S7 were we provide a complete data set
233 containing (in column 9) the kind of measurement technique used. As requested also by
234 Rewiever 2 we changed error bar in Table 1, 2 and S7.
235
236

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238
239 Section 5.6 par 2 – remove the tentatively that comes after same as
240

241 We removed the expression
242
243

244 Conclusion 8 – is a 1.5 m discrepancy significant? In the introduction the reader is told that
245 the uncertainty associated with coral reefs is +/- 5 m – a 1.5 m discrepancy in that context
246 is relatively small – how and why is it significant in the context of FTN?
247

248 In the present study we use tidal notches that are much better sea-level markers than
249 corals. The uncertainty stipulated by us for the FTNs is maximum 0.25 m, typically 0.1 m
250 or less. Therefore, we retain that the observed discrepancy is significant.
251
252

253 Fig 1 – key has both m and km – should it just be km? [metres and km (not Km)].
254

255 Fig. 1: we corrected metres and changed km, also cleared the caption on sections B, C, D,
256 E, F, G .
257

258 Fig 2 – coverage of the notch by fans or aeolianites? What does the downward arrow in
259 the land block indicate?
260

261 We added in section C of Fig. 2 the phrase "sea level going down" above the arrow. In the
262 caption of Fig. 2 we wrote " the final coverage by detrital fans or aeolianites deposits
263 preserves the notches from the dissolution."
264

265 Fig 3 mentions aeolian erosion of the FTN – but these are not aeolian features – should
266 the word be marine? (subaerial and marine rather than chemical and aeolian?; unclear).
267 Decimal places not needed on the scale bar
268

269 We corrected in the ms the caption changing the word aeolian with subaerial :
270

271 **Fig. 3.** Sections of fossil and present tidal notch morphology. The letters refer to the width (w), depth (d)
272 and the base of the notch (c). On the right an overlap between the present and the fossil tidal notch (for
273 the sites 52, 71 and 2 of Table 1) morphology highlights the marine and aeolian subaerial erosion that
274 slightly modified the original morphology, but preserves a similar width.
275
276
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278

279 Fig 10 – there is no green on this figure
280

281 We changed the caption:
282

283 **Fig. 10.** In blue, the Lisiecki and Raymo (2005) curve corrected by Stocchi et al. (2017) for GIA calculated
284 for Custonaci, Sicily. In red, the same corrected curve for a rate of vertical tectonic movement of 0.81
285 mm/a. In yellow, the calculated age of the uplifted tidal notches of Table 3.
286
287

288 Fig 12 it is not clear how these maps are predicted.
289

290 Description of how maps in Fig. 2 are predicted is given now in the caption of Fig. 2.
291
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298 Fig 4 is referred to on p 10 'Overall, the maximum peaks predicted according to ICE-5G
299 and ICE-6G could explain the observed lower limits (Fig. 12).' but it is not clear how this
300 statement related to Fig 12.
301

302 We have rephrased the sentence in the ms
303

304 Similarly on p 16 'Based on the curve corrected with tectonics in Fig. 12' – there is no
305 curve in Fig 12. Unclear.
306

307 We corrected in the quotation on ms of Fig. 12 in Fig. 10
308

309 Fig 13 – what does 'projected from north' and 'projected from south' mean? The latter is a
310 black dot but there are no black dots anywhere on the Fig.
311

312 The two sites in Tuscany and Sicily have the highest projection compared to all the others,
313 so we preferred to show these two sites in a different way. We added a sentence in the
314 text about the projection. We changed Fig. 13 now the “white” dots are clearly visible.
315

316
317 **Table 4 Most of the references in this table do not appear in the reference list.**
318

319 Thanks, we added the lacking references:
320

321 Cucchi, F., Forti, F., Furlani, S. 2006. Erosion/Dissolution Rates Of Limestone Along The
322 Western Istrian Shoreline And The Gulf Of Trieste. *Geografia Fisica e Dinamica*
323 *Quaternaria* 29, 61-69.
324

325 De Waele, J., Furlani, S. 2013. Seawater and biokarst effects on coastal karst. In:
326 Shroeder, J.F., Frumkin A. (Eds), *Treatise on Geomorphology*, Vol. 6, Elsevier,
327 Amsterdam, 341-350.
328

329
330 Gomez-Pujol, L., Fornos, J.J., Swantesson, J.O.H. 2006. Rock surface millimeter-scale
331 roughness and weathering of supratidal Mallcan carbonate coasts (Balearic
332 Islands). *Earth Surface Processes and Landforms* 31(14), 1792-1801.
333

334
335
336 Moses, C.A. 2013. Tropical rock coasts: Cliff, notch and platform erosion dynamics.
337 *Progress in Physical Geography* 37(2), 206-226.
338

339 Moses, C.A., Robinson, D., Kazmer, M., Williams, R. 2015. *Earth Surface Processes*
340 *and Landforms* 40(6), 771-782.
341

342 Swantesson, J.O.H., Moses, C.A., Berg, G.E., Jansson, K.M., 2006. Methods for
343 measuring shore platform micro erosion: A comparison of the micro-erosion meter and
344 laser scanner. *Zeitschrift fur Geomorphologie N.F. Suppl.* 144, 137-151.
345

346
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348 **-Reviewer 2**
349

350 - My detailed comments are both on the PDF and the letter to the editor, attach.
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357 The paper contains a large amount of data: re-assessed previous observations and newly
358 measure notches' parameters (elevations, width, etc.) compared to GIA evaluations for the
359 MIS5e in various places mainly in central Mediterranean but with a comparison both to
360 Spain in the west and to Israel in the east. The figures are of high quality (see some
361 remarks below regarding them) and present the data clearly. The paper is important to the
362 relative sea level (RSL) community of the Mediterranean and beyond. Therefore,
363 I recommend the paper for publication, following the corrections suggested below and in
364 the text.
365

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368 In general:

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370 The paper presents comparison of modern morphological features of notches to fossil ones,
371 mainly to those dated to the MIS5.5, from stable coasts, that are now exist in various
372 elevations. The field data is compared to GIA calculations but the final conclusion is that
373 the GIA cannot be the only explanation and other crustal movements are assumed.
374 Therefore, to my opinion the title does not fit the final conclusion that "Our work shows
375 that, besides GIA, even in areas considered tectonically stable, additional vertical tectonic
376 movements may occur with a magnitude that is significantly larger than the GIA". To my
377 understanding this challenging and interesting conclusion claims that there are other
378 crustal processes, not only the GIA as a suggested mechanism for various elevations of
379 notches (or other sea level indicators). In cases, these other factors are even more
380 effective than the GIA and the part of the title: "implications for Glacial Isostatic Adjustment
381 model predictions" is not representing this conclusion. It even contradicts it. Therefore, I
382 can suggest a better title: "Last Interglacial tidal notches in tectonically stable coasts in the
383 Mediterranean Sea: various factors involved in their elevations".
384
385

386 As suggested by reviewer 2 we changed the title in:

387
388 Morphometry and elevation of the Last Interglacial tidal notches in tectonically stable
389 coasts of the Mediterranean Sea.
390

391 The paper actually deals with the MIS5.5 notches. Like other indications from this period, they
392 add important and significant data to the records that already exist. To my opinion, the MIS
393 11, 21 and 25 notches do not contribute to the discussion and I suggest deleting them
394 from the paper.
395
396

397 It is true that most of the data concerns the FTN aged to MIS 5.5. However, we have
398 discovered and measured 6 higher and older tidal notches that show a threefold larger
399 width than the FTN or PTN. This observation allows us to reach the important result that
400 the tide amplitude in the Mediterranean Sea was threefold larger in pre-MIS 5.5 times. This
401 result stems from a morphometric observation that is the main goal/method of the paper.
402 Therefore we propose to maintain in the paper the section on the older FTNs. In addition
403 as for the uplifted notches studied in the Custonaci area (sites 75, 76, 77, 78 of Table 2)
404 we provided a precise age (Stocchi et al., 2017) we cancelled the FTN ages (sites 79, 80
405 of Table 2) because far from Custonaci, in column 11 of Table 2 we decided to write more
406 simply "Middle Pleistocene".
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The Introduction need corrections/additions: please follow my remarks in the text. 2.4; the GIA factor, is well written .

arrow 42 Using various methods

We modified and added this phrase and many comment on corals uncertain as requested also by Rev. 1:

the elevation above the present sea level (p.s.l.) of the highstand, measured in globally stable areas (Rovere et al., 2016), has been estimated based on coral reefs using various methods (Bard et al., 1990; Chen et al., 1991; Chappel et al., 1996; Schellmann and Radtke, 2004; Blanchon et al., 2009; Dutton et al., 2015). These estimates show a significant uncertainty (some meters) in the assessment of the palaeo sea level (Muhs et al., 2017) because corals do not live at sea level.

I think that an addition of summary of other methods used for assessing the elevations of the MIS5.5, each with it's uncertainties, is needed.

We added in the manuscript a reference to a paper that discusses on the measurement for assessing elevation of the MIS 5.5 (Rovere et al., 2016). In our paper we only present measurements of tidal notches; in the section Method we described with details the different measurement systems and their error bar.

Observation on Section 2.1

Delete "the oceans" if you do not mention exactly where.

We deleted "in the Oceans" as requested by the reviewer, because the paper regards only the Mediterranean area.

what is the meaning of this limit of 4.0 m? Not clear.

4.0 m is the maximum width of a tidal notch, according to the local tide, as suggested by Trenhaile (2015).

The sentence has to be corrected: it has to be: "half of the notches are in carbonate rocks" right? otherwise there is no sense in the sentence.

We removed the sentence:

~~Nearly half of the Mediterranean's rocky coasts are generated on carbonate rocks (Furlani et al., 2014b) as reef notches.~~

Also, while the timing of the onset of the MIS 5.5 acme is relatively simultaneous, mostly taking place from 129 ka to 126 ka, the timing of the demise of the LIG acme is more variable and ranges from 122 ka to 113 ka (Rovere et al., 2016). I suggest to add also a short paragraph explaining that different GIA models yield different contributions. It's important. No model is "the Bible"....

473
474
475 We have expanded the original Section 3.2 Glacial- and hydro-isostatic adjustment by
476 including further details on the GIA models in general and on the contribution of the ice-
477 sheet models, which are indeed forcing functions within the formalism of the Sea Level
478 Equation, i.e. the equation that relates RSL changes to GIA through the imposition of mass
479 conservation.
480
481

482
483 Yes the three ice sheet models have different ice thickness variations in space and time
484 and are characterized by different lengths of the MIS 5 interval. Actually ICE-5G and ICE-
485 6G share the same length, while ANICE-SELEN is characterized by a longer interglacial.
486
487

488 **Methods:** in chapter 3.1 please see my remarks, mainly regarding the uncertainties: the
489 various error ranges need be explained
490

491
492 **Arrow 114** there is a repetition. Refer to Antonioli 2015 in the first sentence and delete the
493 second.
494

495 we deleted arrows 114 and 113:

496
497 ~~When well-preserved, this landform is the most precise marker of past sea levels because its width~~
498 ~~is closely linked to the local tidal range.~~
499

500
501
502 **arrow 135** Well dated deposits. The dating of the notches is not trivial and it has to be
503 presented in a paragraph in the Introduction.
504

505 We changed it between arrows 123 and 127 :

506
507
508 ~~In the Mediterranean, fossil coral reefs are quite rare, while cemented fossil deposits~~
509 ~~containing Senegalese fauna (*Persististrombus latus* and others molluscs) are often found near~~
510 ~~and at the same elevation of the measured fossil notches. This correspondence in elevation~~
511 ~~made possible the chronological attribution of the measured notches.~~
512

513
514 In the Mediterranean Sea, the prevailing tide is microtidal, and several late Holocene tidal notches, mainly
515 on carbonates, occur (e.g. Benac et al., 2004, 2008; Antonioli et al., 2007; Furlani et al., 2011, 2014a). These
516 considerations allow us to discuss data on the sea level elevation reached during the MIS 5.5 highstand. The
517 obtained values have been corrected on the basis of GIA and other vertical tectonic movements that we
518 located on the basis of a large amount of observed data.
519
520

521
522 **arrow 207** But we have to bear in mind that these are totally different time scales....
523

524 We are aware of this, but we point that there is a strong correlation between the vertical
525 tectonic movements detected at geological and at instrumental time scales. We have
526 however simplified the section
527

528 **arrow 229** Either explain that 5e was the previous terminology or use the same
529 terminology of 5.5
530
531

532
533
534
535 A requested also by Rev. 1 we cancelled 5e and used always MIS 5.5.
536

537 **arrow 241 Add: all attributed to the MIS 5.5**
538

539 We added this phrase in the ms
540

541 **243-248 But what information about the 5.5 sea levels this section obtain?**
542

543 See also the reply to Rev 1, anyway we removed the sentence:
544

545 ~~A recent integrated study (Amorosi et al., 2014; Negri et al., 2015) of Fronte Section~~
546 ~~near Taranto, Italy detailed one of the more representative and thick sections of the MIS~~
547 ~~5.5 along the coasts of the Mediterranean Sea. Facies analysis, detailed macro- and~~
548 ~~microfaunal characterization and sequence stratigraphy (using Senegalese fauna and ten~~
549 ~~U-series dates on Cladocora caespitosa samples) permitted an unequivocal MIS 5.5 age~~
550 ~~(132–116ka) identification. These results show the composite section to be a very~~
551 ~~promising candidate (named Tarentiano) in the search for the Upper Pleistocene global~~
552 ~~boundary stratotype section and point (GSSP).~~
553
554
555

556 **arrow 263 what do you mean by "historical". I suggest to delete and just to refer to this paper.**
557

558 we removed the word historical
559

560 **arrow 340 why corrected by 3 cm? Explain**
561

562
563 It is explained in the manuscript : "The measure was corrected by 3 cm; this value
564 corresponds to the estimated average width of the biological rim (Vermetids, Corallinae
565 Algae and others living at Present sea level) once formed and currently eroded at the base
566 of a FTN".
567

568 **Arrow 350 Please explain why 5 cm uncertainty.**
569

570 We performed a new clearer calculation of the uncertainty (described in the text) which
571 derives from the summed contribution of: 1) marker identification error; 2) instrumental
572 error; 3) lack of vermetid rim.
573

574 **MARKER IDENTIFICATION ERROR: ± 2.5 cm**
575

576 **INSTRUMENTAL ERROR**
577

578
579 a) ± 5.0 cm instrumental error for levelling, total station, GPS
580

581 b) ± 1.0 cm instrumental error for invar telescopic rod (assumed vertically positioned)
582

583 c) ± 15.0 cm instrumental error for the tape
584

585 d) ± 50.0 cm instrumental error for digital altimeter used for the older more uploifted notches
586

587 in case of lack of the vermetid reem: ± 10 cm
588
589
590

591
592
593 in the section Method we better explained how assigned the uncertain depending on the kind
594 of measurement technique. Here the modification (in red) in the ms:
595
596

597 The measurements of the 80 studied sites (Tables 1 and 2 and table S7) were performed using
598 different tools and with an estimated error ranging from ± 1 up to ± 5 cm along the vertical error
599 depending on both the tool and the adopted reference level (MSL, vermetid reef etc., see Fig. 5
600 and S5). All measurements were referred to the base of the PTN or zones where the vermetid reef
601 was present and considered as representative of the MSL ($H = 0$). Vertical profiles along the notch
602 sections were realized through several measurements. An uncertainty of ± 2.5 cm was assumed to
603 account for the identification of the marker.
604
605
606
607

608 The tools we used and related instrumental uncertainty are the following:
609

610 **a)** Global Positioning System/Real Time Kinematic (GPS/RTK) technique. In eight sites (50, 51, 52,
611 54, 74, 75, 79 and 80, respectively, in Figs. 4 and 5; Tables 1 and 2, table S7), we used the
612 GPS/RTK technique which has an accuracy better than ± 3 cm along the vertical. This depends on
613 both the tool and the adopted measurement base (MSL, vermetid reef etc., see S5), but it often
614 depends on the setting of MSL. An accuracy of ± 5 cm was estimated.
615

616 **b)** Levelling surveys. Sites 50, 51, 52 and 54 were surveyed by a levelling technique, using a Leica
617 Runner4 instrument. Elevation data were referred to the local sea level at the time of the surveys
618 and corrected for tides by the nearest tide station (Fig. 5). An accuracy of ± 5 cm was estimated
619

620 **c)** Total station. Sites 79 and 80 were surveyed with a Total Station Leica TCRP 1203, equipped
621 with an infrared laser beam, capable of capturing targets at a distance up to one km. For the
622 measurements in the range of about 700 m, we used the laser beam without a prism, keeping a
623 precision of a few mm along the distance. (Fig. 5). An accuracy of ± 5 cm along the vertical was
624 estimated
625
626

627 **d)** Telescopic rod. In 19 sites (Figs. 4 and 5; Tables 1 and 2, table S7), a 10 m long telescopic
628 measuring gauge was used (Telefix). This device provides direct readings on a graduated tape and
629 is built with non-extensible material which ensures an accuracy of about 3 mm when fully extended
630 to 10 m. We estimated an error comprised from 1 to 5 cm depending on the morphological
631 conditions of the PTN and on the position of the MIS 5.5 FTN (Figure in S5). This is always used
632 when the FTN is orthogonal above the PTN. Otherwise, when a few degrees of inclination occurred
633 ($1-6^\circ$) between the platforms of the PTN and the FTN, the top of the instrument was placed a few
634 cm from the FTN base. The level was defined by an operator located on a nearby boat and were
635 taken photos to roughly verify the positioning of the rod with respect to the significant
636 morphologies. An accuracy of ± 1 cm along the vertical was estimated.
637
638
639

640 **d)** Tape. In 46 sites (Figs. 4 and 5; Tables 1 and 2, Table S7), we used a 20 m long measuring
641 tape, positioned on morphological markers by two operators. This measurement tool was used in
642 sites where the cliff was not back drawn and the tape could therefore be positioned vertically or
643 with an acceptable slant (Figure S5). The use of the tape was done with an operator on the FTN
644 and one on the PTN that is in the sea. Because of the presence of some vertical offset in the
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646
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652 position of the two markers, and resulting tilt of the tape from the vertical, these measurements
653 have been assigned an error bar of ± 15 cm.
654

655 e) Digital altimeter: In three sites (Figs. 4 and 5; Tables 1, 2 and Figure S5, Table S7) where
656 uplifted notches were far from the present day coast, position and elevation measurements were
657 performed by a digital altimeter (Garmin Oregon 650) with a vertical accuracy of 50 cm and were
658 calibrated with respect to the sea level along the nearby coast. Measurements were taken at the
659 base of the FTN and at the vermetid platform. An accuracy of ± 50 cm along the vertical was
660 estimated.
661

662 When the Vermetid rim was lacking, an uncertainty of ± 10 cm was summed to the marker
663 identification and instrumental error.
664
665
666
667

668 arrow 358 The top, living part of the reef?

669
670 Yes

671
672 Arrow 397 Again, explain why this is the uncertainty

673
674 See below, we added the phrase:

675
676
677 The use of the tape was done with an operator on the FTN and one on the PTN that is in the sea.
678 Because of the presence of some vertical offset in the position of the two markers, and resulting tilt
679 of the tape from the vertical, these measurements have been assigned an error bar of ± 15 cm.
680
681

682 Arrow 486 What is the meaning of the mean?

683
684 the arithmetic mean of all measurements
685
686
687

688 Arrow 518 between what? between the notch and the dated fossil? not clear.
689
690
691

692 We modified in the text adding between the notch

693
694 Arrow 520 This is crucial and needs better explanation since dating of notches is the main
695 challenge.
696

697 We explained it in the Method section

698
699 Arrow 597 Add notches; "on MIS 5 notches morphology"
700

701 Done

702
703 Arrows 603 and what is the explanation for it?
704
705
706
707
708

709
710
711 The mix fresh water\salt water greatly increases the chemical dissolution of limestone and the
712 so deeply carved PTN tend to collapse. We added this remark in the ms
713

714 **Arrow 615** What is the contribution of the elevated rim to the discussion?

715
716 The existence of vermetid rim also during MIS 5.5
717

718 **Arrow 617** The argument is not well presented: do you claim that the fossil notches are
719 wider because the rim is now absent which means more erosion? What about the time
720 factor? The MIS6.5 lasted 15ka years. The notches were not created during the whole
721 period but still, maybe during longer periods?
722

723
724 No, today we haven't the fossil rim, and therefore the fossil notch is wider.
725
726

727 **Results.** See my remarks in the text and please pay specific intention to chapter 4.4 remarks:
728 dating the notches is the main challenge and it's not trivial. It needs better explanation.
729 Chapter 4.5: as mentioned above, to my opinion, the older notches are out of context in
730 the current study: there is no s how they were dated, what is the GIA contribution for these
731 old periods, etc. I suggest deleting 4.5.
732

733
734 See response to Editor Prof. Kandy at the onset of the Rebuttal letter
735

736 **Discussion:** lines 603-616 has to be reviewed. Please see my comments there. The fact that
737 the mean width of fossil notches is higher than the mean of the present ones has to be
738 better explained. Chapter 5.1 is too long and actually not contributing to the Discussion
739 which is mainly about the combination of the notches indicating RSL and the GIA. The
740 discussion regarding the rates is not in place and to my opinion not relevant
741

742 **arrow 603 - 616** See before regarding long-term erosion rates.
743

744 **arrow 667** levering o levelling
745

746 We changed in the manuscript in levering
747

748 **Chapter 5.4** deals with the dating issue that is essential for the subject. The most challenging
749 part of dating the notches is not the discussion about the dating methods or the
750 Senegalese fauna (mainly the *Strombus bubonius*, now known as *Persististrombus latus*)
751 but the correlation between the dated units and the notches (sometimes with a long
752 distances between them). Therefore, the chapter has to be revised: to better explain the
753 correlations made and to shorten the discussion about the fossil fauna.
754

755
756 **As I mentioned above already twice:** to my opinion 5.5 is out of the scope of the paper (see
757 the title), but it's up to the authors to decide whether to leave or to remove it. 5.6: please
758 see my comment there: either combine to 5.1 or delete since it is a repetition.
759
760

761
762 See response to Editor Prof. Kandy at the onset of the Rebuttal letter
763

764 **Arrow 808** Delete the RSL. The GIA signal show elevations.....
765
766
767

768
769
770 We deleted RSL
771

772 Arrow 837 delicate is not the right word
773

774 We removed the sentence:

775 Age of the FTN This is a very delicate aspect of our paper: we define the age of FTN in areas of the
776 Mediterranean
777

778 And changed in:
779

780 In this section of the study, we define the age of FTN in areas of the Mediterranean...
781

782 Arrow 843 the correlation has to be better explained. It's not trivial
783

784 As previously written if the FTN is continuous and at same places it is associated with a dated
785 deposit, we take the dating for the whole notch, we added thgis phrase in the ms:
786
787

788
789 Figure 9 shows that in the sites 41-44 the distance of the dated deposit is more than 20 km. We are in the
790 gulf of Orosei (Sardinia, Italy) one of the wildest and least anthropized coasts of the central Mediterranean
791 sea, the distance between the measure of the FTN and the dated deposit is in this case linked only to the
792 inaccessibility for study the deposits of the MIS 5.5, but on the contrary we are in one of the sites where
793 the FTN is longer and continuous of the entire Mediterranean, between the sites 38 and the 44, the FTN is
794 always constantly exposed and visible, there is no doubt that it is always the same notch and present the
795 same age.
796
797

798
799
800 Arrow 927 This issue has been discussed on chapter 5.1 (lines 603-616). therefore, either
801 copmbine or delete 5.6.
802

803 In Section 5.1 Notch morphometry between arrow 603 – 616 we exposed the
804 **morphometry** data
805

806 In Section 5.6 Tide, In this section we discuss of **TIDE**, I remind that the tidal notch width is
807 stricly connected with the local tide. We added a phrase in Section 5.6 and cancelled
808 some repetitive phrases:
809
810

811 Antonioli et al. (2015) ~~demonstrated~~ that the tidal notches are strictly connected with the local tide. But the
812 width of the present tidal notch shows higher values when compared with the local tide (on average the
813 notch has a width slightly less than twice in respect to the mean tidal range). Comparing the FTN width with
814 the PTN width, our results show that the FTN width (mean 0.73 m) is wider by about 0.14 m than that of
815 the PTN (mean 0.59 m); we interpret this greater amplitude as being due to the lack of the biological reef
816 and to the chemical and mechanical erosion of the notch.
817
818

819 Therefore, we believe that the tides of the Mediterranean Sea during the MIS 5.5 highstand were
820 the same as ~~-Temptatively~~ today. ~~Tentatively~~, considering the mean width of PTNs as 0.59 m and 0.38 m as
821 the current mean Mediterranean tide (Antonioli et al., 2015), we can extrapolate the palaeo-tide of MIS
822 25-21 (when the mean width of the uplifted tidal notches is 1.82 meters), resulting in a possible tide of
823 1.21 m, before 780 ka BP, more than **three** times that of today.
824
825
826

827
828
829 **Conclusions: 1-5 are not conclusions but summary of the results. I suggest deleting**
830 **them and starting the conclusions from 6 (there is no no. 7 and after 6 is no. 8...).**
831

832 We accept the observations of the reviewer and have improved the conclusions as follows:

833
834 points 1, 2 and 3 have been refurbished and merged, eliminating results and illustrating
835 conclusions;

836
837
838 point 4 has been similarly reorganized;

839
840 point 5 has been delated as requested;

841
842 points 6 to 10 (now points 3 to 6) have been rearranged and rewritten.
843

844 New conclusions of ms:

845 846 6. Conclusions

847
848 At 80 sites in Italy and subordinately in the eastern and western Mediterranean Sea (Tables 1 and 2), the
849 MIS 5.5 and few older notches have been accurately measured. The main conclusions of this study are:

850
851 1. The morphometric parameters of the PTN and FTN are broadly similar, with only a slightly larger FTN
852 width due to the lack of the biological reef and to the chemical/mechanical erosion of the cliff during later
853 exposure. This result implies that tide amplitude has not changed in the last 125 ka.
854

855
856 2. Differently, during the MIS 25–21 highstands (1.2–0.6 Ma BP), the Mediterranean tides had amplitude
857 three times larger than today.
858

859 3. The GIA-driven RSL changes within the Mediterranean Basin are regionally varying and significantly
860 different from the eustatic signal. Two main typologies of RSL curves can be expected: monotonous rise
861 followed by a late highstand in the central areas and initial (early) highstand followed by an RSL drop in the
862 marginal regions at the western and eastern borders. Overall, the variability of the maximum GIA elevation
863 is between 1 and 2.5 m, i.e. comparable to the expected eustatic contribution of the GrIS. 10.
864

865 4. Provided that the notches represent the maximum peak of local RSL rise, which may occur at different
866 times and with different elevations from place to place (as explained by GIA), the observed spatial
867 variability of MIS 5.5 notches is 1–12. m. This implies that GIA plays a secondary role in driving the regional
868 variability of the maximum MIS 5.5 RSL elevation, and other regionally varying signals, either geologic or
869 oceanographic, are operating.
870
871

872 5. Geologic processes are represented by volcanic intrusions (e.g. at the Orosei Gulf in Sardinia and at
873 Minturno in Latium), or by tectonic displacement (e.g. continental margin down-faulting in western
874 Sardinia and on the eastern Tyrrhenian coast, or contractional uplift in northern Sicily). These low-rate
875 processes cause a spread of up to 10 m in the FTN elevation, five times larger than the GIA variability, even
876 at sites commonly regarded to be on stable crustal sectors.
877
878

879 6. The elevation of the MIS 5.5 notch at selected sites which are less affected by these low tectonic or
880 volcanic movements has a trend that, along a regional E-W transect, mimics but is 1–2 m lower than the
881 predicted values from the GIA ANICE-SELEN model. The 6.5 m elevated MIS 5.5 notch on the Tyrrhenian
882
883
884
885

886
887
888 margin, which is assumed as a reference elevation, has a 1.5 m discrepancy with the model, thus casting
889 doubt on the currently accepted amount of glacio-eustatic contribution to the RSL during the MIS 5.5.
890
891
892
893

894 **Figures:** The figure number is not mentioned on the figures. Please add (Figure 1, Figure 2,
895 etc. on each one).
896

897 **Figures are all regularly numbered in the Elsevier files, in the creation of the pdf they are**
898 **however put in increasing order**
899

900 Figure 1 B to G, please enlarge the font sizes. In Israel (No. F and in the caption) the notches
901 are in Rosh Hanikra, not in Akko
902

903 **We made all requested variations in the new Figure 1**
904

905 Fig. 2 is a very good figure!! Only the caption has to be improved (mainly the English). If
906 possible, enlarge the font's sizes of 2a.
907
908

909 **We enlarged the font of all sections of new Fig. 2 and improved the caption**
910

911 Fig. 6: Are the curves (model predictions) the same for all sites? This is how it looks...or
912 maybe I'm wrong?
913

914 **The predicted RSL curves are very similar for sites very close to each other. In fact, the**
915 **GIA signal is smooth and generally characterized by a very long wavelength, especially for**
916 **ice-distal regions such as the Mediterranean Sea.**
917
918
919

920 **Fig. 8 Why the data in the figure is up to 80 and in the paper you have up to 86 sites?**
921

922 **In Fig. 8 there are the 80 sites we personally measured (Table 1 and 2). The 6 additional**
923 **sites (Table 3) were published by different Authors with different measurement methods**
924 **and without providing the morphometric parameters.**
925
926

927 **Fig. 9: For sites 39 to 44 the distances are huge. It has to be mentioned in the Discussion,**
928 **relating to the degree of the age accuracy of these sites.**
929

930 **We have done it on the Discussion adding this phrase:**
931

932 **Figure 9 shows that in the sites 41-44 the distance of the dated deposit is more than 20 km.**
933 **We are in the gulf of Orosei (Sardinia, Italy) one of the wildest and least anthropized**
934 **coasts of the central Mediterranean sea, the distance between the measure of the FTN**
935 **and the dated deposit is in this case linked only to the inaccessibility for study the deposits**
936 **of the MIS 5.5, but on the contrary we are in one of the sites where the FTN is longer and**
937 **continuous of the entire Mediterranean, between the sites 38 and the 44, the FTN is**
938 **always constantly exposed and visible, there is no doubt that it is always the same notch**
939 **and has the same age.**
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Fig. 10. Following my comments regarding these ancient notches, I suggest to delete.

As previously discussed we want to leave this result regarding an important tide variation during middle-lower Pleistocene in the Mediterranean sea.

Arrow1097 What time period is it "after 120ka? 117ka is also after 120ka... Not clear

We changed: at 120 ka

Tables: table 2 is missing

NO, Table 2 is on the pdf!!!

Tables 1 and 3 are very well presented (Again, correct in Israel: the notches are in the vicinity of Rosh Hanikra and not Akko)

Yes we corrected the name site. And we added on the caption some explanation about uncertain

Table 4: write the title above as in tables 1 and 3.

The title is already written under the letters A H in Table 4

Pages 52-53: not clear to what they belong.

Not clear the question, the ms contains 30 pages in the pdf,

Why same pictures are presented again?

Not clear the question. If the reviewer 2 refers to the Supplementary Tables S3, S4, S5 (A complete collection of images of all the studied notches (numbers refer to Table 1) in these tables all the studied sites are shown, on the contrary in Fig 4 (not supplementary material), are described some representative morphology of the studied tidal notches.

The paper needs English review. In places, I commented on it, but an overall review will improve the paper.

We made a review from a native English.

1
2
3 **Morphometry and elevation of the Last Interglacial tidal notches in tectonically stable coasts of**
4 **the Mediterranean Sea.**
5
6

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38 Bari, Italy.
39

40
41
42 **Keywords**
43

44 Fossil and Present Tidal Notches, glacial isostatic adjustment (GIA), Vertical tectonic movement
45
46
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49

50
51
52 **ABSTRACT**
53

54 We report detailed morphometric observations on several MIS 5.5 and a few older (MIS 11, 21,
55 25) fossil tidal notches shaped along carbonate coasts at 80 sites in the central Mediterranean Sea
56 and at an additional six sites in the eastern and western Mediterranean. At each site, we
57
58
59

60 performed precise measurements of the fossil tidal notch (FTN) width and depth, and of the
61 elevation of its base relative to the base of the present tidal notch (PTN). The age of the fossil
62 notches is obtained by correlation with biologic material associated with the notches at or very
63 close to the site. This material was previously dated either through radiometric analysis or by its
64 fossiliferous content.
65
66
67
68

69 The width (i.e. the difference in elevation between base and top) of the notches ranges from 1.20
70 to 0.38 m, with a mean of 0.74 m. Although the FTN is always a few centimetres wider than the
71 PTN, probably because of the lack of the biological reef coupled with a small erosional
72 enlargement in the FTN, the broadly comparable width suggests that tide amplitude has not
73 changed since MIS 5.5 times. This result can be extended to the MIS 11 features because of a
74 comparable notch width, but not to the MIS 21 and 25 epochs. Although observational control of
75 these older notches is limited, we regard this result as suggesting that changes in tide amplitude
76 broadly occurred at the Early-Middle Pleistocene transition.
77
78
79

80
81 The investigated MIS 5.5 notches are located in tectonically stable coasts, compared to
82 other sectors of the central Mediterranean Sea where they are uplifted or subsided to ~100 m
83 and over. In these stable areas, the elevation of the base of the MIS 5.5 notch ranges from 2.09 to
84 12.48 m, with a mean of 5.7 m. Such variability, although limited, indicates that small land
85 movements, deriving from slow crustal processes, may have occurred in stable areas. We defined
86 a number of sectors characterized by different geologic histories, where a careful evaluation of
87 local vertical land motion allowed the selection of the best representative elevation of the MIS 5.5
88 peak highstand for each sector. This elevation has been compared against glacial isostatic
89 adjustment (GIA) predictions drawn from a suite of ice-sheet models (ICE-G5, ICE-G6 and ANICE-
90 SELEN) that are used in combination with the same solid Earth model and mantle viscosity
91 parameters. Results indicate that the GIA signal is not the main cause of the observed highstand
92 variability and that other mechanisms are needed. The GIA simulations show that, even within the
93 Mediterranean Basin, the maximum highstand is reached at different times according to the
94 geographical location. Our work shows that, besides GIA, even in areas considered tectonically
95 stable, additional vertical tectonic movements may occur with a magnitude that is significantly
96 larger than the GIA.
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104 Keywords

105 Fossil and Present Tidal Notches, glacial isostatic adjustment (GIA), Vertical tectonic movements

106 1. Introduction

107 1. Introduction

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112 Quantifying the elevation and duration of the high-stand that occurred during the Last interglacial,
113 Marine Isotope Stage (MIS) 5.5, is of key importance as it allows the sensitivity of the Greenland and
114 Antarctic Ice Sheets (GrIS and AIS, respectively) to climate conditions that are warmer than the present day
115 to be assessed (all acronyms are defined in table S1). The MIS 5.5 highstand can, therefore, be used as an
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121 analogue for future scenarios of global warming, which is of key importance to 2100 sea-level projections.
122 The elevation above the present sea level (p.s.l.) of the highstand, measured in globally stable areas
123 (Rovere et al., 2016), has previously been estimated based on coral reefs using various methods (Bard et
124 al., 1990; Chen et al., 1991; Chappel et al., 1996; Schellmann and Radtke, 2004; Blanchon et al., 2009;
125 Dutton et al., 2015). These estimates show a significant uncertainty (some meters) in the assessment of the
126 palaeo sea level (Muhs et al., 2017) because corals do not accurately mark the sea level but live in the
127 photic zone. Furthermore, in many regions of the world coral reefs are absent and cannot be relied on to
128 constrain the height of MIS 5.5 sea levels.
129

130
131 In tectonically stable areas of the Mediterranean Sea (Fig. 1A), fossil tidal notches (FTNs) of MIS 5.5
132 age are found at 6–8 m above present sea level (Ferranti et al., 2006; Lambeck et al., 2011, Present tidal
133 notches or PTNs). The base of a tidal notch is considered the best and most precise marker of average
134 palaeo sea level because its width is closely linked to the local tidal range (Antonioli et al., 2015; Rovere et
135 al., 2016; Lorscheid et al., 2017a). The age of FTNs is constrained through correlation with adjacent marine
136 deposits that are either; 1) radiometrically dated using the Th/U method or 2) contain the
137 “Senegalese” fauna (a biostratigraphically distinct assemblage of marine mollusca the
138 appearance of which, in the Mediterranean, is robustly constrained to MIS 5.5). The Mediterranean Sea is
139 microtidal in character and many examples of late Holocene tidal notches formed in carbonate bedrock
140 occur (e.g. Benac et al., 2004, 2008; Antonioli et al., 2007; Furlani et al., 2011, 2014a). These features allow
141 the relationship between tidal notches and sea level elevation to be discussed and estimates of
142 MIS 5.5 sea level to be assessed and corrected.
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146 The aim of this study is to investigate the role of crustal movements in the height distribution
147 distribution of MIS 5.5 FTNs in the Mediterranean, primarily Italy but also from other locations
148 across the basin. In this study we present a database of the
149 morphometric measurements and height elevation of MIS 5.5 FTNs from across the
150 Mediterranean as well as a summary of the chronological information that has been used to correlate these
151 features to the Last Interglacial. The elevation and morphometric relationship between these MIS 5.5 FTNs
152 and modern tidal notches is discussed and presented in order to make observations about crustal
153 movements (furthermore a number of older TFNs are identified and discussed). The paper then maps the
154 regional variability of the elevation of MIS 5.5 notches and compares this variability with predictions of
155 specifically built GIA models that include different ice-sheet scenarios. The paper concludes by evaluating
156 the residual difference between the measured heights of MIS 5.5 FTNs and the GIA-corrected elevation of
157 notches in the light of tectonic movement.
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163 2. Background setting

164 2.1. The tidal notch

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168 Nearly half of the Mediterranean’s rocky coasts are generated on carbonate rocks (Furlani
169 et al., 2014b). Such coasts are characterized by a typical set of landforms (Taborosi and Kazmer,
170 2013), which are related to a combination of mechanical (Trenhaile, 2002), chemical (Higgins,
171 1980; Furlani et al., 2014a) and biological processes (Torunski, 1979), although recently Trenhaile
172 (2014) has argued that notches form also as a consequence of wetting and drying cycles. While
173 bioerosion plays a role in the lowering of rocks in the intertidal zone, some hard bottom biological
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180 communities can protect the bedrock from erosion (Laborel, 1987; Naylor and Viles, 2002). A
181 ~~common landforms in these settings are Tidal notches, these Tidal notches~~ are indentations or
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183 undercuttings ~~that are~~ mainly cut in steep carbonate cliffs at sea level; they are amongst the most
184 common landforms along the Mediterranean's coasts and range from a few centimetres to several
185 meters in width. Antonioli et al. (2015) defined a tidal notch as the undercutting found at, or near,
186 ~~the tidal level on carbonate sea cliffs shaped with characteristic morphology.~~ Tidal notches have
187 been widely used as sea level indicators for more than 150 years, and many authors have
188 suggested that they are cut by complex and polygenetic processes (Spratt et al., 1895; Carobene,
189 1972; Higgins, 1980; Pirazzoli, 1986; Antonioli et al., 2004, 2006; Kelletat, 2005; Furlani et al.,
190 2011, 2014a; Trenhaile, 2014, 2015; Moses, 2013; Moses et al., 2015). Antonioli et al. (2015)
191 measured the morphometric parameters of notches at 73 sites in the central Mediterranean Sea,
192 together with the occurrence and features of the biological rims at their bases, and they
193 correlated these parameters with wave energy, tidal range and rock lithology. Their conclusions
194 were that *'tidal notches in the Mediterranean are, rather than the effect of a single process, the*
195 *result of several processes that co-occur with different rates'* (pag. 81).
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197
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200

201 When the floor is lacking, a tidal notch is defined as a marine notch (Pirazzoli, 1986;
202 Kelletat, 2005; Boulton and Stewart, 2015; Trenhaile, 2015), ~~which although some authors still is~~
203 ~~sometimes call titled~~ a tidal notch ~~by some authors~~ (e.g. Antonioli et al., 2015; Furlani et al., 2017)
204 in order to distinguish it from an inland notch (Shtober-Zisu et al., 2017). Its shape is, in fact,
205 affected by the local tidal range, with a maximum width, *sensu Antonioli et al. (2015)*, up to 400
206 cm (Trenhaile, 2015). In the Mediterranean Sea, present day notch width ranges from 13 to 95 cm.
207 When the floor is lacking, ~~we define the~~ notch as a roof notch. A notch which develops near the
208 sea floor, with sand and pebbles ~~that which~~ mechanically erode the rock, is defined as an
209 abrasional notch. It has no correlation with sea level, as it shows a depth and width which are
210 different from the local tidal regime (Antonioli et al., 2015).
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2.2. Geotectonic setting of the central Mediterranean Sea

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218 The indented coasts of the Mediterranean Basin and the present configuration of the
219 coastal landscape are the result of the interaction between tectonic and morphoclimatic processes
220 ~~that acted~~ during the long-lasting convergence, active since the Late Cretaceous, between the
221 African and European plates along an east-west boundary (Rosenbaum et al., 2002). ~~The region is~~
222 ~~characterized by n~~Narrow as well as broader zones of seismicity and geodetic deformation, which
223 highlight the position of the major plate boundary and of the boundaries of minor plates whose
224 interiors appear to be largely aseismic (Anzidei et al., 2014; De Mets et al., 2015). ~~characterize the~~
225 ~~region.~~
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229
230 The basins of the central Mediterranean Sea are the result of different tectonic processes
231 (Oldow et al., 2002; Rosenbaum et al., 2002; Anzidei et al., 2014). The Adriatic Sea and ~~the~~
232 surrounding promontories are the remaining parts of the Adriatic continental lithospheric block,
233 caught between Europe and Africa, which served as the foreland domain for the southern Alpine,
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239 Dinarid-Hellenid and Apennine thrust belts. The Tyrrhenian Sea is a back-arc basin that opened
240 behind the Apennines in the wake of the retreating Adriatic-Ionian slab and is partially floored by
241 oceanic crust. The Ionian Sea is a remnant of the old Ionian oceanic lithosphere, closed between
242 the Calabria and Hellenic subductions. The result of this tectonic evolution is a complex mosaic in
243 which, during the Late Pleistocene and the Holocene, areas of recognized tectonic stability
244 (Sardinia, western and southeastern Sicily, Campania, southern Apulia, Liguria and Tuscany)
245 alternated with areas marked by often large vertical movements (eastern Sicily, Calabria,
246 Basilicata, Veneto and Friuli, ~~i~~) (Ferranti et al., 2006, 2010; Antonioli et al., 2009). This pattern of
247 vertical stability or deformation is supported by the analysis of seismicity and of global positioning
248 system (GPS) data (Oldow et al., 2002; Devoti et al., 2017; Serpelloni et al., 2014).

253 In addition to tectonic processes, glacio-eustatic sea level changes driven by astronomical
254 causes induced the extensive reshaping of the coastal areas during the Quaternary. Terraced
255 marine deposits and landforms, such as notches, sea caves, inner margins and paleocliffs, mark
256 the past sea-level stands, which and are found today recognizable below and above present-day
257 sea level. The study of these geomorphological features and the constraining of them
258 chronologically has permitted-allowed the recognition of the regional tectonic behaviour/behavior
259 and the long-term to-rent sea-level trend, which have been summarized in recent papers by
260 Ferranti et al. (2006; 2010), Antonioli et al. (2009) and Furlani et al. (2014a).

266 2.3. The MIS 5.5 highstand

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268 The marine isotope substage (MIS) 5.5 corresponds to the last interglacial period, and its
269 geochronology is based on orbital tuning of high-resolution deep-sea oxygen isotope stratigraphy.
270 The geochronological subunit MIS 5.5 occurred between Termination II (end of MIS 6) and the
271 onset of MIS 5.4 and lasted from 132 to 116 ka (Stirling et al., 1998; Shackleton et al., 2003; Kopp
272 et al., 2009; Murray-Wallace and Woodroffe, 2014). The study of Last Interglacial shorelines dates
273 back at least a century (Gignoux, 1913), and sea level indicators that formed during MIS 5.5 have
274 been reported from over one thousand sites worldwide (Pedoja et al., 2011).

278 With respect to the Mediterranean Sea, since the identification and definition of the
279 Tirreniano interglacial stage (effectively MIS 5.5) by Blanc in Sardinia at Cala Mosca in 1908,
280 numerous studies have been published that have identified and dated hundreds of Last
281 Interglacial, or 'Tyrrhenian', sites throughout the Mediterranean (Blanc, 1936; Malatesta, 1985;
282 Hearty 1986, 1987; Zazo et al., 1999; Lambeck and Bard, 2000; Nisi et al., 2003). Using a
283 compilation of 246 sites, all attributed to the MIS 5.5, Ferranti et al. (2006) found a significant
284 alongshore difference in site elevation from +175 to -125 m in respect to the present sea level,
285 which they attributed to the interplay of regional and local tectonic processes, including faulting
286 and volcanic deformation.

290 A recent integrated study (Amorosi et al., 2014; Negri et al., 2015) of *Fronte Section* near Taranto,
291 Italy detailed one of the most representative and extensive MIS 5.5 sequences to be found in the

296
297
298 **Mediterranean.** Facies analysis, detailed macro- and microfaunal characterization and sequence
299 stratigraphy (using Senegalese fauna and ten U-series dates on *Cladocora caespitosa* samples)
300 permitted an unequivocal MIS 5.5 age (132–116 ka) **to be attributed to these deposits.** These
301 results **portray show** the composite section ~~to be as~~ a very promising candidate (named Tarentiano)
302 in the search for the Upper Pleistocene global boundary stratotype section and point (GSSP).
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305
306 In the Mediterranean Sea, *Cladocora caespitosa* is one of the few scleractinian corals that build
307 extended bioherms and the only one that does so at the present time. Its presence is recorded at
308 depths of a ~~few metres (4–10 m)~~ 4–10 m as well as down to 30–40 m of water depth (Peirano et
309 al., 2004; Silenzi et al., 2005; Peirano et al., 2009). Existing banks of *Cladocora* are reported in
310 Croatia (Kružić and Benković, 2008), ~~the largest of which where~~ the most extensive one that is
311 known in the Mediterranean covers an area of more than 650 m², ~~and is the most extensive~~
312 ~~known from the Mediterranean.~~ The depth of the Croatians banks ranges between is 6 and –21 m.
313 Hence, the presence of this coral as fossil allows for the age determination ~~the age of the past sea-~~
314 ~~level high stands, to be dated but it is definitely not a reliable indicator of the paleo water depth~~
315 ~~depth to be established.~~ The presence in fossil deposits of *Persististrombus latus* (= *Strombus*
316 *bubonius*) and other Senegalese fauna have allowed the dating of thousands of deposits, giving a
317 precise chronological attribution.
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322 Finally, Hearty (1986) used available U/Th dates and the presence of Senegalese fauna on
323 some MIS 5.5 fossil deposits to calibrate **the amino acid ratio of shells from these sediments and**
324 **landforms across** the whole Mediterranean area (in particular, *Arca*, *Glycymeris* and
325 *Cerastoderma*). **Using this approach**, he was able to use the amino acid ratios to infer a MIS 5.5
326 age of undated or barren deposits **from elsewhere in the region.**
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328

329 2.4 "Senegalese fauna".

330

331 In the Mediterranean geological context, the term Senegalese fauna indicates a fossil faunistic
332 assemblage consisting of warm species, from the Atlantic (Gignoux, 1911a, b) where “the most
333 famous and common is *Strombus bubonius* Lamarck 1791” (Gignoux, 1913). Other warm water
334 species are represented by *Patella ferruginea*, *Conus ermineus*, *Gemophos viverratus*, *Cardita*
335 *calyculata senegalensis* and *Hyotissa hyotis*. The gastropod *Persististrombus latus* (Gmelin, 1791)
336 (named until 2010 *S. bubonius*) entered in the Mediterranean sea only during the Tyrrhenian time
337 corresponding to the Last Interglacial Time ; this last term - in the form "Tirreno" - has been
338 proposed for the first time by Issel (1914) and then by Déperet (1918) for indicating the age of
339 raised marine terraced deposits characterised by the presence of Senegalese fauna with or
340 without *P. latus*.
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345 It is generally correlated to the last interglacial (MIS 5.5), which occurred between 132 and 116 ka
346 roughly, but generally extended up to 80k a; this lap of time has been defined thanks to different
347 age determinations performed by means of U/Th analysis on the coral *Cladocora caespitosa* and
348 amino acid racemization analyses on mollusc shells as *Glycymeris sp*, *Arca sp* and *Cerastoderma sp*.
349 associated to the before mentioned taxa (e.g.: Amorosi et al., 2014; Negri et al., 2015 and
350 references therein).
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357 Bonifay and Mars (1963) affirmed that the *S. bubonius* (today *P. latus*) is not the characteristic
358 element of the Tyrrhenian and Senegalese deposits. In fact, it is very important to underline that
359 the presence of this tropical gastropod defines only a fossil facies and not all Tyrrhenian deposits
360 ("*Tirreno*" in Issel, 1914) with warm fauna of Atlantic origin (sensu Gignoux, 1911a,b; 1913) or
361 Senegalese (sensu Bonifay and Mars, 1963).
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369 2.54. Glacial- and hydro-isostatic adjustment
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371 Quantifying the melting of the GrIS and AIS during the MIS 5.5 on the basis of paleo RSL
372 indicators from tectonically stable areas requires that the GIA process ~~to be~~ accounted for
373 (Dutton and Lambeck, 2012). This is usually accomplished by means of numerical modelling. The
374 latter demands that an ice-sheet model, which describes the forcing function (i.e. the surface
375 loading variation), is combined with a solid Earth model, which describes the response function
376 (i.e. solid Earth and geoid deformations). The outcome yields the space- and time-dependant RSL
377 changes that accompany and follow the ice-sheet fluctuations. The GIA-driven RSL changes
378 incorporate all the solid Earth and geoid deformations that stem from the pre-MIS 5.5 glacial-
379 interglacial cycles (in particular the melting of MIS 6 ice sheets) as well as from the retreat of the
380 GrIS and AIS during the actual MIS 5.5 interglacial period. ~~The departure of the GIA-induced RSL~~
381 ~~changes from the eustatic signal is a function of the distance with respect to the ice sheets and of~~
382 ~~the shape and size of the ocean basins. In the proximity of the ice sheets, the RSL changes are at~~
383 ~~odds with respect to the eustatic signal, while, in the far-field sites, the RSL changes are in tune~~
384 ~~with the eustatic signal, but are different because of the solid Earth and gravitational and~~
385 ~~rotational changes that affect the meltwater redistribution. Overall, these studies show that the~~
386 ~~local~~ The predicted local RSL change can be very different from the eustatic signal, the difference
387 being, a function of the distance with respect to the ice sheets and of the shape and size of the
388 ocean basins. and, in particular, it is expected that, even within an enclosed basin such as the
389 Mediterranean Sea, the MIS 5.5 highstand reached different elevations at different times as a
390 function of the geographical location (Lorscheid et al., 2017a; Stocchi et al., 2018). ~~In other words,~~
391 ~~each site experiences a different elevation that occurs at different times, i.e. the transgressions~~
392 ~~are not coeval.~~
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400 Neglecting the GIA might significantly hamper the quantification of the eustatic sea-level
401 peak, which ~~is mostly stems from composed of~~ GrIS and AIS ~~glacio-eustatic contributions~~ melting.
402 In fact, as discussed by Rovere et al. (2016), early global-scale studies did not (properly) take GIA
403 into account and resulted in estimates of 3–6 m above mean sea level (MSL) (Stearns, 1976;
404 Harmon et al., 1981; Neumann and Hearty, 1996; Stirling et al., 1998). However, more recent
405 studies have incorporated state-of-the-art GIA modelling and independently estimated values
406 from 5 to 9.5 m above MSL (Kopp et al., 2009; Dutton and Lambeck, 2012). These recent results
407 suggest that not only did the GrIS and ~~Wwestern~~ AIS collapse, but also the ~~Eeastern~~ AIS might
408 have contributed to global sea level at this time.
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416 In the Mediterranean, few studies up to this point have explicitly included the GIA
417 contribution to the MIS 5.5 RSL fluctuations. As highlighted by Sivan et al. (2016), the local GIA-
418 driven RSL highstand in Israel could contribute from 2–2.5 m to the highstand. Creveling et al.
419 2015 also show that the GIA contribution is significant and cannot be neglected when investigating
420 the tectonic rates of deformation. Rovere et al. (2016), Lorscheid et al. (2017b) and Stocchi et al.
421 (2018) show that the GIA signal is not uniform within the Mediterranean Basin and can contribute
422 from 1–2.5 m of RSL highstand without accounting for extra melting from Greenland and
423 Antarctica. For the latter ice sheets, several chronologies of melting have been proposed so far,
424 but it is still uncertain whether there was a single peak, a two-stand peak or actual fluctuations
425 (see Kopp et al., 2009). Furthermore, Austermann et al. (2017) show that dynamic topography
426 could contribute quite significant subsidence in the Mediterranean that could explain 1–2 m of RSL
427 change at the MIS 5.5. However, these results are not accurate enough for the Mediterranean
428 Basin given the low-resolution model used by the authors. Finally, while the timing of the onset of
429 the MIS 5.5 acme is relatively simultaneous, mostly taking place from 129 ka to 126 ka, the timing
430 of the demise of the LIG acme is more variable and ranges from 122 ka to 113 ka (Rovere et al.,
431 2016).
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437 438 439 440 3. Materials and Methods

441
442 We selected and re-measured the features of a set of FTNs ~~from areas that are already~~
443 ~~known from~~ located in the central Mediterranean Sea (S2, Fig. 1) ~~and, but only in areas that have~~
444 ~~been~~ are considered stable since the MIS 5.5 (Ferranti et al., 2006, 2010; Antonioli et al., 2015). ~~In~~
445 ~~Fig. 1A, the~~ The ~~considered~~ stable areas are indicated as well as the 80 surveyed sites are
446 ~~portrayed, respectively, in Fig. 1 A and Fig. 1 B-E (Fig. 1B-E). We have also found s~~ six additional
447 sites ~~from~~ in other regions, such as Morocco, Gibraltar and France (Fig. 1 F–G) (Rodriguez Vidal et
448 al., 2007, 2010; Abad et al., 2012, 2013) were considered because they, ~~which~~ show carved FTNs
449 along ~~in~~ coasts that are considered stable since the MIS 5.5. All of these were then included in a
450 database (Tables 1, 2, 3 and S7); that included only well-carved FTNs on limestone rocks which
451 presented morphological continuity. We established that a tidal notch it can be ~~is~~ defined as
452 continuous when it can be followed laterally for at least 50 meters.
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461 3.1 Measures

462
463 The measurements of the FTNs were performed from the base of the FTN to the base of
464 the PTN (Figs. 2, 3, 4 and 5). The measure was corrected by 3 cm because it corresponds to the
465 average width of the biological rim once formed and currently eroded at the base of an FTN
466 (Vermetids, Corallinae Algae and others living at Present sea level). This is the reason why no
467 correction has been introduced about sea level, unless in rare cases where a roof notch and an
468 FTN are present (Circeo and Capri, sites 50 and 55), and therefore a PTN base is lacking (Ferranti
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475 and Antonioli, 2007). Even though we recorded the date and time for all measurements, these are
476 the only cases where the measurements of the base of the FTN were referred to the local sea
477 level, corrected for tides.
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480 The measurements of the 80 studied sites (Tables 1 and 2 and table S7) were performed
481 using different tools and with an estimated error ranging from ± 1 up to ± 5 cm along the vertical
482 error depending on both the tool and the adopted reference level (MSL, vermetid reef etc., see
483 Fig. 5 and S5). All measurements were referred to the base of the PTN or zones where the
484 vermetid reef was present and considered as representative of the MSL ($H = 0$). Vertical profiles
485 along the notch sections were realized through several measurements. An uncertainty of ± 2.5 cm
486 was assumed to account for the identification of the marker.
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489 The tools we used and related instrumental uncertainty are the following:
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491
492 **a)** Global Positioning System/Real Time Kinematic (GPS/RTK) technique. In eight sites (50, 51, 52,
493 54, 74, 75, 79 and 80, respectively, in Figs. 4 and 5; Tables 1 and 2, table S7), we used the GPS/RTK
494 technique which has an accuracy better than ± 3 cm along the vertical. This depends on both the
495 tool and the adopted measurement base (MSL, vermetid reef etc., see S5), but it often depends on
496 the setting of MSL. An accuracy of ± 5 cm was estimated.
497
498

499 **b)** Levelling surveys. Sites 50, 51, 52 and 54 were surveyed by a levelling technique, using a Leica
500 Runner4 instrument. Elevation data were referred to the local sea level at the time of the surveys
501 and corrected for tides by the nearest tide station (Fig. 5). An accuracy of ± 5 cm was estimated
502
503

504 **c)** Total station. Sites 79 and 80 were surveyed with a Total Station Leica TCRP 1203, equipped
505 with an infrared laser beam, capable of capturing targets at a distance up to one km. For the
506 measurements in the range of about 700 m, we used the laser beam without a prism, keeping a
507 precision of a few mm along the distance. (Fig. 5). An accuracy of ± 5 cm along the vertical was
508 estimated
509
510

511 **d)** Telescopic rod. In 19 sites (Figs. 4 and 5; Tables 1 and 2, table S7), a 10 m long telescopic
512 measuring gauge was used (Telefix). This device provides direct readings on a graduated tape and
513 is built with non-extensible material which ensures an accuracy of about 3 mm when fully
514 extended to 10 m. We estimated an error comprised from 1 to 5 cm depending on the
515 morphological conditions of the PTN and on the position of the MIS 5.5 FTN (Figure in S5). This is
516 always used when the FTN is orthogonal above the PTN. Otherwise, when a few degrees of
517 inclination occurred ($1-6^\circ$) between the platforms of the PTN and the FTN, the top of the
518 instrument was placed a few cm from the FTN base. The level was defined by an operator located
519 on a nearby boat and were taken photos to roughly verify the positioning of the rod with respect
520 to the significant morphologies. An accuracy of ± 1 cm along the vertical was estimated.
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525 **d)** Tape. In 46 sites (Figs. 4 and 5; Tables 1 and 2, Table S7), we used a 20 m long measuring tape,
526 positioned on morphological markers by two operators. This measurement tool was used in sites
527 where the cliff was not back drawn and the tape could therefore be positioned vertically or with
528 an acceptable slant (Figure S5). The use of the tape was done with an operator on the FTN and
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534 one on the PTN that is in the sea. Because of the presence of some vertical offset in the position of
535 the two markers, and resulting tilt of the tape from the vertical, these measurements have been
536 assigned an error bar of ± 15 cm.
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539 **e)** Digital altimeter: In three sites (Figs. 4 and 5; Tables 1, 2 and Figure S5, Table S7) where
540 uplifted notches were far from the present day coast, position and elevation measurements were
541 performed by a digital altimeter (Garmin Oregon 650) with a vertical accuracy of 50 cm and were
542 calibrated with respect to the sea level along the nearby coast. Measurements were taken at the
543 base of the FTN and at the vermetid platform. An accuracy of ± 50 cm along the vertical was
544 estimated. When the Vermetid rim was lacking, an uncertainty of ± 10 cm was summed to the
545 marker identification and instrumental error. Any other specifications about the formation,
546 morphology and spatial variations of the morphological measurements of the PTN can be found in
547 Antonioli et al. (2015).
548
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550

551 3.2 Glacial- and hydro-isostatic adjustment 552

553 In this paper we investigated the role of GIA in modulating the elevation of the MIS 5 sea-
554 level highstand across the Mediterranean Sea by means of process-based numerical modelling.
555 We employed three different ice-sheet models to (i) quantify the sensitivity of the Mediterranean
556 RSL sites to the GIA process and (ii) evaluate, albeit without recurring specific statistics, which
557 glacio-eustatic scenario better represents the observations.
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559

~~560 The contribution of GIA to regional RSL changes can only be evaluated by means of forward
561 process-based modelling. The numerical models that account for all the relevant GIA feedbacks
562 usually combine a pre-defined ice-sheet model, which is the forcing function consisting in ice-
563 sheets thickness variations, and a solid Earth model that operates as response function by
564 returning solid Earth deformations and mean sea surface (i.e. the geoid) variations. The difference
565 between the coupled geoid variations and solid Earth deformations results in RSL changes.~~
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~~569 We employ the three ice-sheet models to (i) investigate the sensitivity of the Mediterranean RSL
570 sites to the GIA process and (i) evaluate, albeit without recurring specific statistics, which glacio-
571 eustatic scenario better represents the observations.~~
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573

574 ———To evaluate the contribution of GIA to the observed RSL changes from the MIS 5.5, we
575 solved the gravitationally self-consistent sea level equation (SLE) (Farrell and Clark, 1976). The SLE
576 incorporates all the GIA feedbacks and yields RSL changes that accompany and follow continental
577 (i.e. land-based) ice-sheet thickness variations—(Spada and Stocchi, 2007). We make use of of the
578 SELEN Fortran 90 program (Spada and Stocchi, 2007), which solves the SLE by means of the
579 pseudo-spectral approach (Mitrovica and Peltier, 1991). Accordingly, the SLE solution consists of
580 spatio-temporal convolutions where ice-sheets thickness variations are coupled to solid Earth
581 responses and propagated through time in order to account for the time-dependent viscous
582 relaxation of the mantle. At the core of the SLE formalism is the concept that, at any time t since
583 the beginning of the ice-sheet model chronology, the RSL changes of each point of the Earth's
584 surface stem from the solid Earth and geoid deformations induced by all the ice- and water-
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591 loading variations that have occurred since the initial time t^0 . Accordingly, the solid Earth is
592 assumed to be spherically symmetric, radially stratified, self-gravitating, rotating and deformable,
593 but not compressible (Spada et al., 2003). We assume an elastic lithosphere and a Maxwell
594 viscoelastic mantle. We divide the latter into three layers: upper mantle, transition zone and
595 lower mantle. The core of the Earth is considered inviscid.
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600 We consider three global ice-sheet models that describe the last 240 kyrs of fluctuations
601 (i.e. two glacial-interglacial cycles). This is necessary in order to accurately account for the GIA
602 which accompanies and follows the melting of the MIS 6 ice sheets, as well as the GIA during and
603 after the MIS 5e until the present day. Overall, the three ice-sheet models are very different and
604 are characterized by very different eustatic elevations and temporal durations of the last
605 interglacial phase. The three models are the following:
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609 1. ICE-5G (Peltier, 2004): This model describes the ice-sheet thickness variations over North
610 America, Eurasia, Greenland and Antarctica from 26 ka to present. For this time span, ICE-5G was
611 constrained by the means of geological RSL data and modern geodetical observations (Peltier,
612 2004). Prior to 26 ka, the ice-sheet growth is tuned to the delta-18O curve (Lisiecki and Raymo,
613 2005) and is not glaciologically realistic (Peltier, 2004). The chronology starts at 123 ka, when the
614 global ice-sheet volume was smaller than it is today and resulted in a eustatic sea level of ~0.9 m
615 above the present level (mostly due to a smaller GrIS; to be specified). In order to capture the GIA
616 contribution to the MIS 5.5 highstand, we combined in time two consecutive ICE-5G chronologies.
617 This allowed us to simulate the ice-sheet growth towards the MIS 6 glacial maximum and the
618 subsequent retreat during the period from MIS 6 to MIS 5.5 Therefore, after the MIS 5e, the ice-
619 sheet chronology is repeated towards the present day (including the last glacial maximum LGM, of
620 course). However, we do not claim that the MIS 6 glacial maximum was the same as the LGM.
621 According to our reconstructed chronology, the MIS 5.5 interglacial starts at 129.5 ka, which
622 corresponds to the end of the initial cycle, and ends at 122 ka. The maximum peak of 0.9 m
623 equivalent sea level (ESL) starts at 125 ka and ends at 123 ka, therefore resulting in a 2 kyr-long
624 (late) highstand (see red dashed curves in Figs. 6 and 7).
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630 2. ICE-6G (Argus et al., 2014; Peltier et al., 2015): This model represents the latest
631 improvement of the ICE-5G (see previous entry). We apply the same time discretization and
632 chronology of the ICE-5G. According to the ICE-6G, the maximum MIS 5.5 eustatic highstand is
633 ~3.1 m above present-day MSL as a consequence of the GrIS and AIS retreat and occurred from
634 125 to 123 ka (see blue dashed curves in Figs. 6 and 7).
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638 3. ANICE-SELEN (de Boer et al., 2014, 2016): This model describes the global ice-sheet
639 fluctuations that follow the delta-18O stack (Lisiecki and Raymo, 2004) and that dynamically
640 account for all the GIA feedback. ANICE-SELEN, therefore, is the result of a fully and dynamically
641 coupled system and, so far, has been. ~~ANICE-SELEN was not constrained by means of RSL data;~~
642 ~~hence, it is extremely realistic when it comes to the physical processes, but may be locally~~
643 ~~unrealistic in terms of ice margins and the location of domes.~~ We followed the original ANICE-
644 SELEN chronology and, during the MIS 5e, forced the GrIS and AIS to release, respectively, 2 and 5
645 m of equivalent sea level (ESL) (see also Lorscheied et al., 2016; Rovere et al., 2016) Therefore,
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652 under the eustatic approximation, this would result in 7.0 m ubiquitous sea-level highstand from
653 120 ka to 117 ka (see green dashed curves in Figs. 6 and 7).
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655 Overall, the three ice sheet models are very different and they are expected, therefore, to
656 result in different RSL changes not just in the proximity of the formerly glaciated areas, but also at
657 ice distal or far-field sites such as the Mediterranean Sea. Also, it is interesting to compare the
658 response of the Mediterranean basin to two different classes of ice sheet models: (i) ICE-5 and 6G,
659 both the result of RSL data inversions, and (ii) ANICE-SELEN, the result of a pure process-based
660 modeling approach. In fact, while ICE-5 and 6G are built to give an excellent fit with post LGM RSL
661 data, ANICE-SELEN purely follows ice-flow physics and dynamics. Therefore, we expect large
662 regional differences, but also a consistent signal in the Mediterranean. This could prove that,
663 regardless of all the uncertainties in the ice sheet models (no model is perfect or 100% realistic),
664 we can constrain the expected GIA response of the Mediterranean (lower to upper limit), and
665 therefore provide better estimates of the absolute glacio-eustatic value at the MIS 5e (mostly
666 Greenland and Antarctic ice sheets reduction).
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672 ~~We employ the three ice-sheet models to (i) investigate the sensitivity of the~~
673 ~~Mediterranean RSL sites to the GIA process and (ii) evaluate, albeit without recurring specific~~
674 ~~statistics, which glacio-eustatic scenario better represents the observations.~~
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676 4. Results

677 4.1. FTN elevation

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679 The mean elevation of all **measurements** (Figs. 1, 2, 3, S2, S3, S4 and Figure S5; Tables 1
680 and 2) in the studied sites is 5.71 m with a maximum of 12.78 m at Monte d'Argento (southern
681 Latium) and a minimum of 2.09 m (Palinuro, south of Naples). If we do not consider the values
682 lower than 2.5 m (Palinuro, Capo Zafferano and Rosh Hanikra Israel) and higher than 10 m, the
683 average elevation is 5.95 m. We added to the measured sites in Italy six measurements at sites
684 elsewhere in the Mediterranean Sea (Abad et al., 2012, 2013; Rodriguez Vidal et al., 2007, 2015;
685 **Table 3 and Figure S6**), but we did not use these observations for statistical analysis.
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691 4.2 FTN width and comparison with PTN width

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693 The mean width of MIS 5.5 FTN (Figs. 2 and 8; Table 1) is 0.74 m with a maximum of 1.20 m
694 at Levanzo and a minimum of 0.38 m at Palinuro. The PTN mean width is 0.59 m with a maximum
695 of 0.9 m at Levanzo and a minimum of 0.30 m at Palinuro. The FTN/PTN ratio width is 1.28. This
696 value is always larger than 1 (Tables 1 and 2, column 4; Fig. 5). Compared with the PTN widths, the
697 FTN widths are always wider by 10 to 25 cm (Table 1; Figs. 2, 5, S2, S3 and S4).
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701 4.3 FTN depth and comparison with PTN depth

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703 The mean depth of the FTNs (Tables 1 and 2; Figs. 2 and 3) is 0.9 m with a maximum of
704 1.20 m at Capo Caccia (site 2) and a minimum of 0.20 m at Capo Caccia (site 10). In the Orosei Gulf,
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711 near springs with a flow rate of thousands m³/sec, the PTN has a width up to 4 m (Antonioli et al.,
712 2015). The FTN/PTN ratio width is 0.92 (with a maximum of 1.40 at Levanzo, and a minimum of
713 0.16 m at Capo Caccia) (Tables 1 and 2, column 4). Compared with the PTN depths, the FTN depths
714 are almost always smaller (Figs. 3, S3, S4 and S5). Regarding the FTN base (Figs. 2 and 3), the mean
715 of our measures is 0.66 m, with a maximum of 1.80 m at Pedralonga (site 2) and a minimum of
716 0.15 m at San Vito Macari (site 72) (Tables 1 and 2).
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720 721 722 4.4 Age of the fossil notch 723

724 Regarding the age of the fossil notch, for each site, we considered the distance between
725 the notches and the nearest dated fossil deposit which can be correlated to it. The results (Fig. 9;
726 Table 1) show a mean distance of 4.5 km with a maximum distance of 22.9 km (Pedralonga, site
727 44) and a minimum of 0.2 km (Capo Caccia, site 12). Regarding the quality of analyses or markers
728 used, as explained in Table 1, we provide the references for each site. The dating techniques used
729 for the FTN are the following: 1) U/Th analysis on *Cladocora caespitosa* or on speleothems; 2) OSL on
730 sandy deposits; 3) Aminostratigraphy on marine shells; and 4) Correlation to fossil assemblages containing
731 *Persististrombus latus* or other Senegalese fauna.
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737 4.5 FTN older than MIS 5.5 738

739 Uplifted FTN older than MIS 5.5 were studied and measured in Sicily and Apulia (Fig. 1;
740 Table 2, Figure S5; sites 74–80) at Custonaci, Grotta Racchio, Capo Zafferano, Sferracavallo and
741 Grotta Romanelli (the elevation ranged from 9.2 m at Romanelli to 73 m at Custonaci). These
742 notches show a width from 1.5 to 2.12 m, with a mean of 1.82 m and a FTN/PTN ratio of notch
743 depth always higher than 1 (Fig. 10; Tables 1 and 2).
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747 4.6 Glacial- and hydro-isostatic adjustment 748

749 Within the Mediterranean Basin, the predicted GIA-modulated RSL curves for all the three
750 ice-sheet models are significantly different from the eustatic curves (see Figs. 6 and 7). There are
751 significant differences between the predicted RSL curves in the central regions of the basin, such
752 as Italy (Fig. 6) and France (Fig. 7), and the marginal areas, such as Morocco and Israel,
753 respectively, in the western and eastern Mediterranean Sea (Fig. 7a and c). In the central areas, in
754 fact, the RSL curves are characterized by a monotonous RSL rise that lags behind the eustatic
755 signal and that eventually results in a higher than eustatic highstand by the end of the MIS 5.5
756 temporal window (see solid curves w.r.t. dashed curves of Fig. 6). This holds for all three ice-sheet
757 models that, albeit different, are combined in the same mantle viscosity profile. Interestingly,
758 differences between GIA-modulated and eustatic signal are larger for the ANICE-SELEN (see green
759 curves). The predicted RSL curves at the Italian sites all show a relatively fast RSL increase (about
760 0.5–1.0 m) from 125 ka to 123 ka, while the eustatic signal is flat for this time span.
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770 The sites at the western and eastern boundaries (Fig. 7a and c) are characterized by earlier
771 highstand, which is then followed by a relative sea level drop. This holds in particular for the ICE-
772 5G and ICE-6G, while the signal is only visible for ANICE-SELEN within the 125–123 ka time
773 window. The latter, in fact, is characterized by a local RSL drop as opposed to the rise at the Italian
774 sites.
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777 The GIA-driven regional contribution to RSL rise is related to the maximum peak from 1–2.5
778 m within the whole Mediterranean Basin. Notably, higher values are only reached at sites 1–4 for
779 ICE-5G, and the rest of the estimates are within 1.5 m (Fig. 11; Table 5). This implies that GIA alone
780 (leaving out the extra GrIS and AIS glacio-eustatic components) is capable of driving a 1–1.5 m
781 (locally 2.5 m) higher than present sea level during the MIS 5.5. Such a value is comparable to the
782 expected glacio-eustatic contribution of GrIS during the MIS 5.5. The latter, however, shows up at
783 different times according to the geographical location.
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787 The GIA contribution to RSL rise (related to the maximum peak) along the coasts of Italy
788 (including Sardinia and Sicily) is up to 1.5 m (Fig. 12). This holds for all the three ice-sheet models
789 and, therefore, confirms that the GIA signal in the Mediterranean is quite consistent among
790 different ice-sheet chronologies (Fig. 12).
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793 Overall, the predicted maximum peaks according to ICE-5G and ICE-6G (Fig. 12 left) could
794 explain the observed lower limits. On the other hand, the maximum peaks predicted according to
795 ANICE-SELEN fit quite well with some observations and, in general, with the higher limits.
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798 Following from the previous point, GIA results alone are a second-order contributor to variability
799 when compared to the observations. Hence, they can only explain in part the observed regional
800 variations in the maximum peak elevation (see also regional variability in Fig. 11 and Table 5).
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803 5. Discussion

804 5.1 Notch morphometry: comparison with the PTN

805 This study has yielded unprecedented details on the MIS 5.5 notch morphometry that can
806 be compared with the morphometry of the PTN studied by Antonioli et al. (2015). The three
807 morphometric parameters (width, depth and base) of PTNs show small differences depending
808 whether they are located in sheltered or exposed areas. Similar results were also achieved for the
809 FTNs (Tables 1 and 2). Moreover, near large fresh water springs (as described for Sardinia's
810 western coast in Antonioli et al., 2015), PTN depths are noticeably higher (more than 4 m), while
811 FTN remain the same because the PTN so deeply carved tend to collapse.
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817 The main difference between the PTN and the FTN is the width. The average FTN width
818 recorded in 67 sites was 0.73 m, while the average width of the PTN in 59 sites was 0.59 m. The
819 conclusion is that the average width of an FTN is 0.14 m wider than that of a PTN. This difference
820 supports, based on a larger data set, the conclusions of Antonioli et al. (2015), derived from data
821 collected in eight sites.
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829 We explain the FTN width exceeding the PTN width by 0.14 m as a result of a combination
830 of chemical and biological weathering of the carbonate bedrock. The aforementioned processes
831 are responsible also of the lack of the biological rim (Vermetids, Corallinales algae) in the FTN. We
832 argue that a biological rim was present at the base of the FTN during MIS 5.5, based on the
833 morphology of its lower part. Antonioli et al. (2006) and Antonioli et al. (2015) describe a fossil
834 vermetid reef in an uplifted FTN attributed to MIS 5.5 near Taormina. With the disappearance of
835 the rim, the notch was also increasingly more exposed to erosion.
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839 Dissolution rates measured on carbonate rocks in the Mediterranean area show values
840 ranging from 0.01 mm/a to 1 mm/a (Furlani et al., 2014b), with higher rates in correspondence
841 with the mid- or low-tide levels (Furlani et al., 2009; Furlani and Cucchi, 2013). The longest data
842 set covers about 40 years (Furlani et al., 2009; Stephenson et al., 2012). Taking into account
843 significant approximations in the extrapolation of erosion rates for the long-term period, such as
844 hundred thousand years or more, due to the complete lacking of instrumental data older than half
845 century or morphometric proxies, a linear extrapolation over 125,000 years, implies a total
846 amount of erosion of Mesozoic limestones hosting FTNs ranging from 0.125 m to 5 m (Table 4).
847 Uncertainties can be due to the effects of past local climate setting, that could have affected past
848 erosion rates or different geological conditions, such as the shedding of the notch by younger
849 sediments that have now been stripped off. In some cases, limestone lowering rates can be also
850 higher, such as at Mallorca Island (Gomez-Pujol et al., 2006), with the result of the complete
851 disappearance of MIS 5.5 notches. Softer limestones, such as Miocene calcarenites, have higher
852 dissolution rates, with a total estimated erosion of 100 m (Table 4). The latter is not the case for
853 the observed FTNs. The relatively low average difference in width (0.14 m) between FTNs and
854 PTNs calls for erosion rates at the lower boundary of the estimate. The other measured
855 morphometric dimensions of FTNs do not show any systematic difference from those of PTNs.
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862 On the other hand, the preservation of the FTNs at some or several sites and the minimal
863 difference in width with respect to the PTNs could be explained by taking into account subsequent
864 deposition processes which preserved the FTNs, even in the presence of higher dissolution rates.
865 The sediments could have protected the buried forms, at least until their post-LGM exhumation.
866 Many examples of this occurrence have been recorded in many sites in the Orosei Gulf and at
867 Tavolara Island, where traces of LGM eolianites are still found inside the FTNs (Fig. 5i-j).
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870 An FTN changes its morphology and morphometry depending on whether it is covered and
871 preserved by sediments (aeolianites and/or other continental deposits) or not. The final
872 morphometric shape (especially the width) may have a significant enlargement due to karst
873 solution processes, with rates that (on carbonate lithologies) may reach 0.04 mm per year (Furlani
874 et al., 2009, 2010; Furlani and Cucchi, 2013) outside the tidal zone. This is confirmed by the
875 FTN/PTN ratio width that is always greater than 1. The other measured morphometric dimensions
876 of an FTN do not show any peculiar difference from those of a PTN.
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881 882 5.2. Glacial- and hydro-isostatic adjustment 883 884 885

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The departures from the eustasy and the regional variability of the predicted RSL curves (in particular the differences between the central areas and the marginal regions) stem from the ice-induced crustal variations (mostly from Fennoscandia) and the sea-bottom deformations driven by the ocean loading term.

In particular, the monotonous RSL rise and late highstand that are predicted at the Italian sites (Fig. 6) stem from the subsidence of the solid Earth in response to the collapse of the peripheral forebulge (around Fennoscandia) and to ocean load-driven subsidence of the crust. The predicted early highstand in the marginal sites (Fig. 7a and c), which is then followed by an RSL drop, is the result of two processes that are related to both meltwater redistribution and solid Earth deformations. The first is the so-called continental levering, which stems from the lithospheric flexure in response to the loading of the basins and which results in coastal uplift. The second is the migration of meltwater towards the collapsing forebulges. Together, these two processes result in an early highstand (w.r.t. the eustatic signal), which is opposed to the later highstand that is predicted in the central areas (Fig. 6), and the GIA signal is consistent regardless of the ice-sheet models (the predicted GIA variability is smaller if compared to the observations).

Overall, the maximum predicted highstand for the three ice-sheet models do show and confirm that the GIA signal in the Mediterranean is of the order of 1–2.5 m and is quite consistent, regardless of the shape and chronology of the MIS 6 glaciation and deglaciation.

916 5.3 Notch elevation distribution and comparison with GIA predictions

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Measurements of the MIS 5.5 FTN elevation at 74 sites in areas of Italy that are considered tectonically stable **in the literature** (Table 1; Figure 4, Figures S3, S4, S5) show an average value of 5.73 m, with a maximum of 12.78 m and a minimum of 2.09 m.

The studied sites are **far from** tectonically or volcanic active zones. Elsewhere in Italy, **active tectonic or volcanic processes** account for a marked positive or negative departure of the observed MIS 5.5 FTN elevation from the predicted GIA-eustatic elevation, **most notably in the** northwestern Adriatic Sea and **in the** Ionian and Tyrrhenian sides of Calabria (Ferranti et al., 2006, 2010). Nevertheless, we suspect that some of the minor scatter between values at stable sites presented in this paper derives from unaccounted **albeit slow** local tectonic or volcanic processes.

In order to place further constraints on the accurate elevation of the MIS 5.5 FTN, we selected, from the total 74 observed sites in Italy, the 13 sites that we considered less affected by local land motion. **Within these 13 sites, we retained only one elevation datum when multiple observations are available at sites that are few tens of meters to few kilometers apart within a geologically coherent area** (Table 6). We **selected this representative datum** based on the ascertained (or suspected) slow tectonic process acting in each area and on the resulting sign of vertical land motion. When the prevailing process **is** normal faulting or aseismic subsidence related to a passive continental margin **development**, we considered the **highest** elevation found in the area as the most accurate. On the other hand, when arching related to magmatic processes

945 controls coastal deformation and the land motion is uplift, we selected the lowest value (Table 6).
946 Similarly, in areas where folding and thrusting produce uplift parallel to the coastline, the lowest
947 FTN elevation is considered as most reliable. When faulting or folding is at a high angle to the
948 coast, the resulting process is tilting and, thus, an intermediate FTN elevation, as close as possible
949 to the tilt axis, represents the most accurate estimate.
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954 We analysed the selected sites' distribution along a regional scale (~850 km long) E-W
955 transect from the western Sardinia margin to the western Adriatic margin in Apulia, with a
956 manually traced trend line of the observed MIS 5.5 highstand elevation (Fig. 13 All the sites but
957 Talamone in Tuscany and Marettimo in Sicily lay very close to the trace of the transect (yellow
958 dots in Fig. 13). Because the two sites in Tuscany and Sicily are far from the trace compared to all
959 the others, we showed these two sites in a different way (white dots in Fig. 13).
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963 In NW Sardinia, we selected the FTN found at the maximum elevation (5.5 m) out of the 20
964 measurements in the area of Capo Caccia and Punta Giglio (Fig. 1D). As pointed out by Ferranti et
965 al. (2006), NW Sardinia faces the Balearic continental margin of the western Mediterranean Sea,
966 and the decrease in elevation of the FTN from east to west may be the result of fault- or creep-
967 related subsidence (Table 6). Continental margin downthrow is also suspected in SW Sardinia
968 (Buggerru-Masua and S. Antico sectors), so we picked the maximum elevation (3.5 m) as well. It is
969 interesting to note that, on this continental margin, the selected FTN progressively loses 2.5 m of
970 elevation from N (Capo Caccia-Punta Giglio) to S (Buggerru-Masua-S. Antico) over a distance of
971 180 km. Whether this occurrence is fortuitous or reflects the process of a southward tilt of the
972 whole of western Sardinia has not been established. However, being at a prominent continental
973 margin, we chose to start the trend line at the maximum elevation in the north.
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978 In respect to eastern Sardinia, Ferranti et al. (2006) suggested the presence of residual
979 volcanic activity to explain the northward increase in elevation pattern of the FTN over a 25 km
980 distance in the Orosei Gulf (sites 37-44; Fig. 1D). Mariani et al. (2009) modelled this deformation
981 with a magmatic intrusion that post-dates the MIS 5.5 notch, as documented by minor explosive
982 breccia flows that locally cover the notch. Based on this argument, the elevation increase is
983 related to tilting ensuing from intrusion. Because the prevailing land motion is an uplift, we
984 selected the minimum elevation (7.0 m) of the FTN observed at the Pedralonga site (Table 6). In
985 NE Sardinia, the MIS 5.5 notch shows about 2 m difference in elevation from Tavolara (6-7 m) in
986 the south to Capo Figari (4.5-5 m) in the north, over a distance of less than 10 km. Regional NE-
987 SW striking left transcurrent faults that cross the interposed bay could be responsible for the
988 coast-parallel tilt, but they are retained as inactive (Oggiano et al., 2009). With the existing
989 uncertainty, we included in the selection both the lowest elevation at Capo Figari and the highest
990 elevation at Tavolara, assuming a tilt axis lies in between. The trend line crosses the eastern
991 Sardinia margin midway between the observations at Capo Caccia, Tavolara and Capo Figari (Fig
992 13).
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998 On the eastern Tyrrhenian margin, only an FTN observation (Talamone, 4.8 m elevation) is
999 available from Tuscany in the north. This site is projected 250 km southward on the transect and,
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1006 as for the Capo Figari site, has an elevation residing under the trend line, suggesting it could have
1007 been lowered by unaccounted processes.
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1010 South of Talamone, sites in Latium show a 3.4 m south-eastward decrease in elevation
1011 from 9.3 m (Circeo) to 5.9 m (Gaeta) along 50 km of coast which at this location has an E-W trend
1012 (Fig. 1B). We discarded from selection the site of Minturno, which displays the highest measured
1013 elevation in this study (12.48 m, site 54, Figures 11 and S4), because we considered it affected by
1014 processes related to the now extinct Roccamonfina volcano. The last documented activity of the
1015 volcano was at 150 Ka BP, but younger activity could have occurred (Rouchon et al., 2008). We
1016 also suspected that the continental margin rebound affected the 9.3 m elevation of the FTN at
1017 Circeo, and, thus, we excluded this site as well. The remaining three sites have elevations ranging
1018 from 6–6.5 m (Gaeta-Sperlonga) to 8 m (Terracina). The Terracina site lies close to a post-MIS 5.5
1019 extensional fault, and, thus, the footwall uplift may have contributed to a fraction of the observed
1020 elevation. Fortunately, a borehole in the nearby Fondi Plain, located in the immediate hanging wall
1021 of the fault, which has revealed MIS 5.5 deposits at –6 m, allowed making a predictive estimation
1022 of the footwall uplift. By using a ratio of hanging-wall subsidence to footwall uplift of 1:10,
1023 supported by theoretical modelling and observational data (King et al., 1988; Armijo et al., 1996),
1024 the 14 m difference between the FTN at Terracina in the fault footwall and the drilled deposit in its
1025 hanging-wall results in 1.4 m footwall uplift. In terms of difference, the estimated GIA-eustatic
1026 position of the FTN at Terracina is 6.6 m (Table 6). This estimate is strikingly similar to observations
1027 in nearby Sperlonga and Gaeta, suggesting that the trend line passes through the corrected
1028 elevation at Terracina.
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1035 Several FTNs have been measured between Capri Island and Sorrento Peninsula
1036 (Campania). As pointed out by Ferranti and Antonioli (2007), the elevation of the notch at Capri
1037 decreases progressively from southeast (8.0 m) to northwest (5.2 m). The pattern of down-
1038 dropping of the tidal notch is consistent with the active subsidence with a maximum occurring in
1039 the Gulf of Naples, located north of Capri Island, and monocline tilting of the island and the nearby
1040 Sorrento Peninsula. We argue that the axis of tilting at Capri is at an elevation of 7.0 m, which is
1041 the most represented FTN elevation (Tables 1 and 6).
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1045 Further south, in Cilento, contrasting observations come from Palinuro (FTN at 2.1 m) and
1046 from nearby Marina di Camerota - Bulgheria site (FTN at 6.7 m) (Table 1, Figure S4, site 54). In line
1047 with the reasoning for continental margin faults, we regard the higher measurement as the most
1048 accurate.
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1051 The group of FTN sites measured in NW Sicily (Fig. 1E) is placed over an active collisional
1052 margin, where the convergence between Sardinia and Sicily in response to African and European
1053 plate motion is accommodated by thrusting and folding and is expressed by seismicity and
1054 geodetic data (Ferranti et al., 2008; Palano et al., 2012; Serpelloni et al., 2007). Thus, we picked
1055 the lowest observed FTN elevation (8.1 m at Marettimo) as representative of this sector, after
1056 discarding the very low elevation data from Capo Zafferano which could have been affected by
1057 local subsidence. When we projected the Marettimo datum 200 km northward on the trend line, a
1058 positive mismatch of about 2 m with respect to the trend line is estimated (Fig. 13).
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1065 The easternmost observed notch was at an elevation of 8.2 m at Striare in Apulia, at the
1066 southward terminus of the Adriatic Sea. Southern Apulia lies at the eastern tip of the conspicuous
1067 regional uplift of the Calabrian Arc, related to Ionian plate subduction (Ferranti et al., 2006, 2010),
1068 and, thus the FTN elevation could be 1–2 m higher than the trend line because of a far-field
1069 tectonic residual (Fig. 13).
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1073 A comparison between the selected observations of the FTN elevations and the predicted
1074 values from the ANICE-SELEN GIA model reveals that the GIA signal is partly at odds with respect
1075 to the observed trend (Fig. 13). Along the E-W transect, shown in Fig. 13, the GIA signal has
1076 elevations that are up to 4 m higher than the observation points, and 1–3 m higher than the
1077 inferred observational trend. The discrepancy between the GIA predicted values and the
1078 observations is higher in western Sardinia (Buggerru) and at the northeastern Tyrrhenian margin
1079 (Talamone), and progressively decreases to 1–2 m towards the the southeastern Tyrrhenian
1080 (Capri) margins, and on the Adriatic margin (Striare), where it is minimal. The observed and
1081 predicted trends along this transect appears to be comparable in the sector between the Adriatic
1082 and Tyrrhenian margins, with a 1.5–2 m lower elevation for the observed trend. Only the observed
1083 FTN at Terracina has an elevation similar to the predicted value, but, as outlined above, the
1084 elevation at this site has been corrected to 6.6 m.
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1089 The lower-than-predicted observed values in western Sardinia, and possibly at Talamone,
1090 could have been affected by unaccounted marginal tectonic subsidence, and this could alleviate
1091 the discrepancy. On the other hand, the cluster of selected sites on the Latium-Campanian coast
1092 (Terracina, Sperlonga, Capri and Marina di Camerota) seems to define a 6.5 reference value as the
1093 most appropriate. Under this hypothesis, a 1.5 difference with predicted values still remains in the
1094 comparable part of the transect (Fig. 13). This observation allows us to argue that the glacio-
1095 eustatic contribution at the MIS 5.5 was probably lower than most recent estimates (Kopp et al.,
1096 2009).
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1100 1101 1102 5.4 Age of the FTN 1103

1104 In this section of the study, we define the age of FTN in areas of the Mediterranean that
1105 are considered tectonically stable on the basis of correlation to well-known dated sediments
1106 attributed to the MIS 5.5. The latter were dated due to the presence of *Senegalese* fauna or by
1107 means of U/Th on *Cladocora caespitosa* or on speleothems, OSL or aminostratigraphy age
1108 determinations (Table S7). In fact, many FTNs are dated at MIS 5.5 because they are correlated
1109 very closely and at similar elevations with fossiliferous deposits (Fig. 9; Table 1) which contain
1110 *Senegalese* fauna. This argument was debated at the end of the nineties, when some authors
1111 (Hillaire-Marcel et al., 1996; Zazo et al., 1999) indicated that, in fossiliferous deposits on the
1112 southern Spanish coast, there were various levels containing *Persististrombus latus*. The
1113 consequence of this would have been that *Persististrombus* entered the Mediterranean Sea in
1114 various isotopic stages (MIS 11, 7, 5.1 and 5.3). In 2009, Mauz and Antonioli denied this thesis,
1115 arguing that, in the Mediterranean, *Persististrombus* and correlated tropical Senegalese fauna had
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been found only in one level (or terrace in uplifted areas, i.e. Calabria). There are no doubts that the *Persististrombus* gives a precise dating of an FTN. Furthermore, in stable areas, the sea level related to MIS 9 and 11 transgressions (or older) has always remained at similar elevations, and the occurrence of subsequent transgressions at the same elevation has always obliterated the older ones. Finally, Antonioli and Ferranti (1992) in the Orosei Gulf, dated pulmonate molluscs found in the aeolianites that were inside the FTN to MIS 2. Thus confirming that an FTN can be ascribed only to the most recent phase of the high sea level preceding the MIS 2, namely the MIS 5.5. Figure 9 shows that at sites 41-44 the distance between the FTN and the dated deposit is more than 20 km. These sites are located within the gulf of Orosei (Sardinia, Italy) one of the remotest and least anthropized coasts of the central Mediterranean sea. It is, therefore, likely that the distance between the measured FTN and the dated deposit is, in this case, a result of the inaccessibility of this region for study. These sites are some of those where the FTN is longer and more continuous than anywhere in the entire Mediterranean: between sites 38 and the 44, the FTN is constantly exposed and visible. These sites are, therefore, reliably considered to represent the same FTN and be of robust MIS 5.5 age.

5.5 Notches older than MIS 5.5

Uplifted FTNs older than MIS 5.5 were measured in Sicily and Apulia (Fig. 1; Table 2; sites 75–80) at Custonaci and Grotta Racchio (Trapani), Capo Zafferano, Sferracavallo (Pa) and Grotta Romanelli (Lecce), (S4). These uplifted FTN show a mean width of 1.79 m, compared to a mean width of 0.74 m of the MIS 5.5 FTNs. This difference is significant and very obvious, as it is two and a half times wider than MIS 5.5; furthermore, these FTNs are uplifted at an elevation from 9 m and 73 m (in column 5 of Table 2). Although greater in width, these uplifted FTNs cannot be confused with the smoothed notch sensu of Antonioli et al. (2006) (Figs. 2 and 3), which is much wider at 4 m. Therefore, on the basis of the measurements of these FTNs, we hypothesize that the amplitude of the paleo-tide related to the sea level when these FTNs were carved had a larger range than the present and the MIS 5.5 tides.

The uplifted FTNs of Custonaci and Grotta Racchio are located 1 km from Grotta Rumena (Custonaci) where Stocchi et al. (2017) examined a speleothem (the oldest stalactite containing marine hiatuses ever studied) inside an uplifted cave. In this cave, four marine ingressions are preserved: three hiatuses in the speleothem section and the last one, the younger, is an overgrowth of coral on the speleothem and the roof cave. The authors provided the tectonic uplift rate for the last one million years, and, using a multidisciplinary approach (assuming a continuous vertical uplift tectonic at a rate of 0.81 mm/yr), provided the age of the fourth and last marine ingression based on scleractinian coral species (1.1 ± 0.2 Ma). The latter corresponds are related to MIS25 (Stocchi et al., 2017). The cave is presently located at the altitude of 97 ± 0.2 m. In Fig. 10, the blue curve is referred to the chronological attribution of the uplifted FTN (sea level curves in Lisiecki and Raymo [2005], corrected for GIA in Stocchi et al., [2017]); the red curve is corrected with tectonic movements (0.81 mm/y). Comparing the elevations of the studied FTNs, located at 73, 58 and 34 m, with the red curve, the FTNs (green arrows) corresponded with the highstands of

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1182
1183 MIS 25, 21 and 11, respectively. These highstands refer to the last transgression in the Grotta
1184 Rumena (MIS 31), witnessed by corals covering the walls and some stalactites (comprising the
1185 studied hiatus, not the older hiatuses).
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1188 Regarding the FTNs located at 40 m and 23 m, respectively, at Sferracavallo and Arco di
1189 Zafferano, the comparison had less precision because the surrounding area of Palermo was
1190 certainly uplifted during the Middle-Lower Pleistocene, with vertical tectonic uplifting rates
1191 presumably lower than those of Custonaci.
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1194 In the area of Custonaci, the FTN studied at Grotta dei Cavalli (San Vito lo Capo, Table 2, S4,
1195 site 77), was located at an elevation of 34 m. **Based on the curve corrected for tectonics in Fig. 10,**
1196 this highstand could be attributed to MIS 11. Although the width of the FTN has been blunted by
1197 erosion, the measure (0.60 m in Table 2, S4) is fully compatible with the PTN or with the MIS 5.5
1198 FTN. Therefore, this Middle Pleistocene FTN shows a width similar to MIS 5.5, while the other
1199 uplifted FTNs at higher elevations (showing an average width of 1.82 m) are placed in the lower
1200 Early Pleistocene. In this period the highstands and the lowstands (glacial-interglacial, Fig. 12)
1201 occurred with a mean period of 40,000 years, and not at a period of 100,000 years as occurred in
1202 the High and Middle Pleistocene (transgressions MIS 5, 7, 9 and 11). This obvious global climatic
1203 change (established by hundreds of global curves performed all over the world) could have
1204 determined higher tides in the Mediterranean, and the width of the FTN here described is a direct
1205 proof.
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1210 In summary, the red curve in Fig. 10, following Liesiki and Raymo (2005), allows us to
1211 attribute to the FTNs located at 73, 58 and 34 m an age of 950, 850 and 400 ka, respectively. For
1212 the FTNs located in the Palermo area at the elevations of 40 m and 23 m, we can hypothesize a
1213 lower or non-continuous uplift rate compared to what was found in Custonaci, and assess, on the
1214 basis of the width, that they are aged at the Lower Pleistocene. It is possible to hypothesize a
1215 sharp change of tide amplitude presumably during the transition to Middle-Lower Pleistocene
1216 (780 ka BP).
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1222 5.6 Tides 1223

1224 Antonioli et al. (2015) **demonstrated** that the **tidal notches are strictly connected with the**
1225 **local tide. But the** width of the present tidal notch shows higher values when compared with the
1226 local tide (on average the notch has a width slightly less than twice in respect to the mean tidal
1227 range). Comparing the FTN width with the PTN width, our results show that the FTN width (mean
1228 0.73 m) is wider by about 0.14 m than that of the PTN (mean 0.59 m); we interpret this greater
1229 amplitude as being due to the lack of the biological reef and to the chemical and mechanical
1230 erosion of the notch.
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1234 Therefore, we believe that the tides of the Mediterranean Sea during the MIS 5.5 highstand
1235 were the same as **-Temptatively** today. Tentatively, considering the mean width of PTNs as **0.59 m**
1236 **and 0.38 m** as the current mean Mediterranean tide (Antonioli et al., 2015), we can extrapolate
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1242 the palaeo-tide of MIS 25–21 (when the mean width of the uplifted tidal notches is 1.82 meters),
1243 resulting in a possible tide of 1.21 m, before 780 ka BP, more than **three** times that of today.
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1248 6. Conclusions

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1250 At 80 sites **in Italy and subordinately in the eastern and western** Mediterranean Sea (Tables 1 and
1251 2), the MIS 5.5 and few older notches have been accurately measured. **The main conclusions of**
1252 **this study** are:
1253

1254 1. The morphometric parameters of the PTN and FTN are broadly similar, with only a slightly larger
1255 FTN width due to the lack of the biological reef and to the chemical/mechanical erosion of the cliff
1256 during later exposure. This result implies that tide amplitude has not changed in the last 125 ka.
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1259 2. **In contrast**, during the MIS 25–21 highstands (1.2–0.6 Ma BP), the Mediterranean tides had
1260 amplitude three times larger than today.
1261

1262 3. **The GIA-driven RSL changes within the Mediterranean Basin are regionally varying and**
1263 **significantly different from the eustatic signal. Two main typologies of RSL curves can be expected:**
1264 **monotonous rise followed by a late highstand in the central areas and initial (early) highstand**
1265 **followed by an RSL drop in the marginal regions at the western and eastern borders. Overall, the**
1266 **variability of the maximum GIA elevation is between 1 and 2.5 m, i.e. comparable to the expected**
1267 **eustatic contribution of the GrIS. 10.**
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1271 4. Provided that the notches represent the maximum peak of local RSL rise, which may occur at
1272 different times and with different elevations from place to place (as explained by GIA), the
1273 observed spatial variability of MIS 5.5 notches is 1–12. m. This implies that GIA plays a secondary
1274 role in driving the regional variability of the maximum MIS 5.5 RSL elevation, and other regionally
1275 varying signals, either geologic or oceanographic, are operating.
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1277

1278 5. Geologic processes are represented by volcanic intrusions (e.g. at the Orosei Gulf in Sardinia
1279 and at Minturno in Latium), or by tectonic displacement (e.g. continental margin down-faulting in
1280 western Sardinia and on the eastern Tyrrhenian coast, or contractional uplift in northern Sicily).
1281 These low-rate processes cause a spread of up to 10 m in the FTN elevation, five times larger than
1282 the GIA variability, even at sites commonly regarded to be on stable crustal sectors.
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1284

1285 6. **The elevation of the MIS 5.5 notch at selected sites which are less affected by these** low tectonic
1286 **or volcanic movements has a trend that, along a regional E-W transect, mimics but is 1–2 m lower**
1287 **than the predicted values from the GIA ANICE-SELEN model. The 6.5 m elevated MIS 5.5 notch on**
1288 **the Tyrrhenian margin, which is assumed as a reference elevation, has a 1.5 m discrepancy with**
1289 **the model, thus casting doubt on the currently accepted amount of glacio-eustatic contribution to**
1290 **the RSL during the MIS 5.5.**
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1296 Acknowledgements

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1301 *We thank Ian Kendy, editor of Earth Science revue and two anonymous reviewers for comments*
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1303 *Calanques FTN. We thank* Joaquin Rodriguez Vidal who sent us the photographs used in
1304
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1306 *RITMARE and a contribution to the project IGCP 639 - International Geological Correlation*
1307 *Programme 'Sea-level change from minutes to millennia' by UNESCO-IUGS, We also thanks*
1308 *GEOSWIM project*

1310
1311 **FIGURE captions**

1312
1313 **Fig. 1.** Location of the investigated sites along the Mediterranean coasts. A. The red rectangles
1314 indicate the studied areas. The numbers refer to the sites of Table 1. B. White numbers refer to
1315 the altitude of the FTN, see Table 1. C. White numbers refer to the site number indicated in Table
1316 2. D. White numbers refer to the FTN of the sites studied in Sardinia. E. White numbers refer to
1317 the FTN of the sites studied in Sicily, see also Table 1, and the white numbers refer to the sea level
1318 share of the FTN of the sites studied in Sicily, see Table 1. The yellow dots refer to the uplifted FTN
1319 sites (Table 3). F. The white numbers refer to the sites in Israel, indicated in Table 2. G. The white
1320 numbers refer to the site number in France, indicated in Table 2.

1321
1322 **Fig. 2.** a) MIS 5.5 and PTN notches morphological sketch. b) Tidal and smoothed notch as is
1323 possible to observe today in some sections we studied. c) Evolution of the tidal and smoothed
1324 notch during MIS 5.5, the final coverage of fans or aeolianites deposits preserves the notches from
1325 the dissolution.

1326
1327 **Fig. 3.** Sections of fossil and present tidal notch morphology. The letters refer to the width (w),
1328 depth (d) and the base of the notch (c). On the right an overlap between the present and the fossil
1329 tidal notch (for the sites 52, 71 and 2 of Table 1) morphology highlights the marine and aeolian
1330 subaerial erosion that slightly modified the original morphology, but preserves a similar width.

1331
1332 **Fig. 4.** View of some representative morphology of the studied tidal notches. a) Site 5, Sardinia.
1333 b) Site 30, Sardinia. c) Site 38, Sardinia. d) Sites 40 and 48, Sardinia. f) Site 69, Sicily. g) Uplifted FTN
1334 site 76, Sicily. h) Uplifted FTN, site 78, Sicily. See also Tables 1 and 2.

1335
1336 **Fig. 5.** View of the different measurement methods. a) Using the telescopic measuring gauge on
1337 site 38. b) Using tape meter on site 39. c., d., e., f., g. and h. Using DGPS on sites 50, 51, 79 and 52.
1338 i. and j. In Sardinia, near Grotta Biddiriscottai, an FTN filled with aeolianite sediments aged MIS 2.
1339 k) a wall riddled by *Lithophaga* holes under the FTN of site 54. m. In Pianosa, a possible FTN that
1340 we did not use in our database due to a lack of geomorphological lateral continuity. Although we
1341 recorded day and time during each survey (see Tables 1 and 2), we did not applied tidal
1342 corrections because we referred to: a) the base of the PTN, b) the living vermetid reef, except for
1343 the FTN of Capri and Mitigliano whose measurements have been taken with respect to the
1344 corrected tide sea level, due to the lack of the PTN (Ferranti and Antonioli, 2007).

1345
1346 **Fig. 6.** Predicted MIS 5.5 RSL curves at sites along the Italian coastlines according to ICE-5G (red
1347 curves), ICE-6G (blue curves) and ANICE-SELEN (green curves) ice-sheet models. The dashed curves

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1360 represent the eustatic trend, while the solid curves represent the GIA-induced RSL changes. The
1361 RSL curves are computed at each investigated site and are plotted cumulatively for different sub-
1362 regions.
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1367 Fig. 7. Same as for Fig. 6, but for sites in Morocco (a), southern Spain (a), France (b) and Israel (c).
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1369 Fig. 8. The FTN width compared with the PTN width. The FTN widths are always a few cm larger
1370 due to limestone dissolution (see also Fig. 4). On the right, the larger 2 m width of the uplifted
1371 notches, older than last Interglacial period.
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1374 Fig. 9. Distance between the measured site and the nearest site dated using 1) U/th, 2)
1375 aminostratigraphy, 3) ESR/OSL, but above all, 4) presence of *Persististrombus latus* or Senegalese
1376 fauna. The sites are sorted as in Table 1.
1377

1378 Fig. 10. In blue, the Lisiecki and Raymo (2005) curve corrected by Stocchi et al. (2017) for GIA
1379 calculated for Custonaci, Sicily. In red, the same corrected curve for a rate of vertical tectonic
1380 movement of 0.81 mm/a. In yellow, the calculated age of the uplifted tidal notches of Table 3.
1381
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1383 Fig. 11. Maximum predicted RSL highstands according to ICE-5G, ICE-6G and ANICE-SELEN at each
1384 site considered in this study. The sites are displayed and enumerated from left to right as a
1385 function of the longitude. The numbers in the x-axis correspond to the site number. The horizontal
1386 lines correspond to the maximum eustatic value of each ice-sheet model (0.91 m for ICE-5G; 3.1 m
1387 for ICE-6G; 7.0 m for ANICE-SELEN).
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1390 Fig. 12. Predicted “maximum” RSL elevation (w.r.t. present-day) between 120 kyr BP and 110.0 kyr
1391 BP (left) and predicted RSL elevation (w.r.t. present-day) exactly at 117 kyr BP (right). On the left
1392 figure we show the maximum RSL elevation predicted, for each element of the surface mesh,
1393 between 120 and 110 ka. Because of the viscous response of the mantle, in fact, RSL continues to
1394 change also without any further addition of meltwater to the oceans. Hence maximum elevations
1395 are reached at different times according to the geographical location and are followed by RSL
1396 drop. Comparing left with right reveal indeed that in areas such as Gibraltar and Israel, maximum
1397 elevation is reached at 117 ka, and is later followed by RSL drop while other areas experience a
1398 further increase. The RSL drop predicted at Gibraltar and Israel is a consequence of (i) continental
1399 levering (i.e. upward tilt of the continental margins) and (ii) meltwater syphoning (i.e. migration of
1400 sea water towards the surroundings of formerly glaciated areas in N and S hemisphere).
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1406 Fig. 13. Observed and predicted elevation of selected MIS 5.5 FTN sites along an E-W transect
1407 from western Sardinia to southern Apulia. Predicted elevations are from the GIA ANICE-SELEN
1408 model. The trend across observed elevations is traced based on geological constraints (see text for
1409 further details).
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1413 TABLES
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1423 Table 1: MIS 5.5 and Present tidal notches data in the Mediterranean Sea
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1425 1) Site number; 2) Locality and site name; 3) Elevation, uncertain are explained in chapter 3.1 ; 4)
1426 Notch Morphometry; 5) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM=
1427 Not Measured; NC= Not Carved; C= Consumed); 6) Distance (km) and *reference site name for the
1428 age of deposit: 1 Abate et al., 1996; 2 Antonioli, 1991; 3 Antonioli et al., 1994a; 4 Antonioli et al.,
1429 1994b; 5 Antonioli et al., 1999; 6 Antonioli et al., 2002; 7 Blanc and Segre, 1953; 8 Bosellini et al.,
1430 1999; 9 Brancaccio et al., 1986, 1990; 10 Cesaraccio and Puxeddu, 1986; 11 Delicato et al., 1999;
1431 12 Durante, 1975; 13 Esposito et al., 2003; 14 Ferranti and Antonioli, 2007; 15 Hearty P.J., 1986,
1432 1987; 16 Malatesta, 1954a, 1954b, 1970; 17 Mastronuzzi et al., 2007; 18 Orrù and Ulzega, 1986;
1433 19 Orrù and Pasquini, 1992; 20 Orrù et al., 2011; 21 Palmerini and Ulzega, 1969; 22 Pascucci et al.,
1434 2014; 23 Porqueddu et al., 2011; 24 Sanna et al., 2010; 25 Segre, 1951; 26 Segre, 1957; 27 Ulzega
1435 and Ozer, 1980;
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1441
1442 Table 2
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1444 FTNs older than the uplifted MIS 5.5. 1) Site number; 2) Locality and site name; 3) Coordinates; 4)
1445 Measures; 5) Elevation (m) uncertain is explained in the method section 3.1, as regard site 75, the
1446 0.25 m uncertain was due the particular erosion of the base of the FTN ; 6) Average notch
1447 measures (m); 7) Notch Morphometry; 8) Kind of measurement (DGPS= Differential Global
1448 Positioning System; DT= Digital Altimeter) 9) MIS 5.5 elevation; 10) Reference for age; 11) Age MIS
1449 ka.
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1455 Table 3
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1457 Published FTN altitude in the Mediterranean Sea.
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1459 Table 4
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1461 Erosion rates in the intertidal and inner karst in the Mediterranean area. The total erosion for the
1462 last 125 Ka was evaluated considering a constant erosion rate.
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1465 Table 5
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1467 Comparison between GIA prediction with different models and geophysical parameters with the
1468 observed data (FTN elevations).
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1470 Table 6
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1478 Selected sites with MIS 5.5 FTN elevations less affected by tectonic displacement in Italy. See text
1479 for further details.
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1484 Supplementary material
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1488 S1 table Acronyms and definitions.
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1490 S2 File kmz of the geographical coordinates of all sites.
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1492 S3, S4, S5 Figures. A complete collection of images of all the studied notches (numbers refer to
1493 Table 1)
1494

1495 S6 Figures Notches measured in France, Gibiltrair and Morocco, by other authors (refer to Table
1496 3). 1a, b, c: site 81; 2a and 2b: site 82, notch profile and Lithophaga holes; 3: site 83; 4: site 84,
1497 Caleta Hotel. MIS 5.5 FTN and its wave-cut-platform , MIS 5.5 FTN (close up) with borings and
1498 flowstone; 5a and 5b: site 85; 6a and 6b, site 86, from Sisma Ventura et al., 2017 redowned.
1499 Photo 1, 2, 3, 4 courtesy prof. , photo 5 courtesy prof. Kurt Lambeck. Photo 6 from redowned
1500 from Sisma Ventura et al., 2016.
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1504 S7 Table 7: MIS 5.5 and Present tidal notches data in the Mediterranean Sea
1505

1506 1) Site number; 2) Locality and site name; 3) Coordinates; 4) Measures date; 5) Elevation with
1507 uncertain, m; 6) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not
1508 Measured; NC= Not Carved; C= Consumed; 8) Notch morphometry; 9) Kind of measurement: T:
1509 Telefix; M: Tape meter; DGPS: DGPS; 10) Faunal assemblage of the nearest aged fossil deposit;
1510 Distance (km) and reference site name for the age of deposit. 1) Site number; 2) Locality and site
1511 name; 3) Coordinates; 4) Notch Morphometry; 5) Elevation with uncertain, m; 6) Average notch
1512 measures, m; 7) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not
1513 Measured; NC= Not Carved; C= Consumed); 8) Notch morphometry; 9) Kind of measurement; 10)
1514 Faunal assemblages in aged fossil deposit; 11) Thechnique of chronological attribution; 12
1515 Distance (km) from the site used for give the age of deposit. References: 1 Abate et al., 1996; 2
1516 Antonioli, 1991; 3 Antonioli et al., 1994a; 4 Antonioli et al., 1994b; 5 Antonioli et al., 1999; 6
1517 Antonioli et al., 2002; 7 Blanc and Segre, 1953; 8 Bosellini et al., 1999; 9 Brancaccio et al., 1986,
1518 1990; 10 Cesaraccio and Puxeddu, 1986; 11 Delicato et al., 1999; 12 Durante, 1975; 13 Esposito et
1519 al., 2003; 14 Ferranti and Antonioli, 2007; 15 Hearty P.J., 1986, 1987; 16 Malatesta, 1954a, 1954b,
1520 1970; 17 Mastronuzzi et al., 2007; 18 Orrù and Ulzega, 1986; 19 Orrù and Pasquini, 1992; 20 Orrù
1521 et al., 2011; 21 Palmerini and Ulzega, 1969; 22 Pascucci et al., 2014; 23 Porqueddu et al., 2011; 24
1522 Sanna et al., 2010; 25 Segre, 1951; 26 Segre, 1957; 27 Ulzega and Ozer, 1980.
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ABSTRACT

We report detailed morphometric observations on several MIS 5.5 and a few older (MIS 11, 21, 25) fossil tidal notches shaped along carbonate coasts at 80 sites in the central Mediterranean Sea and at an additional six sites in the eastern and western Mediterranean. At each site, we performed precise measurements of the fossil tidal notch (FTN) width and depth, and of the elevation of its base relative to the base of the present tidal notch (PTN). The age of the fossil notches is obtained by correlation with biologic material associated with the notches at or very close to the site. This material was previously dated either through radiometric analysis or by its fossiliferous content.

The width (i.e. the difference in elevation between base and top) of the notches ranges from 1.20 to 0.38 m, with a mean of 0.74 m. Although the FTN is always a few centimetres wider than the PTN, probably because of the lack of the biological reef coupled with a small erosional enlargement in the FTN, the broadly comparable width suggests that tide amplitude has not changed since MIS 5.5 times. This result can be extended to the MIS 11 features because of a comparable notch width, but not to the MIS 21 and 25 epochs. Although observational control of these older notches is limited, we regard this result as suggesting that changes in tide amplitude broadly occurred at the Early-Middle Pleistocene transition.

The investigated MIS 5.5 notches are located in tectonically stable coasts, compared to other sectors of the central Mediterranean Sea where they are uplifted or subsided to ~100 m and over. In these stable areas, the elevation of the base of the MIS 5.5 notch ranges from 2.09 to 12.48 m, with a mean of 5.7 m. Such variability, although limited, indicates that small land movements, deriving from slow crustal processes, may have occurred in stable areas. We defined a number of sectors characterized by different geologic histories, where a careful evaluation of local vertical land motion allowed the selection of the best representative elevation of the MIS 5.5 peak highstand for each sector. This elevation has been compared against glacial isostatic adjustment (GIA) predictions drawn from a suite of ice-sheet models (ICE-G5, ICE-G6 and ANICE-SELEN) that are used in combination with the same solid Earth model and mantle viscosity parameters. Results indicate that the GIA signal is not the main cause of the observed highstand variability and that other mechanisms are needed. The GIA simulations show that, even within the Mediterranean Basin, the maximum highstand is reached at different times according to the geographical location. Our work shows that, besides GIA, even in areas considered tectonically stable, additional vertical tectonic movements may occur with a magnitude that is significantly larger than the GIA.

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3 Morphometry and elevation of the Last Interglacial tidal notches in tectonically stable coasts of
4 the Mediterranean Sea.
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42 Keywords

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44 Fossil and Present Tidal Notches, glacial isostatic adjustment (GIA), Vertical tectonic movement
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50 We report detailed morphometric observations on several MIS 5.5 and a few older (MIS 11, 21,
51 25) fossil tidal notches shaped along carbonate coasts at 80 sites in the central Mediterranean Sea
52 and at an additional six sites in the eastern and western Mediterranean. At each site, we
53 performed precise measurements of the fossil tidal notch (FTN) width and depth, and of the
54 elevation of its base relative to the base of the present tidal notch (PTN). The age of the fossil
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69 enlargement in the FTN, the broadly comparable width suggests that tide amplitude has not
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77 The investigated MIS 5.5 notches are located in tectonically stable coasts, compared to
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84 peak highstand for each sector. This elevation has been compared against glacial isostatic
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87 parameters. Results indicate that the GIA signal is not the main cause of the observed highstand
88 variability and that other mechanisms are needed. The GIA simulations show that, even within the
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90 geographical location. Our work shows that, besides GIA, even in areas considered tectonically
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102 1. Introduction

103 1. Introduction

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109 Quantifying the elevation and duration of the highstand that occurred during the Last interglacial,
110 Marine Isotope Stage (MIS) 5.5, is of key importance as it allows the sensitivity of the Greenland and
111 Antarctic Ice Sheets (GrIS and AIS, respectively) to climate conditions that are warmer than the present day
112 to be assessed (all acronyms are defined in table S1). The MIS 5.5 highstand can, therefore, be used as an
113 analogue for future scenarios of global warming, which is of key importance to 2100 sea-level projections.
114 The elevation above the present sea level (p.s.l.) of the highstand, measured in globally stable areas
115 (Rovere et al., 2016), has previously been estimated based on coral reefs using various methods (Bard et
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121 al., 1990; Chen et al., 1991; Chappel et al., 1996; Schellmann and Radtke, 2004; Blanchon et al., 2009;
122 Dutton et al., 2015). These estimates show a significant uncertainty (some meters) in the assessment of the
123 palaeo sea level (Muhs et al., 2017) because corals do not accurately mark the sea level but live in the
124 photic zone. Furthermore, in many regions of the world coral reefs are absent and cannot be relied on to
125 constrain the height of MIS 5.5 sea levels.
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128 In tectonically stable areas of the Mediterranean Sea (Fig. 1A), fossil tidal notches (FTNs) of MIS 5.5
129 age are found at 6–8 m above present sea level (Ferranti et al., 2006; Lambeck et al., 2011, Present tidal
130 notches or PTNs). The base of a tidal notch is considered the best and most precise marker of average
131 palaeo sea level because its width is closely linked to the local tidal range (Antonioli et al., 2015; Rovere et
132 al., 2016; Lorscheid et al., 2017a). The age of FTNs is constrained through correlation with adjacent marine
133 deposits that are either; 1) radiometrically dated using the Th/U method or 2) contain the “Senegalese”
134 fauna (a biostratigraphically distinct assemblage of marine mollusca the appearance of which, in the
135 Mediterranean, is robustly constrained to MIS 5.5). The Mediterranean Sea is microtidal in character and
136 many examples of late Holocene tidal notches formed in carbonate bedrock occur (e.g. Benac et al., 2004,
137 2008; Antonioli et al., 2007; Furlani et al., 2011, 2014a). These features allow the relationship between tidal
138 notches and sea level elevation to be discussed and estimates of MIS 5.5 sea level to be assessed and
139 corrected.
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143 The aim of this study is to investigate the role of crustal movements in the height distribution of
144 MIS 5.5 FTNs in the Mediterranean, primarily Italy but also from other locations across the basin. In this
145 study we present a database of the morphometric measurements and height elevation of MIS 5.5 FTNs
146 from across the Mediterranean as well as a summary of the chronological information that has been used
147 to correlate these features to the Last Interglacial. The elevation and morphometric relationship between
148 these MIS 5.5 FTNs and modern tidal notches is discussed and presented in order to make observations
149 about crustal movements (furthermore a number of older TFNs are identified and discussed). The paper
150 then maps the regional variability of the elevation of MIS 5.5 notches and compares this variability with
151 predictions of specifically built GIA models that include different ice-sheet scenarios. The paper concludes
152 by evaluating the residual difference between the measured heights of MIS 5.5 FTNs and the GIA-corrected
153 elevation of notches in the light of tectonic movement.
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159 2. Background setting

160 2.1. The tidal notch

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163 Nearly half of the Mediterranean’s rocky coasts are generated on carbonate rocks (Furlani
164 et al., 2014b). Such coasts are characterized by a typical set of landforms (Taborosi and Kazmer,
165 2013), which are related to a combination of mechanical (Trenhaile, 2002), chemical (Higgins,
166 1980; Furlani et al., 2014a) and biological processes (Torunski, 1979), although recently Trenhaile
167 (2014) has argued that notches form also as a consequence of wetting and drying cycles. While
168 bioerosion plays a role in the lowering of rocks in the intertidal zone, some hard bottom biological
169 communities can protect the bedrock from erosion (Laborel, 1987; Naylor and Viles, 2002). Tidal
170 notches are indentations or undercuttings that are mainly cut in steep carbonate cliffs at sea level;
171 they are amongst the most common landforms along the Mediterranean’s coasts and range from
172 a few centimetres to several meters in width. Antonioli et al. (2015) defined a tidal notch as the
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180 undercutting found at, or near, the tidal level on carbonate sea cliffs shaped with characteristic
181 morphology. Tidal notches have been widely used as sea level indicators for more than 150 years,
182 and many authors have suggested that they are cut by complex and polygenetic processes (Spratt
183 et al., 1895; Carobene, 1972; Higgins, 1980; Pirazzoli, 1986; Antonioli et al., 2004, 2006; Kelletat,
184 2005; Furlani et al., 2011, 2014a; Trenhaile, 2014, 2015; Moses, 2013; Moses et al., 2015).
185 Antonioli et al. (2015) measured the morphometric parameters of notches at 73 sites in the
186 central Mediterranean Sea, together with the occurrence and features of the biological rims at
187 their bases, and they correlated these parameters with wave energy, tidal range and rock
188 lithology. Their conclusions were that *'tidal notches in the Mediterranean are, rather than the*
189 *effect of a single process, the result of several processes that co-occur with different rates'*(pag.
190 81).
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195 When the floor is lacking, a tidal notch is defined as a marine notch (Pirazzoli, 1986;
196 Kelletat, 2005; Boulton and Stewart, 2015; Trenhaile, 2015), although some authors still call it a
197 tidal notch (e.g. Antonioli et al., 2015; Furlani et al., 2017) in order to distinguish it from an inland
198 notch (Shtober-Zisu et al., 2017). Its shape is, in fact, affected by the local tidal range, with a
199 maximum width, *sensu* Antonioli et al. (2015), up to 400 cm (Trenhaile, 2015). In the
200 Mediterranean Sea, present day notch width ranges from 13 to 95 cm. When the floor is lacking,
201 we define the notch as a roof notch. A notch which develops near the sea floor, with sand and
202 pebbles that mechanically erode the rock, is defined as an abrasional notch. It has no correlation
203 with sea level, as it shows a depth and width which are different from the local tidal regime
204 (Antonioli et al., 2015).
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211 2.2. Geotectonic setting of the central Mediterranean Sea

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213 The indented coasts of the Mediterranean Basin and the present configuration of the
214 coastal landscape are the result of the interaction between tectonic and morphoclimatic processes
215 that acted during the long-lasting convergence, active since the Late Cretaceous, between the
216 African and European plates along an east-west boundary (Rosenbaum et al., 2002). The region is
217 characterized by narrow as well as broader zones of seismicity and geodetic deformation, which
218 highlight the position of the major plate boundary and of the boundaries of minor plates whose
219 interiors appear to be largely aseismic (Anzidei et al., 2014; De Mets et al., 2015).
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223 The basins of the central Mediterranean Sea are the result of different tectonic processes
224 (Oldow et al., 2002; Rosenbaum et al., 2002; Anzidei et al., 2014). The Adriatic Sea and the
225 surrounding promontories are the remaining parts of the Adriatic continental lithospheric block,
226 caught between Europe and Africa, which served as the foreland domain for the southern Alpine,
227 Dinarid-Hellenid and Apennine thrust belts. The Tyrrhenian Sea is a back-arc basin that opened
228 behind the Apennines in the wake of the retreating Adriatic-Ionian slab and is partially floored by
229 oceanic crust. The Ionian Sea is a remnant of the old Ionian oceanic lithosphere, closed between
230 the Calabria and Hellenic subductions. The result of this tectonic evolution is a complex mosaic in
231 which, during the Late Pleistocene and the Holocene, areas of recognized tectonic stability
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239 (Sardinia, western and southeastern Sicily, Campania, southern Apulia, Liguria and Tuscany)
240 alternated with areas marked by often large vertical movements (eastern Sicily, Calabria,
241 Basilicata, Veneto and Friuli, Ferranti et al., 2006, 2010; Antonioli et al., 2009). This pattern of
242 vertical stability or deformation is supported by the analysis of seismicity and of global positioning
243 system (GPS) data (Oldow et al., 2002; Devoti et al., 2017; Serpelloni et al., 2014).
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246
247 In addition to tectonic processes, glacio-eustatic sea level changes induced the extensive
248 reshaping of the coastal areas during the Quaternary. Terraced marine deposits and landforms,
249 such as notches, sea caves, inner margins and paleocliffs, mark the past sea-level stands, which are
250 found below and above present-day sea level. The study of these geomorphological features has
251 allowed the recognition of the regional tectonic behavior and the long-term sea-level trend, which
252 have been summarized in recent papers by Ferranti et al. (2006; 2010), Antonioli et al. (2009) and
253 Furlani et al. (2014a).
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256 257 258 2.3. The MIS 5.5 highstand 259

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261 The marine isotope substage (MIS) 5.5 corresponds to the last interglacial period. Its
262 geochronology is based on orbital tuning of high-resolution deep-sea oxygen isotope stratigraphy.
263 The geochronological subunit MIS 5.5 occurred between Termination II (end of MIS 6) and the
264 onset of MIS 5.4 and lasted from 132 to 116 ka (Stirling et al., 1998; Shackleton et al., 2003; Kopp
265 et al., 2009; Murray-Wallace and Woodroffe, 2014). The study of Last Interglacial shorelines dates
266 back at least a century (Gignoux, 1913), and sea level indicators that formed during MIS 5.5 have
267 been reported from over one thousand sites worldwide (Pedoja et al., 2011).
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271 With respect to the Mediterranean Sea, since the identification and definition of the
272 *Tirreniano* interglacial stage (effectively MIS 5.5) by Blanc in Sardinia at Cala Mosca in 1908,
273 numerous studies have identified and dated hundreds of Last Interglacial, or 'Tyrrhenian', sites
274 throughout the Mediterranean (Blanc, 1936; Malatesta, 1985; Hearty 1986, 1987; Zazo et al.,
275 1999; Lambeck and Bard, 2000; Nisi et al., 2003). Using a compilation of 246 sites, all attributed to
276 the MIS 5.5, Ferranti et al. (2006) found a significant alongshore difference in site elevation from
277 +175 to -125 m in respect to the present sea level, which they attributed to the interplay of
278 regional and local tectonic processes, including faulting and volcanic deformation.
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282 A recent integrated study (Amorosi et al., 2014; Negri et al., 2015) of *Fronte Section* near Taranto,
283 Italy detailed one of the most representative and extensive MIS 5.5 sequences to be found in the
284 Mediterranean. Facies analysis, detailed macro- and microfaunal characterization and sequence
285 stratigraphy (using Senegalese fauna and ten U-series dates on *Cladocora caespitosa* samples)
286 permitted an unequivocal MIS 5.5 age (132–116 ka) to be attributed to these deposits. These
287 results portray the composite section as a very promising candidate (named Tarentiano) in the
288 search for the Upper Pleistocene global boundary stratotype section and point (GSSP).
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292 In the Mediterranean Sea, *Cladocora caespitosa* is one of the few scleractinian corals that build
293 extended bioherms and the only one that does so at the present time. Its presence is recorded at
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298 depths of a 4-10 m as well as down to 30–40 m (Peirano et al., 2004; Silenzi et al., 2005; Peirano et
299 al., 2009). Existing banks of *Cladocora* are reported in Croatia (Kružić and Benković, 2008), where
300 the most extensive one that is known in the Mediterranean covers an area of more than 650 m².
301 The depth of the Croatians banks ranges between 6 and 21 m. Hence, the presence of this coral as
302 fossil allows for the age determination of the past sea-level stands, but it is definitely not a reliable
303 indicator of paleo water depth. The presence in fossil deposits of *Persististrombus latus* (=
304 *Strombus bubonius*) and other Senegalese fauna have allowed the dating of thousands of deposits,
305 giving a precise chronological attribution.
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309 Finally, Hearty (1986) used available U/Th dates and the presence of Senegalese fauna on
310 some MIS 5.5 fossil deposits to calibrate the amino acid ratio of shells from these sediments and
311 landforms across the whole Mediterranean area (in particular, *Arca*, *Glycymeris* and
312 *Cerastoderma*). Using this approach, he was able to use the amino acid ratios to infer a MIS 5.5
313 age of undated or barren deposits from elsewhere in the region.
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317 2.4 "Senegalese fauna"

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319 In the Mediterranean geological context, the term Senegalese fauna indicates a fossil faunistic
320 assemblage consisting of warm species, from the Atlantic (Gignoux, 1911a, b) where “the most
321 famous and common is *Strombus bubonius* Lamarck 1791” (Gignoux, 1913). Other warm water
322 species are represented by *Patella ferruginea*, *Conus ermineus*, *Gemophos viverratus*, *Cardita*
323 *calyculata senegalensis* and *Hyotissa hyotis*. The gastropod *Persististrombus latus* (Gmelin, 1791)
324 (named until 2010 *S. bubonius*) entered in the Mediterranean sea only during the Tyrrhenian time
325 corresponding to the Last Interglacial Time ; this last term - in the form "Tirreno" - has been
326 proposed for the first time by Issel (1914) and then by Dépéret (1918) for indicating the age of
327 raised marine terraced deposits characterised by the presence of Senegalese fauna with or
328 without *P. latus*.
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332 It is generally correlated to the last interglacial (MIS 5.5), which occurred between 132 and 116 ka
333 roughly, but generally extended up to 80k a; this lap of time has been defined thanks to different
334 age determinations performed by means of U/Th analysis on the coral *Cladocora caespitosa* and
335 amino acid racemization analyses on mollusc shells as *Glycymeris sp*, *Arca sp* and *Cerastoderma sp*.
336 associated to the before mentioned taxa (e.g.: Amorosi et al., 2014; Negri et al., 2015 and
337 references therein).
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341 Bonifay and Mars (1963) affirmed that the *S. bubonius* (today *P. latus*) is not the characteristic
342 element of the Tyrrhenian and Senegalese deposits. In fact, it is very important to underline that
343 the presence of this tropical gastropod defines only a fossil facies and not all Tyrrhenian deposits
344 ("Tirreno" in Issel, 1914) with warm fauna of Atlantic origin (sensu Gignoux, 1911a,b; 1913) or
345 Senegalese (sensu Bonifay and Mars, 1963).
346
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348 2.5. Glacial- and hydro-isostatic adjustment

349
350 Quantifying the melting of the GrIS and AIS during the MIS 5.5 on the basis of paleo RSL
351 indicators from tectonically stable areas requires that the GIA process is accounted for (Dutton
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357 and Lambeck, 2012). This is usually accomplished by means of numerical modelling. The latter
358 demands that an ice-sheet model, which describes the forcing function (i.e. the surface loading
359 variation), is combined with a solid Earth model, which describes the response function (i.e. solid
360 Earth and geoid deformations). The outcome yields the space- and time-dependant RSL changes
361 that accompany and follow the ice-sheet fluctuations. The GIA-driven RSL changes incorporate all
362 the solid Earth and geoid deformations that stem from the pre-MIS 5.5 glacial-interglacial cycles
363 (in particular the melting of MIS 6 ice sheets) as well as from the retreat of the GrIS and AIS during
364 the actual MIS 5.5 interglacial period. The predicted local RSL change can be very different from
365 the eustatic signal, the difference being a function of the distance with respect to the ice sheets
366 and of the shape and size of the ocean basins. It is expected that, even within an enclosed basin
367 such as the Mediterranean Sea, the MIS 5.5 highstand reached different elevations at different
368 times as a function of the geographical location (Lorscheid et al., 2017a; Stocchi et al., 2018).

373
374 Neglecting the GIA might significantly hamper the quantification of the eustatic sea-level
375 peak, which mostly stems from GrIS and AIS melting. In fact, as discussed by Rovere et al. (2016),
376 early global-scale studies did not (properly) take GIA into account and resulted in estimates of 3–6
377 m above mean sea level (MSL) (Stearns, 1976; Harmon et al., 1981; Neumann and Hearty, 1996;
378 Stirling et al., 1998). However, more recent studies have incorporated state-of-the-art GIA
379 modelling and independently estimated values from 5 to 9.5 m above MSL (Kopp et al., 2009;
380 Dutton and Lambeck, 2012). These recent results suggest that not only did the GrIS and West AIS
381 collapse, but also the East AIS might have contributed to global sea level at this time.

384
385 In the Mediterranean, few studies up to this point have explicitly included the GIA
386 contribution to the MIS 5.5 RSL fluctuations. As highlighted by Sivan et al. (2016), the local GIA-
387 driven RSL highstand in Israel could contribute from 2–2.5 m to the highstand. Creveling et al.
388 2015 also show that the GIA contribution is significant and cannot be neglected when investigating
389 the tectonic rates of deformation. Rovere et al. (2016), Lorscheid et al. (2017b) and Stocchi et al.
390 (2018) show that the GIA signal is not uniform within the Mediterranean Basin and can contribute
391 from 1–2.5 m of RSL highstand without accounting for extra melting from Greenland and
392 Antarctica. For the latter ice sheets, several chronologies of melting have been proposed so far,
393 but it is still uncertain whether there was a single peak, a two-stand peak or actual fluctuations
394 (see Kopp et al., 2009). Furthermore, Austermann et al. (2017) show that dynamic topography
395 could contribute quite significant subsidence in the Mediterranean that could explain 1–2 m of RSL
396 change at the MIS 5.5. However, these results are not accurate enough for the Mediterranean
397 Basin given the low-resolution model used by the authors. Finally, while the timing of the onset of
398 the MIS 5.5 acme is relatively simultaneous, mostly taking place from 129 ka to 126 ka, the timing
399 of the demise of the LIG acme is more variable and ranges from 122 ka to 113 ka (Rovere et al.,
400 2016).

401 402 403 404 405 406 407 408 3. Materials and Methods 409 410 411 412 413

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416 We selected and re-measured the features of a set of FTNs from areas that are located in
417 the central Mediterranean Sea (S2, Fig. 1) and that are considered stable since the MIS 5.5
419 (Ferranti et al., 2006, 2010; Antonioli et al., 2015). The stable areas as well as the 80 surveyed sites
420 are portrayed, respectively, in Fig. 1 A and Fig.1 B-E. Six additional sites from other regions such as
421 Morocco, Gibraltar and France (Fig. 1 F-G) (Rodriguez Vidal et al., 2007, 2010; Abad et al., 2012,
422 2013) were considered because they show carved FTNs along coasts that are considered stable
423 since the MIS 5.5. All of these were then included in a database (Tables 1, 2, 3 and S7) that
424 included only well-carved FTNs on limestone rocks which presented morphological continuity. We
425 established that a tidal notch can be defined continuous when it can be followed laterally for at
426 least 50 meters.
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431 432 3.1 Measures 433

434 The measurements of the FTNs were performed from the base of the FTN to the base of
435 the PTN (**Figs. 2, 3, 4 and 5**). The measure was corrected by 3 cm because it corresponds to the
436 average width of the biological rim once formed and currently eroded at the base of an FTN
437 (Vermetids, Corallinae Algae and others living at Present sea level). This is the reason why no
438 correction has been introduced about sea level, unless in rare cases where a roof notch and an
439 FTN are present (Circeo and Capri, sites 50 and 55), and therefore a PTN base is lacking (Ferranti
440 and Antonioli, 2007). Even though we recorded the date and time for all measurements, these are
441 the only cases where the measurements of the base of the FTN were referred to the local sea
442 level, corrected for tides.
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446 The measurements of the 80 studied sites (**Tables 1 and 2 and table S7**) were performed
447 using different tools and with an estimated error ranging from ± 1 up to ± 5 cm along the vertical
448 error depending on both the tool and the adopted reference level (MSL, vermetid reef etc., see
449 **Fig. 5 and S5**). All measurements were referred to the base of the PTN or zones where the
450 vermetid reef was present and considered as representative of the MSL ($H = 0$). Vertical profiles
451 along the notch sections were realized through several measurements. An uncertainty of ± 2.5 cm
452 was assumed to account for the identification of the marker.
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456 The tools we used and related instrumental uncertainty are the following:
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458 **a)** Global Positioning System/Real Time Kinematic (GPS/RTK) technique. In eight sites (50, 51, 52,
459 54, 74, 75, 79 and 80, respectively, in **Figs. 4 and 5; Tables 1 and 2, table S7**), we used the GPS/RTK
460 technique which has an accuracy better than ± 3 cm along the vertical. This depends on both the
461 tool and the adopted measurement base (MSL, vermetid reef etc., see **S5**), but it often depends on
462 the setting of MSL. An accuracy of ± 5 cm was estimated.
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465 **b)** Levelling surveys. Sites 50, 51, 52 and 54 were surveyed by a levelling technique, using a Leica
466 Runner4 instrument. Elevation data were referred to the local sea level at the time of the surveys
467 and corrected for tides by the nearest tide station (**Fig. 5**). An accuracy of ± 5 cm was estimated
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475 **c)** Total station. Sites 79 and 80 were surveyed with a Total Station Leica TCRP 1203, equipped
476 with an infrared laser beam, capable of capturing targets at a distance up to one km. For the
477 measurements in the range of about 700 m, we used the laser beam without a prism, keeping a
478 precision of a few mm along the distance. (**Fig. 5**). An accuracy of ± 5 cm along the vertical was
479 estimated
480
481

482 **d)** Telescopic rod. In 19 sites (**Figs. 4 and 5; Tables 1 and 2, table S7**), a 10 m long telescopic
483 measuring gauge was used (Telefix). This device provides direct readings on a graduated tape and
484 is built with non-extensible material which ensures an accuracy of about 3 mm when fully
485 extended to 10 m. We estimated an error comprised from 1 to 5 cm depending on the
486 morphological conditions of the PTN and on the position of the MIS 5.5 FTN (**Figure in S5**). This is
487 always used when the FTN is orthogonal above the PTN. Otherwise, when a few degrees of
488 inclination occurred ($1-6^\circ$) between the platforms of the PTN and the FTN, the top of the
489 instrument was placed a few cm from the FTN base. The level was defined by an operator located
490 on a nearby boat and were taken photos to roughly verify the positioning of the rod with respect
491 to the significant morphologies. An accuracy of ± 1 cm along the vertical was estimated.
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496 **d)** Tape. In 46 sites (**Figs. 4 and 5; Tables 1 and 2, Table S7**), we used a 20 m long measuring tape,
497 positioned on morphological markers by two operators. This measurement tool was used in sites
498 where the cliff was not back drawn and the tape could therefore be positioned vertically or with
499 an acceptable slant (**Figure S5**). The use of the tape was done with an operator on the FTN and
500 one on the PTN that is in the sea. Because of the presence of some vertical offset in the position of
501 the two markers, and resulting tilt of the tape from the vertical, these measurements have been
502 assigned an error bar of ± 15 cm.
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506 **e)** Digital altimeter: In three sites (**Figs. 4 and 5; Tables 1, 2 and Figure S5, Table S7**) where
507 uplifted notches were far from the present day coast, position and elevation measurements were
508 performed by a digital altimeter (Garmin Oregon 650) with a vertical accuracy of 50 cm and were
509 calibrated with respect to the sea level along the nearby coast. Measurements were taken at the
510 base of the FTN and at the vermetid platform. An accuracy of ± 50 cm along the vertical was
511 estimated. When the Vermetid rim was lacking, an uncertainty of ± 10 cm was summed to the
512 marker identification and instrumental error. Any other specifications about the formation,
513 morphology and spatial variations of the morphological measurements of the PTN can be found in
514 Antonioli et al. (2015).
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518 3.2 Glacial- and hydro-isostatic adjustment

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520
521 In this paper we investigated the role of GIA in modulating the elevation of the MIS 5 sea-
522 level highstand across the Mediterranean Sea by means of process-based numerical modelling.
523 We employed three different ice-sheet models to (i) quantify the sensitivity of the Mediterranean
524 RSL sites to the GIA process and (ii) evaluate, albeit without recurring specific statistics, which
525 glacio-eustatic scenario better represents the observations.
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534 To evaluate the contribution of GIA to the observed RSL changes from the MIS 5.5, we
535 solved the gravitationally self-consistent sea level equation (SLE) (Farrell and Clark, 1976). The SLE
536 incorporates all the GIA feedbacks and yields RSL changes that accompany and follow continental
537 (i.e. land-based) ice-sheet thickness variations. We make use of of the SELEN Fortran 90 program
538 (Spada and Stocchi, 2007), which solves the SLE by means of the pseudo-spectral approach
539 (Mitrovica and Peltier, 1991). Accordingly, the SLE solution consists of spatio-temporal
540 convolutions where ice-sheets thickness variations are coupled to solid Earth responses and
541 propagated through time in order to account for the time-dependent viscous relaxation of the
542 mantle. At the core of the SLE formalism is the concept that, at any time t since the beginning of
543 the ice-sheet model chronology, the RSL changes of each point of the Earth's surface stem from
544 the solid Earth and geoid deformations induced by all the ice- and water-loading variations that
545 have occurred since the initial time t^0 . Accordingly, the solid Earth is assumed to be spherically
546 symmetric, radially stratified, self-gravitating, rotating and deformable, but not compressible
547 (Spada et al., 2003). We assume an elastic lithosphere and a Maxwell viscoelastic mantle. We
548 devide the latter into three layers: upper mantle, transition zone and lower mantle. The core of
549 the Earth is considered inviscid.
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556 We consider three global ice-sheet models that describe the last 240 kyrs of fluctuations
557 (i.e. two glacial-interglacial cycles). This is necessary in order to accurately account for the GIA
558 which accompanies and follows the melting of the MIS 6 ice sheets, as well as the GIA during and
559 after the MIS 5e until the present day. Overall, the three ice-sheet models are very different and
560 are characterized by very different eustatic elevations and temporal durations of the last
561 interglacial phase. The three models are the following:
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564
565 1. ICE-5G (Peltier, 2004): This model describes the ice-sheet thickness variations over North
566 America, Eurasia, Greenland and Antarctica from 26 ka to present. For this time span, ICE-5G was
567 constrained by the means of geological RSL data and modern geodetical observations (Peltier,
568 2004). Prior to 26 ka, the ice-sheet growth is tuned to the delta-18O curve (Lisieki and Raymo,
569 2005) and is not glaciologically realistic (Peltier, 2004). The chronology starts at 123 ka, when the
570 global ice-sheet volume was smaller than it is today and resulted in a eustatic sea level of ~ 0.9 m
571 above the present level (mostly due to a smaller GrIS; to be specified). In order to capture the GIA
572 contribution to the MIS 5.5 highstand, we combined in time two consecutive ICE-5G chronologies.
573 This allowed us to simulate the ice-sheet growth towards the MIS 6 glacial maximum and the
574 subsequent retreat during the period from MIS 6 to MIS 5.5 Therefore, after the MIS 5e, the ice-
575 sheet chronology is repeated towards the present day (including the last glacial maximum LGM, of
576 course). However, we do not claim that the MIS 6 glacial maximum was the same as the LGM.
577 According to our reconstructed chronology, the MIS 5.5 interglacial starts at 129.5 ka, which
578 corresponds to the end of the initial cycle, and ends at 122 ka. The maximum peak of 0.9 m
579 equivalent sea level (ESL) starts at 125 ka and ends at 123 ka, therefore resulting in a 2 kyr-long
580 (late) highstand (see red dashed curves in **Figs. 6 and 7**).
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586 2. ICE-6G (Argus et al., 2014; Peltier et al., 2015): This model represents the latest
587 improvement of the ICE-5G (see previous entry). We apply the same time discretization and
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593 chronology of the ICE-5G. According to the ICE-6G, the maximum MIS 5.5 eustatic highstand is
594 ~3.1 m above present-day MSL as a consequence of the GrIS and AIS retreat and occurred from
595 125 to 123 ka (see blue dashed curves in Figs. 6 and 7).
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598 3. ANICE-SELEN (de Boer et al., 2014, 2016): This model describes the global ice-sheet
599 fluctuations that follow the delta-18O stack (Lisiecki and Raymo, 2004) and that dynamically
600 account for all the GIA feedback. ANICE-SELEN, therefore, is the result of a fully and dynamically
601 coupled system and, so far, has been not constrained by means of RSL data. We followed the
602 original ANICE-SELEN chronology and, during the MIS 5e, forced the GrIS and AIS to release,
603 respectively, 2 and 5 m of equivalent sea level (ESR) (see also Lorscheied et al., 2016; Rovere et al.,
604 2016) Therefore, under the eustatic approximation, this would result in 7.0 m ubiquitous sea-level
605 highstand from 120 ka to 117 ka (see green dashed curves in Figs. 6 and 7).
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609 Overall, the three ice sheet models are very different and they are expected, therefore, to
610 result in different RSL changes not just in the proximity of the formerly glaciated areas, but also at
611 ice distal or far-field sites such as the Mediterranean Sea. Also, it is interesting to compare the
612 response of the Mediterranean basin to two different classes of ice sheet models: (i) ICE-5 and 6G,
613 both the result of RSL data inversions, and (ii) ANICE-SELEN, the result of a pure process-based
614 modeling approach. In fact, while ICE-5 and 6G are built to give an excellent fit with post LGM RSL
615 data, ANICE-SELEN purely follows ice-flow physics and dynamics. Therefore, we expect large
616 regional differences, but also a consistent signal in the Mediterranean. This could prove that,
617 regardless of all the uncertainties in the ice sheet models (no model is perfect or 100% realistic),
618 we can constrain the expected GIA response of the Mediterranean (lower to upper limit), and
619 therefore provide better estimates of the absolute glacio-eustatic value at the MIS 5e (mostly
620 Greenland and Antarctic ice sheets reduction).
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628 4. Results

629 4.1. FTN elevation

630 The mean elevation of all measurementss (Figs. 1, 2, 3, S2, S3, S4 and Figure S5; Tables 1
631 and 2) in the studied sites is 5.71 m with a maximum of 12.78 m at Monte d'Argento (southern
632 Latium) and a minimum of 2.09 m (Palinuro, south of Naples). If we do not consider the values
633 lower than 2.5 m (Palinuro, Capo Zafferano and Rosh Hanikra Israel) and higher than 10 m, the
634 average elevation is 5.95 m. We added to the measured sites in Italy six measurements at sites
635 elsewhere in the Mediterranean Sea (Abad et al., 2012, 2013; Rodriguez Vidal et al., 2007, 2015;
636 **Table 3 and Figure S6**), but we did not use these observations for statistical analysis.
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643 4.2 FTN width and comparison with PTN width

644 The mean width of MIS 5.5 FTN (Figs. 2 and 8; Table 1) is 0.74 m with a maximum of 1.20 m
645 at Levanzo and a minimum of 0.38 m at Palinuro. The PTN mean width is 0.59 m with a maximum
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652 of 0.9 m at Levanzo and a minimum of 0.30 m at Palinuro. The FTN/PTN ratio width is 1.28. This
653 value is always larger than 1 (Tables 1 and 2, column 4; Fig. 5). Compared with the PTN widths, the
654 FTN widths are always wider by 10 to 25 cm (Table 1; Figs. 2, 5, S2, S3 and S4).
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657 4.3 FTN depth and comparison with PTN depth 658

659 The mean depth of the FTNs (Tables 1 and 2; Figs. 2 and 3) is 0.9 m with a maximum of
660 1.20 m at Capo Caccia (site 2) and a minimum of 0.20 m at Capo Caccia (site 10). In the Orosei Gulf,
661 near springs with a flow rate of thousands m³/sec, the PTN has a width up to 4 m (Antonioli et al.,
662 2015). The FTN/PTN ratio width is 0.92 (with a maximum of 1.40 at Levanzo, and a minimum of
663 0.16 m at Capo Caccia) (Tables 1 and 2, column 4). Compared with the PTN depths, the FTN depths
664 are almost always smaller (Figs. 3, S3, S4 and S5). Regarding the FTN base (Figs. 2 and 3), the mean
665 of our measures is 0.66 m, with a maximum of 1.80 m at Pedralonga (site 2) and a minimum of
666 0.15 m at San Vito Macari (site 72) (Tables 1 and 2).
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672 4.4 Age of the fossil notch 673

674 Regarding the age of the fossil notch, for each site, we considered the distance between
675 the notches and the nearest dated fossil deposit which can be correlated to it. The results (**Fig. 9;**
676 **Table 1**) show a mean distance of 4.5 km with a maximum distance of 22.9 km (Pedralonga, site
677 44) and a minimum of 0.2 km (Capo Caccia, site 12). Regarding the quality of analyses or markers
678 used, as explained in Table 1, we provide the references for each site. The dating techniques used
679 for the FTN are the following: 1) U/Th analysis on *Cladocora caespitosa* or on speleothems; 2) OSL on
680 sandy deposits; 3) Aminostratigraphy on marine shells; and 4) Correlation to fossil assemblages containing
681 *Persististrombus latus* or other Senegalese fauna.
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687 4.5 FTN older than MIS 5.5 688

689 Uplifted FTN older than MIS 5.5 were studied and measured in Sicily and Apulia (**Fig. 1;**
690 **Table 2, Figure S5; sites 74–80**) at Custonaci, Grotta Racchio, Capo Zafferano, Sferracavallo and
691 Grotta Romanelli (the elevation ranged from 9.2 m at Romanelli to 73 m at Custonaci). These
692 notches show a width from 1.5 to 2.12 m, with a mean of 1.82 m and a FTN/PTN ratio of notch
693 depth always higher than 1 (Fig. 10; Tables 1 and 2).
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698 4.6 Glacial- and hydro-isostatic adjustment 699

700 Within the Mediterranean Basin, the predicted GIA-modulated RSL curves for all the three
701 ice-sheet models are significantly different from the eustatic curves (see Figs. 6 and 7). There are
702 significant differences between the predicted RSL curves in the central regions of the basin, such
703 as Italy (Fig. 6) and France (Fig. 7), and the marginal areas, such as Morocco and Israel,
704 respectively, in the western and eastern Mediterranean Sea (Fig. 7a and c). In the central areas, in
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711 fact, the RSL curves are characterized by a monotonous RSL rise that lags behind the eustatic
712 signal and that eventually results in a higher than eustatic highstand by the end of the MIS 5.5
713 temporal window (see solid curves w.r.t. dashed curves of Fig. 6). This holds for all three ice-sheet
714 models that, albeit different, are combined in the same mantle viscosity profile. Interestingly,
715 differences between GIA-modulated and eustatic signal are larger for the ANICE-SELEN (see green
716 curves). The predicted RSL curves at the Italian sites all show a relatively fast RSL increase (about
717 0.5–1.0 m) from 125 ka to 123 ka, while the eustatic signal is flat for this time span.
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721 The sites at the western and eastern boundaries (Fig. 7a and c) are characterized by earlier
722 highstand, which is then followed by a relative sea level drop. This holds in particular for the ICE-
723 5G and ICE-6G, while the signal is only visible for ANICE-SELEN within the 125–123 ka time
724 window. The latter, in fact, is characterized by a local RSL drop as opposed to the rise at the Italian
725 sites.
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728 The GIA-driven regional contribution to RSL rise is related to the maximum peak from 1–2.5
729 m within the whole Mediterranean Basin. Notably, higher values are only reached at sites 1–4 for
730 ICE-5G, and the rest of the estimates are within 1.5 m (Fig. 11; Table 5). This implies that GIA alone
731 (leaving out the extra GrIS and AIS glacio-eustatic components) is capable of driving a 1–1.5 m
732 (locally 2.5 m) higher than present sea level during the MIS 5.5. Such a value is comparable to the
733 expected glacio-eustatic contribution of GrIS during the MIS 5.5 The latter, however, shows up at
734 different times according to the geographical location.
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738 The GIA contribution to RSL rise (related to the maximum peak) along the coasts of Italy
739 (including Sardinia and Sicily) is up to 1.5 m (Fig. 12). This holds for all the three ice-sheet models
740 and, therefore, confirms that the GIA signal in the Mediterranean is quite consistent among
741 different ice-sheet chronologies (Fig. 12).
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744 Overall, the predicted maximum peaks according to ICE-5G and ICE-6G (Fig. 12 left) could
745 explain the observed lower limits. On the other hand, the maximum peaks predicted according to
746 ANICE-SELEN fit quite well with some observations and, in general, with the higher limits.
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749 Following from the previous point, GIA results alone are a second-order contributor to variability
750 when compared to the observations. Hence, they can only explain in part the observed regional
751 variations in the maximum peak elevation (see also regional variability in Fig. 11 and Table 5).
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754 5. Discussion

755 5.1 Notch morphometry: comparison with the PTN

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757 This study has yielded unprecedented details on the MIS 5.5 notch morphometry that can
758 be compared with the morphometry of the PTN studied by Antonioli et al. (2015). The three
759 morphometric parameters (width, depth and base) of PTNs show small differences depending
760 whether they are located in sheltered or exposed areas. Similar results were also achieved for the
761 FTNs (Tables 1 and 2). Moreover, near large fresh water springs (as described for Sardinia's
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770 western coast in Antonioli et al., 2015), PTN depths are noticeably higher (more than 4 m), while
771 FTN remain the same because the PTN so deeply carved tend to collapse.
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773 The main difference between the PTN and the FTN is the width. The average FTN width
774 recorded in 67 sites was 0.73 m, while the average width of the PTN in 59 sites was 0.59 m. The
775 conclusion is that the average width of an FTN is 0.14 m wider than that of a PTN. This difference
776 supports, based on a larger data set, the conclusions of Antonioli et al. (2015), derived from data
777 collected in eight sites.
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780 We explain the FTN width exceeding the PTN width by 0.14 m as a result of a combination
781 of chemical and biological weathering of the carbonate bedrock. The aforementioned processes
782 are responsible also of the lack of the biological rim (Vermetids, Corallinales algae) in the FTN. We
783 argue that a biological rim was present at the base of the FTN during MIS 5.5, based on the
784 morphology of its lower part. Antonioli et al. (2006) and Antonioli et al. (2015) describe a fossil
785 vermetid reef in an uplifted FTN attributed to MIS 5.5 near Taormina. With the disappearance of
786 the rim, the notch was also increasingly more exposed to erosion.
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790 Dissolution rates measured on carbonate rocks in the Mediterranean area show values
791 ranging from 0.01 mm/a to 1 mm/a (Furlani et al., 2014b), with higher rates in correspondence
792 with the mid- or low-tide levels (Furlani et al., 2009; Furlani and Cucchi, 2013). The longest data
793 set covers about 40 years (Furlani et al., 2009; Stephenson et al., 2012). Taking into account
794 significant approximations in the extrapolation of erosion rates for the long-term period, such as
795 hundred thousand years or more, due to the complete lacking of instrumental data older than half
796 century or morphometric proxies, a linear extrapolation over 125,000 years, implies a total
797 amount of erosion of Mesozoic limestones hosting FTNs ranging from 0.125 m to 5 m (**Table 4**).
798 Uncertainties can be due to the effects of past local climate setting, that could have affected past
799 erosion rates or different geological conditions, such as the shedding of the notch by younger
800 sediments that have now been stripped off. In some cases, limestone lowering rates can be also
801 higher, such as at Mallorca Island (Gomez-Pujol et al., 2006), with the result of the complete
802 disappearance of MIS 5.5 notches. Softer limestones, such as Miocene calcarenites, have higher
803 dissolution rates, with a total estimated erosion of 100 m (**Table 4**). The latter is not the case for
804 the observed FTNs. The relatively low average difference in width (0.14 m) between FTNs and
805 PTNs calls for erosion rates at the lower boundary of the estimate. The other measured
806 morphometric dimensions of FTNs do not show any systematic difference from those of PTNs.
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813 On the other hand, the preservation of the FTNs at some or several sites and the minimal
814 difference in width with respect to the PTNs could be explained by taking into account subsequent
815 deposition processes which preserved the FTNs, even in the presence of higher dissolution rates.
816 The sediments could have protected the buried forms, at least until their post-LGM exhumation.
817 Many examples of this occurrence have been recorded in many sites in the Orosei Gulf and at
818 Tavolara Island, where traces of LGM eolianites are still found inside the FTNs (Fig. 5i-j).
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822 An FTN changes its morphology and morphometry depending on whether it is covered and
823 preserved by sediments (aeolianites and/or other continental deposits) or not. The final
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829 morphometric shape (especially the width) may have a significant enlargement due to karst
830 solution processes, with rates that (on carbonate lithologies) may reach 0.04 mm per year (Furlani
831 et al., 2009, 2010; Furlani and Cucchi, 2013) outside the tidal zone. This is confirmed by the
832 FTN/PTN ratio width that is always greater than 1. The other measured morphometric dimensions
833 of an FTN do not show any peculiar difference from those of a PTN.
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838 5.2. Glacial- and hydro-isostatic adjustment

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840 The departures from the eustasy and the regional variability of the predicted RSL curves (in
841 particular the differences between the central areas and the marginal regions) stem from the ice-
842 induced crustal variations (mostly from Fennoscandia) and the sea-bottom deformations driven by
843 the ocean loading term.
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847 In particular, the monotonous RSL rise and late highstand that are predicted at the Italian
848 sites (Fig. 6) stem from the subsidence of the solid Earth in response to the collapse of the
849 peripheral forebulge (around Fennoscandia) and to ocean load-driven subsidence of the crust. The
850 predicted early highstand in the marginal sites (Fig. 7a and c), which is then followed by an RSL
851 drop, is the result of two processes that are related to both meltwater redistribution and solid
852 Earth deformations. The first is the so-called continental levering, which stems from the
853 lithospheric flexure in response to the loading of the basins and which results in coastal uplift. The
854 second is the migration of meltwater towards the collapsing forebulges. Together, these two
855 processes result in an early highstand (w.r.t. the eustatic signal), which is opposed to the later
856 highstand that is predicted in the central areas (Fig. 6), and the GIA signal is consistent regardless
857 of the ice-sheet models (the predicted GIA variability is smaller if compared to the observations).
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862 Overall, the maximum predicted highstand for the three ice-sheet models do show and
863 confirm that the GIA signal in the Mediterranean is of the order of 1–2.5 m and is quite consistent,
864 regardless of the shape and chronology of the MIS 6 glaciation and deglaciation.
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868 5.3 Notch elevation distribution and comparison with GIA predictions

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870 Measurements of the MIS 5.5 FTN elevation at 74 sites in areas of Italy that are considered
871 tectonically stable in the literature (Table 1; Figure 4, Figures S3, S4, S5) show an average value of
872 5.73 m, with a maximum of 12.78 m and a minimum of 2.09 m.
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876 The studied sites are far from tectonically or volcanic active zones. Elsewhere in Italy, active
877 tectonic or volcanic processes account for a marked positive or negative departure of the
878 observed MIS 5.5 FTN elevation from the predicted GIA-eustatic elevation, most notably in the
879 northwestern Adriatic Sea and in the Ionian and Tyrrhenian sides of Calabria (Ferranti et al., 2006,
880 2010). Nevertheless, we suspect that some of the minor scatter between values at stable sites
881 presented in this paper derives from unaccounted albeit slow local tectonic or volcanic processes.
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In order to place further constraints on the accurate elevation of the MIS 5.5 FTN, we selected, from the total 74 observed sites in Italy, the 13 sites that we considered less affected by local land motion. Within these 13 sites, we retained only one elevation datum when multiple observations are available at sites that are few tens of meters to few kilometers apart within a geologically coherent area (**Table 6**). We selected this representative datum based on the ascertained (or suspected) slow tectonic process acting in each area and on the resulting sign of vertical land motion. When the prevailing process is normal faulting or aseismic subsidence related to a passive continental margin development, we considered the highest elevation found in the area as the most accurate. On the other hand, when arching related to magmatic processes controls coastal deformation and the land motion is uplift, we selected the lowest value (Table 6). Similarly, in areas where folding and thrusting produce uplift parallel to the coastline, the lowest FTN elevation is considered as most reliable. When faulting or folding is at a high angle to the coast, the resulting process is tilting and, thus, an intermediate FTN elevation, as close as possible to the tilt axis, represents the most accurate estimate.

We analysed the selected sites' distribution along a regional scale (~850 km long) E-W transect from the western Sardinia margin to the western Adriatic margin in Apulia, with a manually traced trend line of the observed MIS 5.5 highstand elevation (**Fig. 13** All the sites but Talamone in Tuscany and Marettimo in Sicily lay very close to the trace of the transect (yellow dots in Fig. 13). Because the two sites in Tuscany and Sicily are far from the trace compared to all the others, we showed these two sites in a different way (white dots in Fig. 13).

In NW Sardinia, we selected the FTN found at the maximum elevation (5.5 m) out of the 20 measurements in the area of Capo Caccia and Punta Giglio (Fig. 1D). As pointed out by Ferranti et al. (2006), NW Sardinia faces the Balearic continental margin of the western Mediterranean Sea, and the decrease in elevation of the FTN from east to west may be the result of fault- or creep-related subsidence (Table 6). Continental margin downthrow is also suspected in SW Sardinia (Buggerru-Masua and S. Antico sectors), so we picked the maximum elevation (3.5 m) as well. It is interesting to note that, on this continental margin, the selected FTN progressively loses 2.5 m of elevation from N (Capo Caccia-Punta Giglio) to S (Buggerru-Masua-S.Antioco) over a distance of 180 km. Whether this occurrence is fortuitous or reflects the process of a southward tilt of the whole of western Sardinia has not been established. However, being at a prominent continental margin, we chose to start the trend line at the maximum elevation in the north.

In respect to eastern Sardinia, Ferranti et al. (2006) suggested the presence of residual volcanic activity to explain the northward increase in elevation pattern of the FTN over a 25 km distance in the Orosei Gulf (sites 37–44; Fig. 1D). Mariani et al. (2009) modelled this deformation with a magmatic intrusion that post-dates the MIS 5.5 notch, as documented by minor explosive breccia flows that locally cover the notch. Based on this argument, the elevation increase is related to tilting ensuing from intrusion. Because the prevailing land motion is an uplift, we selected the minimum elevation (7.0 m) of the FTN observed at the Pedralonga site (Table 6). In NE Sardinia, the MIS 5.5 notch shows about 2 m difference in elevation from Tavolara (6–7 m) in the south to Capo Figari (4.5–5 m) in the north, over a distance of less than 10 km. Regional NE-

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947 SW striking left transcurrent faults that cross the interposed bay could be responsible for the
948 coast-parallel tilt, but they are retained as inactive (Oggiano et al., 2009). With the existing
949 uncertainty, we included in the selection both the lowest elevation at Capo Figari and the highest
950 elevation at Tavolara, assuming a tilt axis lies in between. The trend line crosses the eastern
951 Sardinia margin midway between the observations at Capo Caccia, Tavolara and Capo Figari (Fig
952 13).
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956 On the eastern Tyrrhenian margin, only an FTN observation (Talamone, 4.8 m elevation) is
957 available from Tuscany in the north. This site is projected 250 km southward on the transect and,
958 as for the Capo Figari site, has an elevation residing under the trend line, suggesting it could have
959 been lowered by unaccounted processes.
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962 South of Talamone, sites in Latium show a 3.4 m south-eastward decrease in elevation
963 from 9.3 m (Circeo) to 5.9 m (Gaeta) along 50 km of coast which at this location has an E-W trend
964 (Fig. 1B). We discarded from selection the site of Minturno, which displays the highest measured
965 elevation in this study (12.48 m, site 54, Figures 11 and S4), because we considered it affected by
966 processes related to the now extinct Roccamonfina volcano. The last documented activity of the
967 volcano was at 150 Ka BP, but younger activity could have occurred (Rouchon et al., 2008). We
968 also suspected that the continental margin rebound affected the 9.3 m elevation of the FTN at
969 Circeo, and, thus, we excluded this site as well. The remaining three sites have elevations ranging
970 from 6–6.5 m (Gaeta-Sperlonga) to 8 m (Terracina). The Terracina site lies close to a post-MIS 5.5
971 extensional fault, and, thus, the footwall uplift may have contributed to a fraction of the observed
972 elevation. Fortunately, a borehole in the nearby Fondi Plain, located in the immediate hanging wall
973 of the fault, which has revealed MIS 5.5 deposits at –6 m, allowed making a predictive estimation
974 of the footwall uplift. By using a ratio of hanging-wall subsidence to footwall uplift of 1:10,
975 supported by theoretical modelling and observational data (King et al., 1988; Armijo et al., 1996),
976 the 14 m difference between the FTN at Terracina in the fault footwall and the drilled deposit in its
977 hanging-wall results in 1.4 m footwall uplift. In terms of difference, the estimated GIA-eustatic
978 position of the FTN at Terracina is 6.6 m (Table 6). This estimate is strikingly similar to observations
979 in nearby Sperlonga and Gaeta, suggesting that the trend line passes through the corrected
980 elevation at Terracina.
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987 Several FTNs have been measured between Capri Island and Sorrento Peninsula
988 (Campania). As pointed out by Ferranti and Antonioli (2007), the elevation of the notch at Capri
989 decreases progressively from southeast (8.0 m) to northwest (5.2 m). The pattern of down-
990 dropping of the tidal notch is consistent with the active subsidence with a maximum occurring in
991 the Gulf of Naples, located north of Capri Island, and monocline tilting of the island and the nearby
992 Sorrento Peninsula. We argue that the axis of tilting at Capri is at an elevation of 7.0 m, which is
993 the most represented FTN elevation (Tables 1 and 6).
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997 Further south, in Cilento, contrasting observations come from Palinuro (FTN at 2.1 m) and
998 from nearby Marina di Camerota - Bulgheria site (FTN at 6.7 m) (Table 1, Figure S4, site 54). In line
999 with the reasoning for continental margin faults, we regard the higher measurement as the most
1000 accurate.
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1006 The group of FTN sites measured in NW Sicily (Fig. 1E) is placed over an active collisional
1007 margin, where the convergence between Sardinia and Sicily in response to African and European
1008 plate motion is accommodated by thrusting and folding and is expressed by seismicity and
1009 geodetic data (Ferranti et al., 2008; Palano et al., 2012; Serpelloni et al., 2007). Thus, we picked
1010 the lowest observed FTN elevation (8.1 m at Marettimo) as representative of this sector, after
1011 discarding the very low elevation data from Capo Zafferano which could have been affected by
1012 local subsidence. When we projected the Marettimo datum 200 km northward on the trend line, a
1013 positive mismatch of about 2 m with respect to the trend line is estimated (Fig. 13).
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1017 The easternmost observed notch was at an elevation of 8.2 m at Striare in Apulia, at the
1018 southward terminus of the Adriatic Sea. Southern Apulia lies at the eastern tip of the conspicuous
1019 regional uplift of the Calabrian Arc, related to Ionian plate subduction (Ferranti et al., 2006, 2010),
1020 and, thus the FTN elevation could be 1–2 m higher than the trend line because of a far-field
1021 tectonic residual (Fig. 13).
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1025 A comparison between the selected observations of the FTN elevations and the predicted
1026 values from the ANICE-SELEN GIA model reveals that the GIA signal is partly at odds with respect
1027 to the observed trend (Fig. 13). Along the E-W transect, shown in Fig. 13, the GIA signal has
1028 elevations that are up to 4 m higher than the observation points, and 1–3 m higher than the
1029 inferred observational trend. The discrepancy between the GIA predicted values and the
1030 observations is higher in western Sardinia (Buggerru) and at the northeastern Tyrrhenian margin
1031 (Talamone), and progressively decreases to 1–2 m towards the the southeastern Tyrrhenian
1032 (Capri) margins, and on the Adriatic margin (Striare), where it is minimal. The observed and
1033 predicted trends along this transect appears to be comparable in the sector between the Adriatic
1034 and Tyrrhenian margins, with a 1.5–2 m lower elevation for the observed trend. Only the observed
1035 FTN at Terracina has an elevation similar to the predicted value, but, as outlined above, the
1036 elevation at this site has been corrected to 6.6 m.
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1041 The lower-than-predicted observed values in western Sardinia, and possibly at Talamone,
1042 could have been affected by unaccounted marginal tectonic subsidence, and this could alleviate
1043 the discrepancy. On the other hand, the cluster of selected sites on the Latium-Campanian coast
1044 (Terracina, Sperlonga, Capri and Marina di Camerota) seems to define a 6.5 reference value as the
1045 most appropriate. Under this hypothesis, a 1.5 difference with predicted values still remains in the
1046 comparable part of the transect (Fig. 13). This observation allows us to argue that the glacio-
1047 eustatic contribution at the MIS 5.5 was probably lower than most recent estimates (Kopp et al.,
1048 2009).
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1052 1053 1054 5.4 Age of the FTN 1055

1056 In this section of the study, we define the age of FTN in areas of the Mediterranean that
1057 are considered tectonically stable on the basis of correlation to well-known dated sediments
1058 attributed to the MIS 5.5. The latter were dated due to the presence of *Senegalese* fauna or by
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1065 means of U/Th on *Cladocora caespitosa* or on speleothems, OSL or aminostratigraphy age
1066 determinations (Table S7). In fact, many FTNs are dated at MIS 5.5 because they are correlated
1067 very closely and at similar elevations with fossiliferous deposits (Fig. 9; Table 1) which contain
1068 Senegalese fauna. This argument was debated at the end of the nineties, when some authors
1069 (Hillaire-Marcel et al., 1996; Zazo et al., 1999) indicated that, in fossiliferous deposits on the
1070 southern Spanish coast, there were various levels containing *Persististrombus latus*. The
1071 consequence of this would have been that *Persististrombus* entered the Mediterranean Sea in
1072 various isotopic stages (MIS 11, 7, 5.1 and 5.3). In 2009, Mauz and Antonioli denied this thesis,
1073 arguing that, in the Mediterranean, *Persististrombus* and correlated tropical Senegalese fauna had
1074 been found only in one level (or terrace in uplifted areas, i.e. Calabria). There are no doubts that
1075 the *Persististrombus* gives a precise dating of an FTN. Furthermore, in stable areas, the sea level
1076 related to MIS 9 and 11 transgressions (or older) has always remained at similar elevations, and
1077 the occurrence of subsequent transgressions at the same elevation has always obliterated the
1078 older ones. Finally, Antonioli and Ferranti (1992) in the Orosei Gulf, dated pulmonate molluscs
1079 found in the aeolianites that were inside the FTN to MIS 2. Thus confirming that an FTN can be
1080 ascribed only to the most recent phase of the high sea level preceding the MIS 2, namely the MIS
1081 5.5. Figure 9 shows that at sites 41-44 the distance between the FTN and the dated deposit is
1082 more than 20 km. These sites are located within the gulf of Orosei (Sardinia, Italy) one of the
1083 remotest and least anthropized coasts of the central Mediterranean sea. It is, therefore, likely that
1084 the distance between the measured FTN and the dated deposit is, in this case, a result of the
1085 inaccessibility of this region for study. These sites are some of those where the FTN is longer and
1086 more continuous than anywhere in the entire Mediterranean: between sites 38 and the 44, the
1087 FTN is constantly exposed and visible. These sites are, therefore, reliably considered to represent
1088 the same FTN and be of robust MIS 5.5 age.

1099 5.5 Notches older than MIS 5.5

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1101 Uplifted FTNs older than MIS 5.5 were measured in Sicily and Apulia (Fig. 1; Table 2; sites
1102 75–80) at Custonaci and Grotta Racchio (Trapani), Capo Zafferano, Sferracavallo (Pa) and Grotta
1103 Romanelli (Lecce), (S4). These uplifted FTN show a mean width of 1.79 m, compared to a mean
1104 width of 0.74 m of the MIS 5.5 FTNs. This difference is significant and very obvious, as it is two and
1105 a half times wider than MIS 5.5; furthermore, these FTNs are uplifted at an elevation from 9 m and
1106 73 m (in column 5 of Table 2). Although greater in width, these uplifted FTNs cannot be confused
1107 with the smoothed notch sensu of Antonioli et al. (2006) (Figs. 2 and 3), which is much wider at 4
1108 m. Therefore, on the basis of the measurements of these FTNs, we hypothesize that the amplitude
1109 of the paleo-tide related to the sea level when these FTNs were carved had a larger range than the
1110 present and the MIS 5.5 tides.

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1115 The uplifted FTNs of Custonaci and Grotta Racchio are located 1 km from Grotta Rumena
1116 (Custonaci) where Stocchi et al. (2017) examined a speleothem (the oldest stalactite containing
1117 marine hiatuses ever studied) inside an uplifted cave. In this cave, four marine ingressions are
1118 preserved: three hiatuses in the speleothem section and the last one, the younger, is an
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overgrowth of coral on the speleothem and the roof cave. The authors provided the tectonic uplift rate for the last one million years, and, using a multidisciplinary approach (assuming a continuous vertical uplift tectonic at a rate of 0.81 mm/yr), provided the age of the fourth and last marine ingression based on scleractinian coral species (1.1 ± 0.2 Ma). The latter corresponds are related to MIS25 (Stocchi et al.,2017). The cave is presently located at the altitude of 97 ± 0.2 m. In **Fig. 10**, the blue curve is referred to the chronological attribution of the uplifted FTN (sea level curves in Lisiecki and Raymo [2005], corrected for GIA in Stocchi et al., [2017]); the red curve is corrected with tectonic movements (0.81 mm/y). Comparing the elevations of the studied FTNs, located at 73, 58 and 34 m, with the red curve, the FTNs (green arrows) corresponded with the highstands of MIS 25, 21 and 11, respectively. These highstands refer to the last transgression in the Grotta Rumena (MIS 31), witnessed by corals covering the walls and some stalactites (comprising the studied hiatus, not the older hiatuses).

Regarding the FTNs located at 40 m and 23 m, respectively, at Sferracavallo and Arco di Zafferano, the comparison had less precision because the surrounding area of Palermo was certainly uplifted during the Middle-Lower Pleistocene, with vertical tectonic uplifting rates presumably lower than those of Custonaci.

In the area of Custonaci, the FTN studied at Grotta dei Cavalli (San Vito lo Capo, Table 2, S4, site 77), was located at an elevation of 34 m. Based on the curve corrected for tectonics in Fig. 10, this highstand could be attributed to MIS 11. Although the width of the FTN has been blunted by erosion, the measure (0.60 m in Table 2, S4) is fully compatible with the PTN or with the MIS 5.5 FTN. Therefore, this Middle Pleistocene FTN shows a width similar to MIS 5.5, while the other uplifted FTNs at higher elevations (showing an average width of 1.82 m) are placed in the lower Early Pleistocene. In this period the highstands and the lowstands (glacial-interglacial, Fig. 12) occurred with a mean period of 40,000 years, and not at a period of 100,000 years as occurred in the High and Middle Pleistocene (transgressions MIS 5, 7, 9 and 11). This obvious global climatic change (established by hundreds of global curves performed all over the world) could have determined higher tides in the Mediterranean, and the width of the FTN here described is a direct proof.

In summary, the red curve in Fig. 10, following Lisiecki and Raymo (2005), allows us to attribute to the FTNs located at 73, 58 and 34 m an age of 950, 850 and 400 ka, respectively. For the FTNs located in the Palermo area at the elevations of 40 m and 23 m, we can hypothesize a lower or non-continuous uplift rate compared to what was found in Custonaci, and assess, on the basis of the width, that they are aged at the Lower Pleistocene. It is possible to hypothesize a sharp change of tide amplitude presumably during the transition to Middle-Lower Pleistocene (780 ka BP).

5.6 Tides

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1183 Antonioli et al. (2015) demonstrated that the tidal notches are strictly connected with the
1184 local tide. But the width of the present tidal notch shows higher values when compared with the
1185 local tide (on average the notch has a width slightly less than twice in respect to the mean tidal
1186 range). Comparing the FTN width with the PTN width, our results show that the FTN width (mean
1187 0.73 m) is wider by about 0.14 m than that of the PTN (mean 0.59 m); we interpret this greater
1188 amplitude as being due to the lack of the biological reef and to the chemical and mechanical
1189 erosion of the notch.
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1193 Therefore, we believe that the tides of the Mediterranean Sea during the MIS 5.5 highstand
1194 were the same as ~~Tentatively~~ today. Tentatively, considering the mean width of PTNs as 0.59 m
1195 and 0.38 m as the current mean Mediterranean tide (Antonioli et al., 2015), we can extrapolate
1196 the palaeo-tide of MIS 25–21 (when the mean width of the uplifted tidal notches is 1.82 meters),
1197 resulting in a possible tide of 1.21 m, before 780 ka BP, more than three times that of today.
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1201 1202 6. Conclusions

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1204 At 80 sites in Italy and subordinately in the eastern and western Mediterranean Sea (**Tables 1 and**
1205 **2**), the MIS 5.5 and few older notches have been accurately measured. The main conclusions of
1206 this study are:
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1209 1. The morphometric parameters of the PTN and FTN are broadly similar, with only a slightly larger
1210 FTN width due to the lack of the biological reef and to the chemical/mechanical erosion of the cliff
1211 during later exposure. This result implies that tide amplitude has not changed in the last 125 ka.
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1214 2. In contrast, during the MIS 25–21 highstands (1.2–0.6 Ma BP), the Mediterranean tides had
1215 amplitude three times larger than today.
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1218 3. The GIA-driven RSL changes within the Mediterranean Basin are regionally varying and
1219 significantly different from the eustatic signal. Two main typologies of RSL curves can be expected:
1220 monotonous rise followed by a late highstand in the central areas and initial (early) highstand
1221 followed by an RSL drop in the marginal regions at the western and eastern borders. Overall, the
1222 variability of the maximum GIA elevation is between 1 and 2.5 m, i.e. comparable to the expected
1223 eustatic contribution of the GrIS. 10.
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1226 4. Provided that the notches represent the maximum peak of local RSL rise, which may occur at
1227 different times and with different elevations from place to place (as explained by GIA), the
1228 observed spatial variability of MIS 5.5 notches is 1–12. m. This implies that GIA plays a secondary
1229 role in driving the regional variability of the maximum MIS 5.5 RSL elevation, and other regionally
1230 varying signals, either geologic or oceanographic, are operating.
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1233 5. Geologic processes are represented by volcanic intrusions (e.g. at the Orosei Gulf in Sardinia
1234 and at Minturno in Latium), or by tectonic displacement (e.g. continental margin down-faulting in
1235 western Sardinia and on the eastern Tyrrhenian coast, or contractional uplift in northern Sicily).
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1242 These low-rate processes cause a spread of up to 10 m in the FTN elevation, five times larger than
1243 the GIA variability, even at sites commonly regarded to be on stable crustal sectors.
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1246 6. The elevation of the MIS 5.5 notch at selected sites which are less affected by these low tectonic
1247 or volcanic movements has a trend that, along a regional E-W transect, mimics but is 1–2 m lower
1248 than the predicted values from the GIA ANICE-SELEN model. The 6.5 m elevated MIS 5.5 notch on
1249 the Tyrrhenian margin, which is assumed as a reference elevation, has a 1.5 m discrepancy with
1250 the model, thus casting doubt on the currently accepted amount of glacio-eustatic contribution to
1251 the RSL during the MIS 5.5.
1252
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1256
1257 *We thank Ian Kendy, editor of Earth Science revue and two anonymous reviewers for comments*
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1261 *RITMARE and a contribution to the project IGCP 639 - International Geological Correlation*
1262 *Programme 'Sea-level change from minutes to millennia' by UNESCO-IUGS, We also thanks*
1263 *GEOSWIM project*
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1268 1269 FIGURE captions

1270
1271 **Fig. 1.** Location of the investigated sites along the Mediterranean coasts. A. The red rectangles
1272 indicate the studied areas. The numbers refer to the sites of Table 1. B. White numbers refer to
1273 the altitude of the FTN, see Table 1. C. White numbers refer to the site number indicated in Table
1274 2. D. White numbers refer to the FTN of the sites studied in Sardinia. E. White numbers refer to
1275 the FTN of the sites studied in Sicily, see also Table 1, and the white numbers refer to the sea level
1276 share of the FTN of the sites studied in Sicily, see Table 1. The yellow dots refer to the uplifted FTN
1277 sites (Table 3). F. The white numbers refer to the sites in Israel, indicated in Table 2. G. The white
1278 numbers refer to the site number in France, indicated in Table 2.
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1282 **Fig. 2.** a) MIS 5.5 and PTN notches morphological sketch. b) Tidal and smoothed notch as is
1283 possible to observe today in some sections we studied. c) Evolution of the tidal and smoothed
1284 notch during MIS 5.5, the final coverage of fans or aeolianites deposits preserves the notches from
1285 the dissolution.
1286

1287
1288 **Fig. 3.** Sections of fossil and present tidal notch morphology. The letters refer to the width (w),
1289 depth (d) and the base of the notch (c). On the right an overlap between the present and the fossil
1290 tidal notch (for the sites 52, 71 and 2 of Table 1) morphology highlights the marine and aeolian
1291 subaerial erosion that slightly modified the original morphology, but preserves a similar width.
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1294 **Fig. 4.** View of some representative morphology of the studied tidal notches. a) Site 5, Sardinia.
1295 b) Site 30, Sardinia. c) Site 38, Sardinia. d) Sites 40 and 48, Sardinia. f) Site 69, Sicily. g) Uplifted FTN
1296 site 76, Sicily. h) Uplifted FTN, site 78, Sicily. See also Tables 1 and 2.
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1301 **Fig. 5.** View of the different measurement methods. a) Using the telescopic measuring gauge on
1302 site 38. b) Using tape meter on site 39. c., d., e., f., g. and h. Using DGPS on sites 50, 51, 79 and 52.
1303 i. and j. In Sardinia, near Grotta Biddiriscottai, an FTN filled with aeolianite sediments aged MIS 2.
1304 k) a wall riddled by *Lithophaga* holes under the FTN of site 54. m. In Pianosa, a possible FTN that
1305 we did not use in our database due to a lack of geomorphological lateral continuity. Although we
1306 recorded day and time during each survey (see Tables 1 and 2), we did not applied tidal
1307 corrections because we referred to: a) the base of the PTN, b) the living vermetid reef, except for
1308 the FTN of Capri and Mitigliano whose measurements have been taken with respect to the
1309 corrected tide sea level, due to the lack of the PTN (Ferranti and Antonioli, 2007).

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1313 **Fig. 6.** Predicted MIS 5.5 RSL curves at sites along the Italian coastlines according to ICE-5G (red
1314 curves), ICE-6G (blue curves) and ANICE-SELEN (green curves) ice-sheet models. The dashed curves
1315 represent the eustatic trend, while the solid curves represent the GIA-induced RSL changes. The
1316 RSL curves are computed at each investigated site and are plotted cumulatively for different sub-
1317 regions.
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1323 Fig. 7. Same as for Fig. 6, but for sites in Morocco (a), southern Spain (a), France (b) and Israel (c).
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1325 Fig. 8. The FTN width compared with the PTN width. The FTN widths are always a few cm larger
1326 due to limestone dissolution (see also Fig. 4). On the right, the larger 2 m width of the uplifted
1327 notches, older than last Interglacial period.
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1330 Fig. 9. Distance between the measured site and the nearest site dated using 1) U/th, 2)
1331 aminostratigraphy, 3) ESR/OSL, but above all, 4) presence of *Persististrombus latus* or Senegalese
1332 fauna. The sites are sorted as in Table 1.
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1334 Fig. 10. In blue, the Lisiecki and Raymo (2005) curve corrected by Stocchi et al. (2017) for GIA
1335 calculated for Custonaci, Sicily. In red, the same corrected curve for a rate of vertical tectonic
1336 movement of 0.81 mm/a. In yellow, the calculated age of the uplifted tidal notches of Table 3.
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1339 Fig. 11. Maximum predicted RSL highstands according to ICE-5G, ICE-6G and ANICE-SELEN at each
1340 site considered in this study. The sites are displayed and enumerated from left to right as a
1341 function of the longitude. The numbers in the x-axis correspond to the site number. The horizontal
1342 lines correspond to the maximum eustatic value of each ice-sheet model (0.91 m for ICE-5G; 3.1 m
1343 for ICE-6G; 7.0 m for ANICE-SELEN).
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1346 Fig. 12. Predicted "maximum" RSL elevation (w.r.t. present-day) between 120 kyr BP and 110.0 kyr
1347 BP (left) and predicted RSL elevation (w.r.t. present-day) exactly at 117 kyr BP (right). On the left
1348 figure we show the maximum RSL elevation predicted, for each element of the surface mesh,
1349 between 120 and 110 ka. Because of the viscous response of the mantle, in fact, RSL continues to
1350 change also without any further addition of meltwater to the oceans. Hence maximum elevations
1351 are reached at different times according to the geographical location and are followed by RSL
1352 drop. Comparing left with right reveal indeed that in areas such as Gibraltar and Israel, maximum
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elevation is reached at 117 ka, and is later followed by RSL drop while other areas experience a further increase. The RSL drop predicted at Gibraltar and Israel is a consequence of (i) continental levering (i.e. upward tilt of the continental margins) and (ii) meltwater syphoning (i.e. migration of sea water towards the surroundings of formerly glaciated areas in N and S hemisphere).

Fig. 13. Observed and predicted elevation of selected MIS 5.5 FTN sites along an E-W transect from western Sardinia to southern Apulia. Predicted elevations are from the GIA ANICE-SELEN model. The trend across observed elevations is traced based on geological constraints (see text for further details).

TABLES

Table 1: MIS 5.5 and Present tidal notches data in the Mediterranean Sea

1) Site number; 2) Locality and site name; 3) Elevation, uncertain are explained in chapter 3.1 ; 4) Notch Morphometry; 5) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not Measured; NC= Not Carved; C= Consumed); 6) Distance (km) and *reference site name for the age of deposit: 1 Abate et al., 1996; 2 Antonioli, 1991; 3 Antonioli et al., 1994a; 4 Antonioli et al., 1994b; 5 Antonioli et al., 1999; 6 Antonioli et al., 2002; 7 Blanc and Segre, 1953; 8 Bosellini et al., 1999; 9 Brancaccio et al., 1986, 1990; 10 Cesaraccio and Puxeddu, 1986; 11 Delicato et al., 1999; 12 Durante, 1975; 13 Esposito et al., 2003; 14 Ferranti and Antonioli, 2007; 15 Hearty P.J., 1986, 1987; 16 Malatesta, 1954a, 1954b, 1970; 17 Mastronuzzi et al., 2007; 18 Orrù and Ulzega, 1986; 19 Orrù and Pasquini, 1992; 20 Orrù et al., 2011; 21 Palmerini and Ulzega, 1969; 22 Pascucci et al., 2014; 23 Porqueddu et al., 2011; 24 Sanna et al., 2010; 25 Segre, 1951; 26 Segre, 1957; 27 Ulzega and Ozer, 1980;

Table 2

FTNs older than the uplifted MIS 5.5. 1) Site number; 2) Locality and site name; 3) Coordinates; 4) Measures; 5) Elevation (m) uncertain is explained in the method section 3.1, as regard site 75, the 0.25 m uncertain was due the particular erosion of the base of the FTN ; 6) Average notch measures (m); 7) Notch Morphometry; 8) Kind of measurement (DGPS= Differential Global Positioning System; DT= Digital Altimeter) 9) MIS 5.5 elevation; 10) Reference for age; 11) Age MIS ka.

Table 3

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1419 Published FTN altitude in the Mediterranean Sea.
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1421 Table 4
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1423 Erosion rates in the intertidal and inner karst in the Mediterranean area. The total erosion for the
1424 last 125 Ka was evaluated considering a constant erosion rate.
1425

1426 Table 5
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1428 Comparison between GIA prediction with different models and geophysical parameters with the
1429 observed data (FTN elevations).
1430

1431 Table 6
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1433 Selected sites with MIS 5.5 FTN elevations less affected by tectonic displacement in Italy. See text
1434 for further details.
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1439 Supplementary material
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1444 S1 table Acronyms and definitions.
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1446 S2 File kmz of the geographical coordinates of all sites.
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1448 S3, S4, S5 Figures. A complete collection of images of all the studied notches (numbers refer to
1449 Table 1)
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1451 S6 Figures Notches measured in France, Gibiltrair and Morocco, by other authors (refer to Table
1452 3). 1a, b, c: site 81; 2a and 2b: site 82, notch profile and Lithophaga holes; 3: site 83; 4: site 84,
1453 Caleta Hotel. MIS 5.5 FTN and its wave-cut-platform , MIS 5.5 FTN (close up) with borings and
1454 flowstone; 5a and 5b: site 85; 6a and 6b, site 86, from Sisma Ventura et al., 2017 redrowned.
1455 Photo 1, 2, 3, 4 courtesy prof. , photo 5 courtesy prof. Kurt Lambeck. Photo 6 from redrowned
1456 from Sisma Ventura et al., 2016.
1457
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1459
1460 S7 Table 7: MIS 5.5 and Present tidal notches data in the Mediterranean Sea
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1462 1) Site number; 2) Locality and site name; 3) Coordinates; 4) Measures date; 5) Elevation with
1463 uncertain, m; 6) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not
1464 Measured; NC= Not Carved; C= Consumed; 8) Notch morphometry; 9) Kind of measurement: T:
1465 Telefix; M: Tape meter; DGPS: DGPS; 10) Faunal assemblage of the nearest aged fossil deposit;
1466 Distance (km) and reference site name for the age of deposit. 1) Site number; 2) Locality and site
1467 name; 3) Coordinates; 4) Notch Morphometry; 5) Elevation with uncertain, m; 6) Average notch
1468 measures, m; 7) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not
1469 Measured; NC= Not Carved; C= Consumed); 8) Notch morphometry; 9) Kind of measurement; 10)
1470 Faunal assemblages in aged fossil deposit; 11) Thechnique of chronological attribution; 12
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1478 Distance (km) from the site used for give the age of deposit. References: 1 Abate et al., 1996; 2
1479 Antonioli, 1991; 3 Antonioli et al., 1994a; 4 Antonioli et al., 1994b; 5 Antonioli et al., 1999; 6
1480 Antonioli et al., 2002; 7 Blanc and Segre, 1953; 8 Bosellini et al., 1999; 9 Brancaccio et al., 1986,
1482 1990; 10 Cesaraccio and Puxeddu, 1986; 11 Delicato et al., 1999; 12 Durante, 1975; 13 Esposito et
1483 al., 2003; 14 Ferranti and Antonioli, 2007; 15 Hearty P.J., 1986, 1987; 16 Malatesta, 1954a, 1954b,
1484 1970; 17 Mastronuzzi et al., 2007; 18 Orrù and Ulzega, 1986; 19 Orrù and Pasquini, 1992; 20 Orrù
1485 et al., 2011; 21 Palmerini and Ulzega, 1969; 22 Pascucci et al., 2014; 23 Porqueddu et al., 2011; 24
1486 Sanna et al., 2010; 25 Segre, 1951; 26 Segre, 1957; 27 Ulzega and Ozer, 1980.
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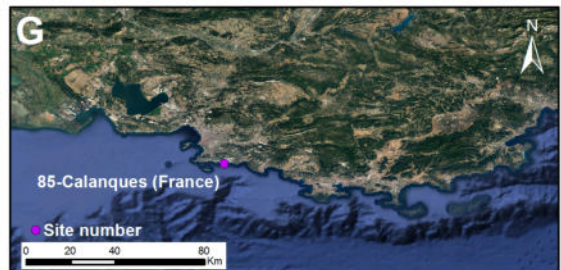
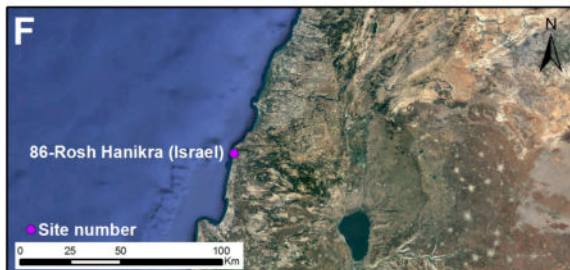
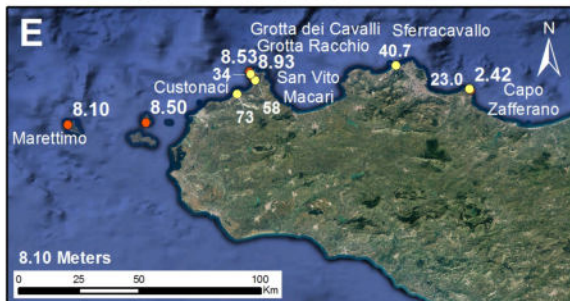
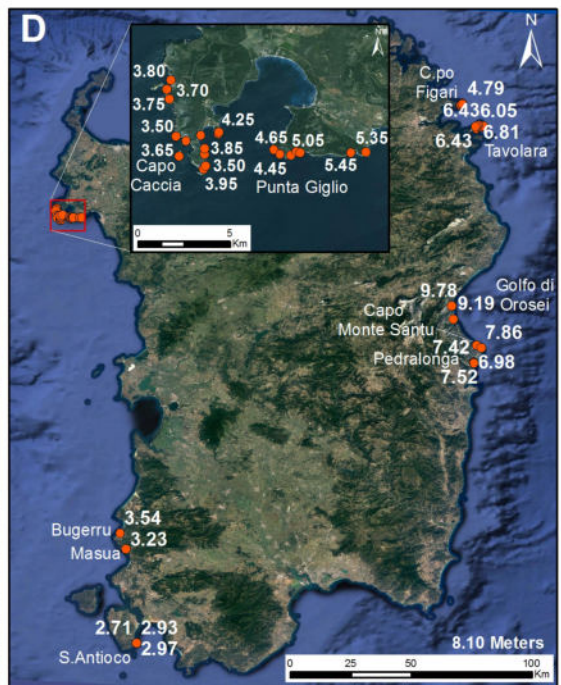
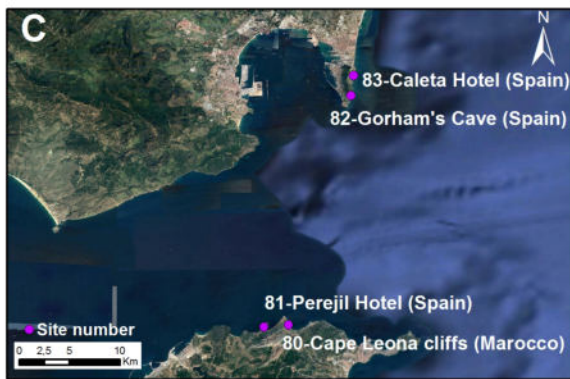
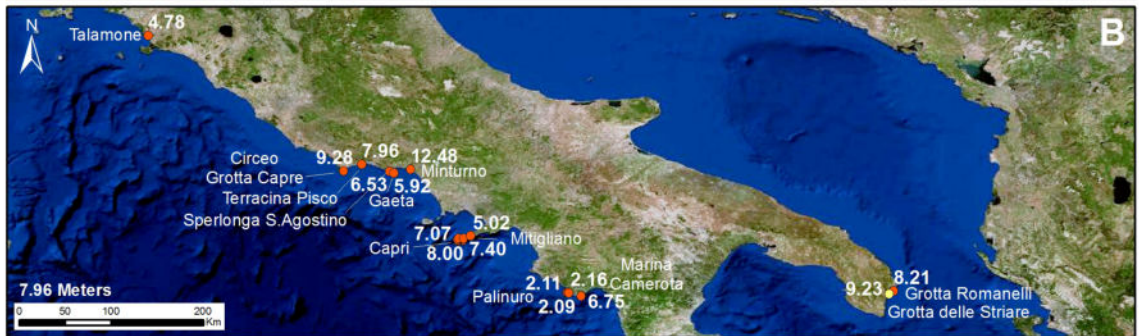
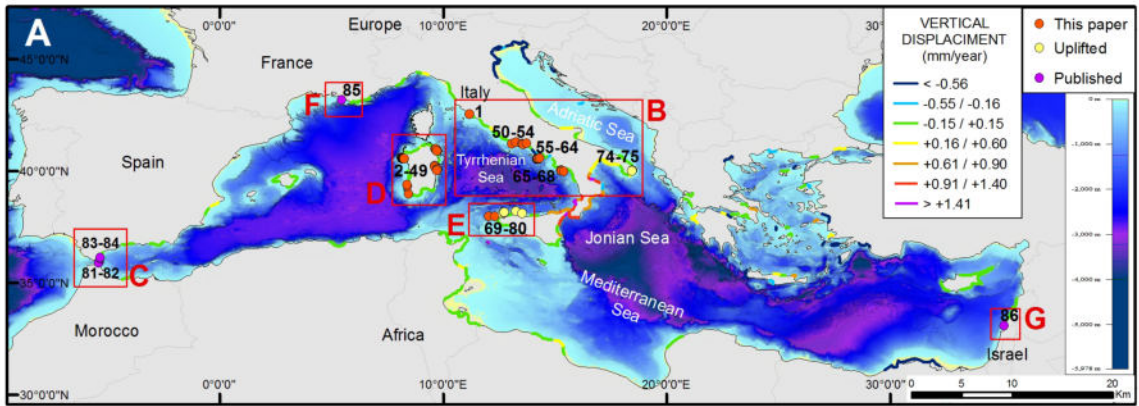
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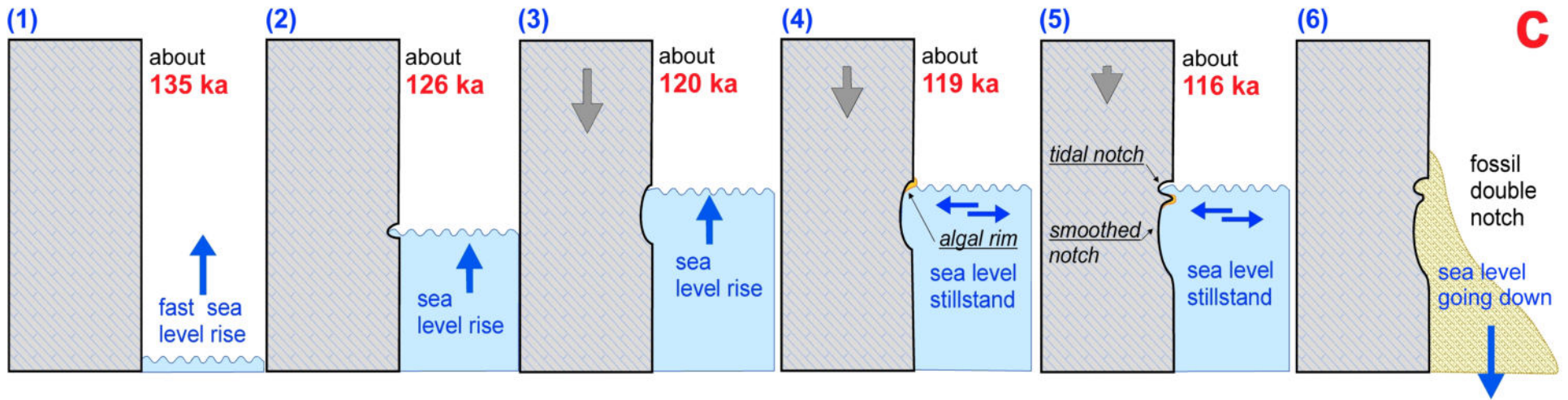
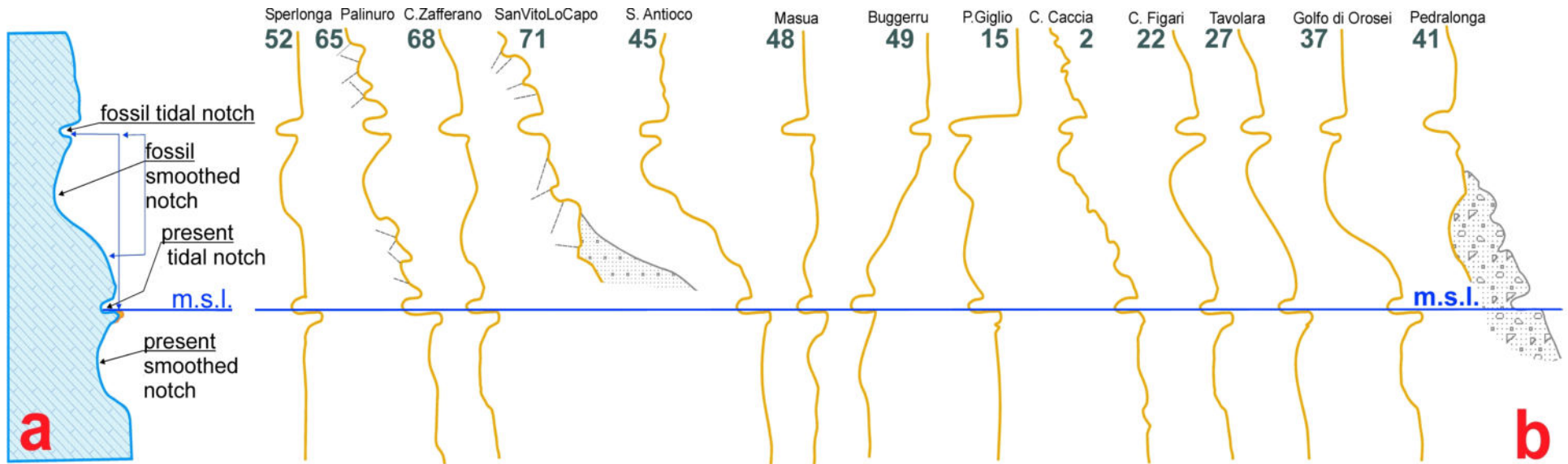
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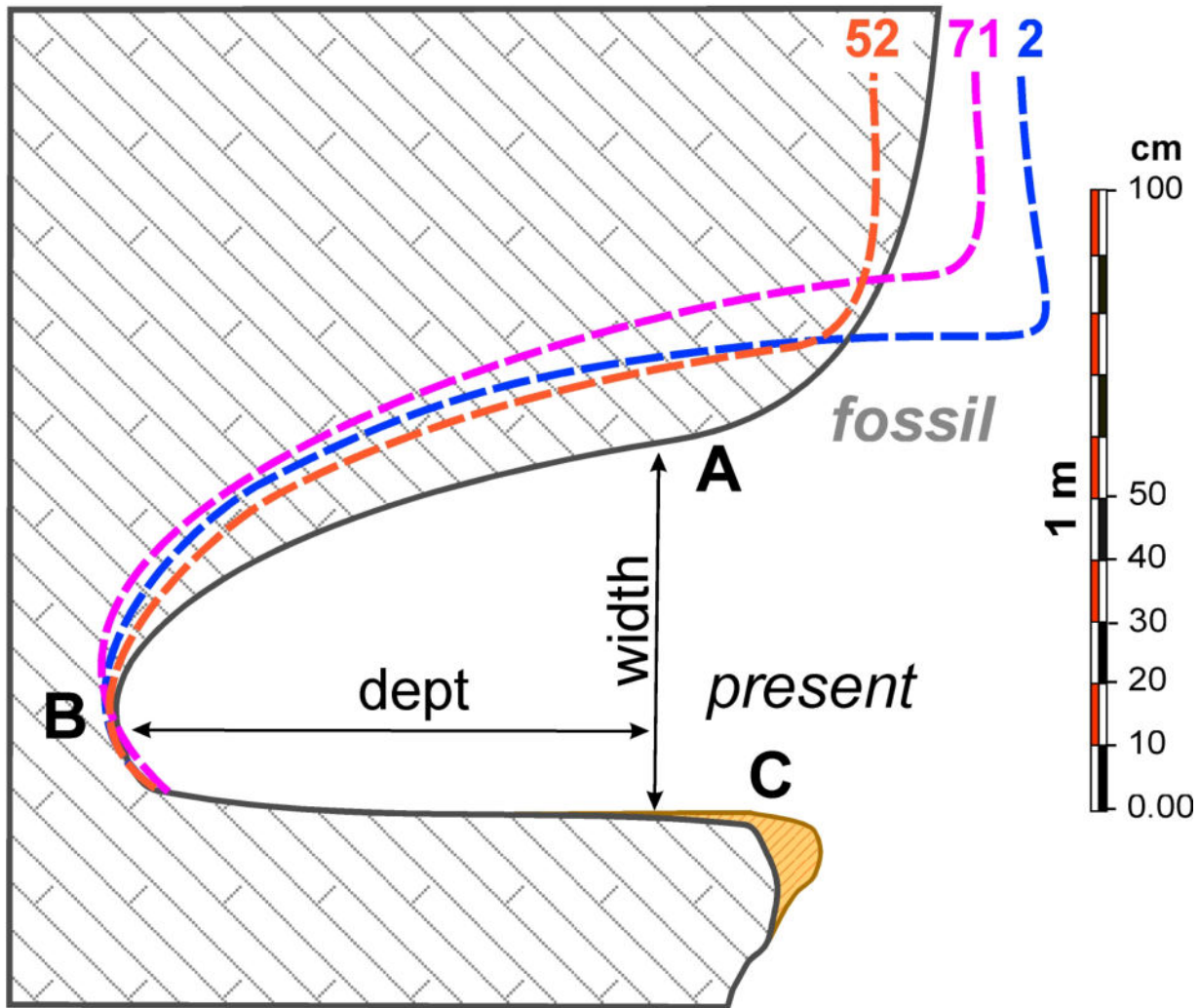
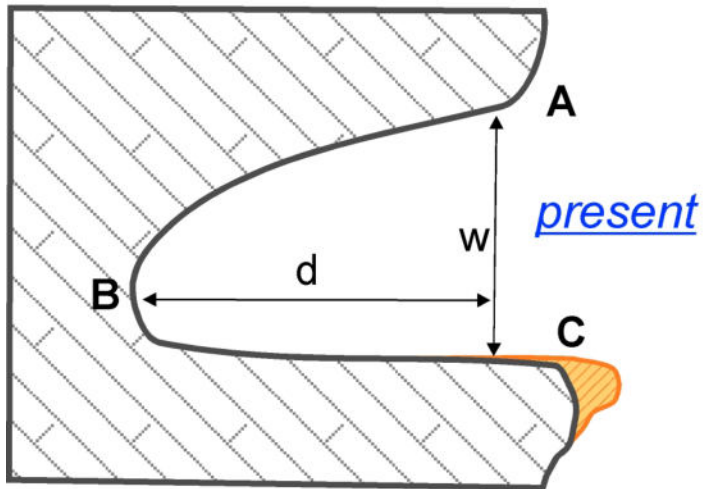
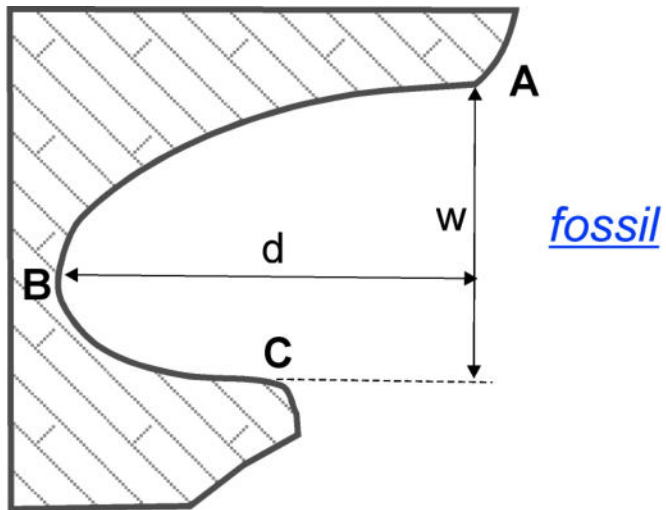
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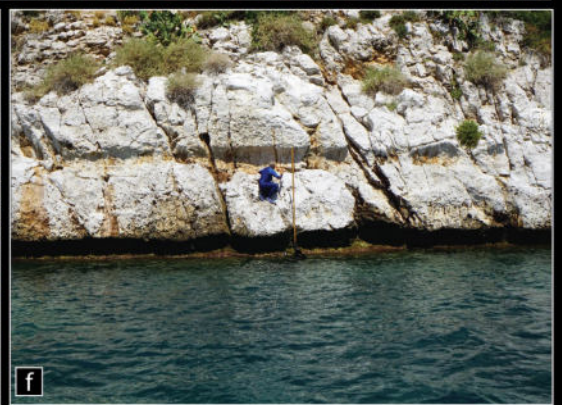
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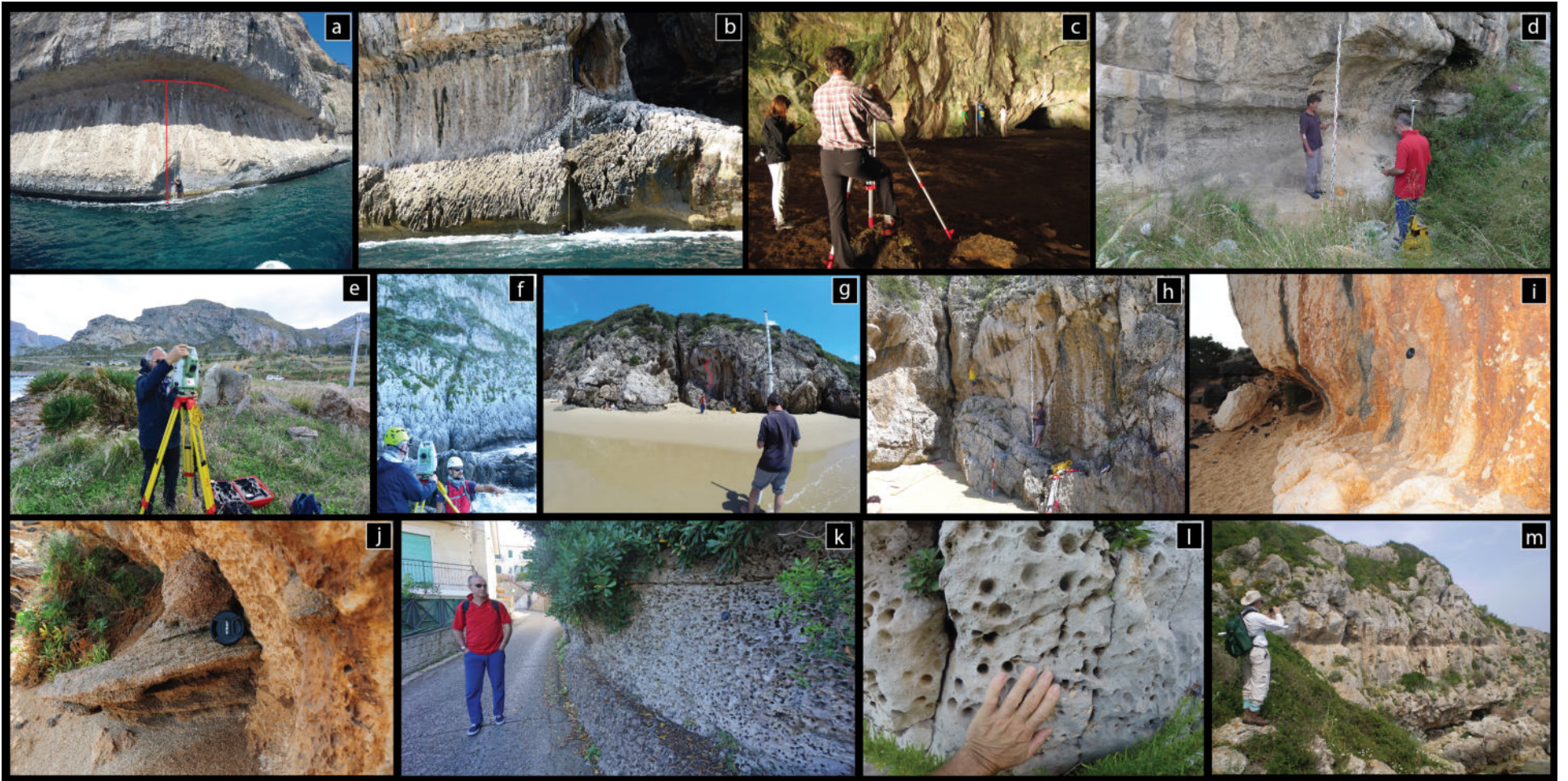
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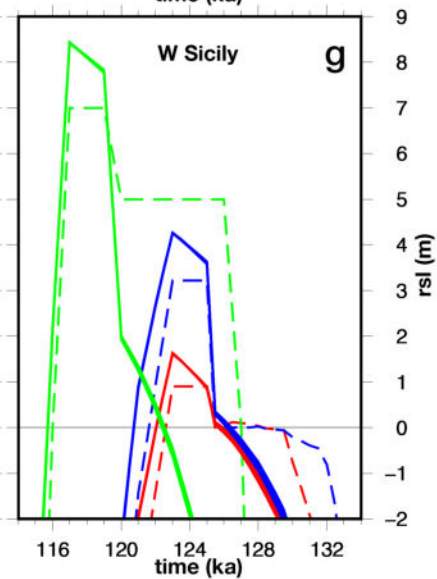
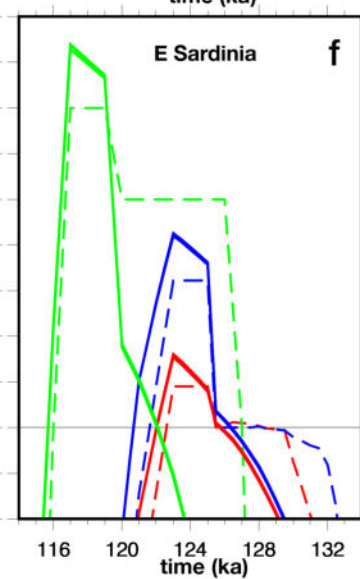
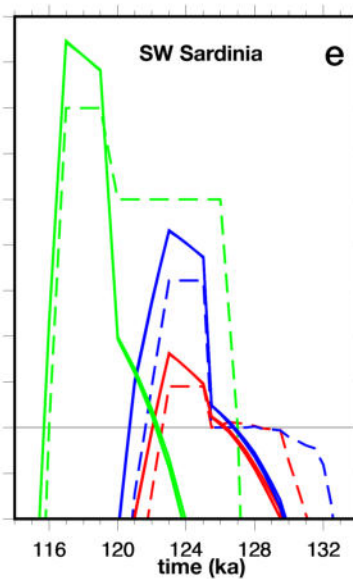
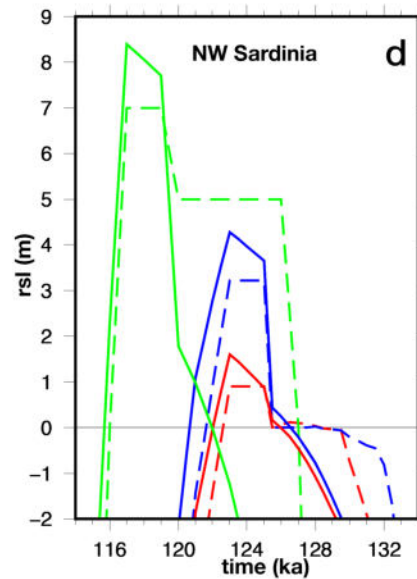
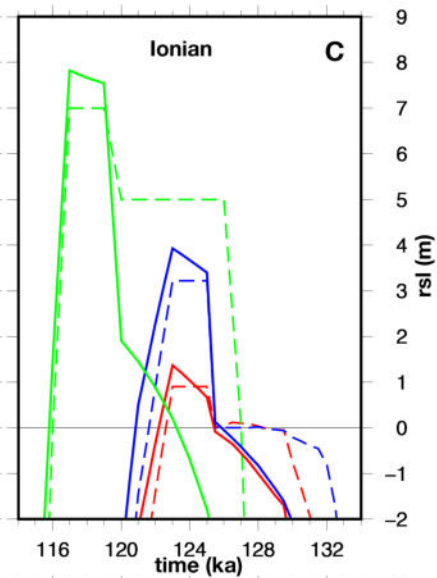
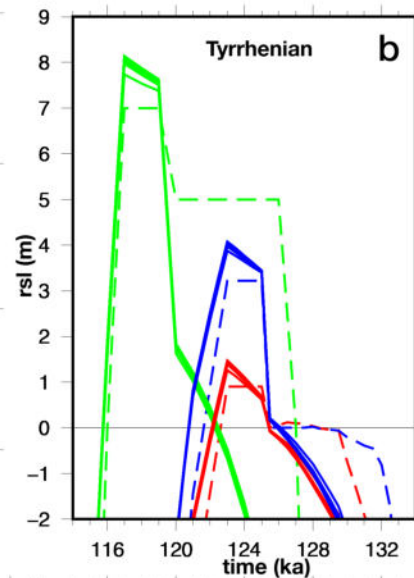
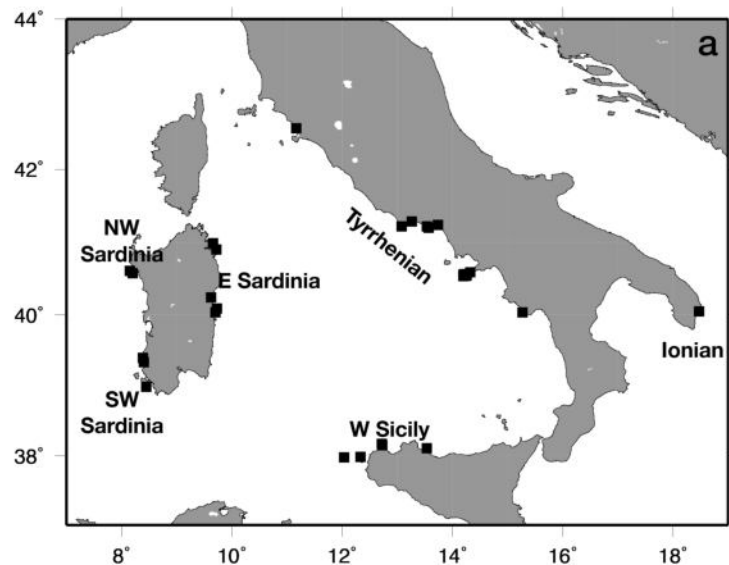


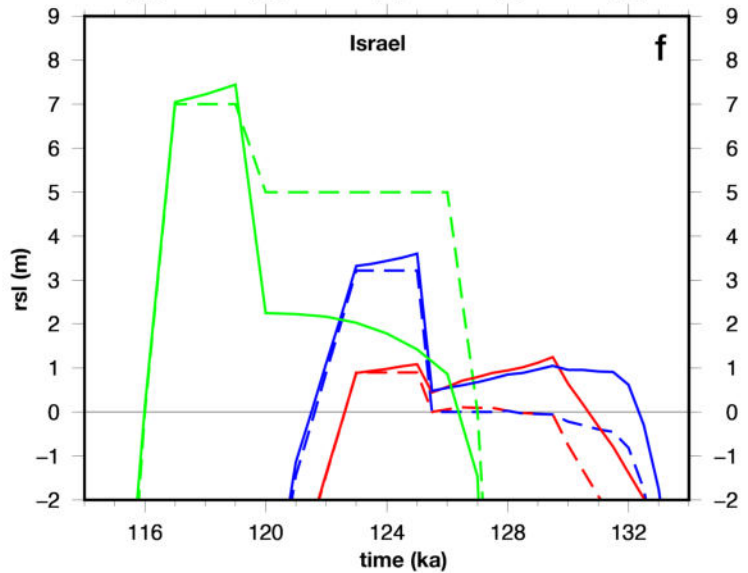
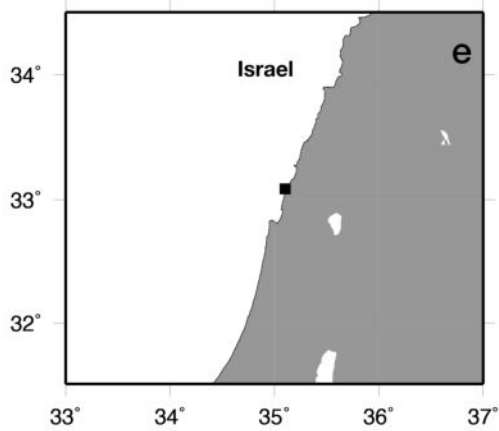
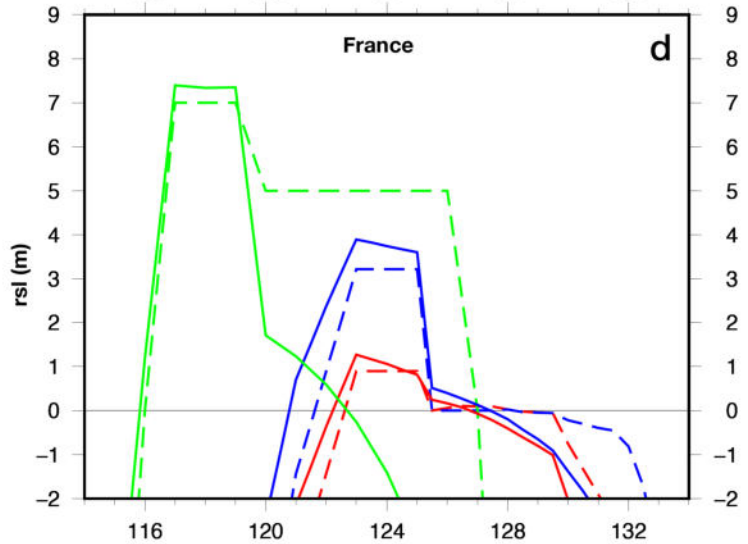
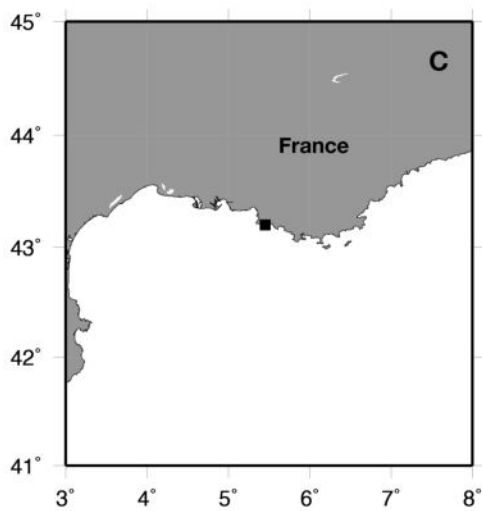
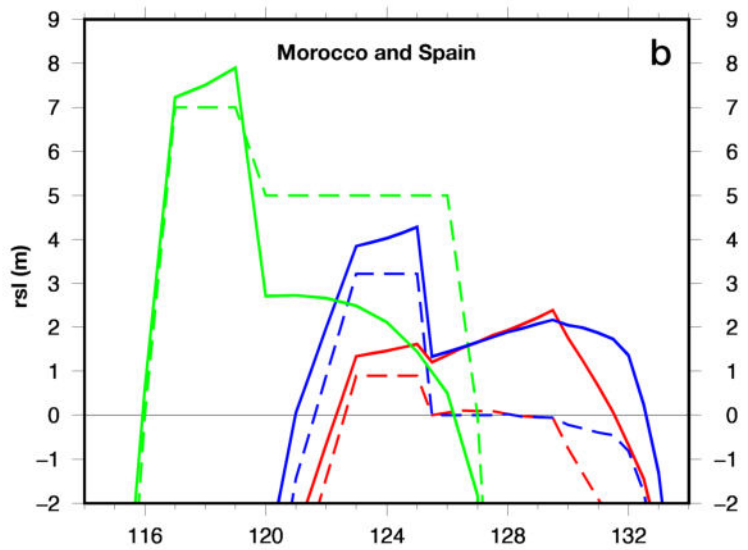
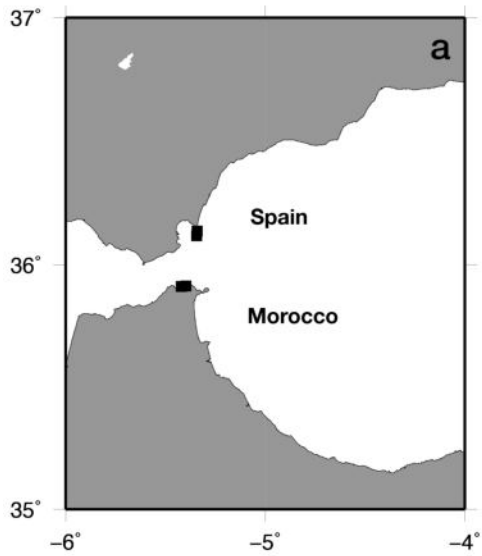


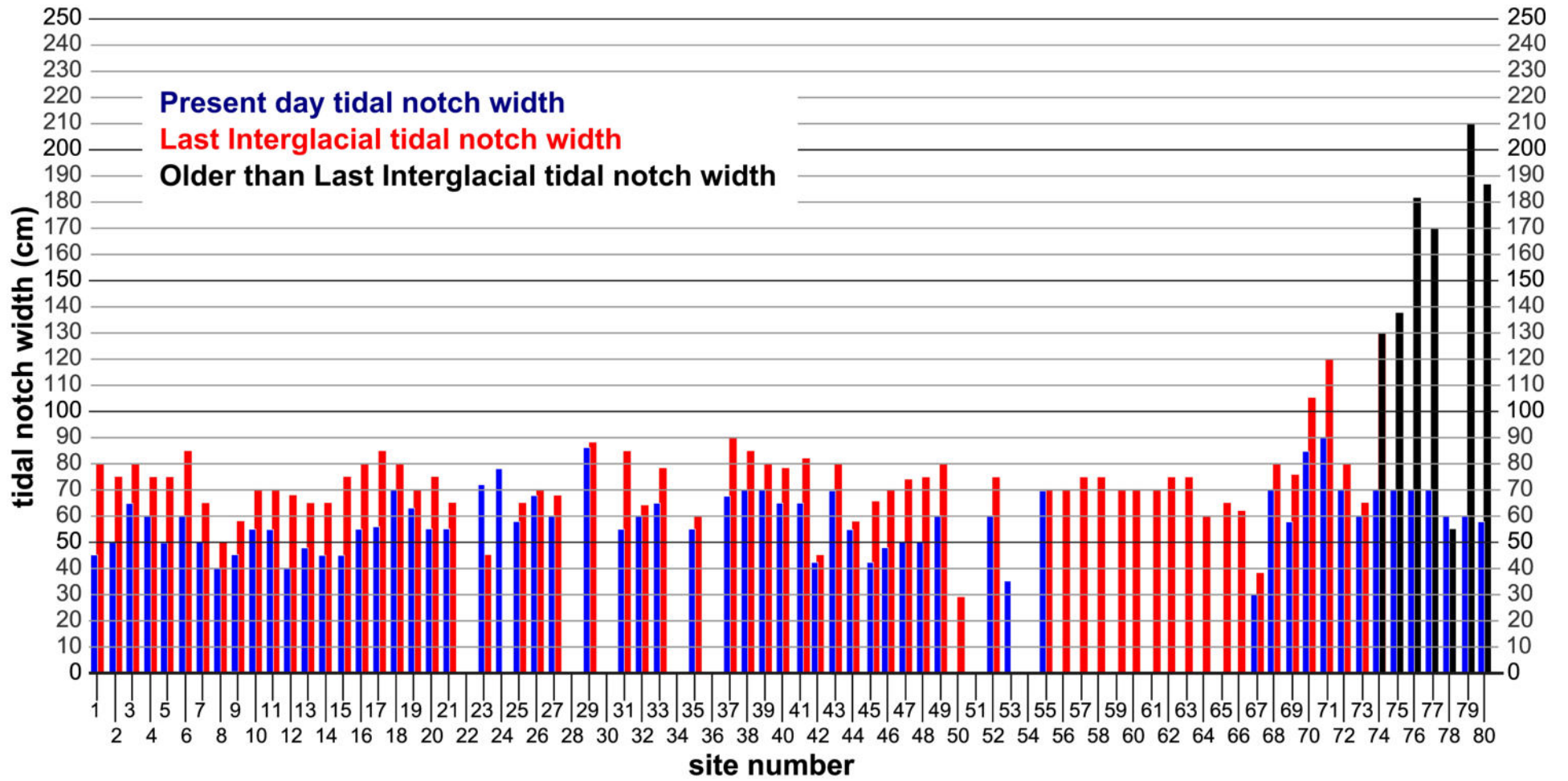


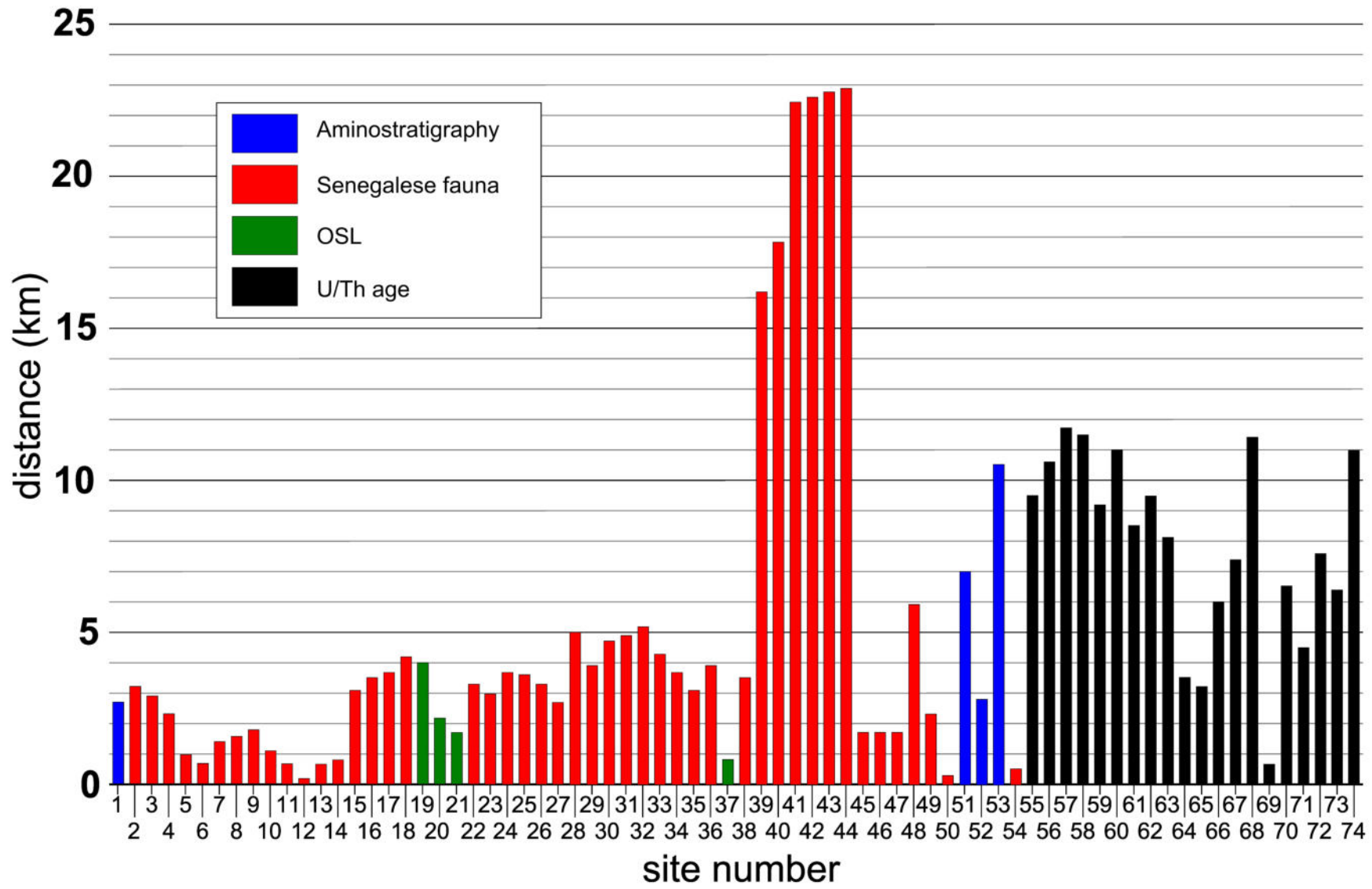


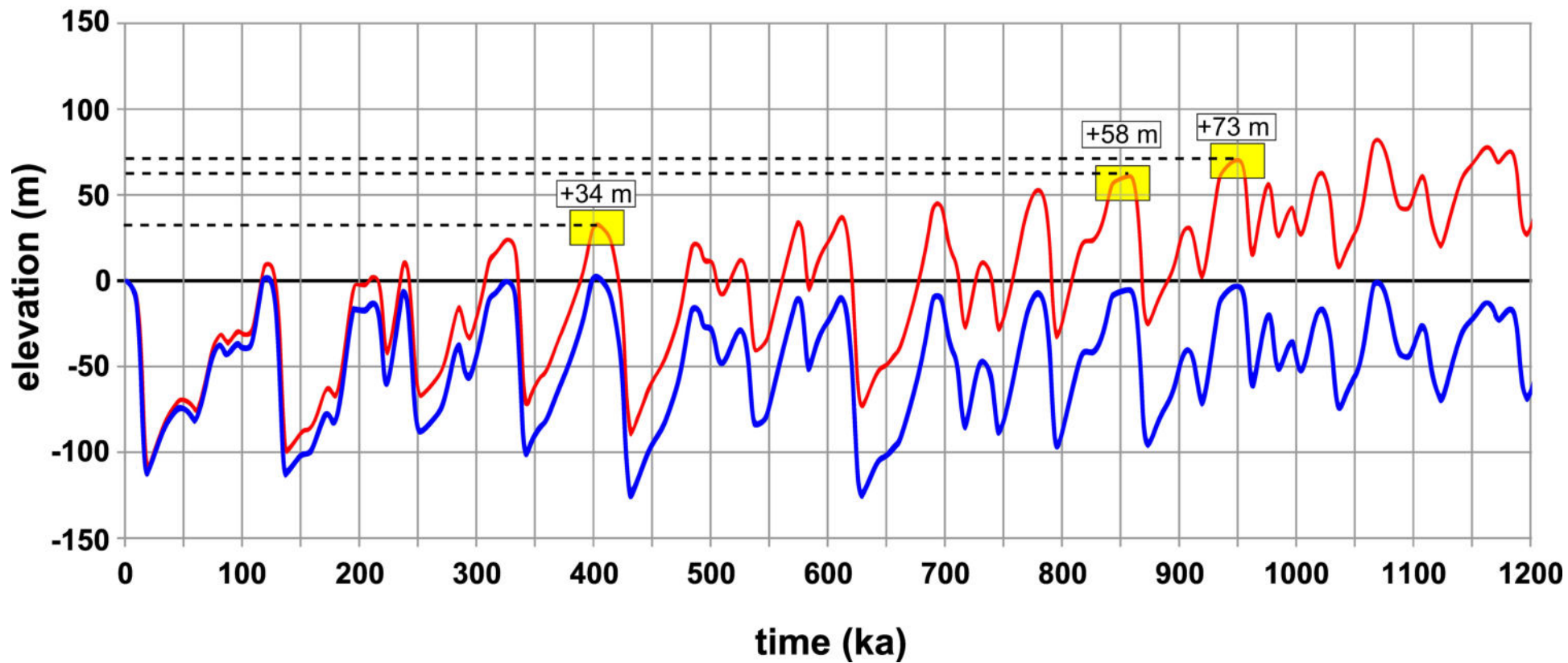


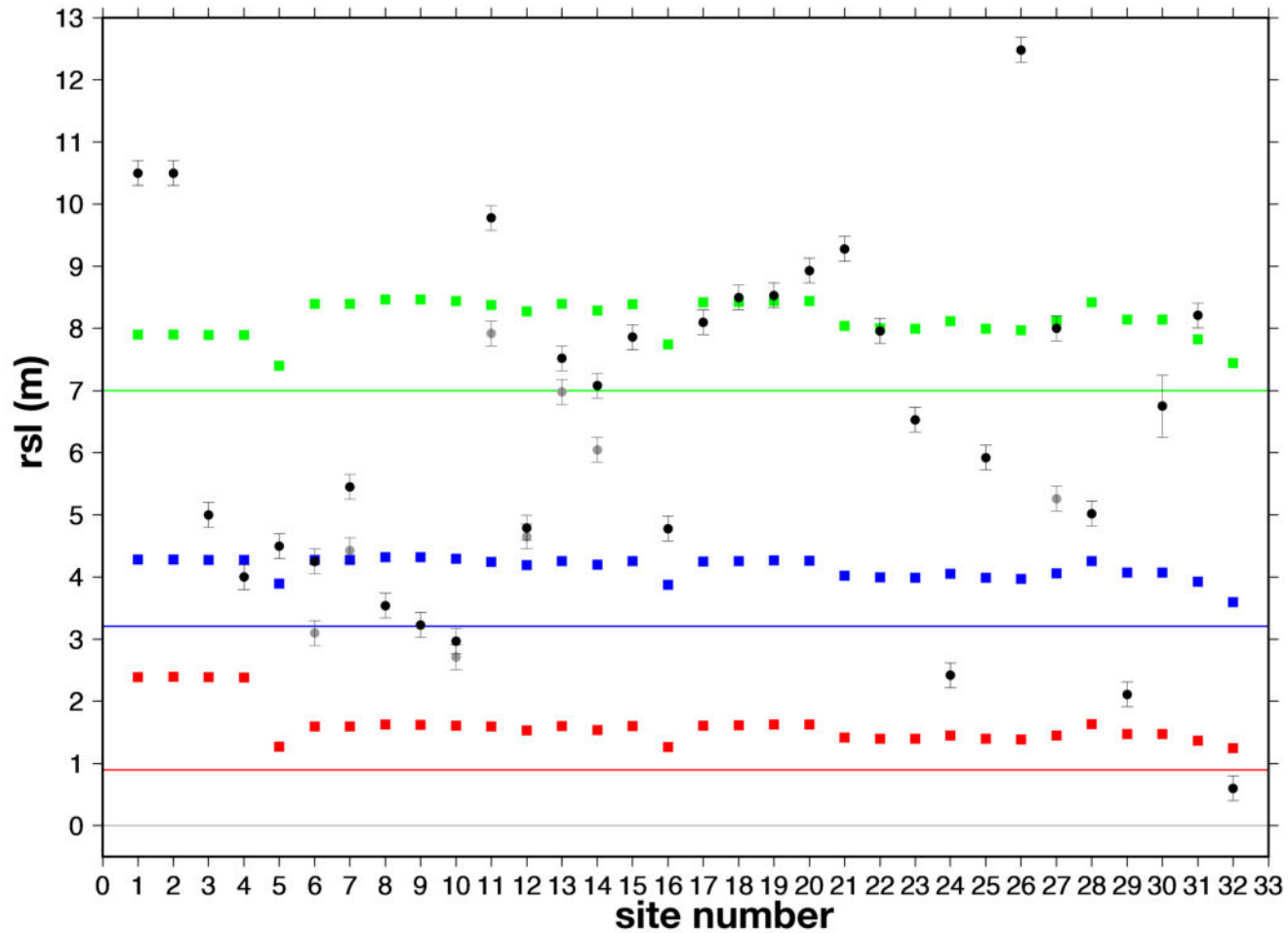












maximum predicted high stand



ICE-5g



ICE-6G



ANICE-SELEN

maximum eustatic high stand



ICE-5g



ICE-6G



ANICE-SELEN

Observed limits

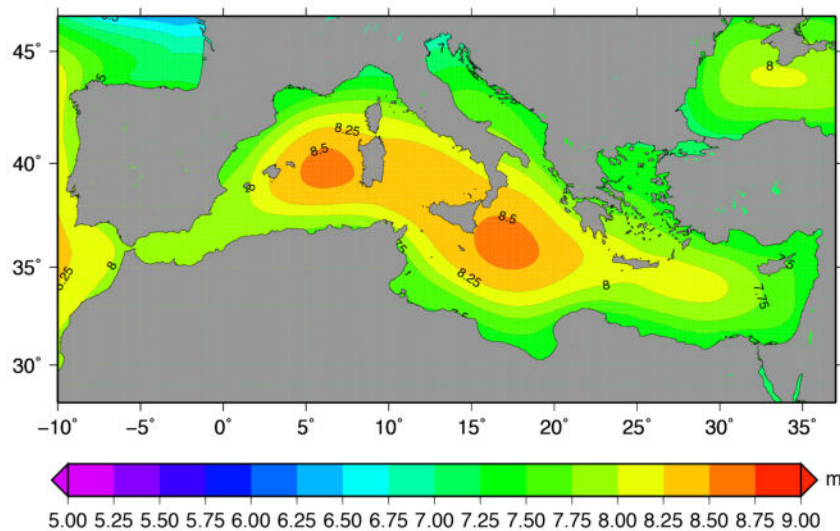


upper



lower

Maximum predicted RSL after 120 ka



Predicted RSL at 117 ka

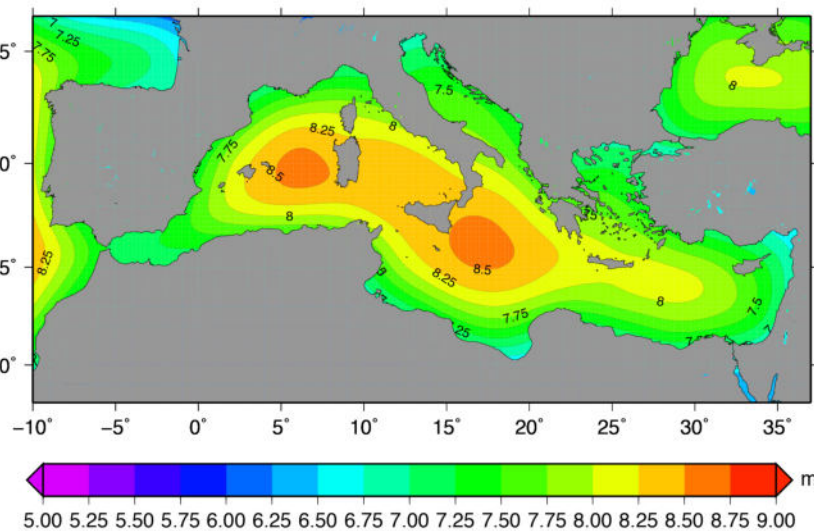




Table 1: MIS 5.5 and Present tidal notches data in the Mediterranean Sea

1) Site number; 2) Locality and site name; 3) Elevation, **uncertain are explained in chapter 3.1**; 4) Notch Morphometry; 5) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not Measured; NC= Not Carved; C= Consumed); 6) Distance (km) and *reference site name for the age of deposit: ¹ Abate et al., 1996; ² Antonioli, 1991; ³ Antonioli et al., 1994a; ⁴ Antonioli et al., 1994b; ⁵ Antonioli et al., 1999; ⁶ Antonioli et al., 2002; ⁷ Blanc and Segre, 1953; ⁸ Bosellini et al., 1999; ⁹ Brancaccio et al., 1986, 1990; ¹⁰ Cesaraccio and Puxeddu, 1986; ¹¹ Delicato et al., 1999; ¹² Durante, 1975; ¹³ Esposito et al., 2003; ¹⁴ Ferranti and Antonioli, 2007; ¹⁵ Hearty P.J., 1986, 1987; ¹⁶ Malatesta, 1954a, 1954b, 1970; ¹⁷ Mastronuzzi et al., 2007; ¹⁸ Orrù and Ulzega, 1986; ¹⁹ Orrù and Pasquini, 1992; ²⁰ Orrù et al., 2011; ²¹ Palmerini and Ulzega, 1969; ²² Pascucci et al., 2014; ²³ Porqueddu et al., 2011; ²⁴ Sanna et al., 2010; ²⁵ Segre, 1951; ²⁶ Segre, 1957; ²⁷ Ulzega and Ozer, 1980;

1 Site N	2 Locality (site name)	3 Elevation with uncertainty (m)	4 Average notch morphometry (m)			5 Type of Notch	6 Distance (km) and *reference site name from the site that allowed the age of deposit
			MIS 5.5 (FTN) Present (PTN)				
			width	depth	base		
1	Talamone	4.78 ± 0.275	0.80 0.45	0.60 0.60	0.45 0.15	MTN PTN	¹⁵ (2,7) Campo Regio
2	Capo Caccia	3.80 ± 0.035	0.75 0.50	0.20 0.12	0.20 0.80	MTN PTN	¹⁶ (3,2) Dragonara
3		3.70 ± 0.035	0.80 0.65	0.60 0.12	0.60 0.80	MTN PTN	¹⁶ (2,9)
4		3.75 ± 0.035	0.75 0.60	0.55 0.60	0.55 0.80	MTN PTN	¹⁶ (2,3)
5		3.50 ± 0.035	0.75 0.50	0.25 0.10	0.25 0.80	MTN PTN	¹⁶ (1,0)
6		3.10 ± 0.035	0.85 0.60	0.60 0.11	0.60 0.80	MTN PTN	¹⁶ (0,7)
7		3.65 ± 0.035	0.65 0.50	0.30 0.30	0.30 0.80	MTN PTN	¹⁶ (1,4)
8		3.95 ± 0.035	0.50 0.40	0.25 0.30	0.25 0.70	MTN PTN	¹⁶ (1,6)
9		3.50 ± 0.035	0.58 0.45	0.40 0.40	0.40 0.80	MTN PTN	¹⁶ (1,8)
10		3.85 ± 0.035	0.70 0.55	0.20 0.20	0.35 0.80	MTN PTN	¹⁶ (1,1)
11		3.85 ± 0.035	0.70 0.55	0.20 0.20	0.30 0.80	MTN PTN	¹⁶ (0,7)
12		3.86 ± 0.035	0.68 0.40	0.20 0.20	0.30 0.90	MTN PTN	¹⁶ (0,2)
13		4.05 ± 0.035	0.65 0.48	0.38 0.40	0.40 0.80	MTN PTN	¹⁶ (0,7)
14		4.25± 0.035	0.65 0.45	0.40 0.40	0.40 0.90	MTN PTN	¹⁶ (0,8)
15	Punta Giglio	4.65± 0.035	0.75 0.45	0.60 0.43	0.60 0.60	MTN PTN	¹⁶ (3,1)
16		4.43± 0.035	0.80 0.55	0.60 0.65	0.60 0.10	MTN PTN	¹⁶ (3,5)
17		4.45± 0.035	0.85 0.56	0.60 0.60	0.60 0.12	MTN PTN	¹⁶ (3,7)
18		5.05± 0.035	0.80 0.70	0.65 0.60	0.65 0.15	MTN PTN	²² (4,1)
19		5.25± 0.035	0.70 0.63	0.60 0.60	0.60 0.90	MTN PTN	²² (4,0)
20		5.45± 0.035	0.75 0.55	0.65 0.60	0.70 0.12	MTN PTN	²² (2,2)

21		5.35± 0.035	0.65 0.55	0.65 0.60	0.60 0.80	MTN PTN	22 (1,7)
22	Capo Figari	4.77± 0.135	-	-	-	NM NM	25 (3,3) Golfo Aranci
23		4.79± 0.135	0.45 0.72	0.50 0.80	0.25 0.30	MTN PTN	25 (3,0) Golfo Aranci
24		4.72± 0.135	- 0.78	- 0.60	- 0.58	NM PTN	25 (3,7) Golfo Aranci
25		4.79± 0.035	0.65 0.58	0.50 0.63	0.95 0.48	MTN PTN	25 (3,6) Golfo Aranci
26		4.65± 0.035	0.70 0.68	0.40 0.58	- 0.12	MTN PTN	25 (3,3) Golfo Aranci
27	Tavolara	6.93± 0.035	0.68 0.60	0.50 0.82	0.95 -	MTN PTN	19, 23 (2,7) Spalmatore di Terra
28		7.08± 0.135	-	-	-	NM NM	19, 23 (5) Spalmatore di Terra
29		6.97± 0.135	0.88 0.86	0.55 0.102	- 0.47	MTN PTN	19, 23 (3,9) Spalmatore di Terra,
30		6.93± 0.135	-	-	-	NM NM	19, 23 (4,7) Spalmatore di Terra
31		6.89± 0.135	0.85 0.55	0.60 0.145	- 0.30	MTN PTN	19, 23 (4,9) Spalmatore di Terra
32		6.13± 0.135	0.64 0.60	0.56 0.60	0.60 0.35	MTN PTN	19, 23 (5,2) Spalmatore di Terra
33		6.81± 0.135	0.78 0.65	0.30 0.35	- 0.35	MTN PTN	19, 23 (4,3) Spalmatore di Terra
34		6.43± 0.135	-	-	-	NM NM	19, 23 (3,7) Spalmatore di Terra
35		6.05± 0.135	0.60 0.55	0.55 0.50	0.60 -	MTN PTN	19, 23 (3,1) Spalmatore di Terra
36		6.43± 0.135	-	-	-	NM NM	19, 23 (3,9) Spalmatore di terra
37	Golfo Orosei (North-East Sardinia)	9.78 ± 0.035	0.90 0.68	0.35 0.70	0.60 0.12	MTN PTN	24 (0,8) Bue marino
38		9.19 ± 0.035	0.85 0.70	0.40 0.80	0.12 0.11	MTN PTN	27 (3,5) Cala Luna
39		7.92 ± 0.035	0.80 0.70	0.25 0.80	0.40 -	MTN PTN	27 (16,2) Cala Luna
40	Capo Monte Santu	7.86 ± 0.035	0.78 0.65	0.60 0.80	0.65 0.95	MTN PTN	27 (17,8) Cala Luna
41	Pedralonga	7.51 ± 0.135	0.82 0.65	0.90 0.90	0.135 0.10	MTN PTN	27 (22,4) Cala Luna
42		7.52 ± 0.135	0.45 0.42	0.80 0.90	0.18 0.135	MTN PTN	27 (22,6) Cala Luna
43		7.42 ± 0.135	0.87 0.70	0.50 0.50	0.14 0.90	MTN PTN	27 (22,75) Cala Luna
44		6.98 ± 0.135	0.58 0.55	0.40 0.46	0.90 0.12	MTN PTN	27 (22,9) Cala Luna
45	Sant'Antioco	2.97± 0.175	0.66 0.42	0.30 0.30	0.68 0.80	MTN PTN	27 (1,7) Maladroxia
46		2.93± 0.275	0.70 0.48	0.90 0.30	0.11 0.80	MTN PTN RN	27 (1,7) Maladroxia
47		2.71± 0.275	0.74 0.50	0.48 0.43	0.105 0.84	MTN PTN	20, 27 (1,7) Maladroxia

48	Masua	3.23± 0.175	0.75 0.50	0.50 0.50	0.60 0.70	MTN PTN	¹⁸ (5,9) Fontanamare
49	Buggerru	3.54± 0.175	0.80 0.60	0.60 0.80	0.70 0.70	MTN PTN	^{10, 21} (2,3) Buggerru – Rio Mannu
50	Circeo (Grotta delle Capre)	9.28± 0.175	0.29 -	0.08 -	0.08 -	MTN NC	^{7, 12} (0.3) Grotta del Fossellone
51	Terracina (Pisco Montano)	7,96± 0.175	- -	- -	- -	C NC	² (7,0)
52	Sperlonga (Sant'Agostino)	6,53± 0.175	0.75 0.60	0.60 0.70	0.45 0.45	MTN PTN	² (2,8)
53	Gaeta (Grotta del Turco)	5.92± 0.275	- 0.35	- 0.40	- 0.35	C PTN	² (10,5)
54	Minturno (Monte d'Argento)	12,48± 0.175	- -	- -	- -	C NM	^{11, 26} (0,5) West side Monte.D'Argento
55	Capri (est)	7,40± 0.275	0.70 -	0.50 -	0.50 -	MTN RN	^{9, 14} (9,5)
56	Capri (Tragara)	8.0± 0.275	0.70 -	0.45 -	0.45 -	MTN RN	^{9, 14} (10,6)
57	Capri (Grotta Fontelina)	7.10± 0.275	0.75 -	0.60 -	0.60 -	MTN RN	^{9, 14} (11,7)
58	Capri (Grotta Verde)	6,97± 0.275	0.75 -	0.65 -	0.80 -	MTN RN	^{9, 14} (11,5)
59	Capri (Cala Articola)	6,32± 0.275	0.70 -	0.60 -	0.70 -	MTN RN	^{9, 14} (9,2)
60	Capri (Punta del Pino)	7,07± 0.275	0.70 -	0.75 -	0.80 -	MTN RN	^{9, 14} (11)
61	Capri (Grotta Jannarella)	6,97± 0.275	0.70 -	0.45 -	0.80 -	MTN RN	^{9, 14} (8,5)
62	Capri (Grotta Binocolo)	5,26± 0.275	0.75 -	0.60 -	0.60 -	MTN RN	^{9, 14} (9,5)
63	Capri (Scoglio Ricotta)	7,00± 0.275	0.75 -	0.45 -	0.80 -	MTN RN	^{9, 14} (8,1)
64	Mitigliano	5,02± 0.275	0.60 -	0.70 -	0.40 -	MTN RN	⁹ (3,5)
65	Palinuro	2,11± 0.275	0.65 -	0.60 -	0.60 -	MTN RN	^{3, 13} (3,2)
66		2,16± 0.275	0.62 -	0.40 -	0.40 -	MTN RN	^{3, 13} (6,0)
67		2,09± 0.275	0.38 0.30	0.20 0.25	0.48 0.55	MTN PTN	^{3, 13} (7,4)
68	Marina di Camerota	6,75 ± 0.275	0.80	-	-	MTN	^{3, 13} (11.4)
69	Capo Zafferano	2.42± 0,075	0.76 0.58	0.52 0.37	0.55 0.45	MTN PTN	⁴ (0,7)
70	Marettimo	8.10± 0,175	1.05 0.85	0.60 0.30	0.70 0.60	MTN PTN	^{1, 5, 16} (6,5)
71	Levanzo	8,50± 0.275	1.2 0.90	0.80 0.80	0.11 0.90	MTN PTN	this paper (4,5)
72	San Vito Lo Capo (Cala Mancina)	8,53± 0.275	0.80 0.70	0.85 0.85	0.70 0.60	MTN PTN	^{5, 6} (7,6)
73	San Vito Lo Capo (Macari)	8,93± 0.275	0.65 0.60	0.60 0.80	0.15 0.68	MTN PTN	^{5, 6} (6,4)
74	Santa Cesarea Terme (Grotta delle Striare)	8,21± 0.275	1.3 0.70	-	-	MTN PTN	^{8, 17} (22)

1 Site N	2 Locality (site name)	3 Coordinates	4 Measures Date and Time (UTC +2)	5 Elevation (m)	6 Average notch measures (m)			7 Notch Morphometry	8 Kind of measurement	9 MIS 5.5 Elevation (m)	10 Reference (s) for age	11 Age MIS ka
					MIS 5.5 Present							
					width	depth	base					
75	Castro (Grotta Romanelli)	40°00' 58.2900" N" 18°26' 00.0300"E"	24.02.2017 11.45 2001	9.25 ±0.135	1.38 0.70	0.88 0.75	- -	2,11	DGPS	-	Mastronuzzi et al., 2007	400-600 MIS11-13
76	Custonaci	38° 05' 37.2000" N" 12°40' 12.9600"E"	11.11.2016 15.00	73 ±0.50	1.82 0.70	0.68 -	0.11	2,6	DT	12	Stocchi et al., 2017;	950 MIS 25
77	San Vito Lo Capo (Grotta Racchio)	38°08' 44.5800" N" 12°44' 17.8200"E"	11.2016 16.15	58 ±0.50	1.70 0.70	0.90 -	-	2,43	DT	8	Stocchi et al., 2017;	783 MIS 21
78	San Vito Lo Capo (Grotta dei Cavalli)	38° 10' 04.5600" N" 12° 43' 12.5400"E"	11.11.2016 10.55	34 ±0.50	0.55 0.60	0.20 -	0.20	0,92	DT	8	Antonioli et al., 1997;	400 MIS 11
79	Sferracavallo	38°11' 58.7400" N" 13°15' 43.3200"E"	29.10.2016 11.08	40.72 ±0.135	2.10 0.60	0.13 -	-	3,5	DGPS	3.0	Hearty, 1986; Antonioli et al., 1997;	611 ? MIS ?
80	Capo Zafferano (Arco di Zafferano)	38°06' 43.5000" N" 13°32' 05.9400"E"	29.10.2016 17.45	23.02 ±0.135	1.87 0.58	0.80 -	-	3,22	DGPS	2.42	Antonioli et al., 1994b;	323 ? MIS ?

Table 2
FTN older than MIS 5.5 uplifted

1) Site number; 2) Locality and site name; 3) Coordinates; 4) Measures; 5) Elevation (m), **uncertain are explained in the chapter 3.1**; e; 6) Average notch measures (m); 7) Notch Morphometry; 8) Kind of measurement (DGPS= Differential Global Positioning System; DT= Digital Altimeter) 9) MIS 5.5 elevation; 10) Reference for age; 11) Age MIS ka.

Table 3**Published FTN altitude in Mediterranean Sea**

1) Site number; 2) Locality and site name; 3) Coordinates; 4) Elevation 5) Notch morphometry; 6) Reference

1 Site N	2 Locality (site name)	3 Coordinates	4 Base of the notch elevation (m)	5 Average notch measures (m)		6 Reference(s)
				width	depth	
81	Cape Leona cliffs (Morocco)	35°55'16.84" N 5°24'05.75" W	10-11	2.1	0.25	Abad et al., 2013;
82	Perejil Island (Morocco)	35°54'46.17" N 5°25'00.64" W	10-11	2.1	0.25	Abad et al., 2013;
83	Gorham's Cave (Spain)	36°07'10.51" N 5°20'32.48" W	5	-	-	Rodriguez-Vidal et al., 2015;
84	Caleta Hotel (Spain)	36°8'13.03"N 5°20'25.76" W	5	1.7	1.4	Rodriguez-Vidal et al., 2007;
85	Calanques (France)	43°12'07.99" N 5°27'14.24" W	4-5	-	-	Photo by K. Lambeck;
86	Rosh Hanikra (Israel)	33°05'08.18" N 35°06'13.13" W	0.50 -0.75	0.9 - 1.8	-	Sisma Ventura et al., 2016;

A	B	C	D	E	F	G	H
Location	Lithology	Method	Intertidal erosion rates (mm/yr)	Supratidal/Inner karst rates (mm/yr)	Reference	Total estimated erosion in 125 Ka (m)	Notes
Gulf of Piran (Slovenia)	Intertidal Mesozoic limestones	TMEM	0.07-1.114	/	Torunski 1979	/	
NE Adriatic (Italy, Croatia)	Intertidal Mesozoic limestones	MEM, TMEM	0.01-0.34	0,001-0,04	Cucchi et al. 2006	0.125-5	
NE Adriatic (Italy, Croatia)	Intertidal Mesozoic limestones	MEM, TMEM	0.01-2.966	0,011-0,04	Furlani et al. 2009	1.375-5	
NE Adriatic (Italy, Croatia)	Intertidal Mesozoic limestones	MEM, TMEM	0.01-0.970	0,001-0,02	Furlani et al. 2011a	0.125-2.5	
NE Adriatic (Italy, Croatia)	Intertidal Mesozoic limestones	MEM, TMEM	0,001-0,3	/	Furlani and Cucchi, 2013	/	Measures collected on a vertical limestone slab in the tidal zone
Mallorca (Balearic Is.)	Supratidal Cretaceous Limestone	MEM, LS, Biological survey	/	0.007-0.482	Swantesson et al. 2006	0.875-60.25	
Mallorca (Balearic Islands)	Supratidal Upper Miocene Reef Limestone	MEM, LS, Biological survey	/	0.003-0.814	Swantesson et al. 2006	0.375-101.75	

Mallorca (Balearic Is.)	Supratidal Upper Miocene calcarenite	MEM, LS, Biological survey	/	0.003-2.095	Swantesson et al. 2006	0.375- 261.875	
Mallorca (Balearic Is.)	Supratidal Upper Miocene calcarenite	MEM, LS, Biological survey	/	0.004-0.369	Swantesson et al. 2006	0.5-46.125	
Mallorca (Balearic Is.)	Supratidal Jurassic Dolomite breccias	MEM, LS, Biological survey	/	0.011-0.997	Swantesson et al. 2006	1.375- 124.625	
Mallorca (Balearic Islands)	Intertidal Upper Miocene Calcarenite	TMEM	0.80-1.18	/	Gómez- Pujol, 2006	/	
Circeo (Central Italy)	Mesozoic limestone	MEM	/	0.01-0.03	this paper	1.25-3.75	Inside MIS5.5 notch

table 4

NAME	Number in Fig	Site number in Table 1	ICE-5G	ICE-6G	ANICE-SELEN
Perejil_island_(Morocco)	1	82	2.39	4.28	7.90
Cape_Leona_cliffs_(Morocco)	2	81	2.39	4.27	7.90
Gorham's_Cave_(Spain)	3	83	2.39	4.27	7.89
Caleta_Hotel(Spain)	4	84	2.38	4.27	7.89
Calanques_(France)	5	85	1.27	3.89	7.40
Capo_Caccia	6	14	1.59	4.27	8.40
Punta_Giglio	7	20	1.59	4.27	8.40
Buggerru	8	49	1.62	4.32	8.47
Masua	9	48	1.62	4.32	8.47
Sant'Antioco	10	45	1.61	4.30	8.44
Golfo_Orosei_(Nord)	11	37	1.93	4.24	8.38
Capo_Figari	12	23	1.53	4.19	8.28
Pedralonga	13	42	1.60	4.26	8.40
Tavolara	14	28	1.54	4.20	8.29
Capo_Monte_Santu	15	40	1.60	4.25	8.39
Talamone	16	1	1.26	3.87	7.74
Marettimo	17	70	1.60	4.25	8.42
Levanzo	18	71	1.62	4.25	8.43
San_Vito_Lo_Capo_(Ca. Mancina)	19	72	1.62	4.27	8.44
San_Vito_Lo_Capo_(Macari)	20	73	1.62	4.26	8.44
Circeo_(Grotta_delle_Capre)	21	50	1.42	4.02	8.04
Terracina_(Pisco_Montano)	22	51	1.40	3.40	8.01
Sperlonga_(Sant'Agostino)	23	52	1.38	3.99	7.99
Capo_Zafferano	24	69	1.44	4.05	8.11
Gaeta_(Grotta_del_Turco)	25	53	1.40	3.99	7.99
Minturno_(Monte_d'Argento)	26	54	1.38	3.97	7.97
Capri_(Punta_del_Pino)	27	57	1.45	4.06	8.13
Mitigliano	28	64	1.63	4.26	8.42
Palinuro	29	65	1.47	4.07	8.14
Marina di Camerota	30	68	1.47	4.07	8.14
Santa_Cesarea_Term	31	74	1.36	3.93	7.82

Akko_(Israel)	32	86	1.25	3.60	7.44
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Domain	Coastal sector	Locality	Site number	Coordinate	Elevation (m a.s.l)	Land motion process	Predicted effect on FTN	Selection criteria
E Balearic	W Sardinia	Punta Giglio + Capo Caccia	20	40° 34' 16.0069" N" 8° 14' 10.3907"E"	5,5	Continental margin faulting	subsidence	Highest FTN elevation
		Buggerru	49	39° 23' 40.7856" N" 8° 23' 10.2609"E"	3,5	Continental margin faulting	subsidence	Highest FTN elevation
W Tyrrhenian	E Sardinia	Pedralonga	44	40° 01' 45.3626" N" 9° 42' 21.1162"E"	7,0	Volcanic intrusion	uplift	Lowest FTN elevation
		Capo Figari	26	40° 59' 38.3400" N" 9° 39' 46.9800"E"	4,7	Continental margin faulting	uplift	Lowest FTN elevation
		Tavolara	28	40° 54' 10.0597" N" 9° 42' 57.2631"E"	7,1	Continental margin faulting	uplift	Highest FTN elevation
E Tyrrhenian	Tuscany	Talamone	1	42°33' 03.2309" N" 11°09' 55.0274"E"	4,8	N/A	N/A	FTN elevation
	Latium	Terracina	51	41° 17' 17.6752" N" 13° 15' 36.1267"E"	8,0 (6,6)*	Continental margin faulting	uplift	Highest FTN elevation*
		Sperlonga	52	41° 13' 06.4207" N" 13° 31' 57.3519"E"	6,5	N/A	N/A	FTN elevation
		Gaeta	53	41° 12' 16.5378" N" 13° 34' 17.8325"E"	5,9	N/A	N/A	FTN elevation
	Campania	Capri	57	40° 32' 38.1002" N" 14° 14' 59.6253"E"	7,0	Continental margin tilting	levering	FTN at tilt axis
		Marina Camerota	68	39°59'42.09" N 15°24'46.71 E"	6,7	Continental margin faulting	uplift	Highest FTN elevation
W Adriatic	Apulia	Striare	74	40° 02' 47.1900" N" 18° 28' 34.0700"E"	8,2	Subduction-related doming	uplift	Lowest FTN elevation
S Tyrrhenian	Sicily	Marettimo	70	37° 58' 46.7663" N" 12° 02' 21.0449"E"	8,11	Collisional folding	uplift	Lowest FTN elevation
* corrected to 6.6 m								

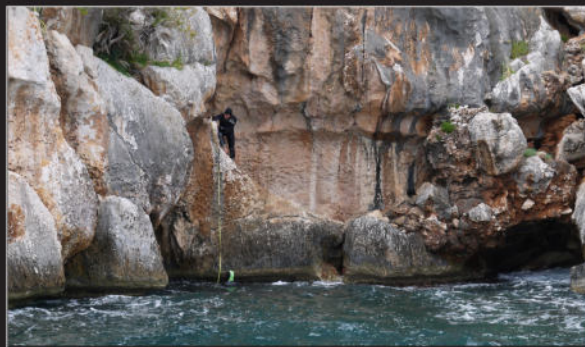
Table 6

Table S1

1. Tidal notch: indentation or undercutting at sea level, mainly cut in steep carbonate cliffs;
2. GIA: Glacial- and Hydro-Isostatic Adjustment is the process that drives solid Earth and mean sea surface (geoid) variations as a consequence of continental ice-sheets fluctuations.
3. MIS: Marine Isotopic Stage;
4. FTN: fossil tidal notch;
5. PTN: present tidal notch;
6. Base: the lower part of the notch,
7. Top: the higher part of the notch;
8. Width: difference in elevation between base and top of the notch;
9. Depth: Distance between the profile of the cliff and the most internal part of the notch;
10. Elevation: distance between the bases of FTN and PTN;
11. Senegalese fauna: originally defined in the Italian Mediterranean by Gignoux (1913) and Issel (1914). This fauna is mainly characterized by the gastropod *Persististrombus latus* Gmelin, 1791 (syn: *Strombus bubonius* Lamarck, 1822) and others mollusca that colonized the Mediterranean Sea during a time span which these authors called the Tyrrhenian (i.e. MIS 5.5, approx 132-116 ka);
12. Roof notch: a tidal notch lacking the floor (base);
13. Abrasional notch: a notch developed near the sea floor, where sand and pebbles mechanically hit the rock;
14. GPS/RTK surveys: Global Positioning System measurements (GPS) in the Real Time Kinematic technique (RTK), which is an enhancement of GPS that improves location accuracy in real time and with 3D centimetric accuracy.
15. OSL: optically stimulated luminescence, is a late Quaternary dating technique used to date the last time quartz sediment was exposed to light;
16. Aminostatigraphy: the measurement of the extent of amino acid racemization in biological deposits in order to estimate their age.



1 Talamone



2 Capo Caccia



18 Punta Giglio



26 Capo Figari



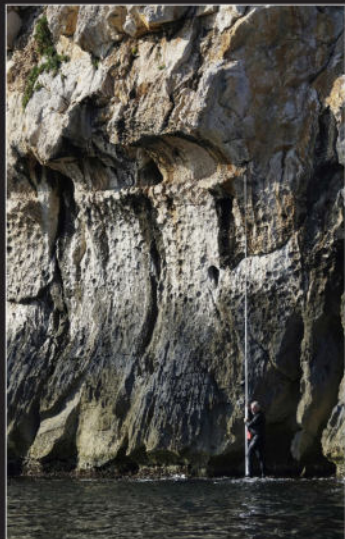
38 Golfo Orosei Nord



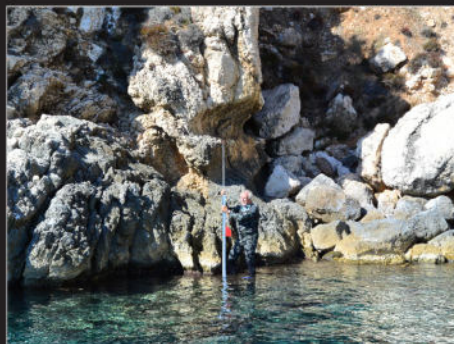
40 Capo Monte Santu



42 Pedralonga



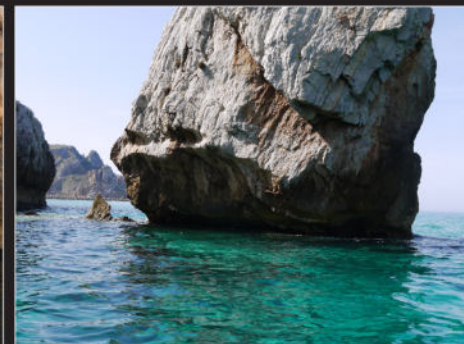
32 Tavolara



45 Sant'Antioco



48 Masua



49 Buggerru



50 Circeo - Grotta della Capre



51 Terracina - Pisco



52 Sperlonga - Sant'Agostino



52 Sperlonga - Sant'Agostino



53 Gaeta - Grotta del Turco



54 Monte d'Argento



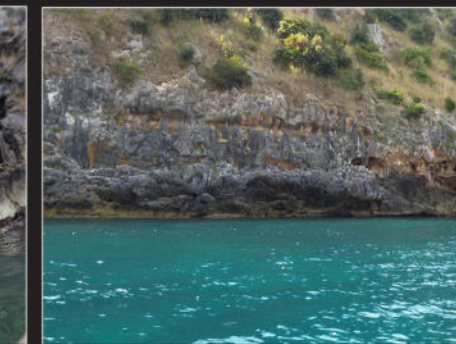
56 Capri



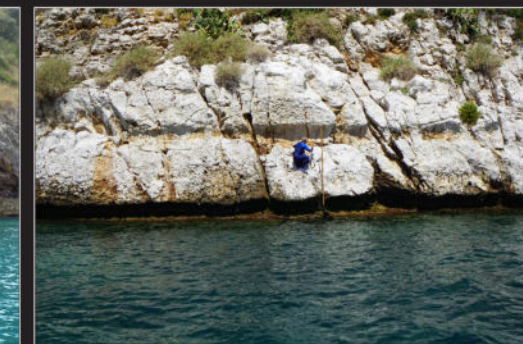
64 Mitigliano



65 Palinuro



68 Marina di Camerota



69 Capo Zafferano



70 Marettimo



71 Levanzo



72 San Vito - Cala Mancina



73 San Vito - Macari



74 Grotta della Striare



75 Grotta Romanelli



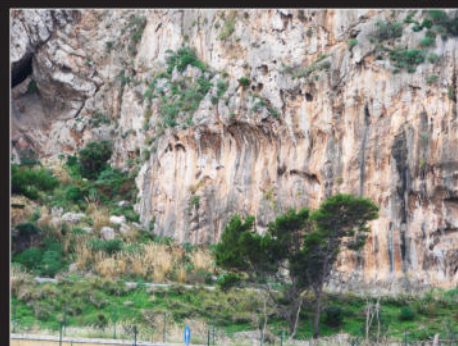
76 Custonaci



77 Grotta Racchio



78 Grotta dei Cavalli

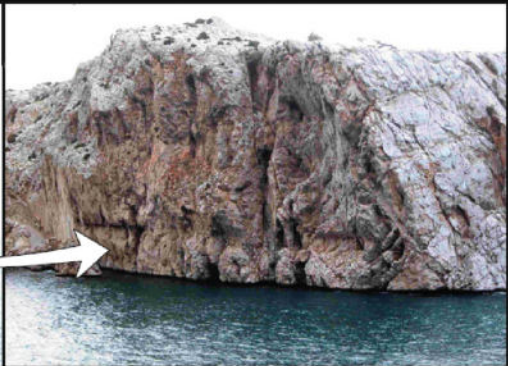
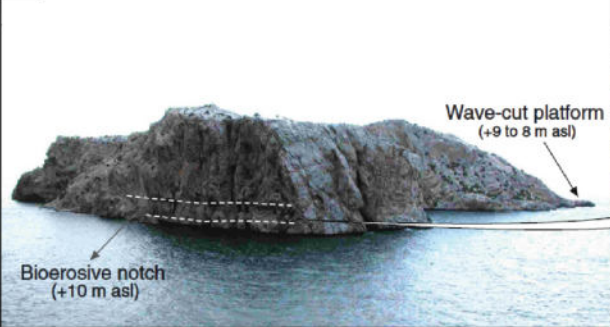


79 Sferracavallo



80 Arco di Zafferano

1a



1b



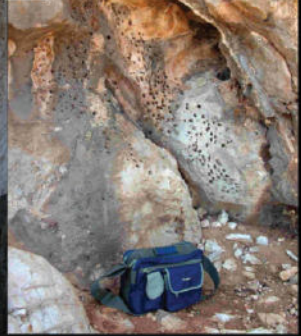
1c



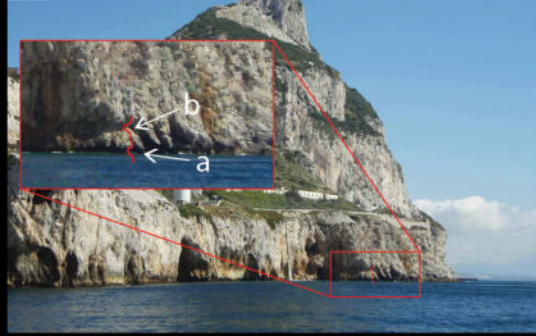
2a



2b



3



4



5a



5b



6a

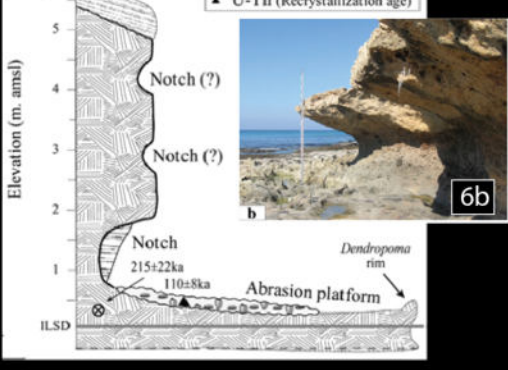


Table 7: MIS 5.5 and Present tidal notches data in the Mediterranean Sea

1) Site number; 2) Locality and site name; 3) Coordinates; 4) Measures date; 5) Elevation with uncertain, m; 6) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not Measured; NC= Not Carved; C= Consumed; 8) Notch morphometry; 9) Kind of measurement: T: Telefix; M: Tape meter; DGPS: DGPS; 10) Faunal assemblage of the nearest aged fossil deposit; Distance (km) and reference site name for the age of deposit:

1) Site number; 2) Locality and site name; 3) Coordinates; 4) Notch Morphometry; 5) Elevation with uncertain, m; 6) Average notch measures, m; 7) Type of Notch: MTN= MIS 5.5 Tidal Notch; PTN= Present Tidal Notch; NM= Not Measured; NC= Not Carved; C= Consumed); 8) Notch morphometry; 9 Kind of measurement; 10) Faunal assemblages in aged fossil deposit; 11) Thechnique of chronological attribution; 12 Distance (km) from the site used for give the age of deposit. References: ¹ Abate et al., 1996; ² Antonioli, 1991; ³ Antonioli et al., 1994a; ⁴ Antonioli et al., 1994b; ⁵ Antonioli et al., 1999; ⁶ Antonioli et al., 2002; ⁷ Blanc and Segre, 1953; ⁸ Bosellini et al., 1999; ⁹ Brancaccio et al., 1986, 1990; ¹⁰ Cesaraccio and Puxeddu, 1986; ¹¹ Delicato et al., 1999; ¹² Durante, 1975; ¹³ Esposito et al., 2003; ¹⁴ Ferranti and Antonioli, 2007; ¹⁵ Hearty P.J., 1986, 1987; ¹⁶ Malatesta, 1954a, 1954b, 1970; ¹⁷ Mastronuzzi et al., 2007; ¹⁸ Orrù and Ulzega, 1986; ¹⁹ Orrù and Pasquini, 1992; ²⁰ Orrù et al., 2011; ²¹ Palmerini and Ulzega, 1969; ²² Pascucci et al., 2014; ²³ Porqueddu et al., 2011; ²⁴ Sanna et al., 2010; ²⁵ Segre, 1951; ²⁶ Segre, 1957; ²⁷ Ulzega and Ozer, 1980.

1 Site N	2 Locality (site name)	3 Coordinates	4 Measures Date and Time (UTC +2)	5 Elevation with uncertainty (m)	6 Average notch measures (m)			7 Type of Notch	8 Notch Morphometry		9 Kind of measure ment	10 Faunal assemblage	11 Technique of chronologic al attribution	12 Distance (km) and reference site name for the age of deposit	13 References
					MIS 5.5 Present				MIS 5.5/present notch average concavity ratio for each locality and (value) for each site						
					width h	depth	base		width ratio	deep ratio					
1	Talamone	42°33' 03.2309" N" 11°09' 55.0274"E	21.10.2016 9.53	4.78 ± 0.275	0.80 0.45	0.60 0.60	0.45 0.15	MTN PTN	1,77	1,00	T	<i>Cerastoderma Glicimeris</i>	Amino- stratigraphy Senegalese fauna	^{16,17} (2,7) Campo Regio ^{16,17} (25,4) Selva Nera	¹⁶ Hearty PJ, Dai Pra G., 1986; ¹⁷ Hearty PJ, Dai Pra G., 1987;
2	Capo Caccia	40° 36' 23.3858" N" 8° 08' 53.2929"E"	06.07.2015 10.10	3.80 ± 0.035	0.75 0.50	0.20 0.12	0.20 0.80	MTN PTN	1,36 (1,50)	0,71 (0,16)	M	<i>Glycymeris g.</i> <i>Strombus b., Conusus t., Patella f.</i> <i>Patella f. Brachydontes senegalensis</i>	OSL Senegalese fauna	²⁵ (9,5) Bombarde ³⁰ (15,8) Cala Bona ¹⁸ (3,2) Dragonara	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
3		40° 36' 07.6595" N" 8° 08' 46.1842"E"	06.07.2015 10.30	3.70 ± 0.035	0.80 0.65	0.60 0.12	0.60 0.80	MTN PTN	(1,23)	(0,50)	M	<i>Glycymeris g.</i> <i>Strombus b., Conusus t., Patella f.</i> <i>Patella f. Brachydontes senegalensis</i>	OSL Senegalese fauna	²⁵ (9,2) ³⁰ (15,7) ¹⁸ (2,9)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
4		40° 35' 50.2719" N" 8° 08' 50.7426"E"	06.07.2015 10.45	3.75 ± 0.035	0.75 0.60	0.55 0.60	0.55 0.80	MTN PTN	(1,25)	(0,91)	M	<i>Glycymeris g.</i> <i>Strombus b., Conusus t., Patella f.</i> <i>Patella f. Brachydontes senegalensis</i>	OSL Senegalese fauna	²⁵ (9,2) ³⁰ (15,5) ¹⁸ (2,3)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;

5		40° 34' 44.8391" N" 8° 09' 01.6537" E"	06.07.2015 10.50	3.50 ± 0.035	0.75 0.50	0.25 0.10	0.25 0.80	MTN PTN	(1,50)	(0,25)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (8,8) ³⁰ (14,7) ¹⁸ (1,0)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
6		40° 34' 37.0535" N" 8° 09' 20.1122" E"	06.07.2015 11.10	3.10 ± 0.035	0.85 0.60	0.60 0.11	0.60 0.80	MTN PTN	(1,42)	(0,54)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (8,5) ³⁰ (14,1) ¹⁸ (0,7)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
7		40° 34' 09.9358" N" 8° 09' 07.6213" E"	06.07.2015 11.30	3.65 ± 0.035	0.65 0.50	0.30 0.30	0.30 0.80	MTN PTN	(1,30)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (8,9) ³⁰ (14,4) ¹⁸ (1,4)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
8		40° 33' 47.4484" N" 8° 09' 50.9292" E"	06.07.2015 11.50	3.95 ± 0.035	0.50 0.40	0.25 0.30	0.25 0.70	MTN PTN	(1,25)	(0,83)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (9,9) ³⁰ (13,2) ¹⁸ (1,6)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
9		40° 33' 53.0497" N" 8° 09' 54.4411" E"	06.07.2015 12.30	3.50 ± 0.035	0.58 0.45	0.40 0.40	0.40 0.80	MTN PTN	(1,29)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (8,7) ³⁰ (13,2) ¹⁸ (1,8)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
10		40° 34' 13.8461" N" 8° 09' 51.9464" E"	06.07.2015 12.45	3.85 ± 0.035	0.70 0.55	0.20 0.20	0.35 0.80	MTN PTN	(1,27)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (7,8) ³⁰ (13,3) ¹⁸ (1,1)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
11		40° 34' 23.8252" N" 8° 09' 52.2129" E"	06.07.2015 13.00	3.85 ± 0.035	0.70 0.55	0.20 0.20	0.30 0.80	MTN PTN	(1,27)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (7,7) ³⁰ (13,4) ¹⁸ (0,7)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;

12		40° 34' 46.6377" N" 8° 09' 45.7522"E"	06.07.2015 13.10	3.86 ± 0.035	0.68 0.40	0.20 0.20	0.30 0.90	MTN PTN	(1,70)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (7,8) ³⁰ (13,7) ¹⁸ (0,2)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
13		40° 34' 49.2217" N" 8° 10' 16.3651"E"	06.07.2015 13.15	4.05 ± 0.035	0.65 0.48	0.38 0.40	0.40 0.80	MTN PTN	(1,35)	(0,95)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (7,11) ³⁰ (13,5) ¹⁸ (0,7)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
14		40° 34' 52.5000" N" 8° 10' 17.9283"E"	06.07.2015 13.30	4.25± 0.035	0.65 0.45	0.40 0.40	0.40 0.90	MTN PTN	(1,44)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (7,7) ³⁰ (13,1) ¹⁸ (0,8)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
15	Punta Giglio	40° 34' 22.0138" N" 8° 11' 54.1236"E"	07.07.2015 09.30	4.65± 0.035	0.75 0.45	0.60 0.43	0.60 0.60	MTN PTN	1,34 (1,66)	1,07 (1,39)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (5,3) ³⁰ (10,6) ¹⁸ (3,1)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
16		40° 34' 13.5433" N" 8° 12' 05.3012"E"	07.07.2015 10.10	4.43± 0.035	0.80 0.55	0.60 0.65	0.60 0.10	MTN PTN	(1,45)	(0,92)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (4,8) ³⁰ (9,8) ¹⁸ (3,5)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
17		40° 34' 11.9178" N" 8° 12' 24.3416"E"	07.07.2015 10.30	4.45± 0.035	0.85 0.56	0.60 0.60	0.60 0.12	MTN PTN	(1,52)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (4,4) ³⁰ (9,6) ¹⁸ (3,7)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
18		40° 34' 18.0312" N" 8° 12' 34.2002"E"	07.07.2015 10.40	5.05± 0.035	0.80 0.70	0.65 0.60	0.65 0.15	MTN PTN	(1,14)	(1,08)	M	<i>Glycymeris g.</i> <i>Strombus b.,</i> <i>Conus t.,</i> <i>Patella f.</i> <i>Patella f.</i> <i>Brachydontes</i> <i>senegalensis</i>	OSL Senegalese fauna	²⁵ (4,1) ³⁰ (9,5) ¹⁸ (4,2)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;

19		40° 34' 16.4426" N" 8° 12' 40.4623"E"	07.07.2015 10.45	5.25± 0.035	0.70 0.63	0.60 0.60	0.60 0.90	MTN PTN	(1,11)	(1,00)	M	<i>Glycymeris g.</i> <i>Strombus b., Conus t., Patella f.</i> <i>Patella f. Brachydontes senegalensis</i>	OSL Senegalese fauna	²⁵ (4,0) ³⁰ (9,5) ¹⁸ (4,2)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
20		40° 34' 16.0069" N" 8° 14' 10.3907"E"	07.07.2015 11.30	5.45± 0.035	0.75 0.55	0.65 0.60	0.70 0.12	MTN PTN	(1,35)	(1,08)	M	<i>Glycymeris g.</i> <i>Strombus b., Conus t., Patella f.</i> <i>Patella f. Brachydontes senegalensis</i>	OSL Senegalese fauna	²⁵ (2,2) ³⁰ (7,5) ¹⁸ (6,3)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
21		40° 34' 16.7601" N" 8° 14' 36.4720"E"	07.07.2015 11.40	5.35± 0.035	0.65 0.55	0.65 0.60	0.60 0.80	MTN PTN	(1,18)	(1,08)	M	<i>Glycymeris g.</i> <i>Strombus b., Conus t., Patella f.</i> <i>Patella f. Brachydontes senegalensis</i>	OSL Senegalese fauna	²⁵ (1,7) ³⁰ (6,9) ¹⁸ (6,8)	²⁵ Pascucci et al., 2014; ³⁰ Ulzega and Ozer, 1980; ¹⁸ Malatesta, 1954,1970;
22	Capo Figari	40° 59' 16.7530" N" 9° 39' 16.2538"E"	15.06.2008 13.15	4.77± 0.135	- -	- -	- -	NM NM	0,92	0,70	M	<i>Conus t. Strombus b</i>	Senegalese fauna	²⁸ (3,3) Golfo Aranci	²⁸ Segre, 1952;
23		40° 59' 24.1901" N" 9° 39' 25.9513"E"	15.06.2008 13.15	4.79± 0.135	0.45 0.72	0.50 0.80	0.25 0.30	MTN PTN	(0,62)	(0,62)	M	<i>Conus t. Strombus b</i>	Senegalese fauna	²⁸ (3,0) Golfo Aranci	²⁸ Segre, 1952;
24		40° 59' 36.7594" N" 9° 39' 42.8390"E"	15.06.2008 13.30	4.72± 0.135	- 0.78	- 0.60	- 0.58	NM PTN	-	-	M	<i>Conus t. Strombus b</i>	Senegalese fauna	²⁸ (3,7) Golfo Aranci	²⁸ Segre, 1952;
25		40° 59' 46.6335" N" 9° 39' 51.7674"E"	16.03.2017 11.30	4.79± 0.035	0.65 0.58	0.50 0.63	0.95 0.48	MTN PTN	(1,12)	(0,79)	T	<i>Conus t. Strombus b</i>	Senegalese fauna	²⁸ (3,6) Golfo Aranci	²⁸ Segre, 1952;
26		40° 59' 38.3400" N" 9° 39' 46.9800"E"	16.03.2017 12.30	4.65± 0.035	0.70 0.68	0.40 0.58	- 0.12	MTN PTN	(1,03)	(0,69)	T	<i>Conus t. Strombus b</i>	Senegalese fauna	²⁸ (3,3) Golfo Aranci	²⁸ Segre, 1952;
27	Tavolara	40° 54' 09.4066" N" 9° 42' 54.7413"E"	31.05.2005 11.30	6,93± 0.035	0.68 0.60	0.50 0.82	0.95 -	MTN PTN	1,17 (1,13)	0,74 (0,61)	T	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (2,7) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
28		40° 54' 10.0597" N" 9° 42' 57.2631"E"	31.05.2005 12.10	7,08± 0.135	- -	- -	- -	NM NM	-	-	M	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (5) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
29		40° 54' 28.8401" N" 9° 43' 42.5178"E"	16.02.2017 15.30	6,97± 0.135	0.88 0.86	0.55 0.102	- 0.47	MTN PTN	(1,02)	(0,54)	T	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (3,9) Spalmatore di Terra,	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
30		40° 54' 33.6501" N" 9° 43' 54.1298"E"	31.05.2005 12.30	6,93± 0.135	- -	- -	- -	NM NM	-	-	M	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (4,7) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
31		40° 54' 36.0387" N" 9° 44' 14.9503"E"	16.02.2017 15.45	6,89± 0.135	0.85 0.55	0.60 0.145	- 0.30	MTN PTN	(1,54)	(0,41)	T	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (4,9) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
32		40° 54' 47.0000" N" 9° 44' 29.0000"E"	31.05.2005 13.05	6,13± 0.135	0.64 0.60	0.56 0.60	0.60 0.35	MTN PTN	(1,06)	(0,93)	M	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (5,2) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
33		40° 55' 02.4486" N" 9° 43' 28.8485"E"	31.05.2005 13.30	6,81± 0.135	0.78 0.65	0.30 0.35	- 0.35	MTN PTN	(1,20)	(0,86)	T	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (4,3) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;
34		40° 54' 52.8101" N" 9° 43' 04.0781"E"	31.05.2005 13.40	6,43± 0.135	- -	- -	- -	NM NM	-	-	M	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	^{26, 21} (3,7) Spalmatore di Terra	²⁶ Porqueddu et al., 2011; ²¹ Orrù and Pasquini, 1992;

35		40° 54' 41.1907" N" 9° 42' 44.5510"E"	16.02.2017 13.45	6,05± 0.135	0.60 0.55	0.55 0.50	0.60 -	MTN PTN	(1,09)	(1,10)	T	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	26, 21 (3,1) Spalmatore di Terra	26 Porqueddu et al., 2011; 21 Orrù and Pasquini, 1992;
36		40° 54' 41.0000" N" 9° 42' 46.0000"E"	31.05.2005 14.00	6,43± 0.135	- -	- -	- -	NM NM	-	-	M	<i>Conus t + Patella f.</i>	Senegalese fauna at +5 m	26, 21 (3,9) Spalmatore di terra	26 Porqueddu et al., 2011; 21 Orrù and Pasquini, 1992;
37	Golfo Orosei (Nord)	40° 14' 30.1709" N" 9° 37' 24.7770"E"	12.07.2016 16.05	9.78 ± 0.035	0.90 0.68	0.35 0.70	0.60 0.12	MTN PTN	1,22 (1,32)	0,44 (0,50)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (0,8) Bue marino 30 (1,9) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
38		40° 11' 35.5522" N" 9° 37' 43.0153"E"	12.07.2016 10.45	9,19 ± 0.035	0.85 0.70	0.40 0.80	0.12 0.11	MTN PTN	(1,21)	(0,50)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (6,1) Bue marino 30 (3,5) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
39		40° 05' 43.5676" N" 9° 42' 59.8173"E"	12.07.2016 12.45	7.92 ± 0.035	0.80 0.70	0.25 0.80	0.40 -	MTN PTN	(1,14)	(0,31)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (18,8) Bue marino 30 (16,2) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
40	Capo Monte Santu	40° 05' 08.3000" N" 9° 43' 56.4700"E"	12.07.2016 13.30	7.86 ± 0.035	0.78 0.65	0.60 0.80	0.65 0.95	MTN PTN	1,20	0,75	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (20,3) Bue marino 30 (17,8) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
41	Pedralonga	40° 01' 54.7435" N" 9° 42' 20.2327"E"	23.09.2016 12.00	7,51 ± 0.135	0.82 0.65	0.90 0.90	0.135 0.10	MTN PTN	1,22 (1,26)	0,92 (1,00)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (25,0) Bue marino 30 (22,4) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
42		40° 01' 54.1288" N" 9° 42' 20.2844"E"	23.09.2016 12.15	7,52 ± 0.135	0.45 0.42	0.80 0.90	0.18 0.135	MTN PTN	(1,07)	(0,89)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (25,4) Bue marino 30 (22,6) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
43		40° 01' 49.0524" N" 9° 42' 19.3672"E"	23.09.2016 12.30	7,42 ± 0.135	0.87 0.70	0.50 0.50	0.14 0.90	MTN PTN	(1,23)	(1,00)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (25,6) Bue marino 30 (22,75) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
44		40° 01' 45.3626" N" 9° 42' 21.1162"E"	23.09.2016 12.45	6,98 ± 0.135	0.58 0.55	0.40 0.46	0.90 0.12	MTN PTN	(1,24)	(0,87)	T	<i>Stalagmite Patella ferruginea</i>	OSL Senegalese fauna	27 (25,8) Bue marino 30 (22,9) Cala Luna	27 Sanna et al., 2010; 30 Ulzega and Ozer, 1980;
45	Sant'Antioco	38° 59' 09.8613" N" 8° 26' 53.8987"E"	24.09.216 10.45	2,97± 0.175	0.66 0.42	0.30 0.30	0.68 0.80	MTN PTN	1,71 (1,57)	1,71 (1,00)	T	<i>Conus t. Strombus b. Conus+ Patella f.</i>	Senegalese fauna	30 (1,7) Maladroxia 30 (11) Cala Su Turcu 22 (6,0) Cala Sapone	30 Ulzega and Ozer, 1980; 22 Orrù et al., 2011;
46		38° 59' 07.9080" N" 8° 26' 55.1040"E"	24.09.216 11.15	2,93± 0.275	0.70 0.48	0.90 0.30 0.05	0.11 0.80 -	MTN PTN RN	(2,08)	(3,00)	T	<i>Conus t. Strombus b. Conus+ Patella f.</i>	Senegalese fauna	30 (1,7) Maladroxia 30 (11) Cala Su Turcu 22 (6,0) Cala Sapone	30 Ulzega and Ozer, 1980; 22 Orrù et al., 2011;
47		38° 59' 06.1726" N" 8° 26' 53.1652"E"	24.09.216 12.30	2,71± 0.275	0.74 0.50	0.48 0.43	0.105 0.84	MTN PTN	(1,48)	(1,12)	T	<i>Conus t. Strombus b. Conus+ Patella f.</i>	Senegalese fauna	30 (1,7) Maladroxia 30 (11) Cala Su Turcu 22 (6,0) Cala Sapone	30 Ulzega and Ozer, 1980; 22 Orrù et al., 2011;
48	Masua	39° 20' 10.5619" N" 8° 24' 27.6915"E"	28.09.2014 9.30	3.23± 0.175	0.75 0.50	0.50 0.50	0.60 0.70	MTN PTN	1,5	1,00	M	<i>Conus t. + Patella f.</i>	Senegalese fauna	20 (5,9) Fontanamare	20 Orrù and Ulzega, 1986;
49	Buggerru	39° 23' 40.7856" N" 8° 23' 10.2609"E"	28.09.2014 11.30	3.54± 0.175	0.80 0.60	0.60 0.80	0.70 0.70	MTN PTN	1,33	0,75	M	<i>Conus t. + Patella f. Conus t + Glycymeris</i>	Senegalese fauna	11 (2,3) Buggerru – Rio Mannu 23 (11) Acqua Durci 23 (15) Rio Piscinas	11 Cesaraccio and Puxeddu, 1986; 23 Palmerini and Ulzega, 1969;
50	Circeo (Grotta delle Capre)	41° 13' 26.0440" N" 13° 04' 57.3301"E"	11.2014 11.30	9.28± 0.175	0.29 -	0.08 -	0.08 -	MTN NC	-	-	DGPS	<i>Persistrombus and other Senegalese fauna</i>	Senegalese fauna	7,13 (0.3) Grotta del Fossellone	7 Blanc and Segre, 1953; 13 Durante, 1975;

51	Terracina (Pisco Montano)	41° 17' 17.6752" N" 13° 15' 36.1267" E"	13.06.2016 15.00	7,96± 0.175	-	-	-	C NC	-	-	DGPS	<i>Cerastoderma</i> <i>sp</i>	Amino- stratigraphy aminozone E	² (7,0)	² Antonioli et al., 1986;
52	Sperlonga (Sant'Agostino)	41° 13' 06.4207" N" 13° 31' 57.3519" E"	13.06.2016 12.10	6,53± 0.175	0.75 0.60	0.60 0.70	0.45 0.45	MTN PTN	1,25	0,86	DGPS	<i>Glycimeris V.</i>	Amino- stratigraphy aminozone E E	³ (2,8)	³ Antonioli et al., 1991;
53	Gaeta (Grotta del Turco)	41° 12' 16.5378" N" 13° 34' 17.8325" E"	15.11.2014 11.40	5.92± 0.275	- 0.35	- 0.40	- 0.35	C PTN	-	-	M	<i>Glycimeris V.</i>	Amino- stratigraphy aminozone E	³ (10,5)	³ Antonioli et al., 1991;
54	Minturno (Monte d'Argento)	41° 14' 23.0097" N" 13° 44' 12.5566" E"	13.06.2016 9.40	12,48± 0.175	-	-	-	C NM	-	-	DGPS	<i>Senegalese</i> <i>fauna</i> <i>Conus</i> <i>textudinarius</i>	Senegalese fauna	^{29,12} (0,5) West side Monte.D'Argento	²⁹ Segre, 1957; ¹² Delicato et al., 1999;
55	Capri (est)	40° 32' 59.3015" N" 14° 15' 28.3630" E"	05.2015	7,40± 0.275	0.70 -	0.50 -	0.50 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (9,5)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
56	Capri (Tragara)	40° 32' 39.5257" N" 14° 15' 11.2623" E"	23.05.2004 10.30	8.0± 0.275	0.70 -	0.45 -	0.45 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10} (10,6)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990;
57	Capri (Grotta Fontelina)	40° 32' 38.1002" N" 14° 14' 59.6253" E"	23.05.2004 10.30	7.10± 0.275	0.75 -	0.60 -	0.60 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (11,7)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
58	Capri (Grotta Verde)	40° 32' 21.4388" N" 14° 13' 15.1499" E"	23.05.2004 10.30	6,97± 0.275	0.75 -	0.65 -	0.80 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (11,5)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
59	Capri (Cala Articola)	40° 32' 18.5965" N" 14° 12' 15.9734" E"	23.05.2004 10.30	6,32± 0.275	0.70 -	0.60 -	0.70 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (9,2)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
60	Capri (Punta del Pino)	40° 32' 27.6567" N" 14° 11' 53.3286" E"	23.05.2004 10.30	7,07± 0.275	0.70 -	0.75 -	0.80 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (11)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
61	Capri (Grotta Jannarella)	40° 33' 13.7133" N" 14° 11' 59.6013" E"	23.05.2004 10.30	6,97± 0.275	0.70 -	0.45 -	0.80 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (8,5)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
62	Capri (Grotta Binocolo)	40° 33' 41.5848" N" 14° 12' 33.2047" E"	23.05.2004 10.30	5,26± 0.275	0.75 -	0.60 -	0.60 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (9,5)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
63	Capri (Scoglio Ricotta)	40° 33' 38.2729" N" 14° 15' 29.8759" E"	23.05.2004 10.30	7,00± 0.275	0.75 -	0.45 -	0.80 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{9,10,15} (8,1)	⁹ Brancaccio et al., 1978; ¹⁰ Brancaccio et al., 1990; ¹⁵ Ferranti and Antonioli 2007;
64	Mitigliano	40° 35' 11.4300" N" 14° 19' 36.8600" E"	01.08.2017 13.40	5,02± 0.275	0.60 -	0.70 -	0.40 -	MTN RN	-	-	M	<i>Persistrombus</i>	U\Th age, Senegalese	^{9,10} (3,5)	⁹ Brancaccio et al., 1978;

												fauna		¹⁰ Brancaccio et al., 1990;	
65	Palinuro	40° 01' 55.3198" N" 15° 16' 26.4856"E"	07.07 2016 13.15	2,11± 0.275	0.65 -	0.60 -	0.60 -	MTN RN	1,27	0,80	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{4,14} (3,2)	⁴ Antonioli et al., 1996; ¹⁴ Esposito et al., 2003;
66		40° 01' 58.4137" N" 15° 16' 56.6662"E"	07.07 2016 13.45	2,16± 0.275	0.62 -	0.40 -	0.40 -	MTN RN	-	-	M	<i>Persistrombus</i> and Senegalese fauna	U\Th age, Senegalese fauna	^{4,14} (6,0)	⁴ Antonioli et al., 1996; ¹⁴ Esposito et al., 2003;
67		40° 01' 29.4110" N" 15° 17' 32.5298"E"	08.07 2016 16.15	2,09± 0.275	0.38 0.30	0.20 0.25	0.48 0.55	MTN PTN	(1,27)	(0,80)	M	<i>Persistrombus</i> and Senegalese fauna	U\Th age, Senegalese fauna	^{4,14} (7,4)	⁴ Antonioli et al., 1996; ¹⁴ Esposito et al., 2003;
68	Marina di Camerota	39°59'42.09" N 15°24'46.71 E"	30.07.2016 10.30	6,75 ± 0.275	80	-	-	MTN	-	-		<i>Persistrombus</i> and Senegalese fauna	U\Th age, Senegalese fauna	^{4,14} (11.4)	⁴ Antonioli et al., 1996; ¹⁴ Esposito et al., 2003;
69	Capo Zafferano	38° 06' 31.6324" N" 13° 32' 19.1686"E"	12.08.2016 11.30	2.42± 0,075	0.76 0.58	0.52 0.37	0.55 0.45	MTN PTN	1,31	1,40	DGPS	<i>Arca</i>	U\Th age, Senegalese fauna	⁴ (0,7)	⁴ Antonioli et al., 1996;
70	Marettimo	37° 58' 46.7663" N" 12° 02' 21.0449"E"	28.05.2014 12.10	8.10± 0,175	1.05 0.85	0.60 0.30	0.70 0.60	MTN PTN	1,23	2,00	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{18,1,5} (6,5)	¹⁸ Malatesta, 1957; ¹ Abate et al., 1996; ⁵ Antonioli et al., 1999c;
71	Levanzo	37° 59' 14.0825" N" 12° 19' 47.4514"E"	06.2015 9.30	8,50± 0.275	1.2 0.90	0.80 0.80	0.11 0.90	MTN PTN	1,33	1,00	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	(4,5)	This paper
72	San Vito Lo Capo (Cala Mancina)	38° 10' 32.4000" N" 12° 43' 01.3800"E"	13.11 2016 11.35	8,53± 0.275	0.80 0.70	0.85 0.85	0.70 0.60	MTN PTN	1,14	1,00	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{5,6} (7,6)	⁵ Antonioli et al., 1999c; ⁶ Antonioli et al., 2002;
73	San Vito Lo Capo (Macari)	38° 09' 18.7200" N" 12° 43' 47.7000"E"	13.11.2016 10.00	8,93± 0.275	0.65 0.60	0.60 0.80	0.15 0.68	MTN PTN	1,08	0,75	M	<i>Persistrombus</i>	U\Th age, Senegalese fauna	^{5,6} (6,4)	⁵ Antonioli et al., 1999c; ⁶ Antonioli et al., 2002;
74	Santa Cesarea Terme (Grotta delle Striare)	40° 02' 47.1900" N" 18° 28' 34.0700"E"	25.11.2016 14.20	8,21± 0.275	1.3 0.70	-	-		-	-	DGPS	-	U\Th age on speleothems	(11)	⁸ Bosellini et al., 1999; ²⁴ Parente 1999; ³¹ Mastronuzzi et al., 2007