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18 April 2024

1 **Stalagmites: from science application to museumization**

2

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11

12 **Abstract**

13 The concept of geoheritage is related to places of geological interest, generally of
14 aesthetic, cultural, socio-economic and/or scientific value. Many geosites are of
15 karstic nature, because of their intrinsic beauty, their singularity and high
16 geodiversity. Caves are among the most visited and economically exploited
17 geological landforms. They constitute geosites as a whole, with their scenic
18 landscapes, hydrogeological importance, and the presence of bewildering natural
19 rock and mineral formations including stalactites, stalagmites, flowstones and
20 many other bizarre speleothem shapes. In some cases, a single speleothem, and
21 the palaeoclimate record it contains, can be on its own of extraordinary
22 importance to science. Once studied, these samples are often stored in research
23 institution collections, rarely accessible to the wide public. In this paper, we
24 report on the museumization of a stalagmite that has delivered a unique and
25 exceptionally long glacial climate record from southern Italy, shedding light on
26 the causes that led to the Neanderthal contraction and Modern Human expansion
27 in this mild Mediterranean climate between 45 and 42 thousands years ago. The
28 proposed museumization aims to demonstrate the potential of speleothems,
29 after scientific application, in terms of educational and tourist resources. This
30 approach allows to highlight the scientific importance of karst and cave geosites
31 to the wide public, promoting their conservation and the valorisation of the
32 studied cave-material.

33

34 Keywords: speleothem; palaeoclimate record; Karst; Museum; Neanderthal,
35 geosites, geological heritage, science communication

36

37 **Introduction**

38 In the past, nature conservation was usually focused on its biological
39 components, while geological features were mainly considered a platform on
40 which biological systems are situated (Sharples 1995). However, in the late
41 nineties, awareness towards the importance to protect the geological heritage
42 has considerably increased (Wimbledon 1996). This led to the identification and
43 protection of geological landforms identified as “geosites”, which are
44 characterised by aesthetic, cultural, socio-economic and/or scientific value
45 (Panizza 2001; Brilha 2016). The birth of the European Association for the
46 Conservation of Geological Heritage – ProGEO dates back to this period;
47 additionally, the research project “GEOSITES” was launched by the International
48 Union of Geological Sciences (IUGS) (Wimbledon 1996). This project, still
49 ongoing, aims to create an international digital inventory of relevant geological
50 sites to support both scientific research and political decision-making for the
51 conservation of the geological heritage. Accordingly, aspects related to
52 geoheritage, geodiversity, geosites, and geomorphosites are now widely
53 discussed among researchers (Panizza 2001; Reynard and Panizza 2007; Pereira
54 and Pereira 2010; Coratza and De Waele 2012; Brilha 2016). In Italy, the project
55 “National Inventory Geosites” started in 2002 and was promoted by the Institute
56 for the Environmental Protection (ISPRA). At a Regional level, further databases
57 exist where geosites are subdivided according to their relevance (i.e. regional or
58 national). Importantly, karst areas and caves are often identified as geosites, and
59 many karst sites are listed as UNESCO World Heritage Sites (Williams 2008).
60 Indeed, these landforms hold a great value in terms of both nature conservation,
61 tourism promotion and scientific research (van Beynen 2011; Delle Rose et al.
62 2014; Santangelo et al. 2015; Ruban 2018; Sardella et al. 2019; Nyssen et al.
63 2020).

64 Cave science developed exponentially over the last years. Several disciplines
65 exploit caves for scientific purposes, among which the most important are
66 archaeology, geology, geography and biology. The results have been brilliant,

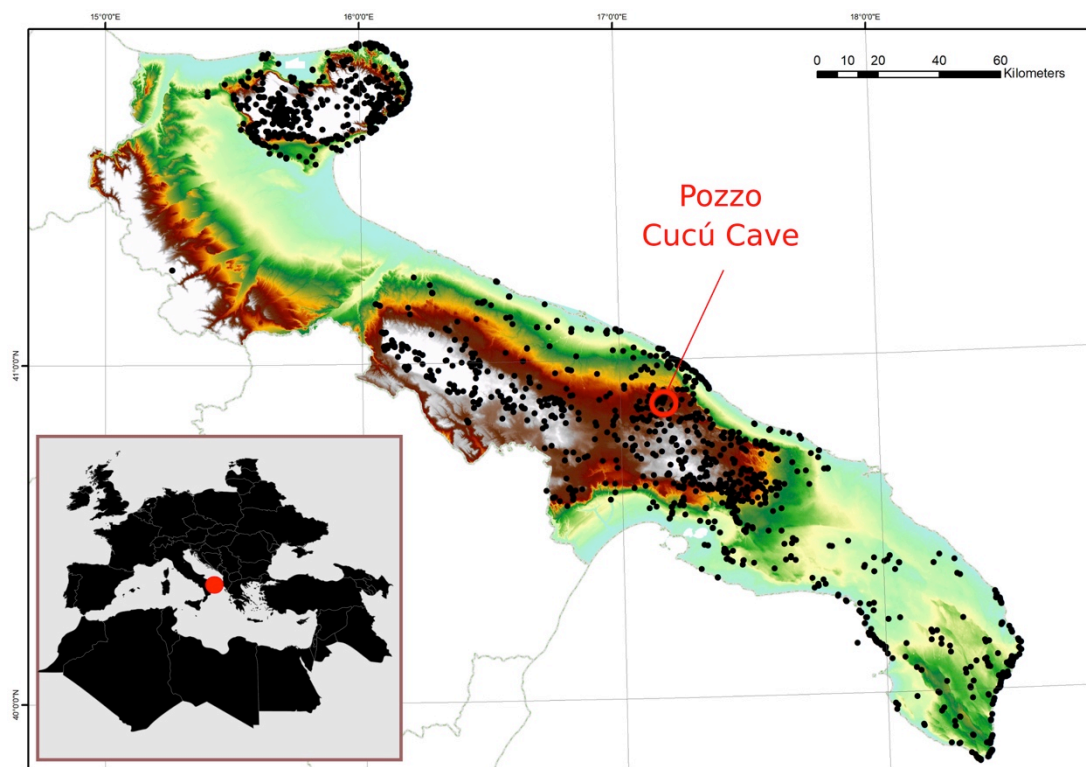
67 with several breakthrough discoveries (Benazzi et al. 2015; Hoffmann et al.
68 2018; Dumitru et al. 2019; Trontelj et al. 2019; Bajo et al. 2020). Furthermore, it
69 is likely that in the near future more and more scientists will frequent caves
70 thanks to the technological advancements in exploration as well as analytical
71 analyses on cave-derived material. For example, a multi-kilometre long karst
72 system has been recently discovered in the Tepui mountains (Venezuela) (Sauro
73 et al. 2018, 2019) that develops within quartzite, a bedrock in which the
74 presence of extensive dissolution caves was considered unlikely until a few years
75 ago (Wray and Sauro 2017). On the other hand, scientific and technological
76 advancement in DNA-based analyses only recently have allowed application on
77 cave chemical precipitates (Stahlschmidt et al. 2019). Although just the presence
78 of humans could compromise their delicate microenvironment, sometimes
79 untouched for even millions of years (Leuko et al. 2017), most of the cave-based
80 studies are non-invasive and/or semi-invasive with respect to the sampled
81 material. Indeed, caves are often equipped with instruments that are removed
82 once the project finishes, as for example in the case of environmental monitoring
83 (Baker et al. 2019) and studies on sound propagation (Revilla-Martín et al.
84 2020). In other circumstances, only negligible amounts of liquid and/or rocky
85 material are sampled, as for mineralogical and hydrogeological studies (Mecchia
86 et al. 2019). Considering archaeological excavations, in most cases trenches are
87 usually around the cave entrance (Romandini et al. 2020), while the cave interior
88 often remains untouched. All in all, these (and other) scientific activities
89 accomplished in caves have no significant consequences for the underground
90 landscape.

91 In the last two decades, cave-based palaeoclimate studies have greatly developed
92 too (Fairchild and Baker 2012). This is because speleothems can be
93 radiometrically dated with extremely high precision by using the uranium-series
94 method. At the same time, speleothems provide a plethora of geochemical
95 (oxygen and carbon stable isotopes, trace elements, etc.) and physical (growth
96 rate, fabric, etc) characteristics that, rigidly constrained in time-series, can be
97 applied as palaeoclimate proxies (McDermott 2004). However, contrarily to
98 other cave-related disciplines, this science requires the removal of a remarkable
99 amount of material, often involving the most iconic elements composing the cave

100 landscape: stalagmites. Although several approaches have been proposed to try
101 to limit the irreversible damage to the cave landscape (Frappier 2008; Spötl and
102 Matthey 2012; Scroxton et al. 2016; Weij et al. 2018), there is almost no way back
103 once stalagmites have been sampled, considering that chemical-physical
104 analyses involve the partial destruction of the stalagmite itself. But not all
105 sampled stalagmites are actually used for producing palaeoclimate data. After
106 slicing and/or preliminary analyses, most of the stalagmites are judged not
107 suitable for more detailed investigations and therefore discarded. In any case,
108 the fate of most sampled stalagmites is to end up in university collections,
109 seldom visited by students or researchers only (de Lima and de Souza Carvalho
110 2020a). Most of the time, they rest in dusty shelves for an undetermined amount
111 of time.

112 This paper presents a way to exploit, stalagmites after scientific applications
113 from an educational point of view. It aims to boost the awareness towards the
114 scientific importance of karst and cave geosites, promoting their conservation
115 and the valorisation of the cave-material studied. We here report the plan of
116 museumization we adopted for a stalagmite sampled in Pozzo Cucù Cave
117 (Southern Italy, figure 1); the geochemical study of this stalagmite was crucial for
118 recent advancements in the field of palaeoclimatology and anthropology
119 (Columbu et al. 2020). The museumization of stalagmites is frequent in
120 geological and natural museums (Currens, 1981), although they are seldom
121 displayed for scientific and didactic purposes. For example, the geological
122 museum of the Courel Mountains UNESCO Global Geopark in Spain shows
123 stalagmites studied by Railsback et al. (2017); similarly, the museum of the
124 Castañar de Ibor cave displays the specimens studied in Alonso-Zarza et al.
125 (2012). Other examples are the Jackson School of Geosciences at the University
126 of Texas in Austin (USA), the Carnegie Museum of Natural History in Pittsburgh
127 (USA), The National Museum of Natural History in Manila (Philippines), the
128 National History Museum in London (the Red Zone), just to mention a few. Some
129 exhibitions have all but a scientific interest, using stalagmites and speleothems
130 as scenic natural sculptures, such as in the Gysean Global Village Folk Museum in
131 Daegu (South Korea) or the Bristol City Museum (UK). Some museums also have
132 reconstructions of entire cave systems, such as in Cincinnati (USA). However, in-

133 detail studies on museumization of speleothems for didactic purposes are still
134 scarce. Accordingly, the aim of this work is to demonstrate that the utility of
135 stalagmites, and all speleothems by extension, continues after scientific
136 application, this time in terms of educational and tourist resources. Aiming to
137 compensate the irreversible damage caused to the cave landscape, and
138 maximize the employment of stalagmites after their removal from their natural
139 environment, this paper suggests to the entire speleothem community an easy-
140 to-do method to valorise this special geoheritage.



141
142 **Figure 1.** Location of Pozzo Cucú Cave (red circle) in Apulia region, Southern Italy.
143 Black dots indicate the >3000 caves mapped in this region (from the Apulian
144 governmental cave registry available on-line).

145

146 **Caves: a conflict between science and conservation**

147 Caves are delicate environments under different perspectives. From a biological
148 point of view, there are species that occasionally frequent underground habitats
149 (i.e. troglonenes and trogophiles), but also organisms (i.e. troglobites) that
150 undergo their whole life cycle in caves. These species have adapted to this dark
151 and oligotrophic environment for thousands and possibly millions years (Culver
152 and Pipan 2019). Their subsistence relies on a subtle equilibrium of their

153 ecosystem, which is sustained by the stable conditions of caves throughout the
154 year (in terms of temperature, moisture, availability of nutrients, etc). The
155 consequences of the human frequentation causes disturbance to cave habitats,
156 leading to an ecological stress for the species that live there. Other ecological
157 niches, although still poorly known, are those constituted by microorganisms
158 (Barton and Northup 2007). Their aggregation into colonies can create
159 morphologies visible at naked eye, as for example vermiculations (Addesso et al.
160 2019). However, most of the time these microorganisms are invisible, and their
161 identification is only possible by DNA studies (Sauro et al. 2018). Although some
162 thrive on organic substances brought into the cave by flowing water, gravity,
163 wind or animals, some are true autotrophs, and geochemical parameters such as
164 water pH and/or mineralization are essential for their subsistence. While human
165 presence can indeed influence these habitats (Leuko et al. 2017), it is important
166 to maintain these niches pristine because, often, microorganisms have evolved in
167 chemical-physical-ecological conditions totally different with respect to the
168 Earth surface, thus can be useful indicators of life conditions of the early Earth
169 and/or other planetary subsurfaces (Boston et al. 2001).

170 Under a geological perspective, caves contain unique mineralogical formations,
171 often peculiar from one cave to another. The uniqueness lies both in the shape
172 and composition, and can consist in giant crystals (Forti and Sanna 2010), rare
173 minerals (Galli et al. 2013) and unusual speleothems (Tisato et al. 2015;
174 Bontognali et al. 2016). In this case the damage can be the modification of
175 chemical/physical parameters inducing the formation of a certain mineralogical
176 species and/or their breakage. For example, cave formations are often white in
177 colour; careless cavers and scientists can irremediably disrupt their original
178 appearance by only touching with dirty hands and/or walking over them with
179 muddy boots.

180 Scientists willing to perform speleothem sampling have to take into account the
181 above reported risks when exploring caves. Additionally, the intended practice is
182 *per-se* invasive, considering the (often conspicuous) removal of material from its
183 original environment. Some research groups follow an *ethos* (Lourenço and
184 Wilson 2013) during sampling campaigns, and only already broken speleothems
185 are removed (Scroxtton et al. 2016; Weij et al. 2018); this approach can be

186 applied both to stalagmites (Chiarini et al. 2017; Woodhead et al. 2019) and
187 flowstones (Columbu et al. 2017a). For several reasons, not all research groups
188 follow these approaches. The will to produce long and continuous palaeoclimate
189 records leads to discard this more conservative approach (Scroxton et al. 2016),
190 although our sample demonstrated a continuous 80 thousand years long
191 palaeoclimate record from a stalagmite found already broken in the cave
192 (Columbu et al. 2020). Also, it can be difficult and time-consuming to only target
193 the broken ones. Sampling campaigns are often accomplished in remote areas,
194 where there is the need to collect as much as possible promising samples in the
195 shortest time. Another practice is to core large flowstones (Columbu et al. 2019b;
196 Regattieri et al. 2019). Eventually, the hole produced by the coring can be easily
197 plugged with cave materials (e.g. sediments), hence reducing the visual impact of
198 sampling. Flowstone coring is rarely accomplished because the genesis of these
199 speleothems, contrary to stalagmites, can produce peculiar geochemical
200 characteristics that impede a correct geochemical interpretation for
201 palaeoclimate purposes. This is a pity, considering that flowstones can
202 potentially produce very long records (Pozzi et al. 2019). The shortcut is to select
203 a still-standing stalagmite that is considered promising for geochemical analyses
204 | (usually candle-shaped stalagmites), and remove it at its base. However, because
205 of the unknowns regarding the speleothem age and the effective feasibility of
206 analyses, this cutting operation is often accomplished on several stalagmites and
207 in multiple caves. Consequently, the original subterranean heritage is
208 compromised irreversibly.

209 Stalagmites could theoretically be reinstalled in caves if, after their sampling,
210 they are not considered adequate for palaeoclimate studies. However, this can
211 only be accomplished if speleothems are not sliced and their internal structure is
212 preliminarily investigated by, for example, X-ray tomography (Walczak et al.
213 2015). As a matter of fact, this time- and money-consuming approach is basically
214 never applied. Preliminary observations could also be carried out by coring,
215 instead of slicing, the selected stalagmite. However, this risky practice (the
216 stalagmite could break into pieces during coring) can only be applied to medium-
217 or large-size stalagmites. In any case, the reinstallation is unlikely in the case of
218 expeditions to remote areas (because of time and resources).

219 Frappier (2008) proposed a screening system to select the most suitable
220 sample(s) avoiding massive sampling; this requires sequential operations, also
221 involving cave monitoring, that are not always affordable by all research groups.
222 It has also been demonstrated that the extraction of mini-cores from in-situ
223 stalagmites can successfully provide useful information on palaeoclimate-driven
224 speleothem growth history (Scropton et al. 2016). Coring is targeted at the
225 bottom and top of stalagmites, thus removal is not necessary. However, this
226 minimally invasive approach is inapplicable if the intent is the creation of proxy-
227 based (i.e. oxygen and carbon stable isotopes) palaeoclimate timeseries from
228 stalagmites.

229 It is evident that speleothem-based palaeoclimate science requires the
230 modification of cave landscapes. Notwithstanding, contrarily to other rocks,
231 stalagmites are usually characterized by an attractive visual aspect, because of
232 the shape, colours and internal fabric. Indeed, after slicing and polishing,
233 speleothems show eye-catching features, the reason why they are often exposed
234 at natural history museums (Currens, 1981). However, the general public is often
235 unaware of the scientific potential of these carbonate deposits. Indeed, the
236 museumization of stalagmites after scientific application could have the twofold
237 aim of valorising a cave component removed from its original collocation while
238 entertaining and educating people on topics related to palaeoclimate and the
239 vulnerable and highly valuable cave environment.

240

241 **The PC stalagmite and its scientific importance**

242 Pozzo Cucù Cave is located in Apulia Region (Southern Italy, figures 1 and 2), in
243 the province of Bari and in the municipality of Castellana Grotte. The latter is a
244 well-known karst area (*Grotte* means caves in Italian), and the Castellana Show
245 Cave is one of the most visited in Italy, with more than 300,000 tickets per year
246 (Parise 2011). An important portion of the local economy relies on this cave,
247 because of tickets profit and employment, as well as the touristic flux attracted
248 by the underground landscape. More or less in the same area, ~50 km west
249 nearby the town of Altamura, there is Lamalunga Cave, which is worldwide
250 famous for hosting the remnants of the so called “Altamura Man”, a pristine
251 skeleton of an ancient Neanderthal man covered by calcite crusts (Vanghi et al.

252 2017). Indeed, Apulia is a hot spot for cave-based anthropological studies
253 because of the multiple findings. For example, the fossils of the oldest European
254 Sapiens have been found in this region (Benazzi et al. 2015). Importantly, this
255 was one of the few areas in continental Europe where Sapiens and Neanderthals
256 shared the same territory, from ~45 to ~42 thousand years ago (hereafter ka),
257 before the extinction of the latter (Benazzi et al. 2011; Higham et al. 2014).



A



B



C



D

258

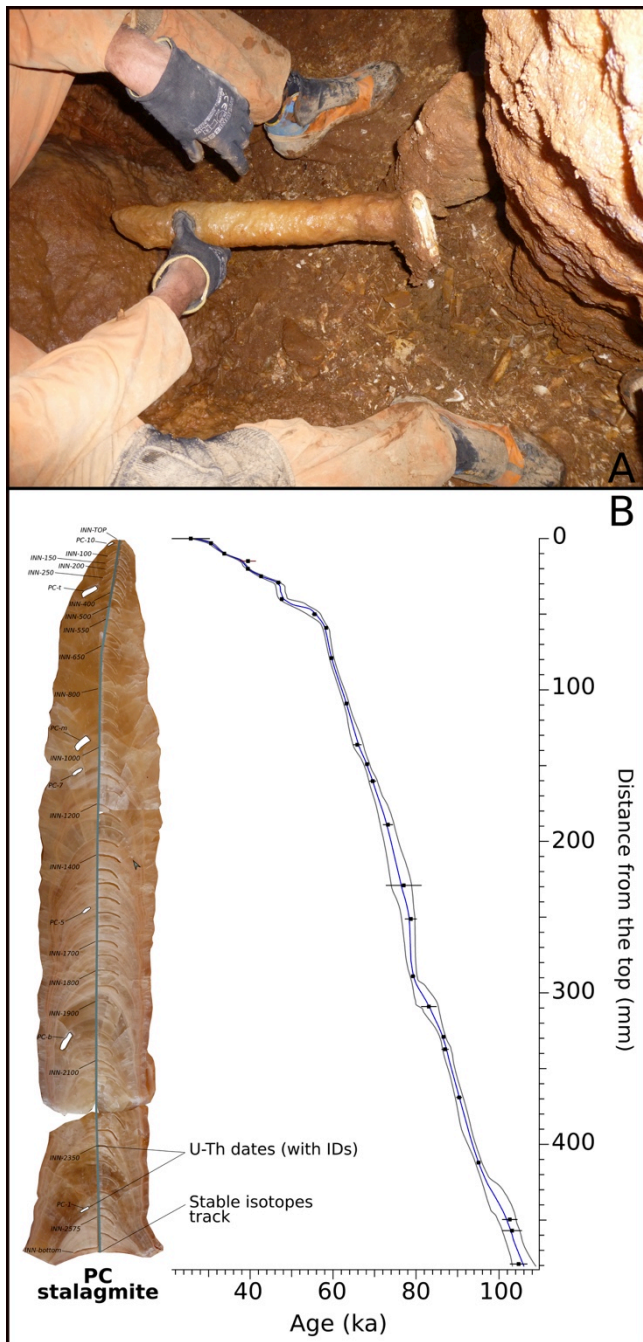
259 **Figure 2.** Caves in Apulia. Pozzo Cucù Cave explored by scientists and local
260 speleologists (A). A Broken stalagmite (B, see the fractures at the base and top) is
261 checked by a scientist (C) in Pozzo Cucù Cave. Grave Santa Lucia Cave (D) and its
262 multitude of white, very delicate, carbonate formations. All photos taken by O.
263 Lacarbonara.

264

265 Pozzo Cucù Cave is included in the Geosite Inventory of the Apulia Region with
266 the code “CGP0357”. Located around 10 km from the Adriatic coastline, it is
267 carved in the Cretaceous limestone plateau belonging to the Calcare di Altamura
268 Formation (figures 1 and 2). The modern entrance, a narrow ~8 m deep pit at
269 ~270 m a.s.l., leads to a subhorizontal environment that stretches for ~300 m. A
270 gate blocks the entrance, and access is allowed for scientific purpose upon
271 permission by local authorities; exploration is permitted to expert speleologists
272 only. This is a valid conservation method, considering that the cave is decorated
273 by pristine carbonate formations, most of which are delicate and could be easily
274 broken by inexperienced visitors (figure 2). PC stalagmite was found detached –
275 but nearby - its original position. It has grown over loose sediments, in part
276 constituted by fossils of large mammals. It is the unstable nature of these
277 sediments that likely caused the fall of the stalagmite, perhaps after earthquakes
278 and/or low discharge flooding. We tend to exclude intense episodes of flooding
279 because: 1) the stalagmite and fossils would have been scattered around the
280 cave; and 2) other evidences of flooding would have been found in the cave. PC
281 appears as a 46 cm long candle-shaped stalagmite, composed of yellowish to
282 brownish calcite. After slicing along the growth axis, the two halves were
283 polished to obtain a better visualization of the internal macrofabrics. The
284 stalagmite exhibits a well-preserved lamination from the bottom to 3/4 of its
285 height, while the remaining portion (i.e. the first ~10 cm from the top) is
286 composed of translucent calcite. After preliminary U-Th dating (n = 3), which
287 attested its possible formation during the last glacial period, dating with very
288 high spatial resolution was carried out along the growth axis, obtaining a total of
289 27 ages. Dating was executed at the Melbourne University (Australia), School of
290 Earth Sciences, following tested protocols (Columbu et al. 2017b, 2019a).
291 Additionally, a stalagmite half was further halved along the growth axis in order

292 to facilitate the operations of high resolution sampling for oxygen ($\delta^{18}\text{O}$) and
293 carbon ($\delta^{13}\text{C}$) stable isotopes. The latter were accomplished at the Innsbruck
294 University (Austria), Institute of Geology, with a spacing of 0.1-0.2 mm for a total
295 of 2659 analyses that followed tested protocols (Moseley et al. 2020). This set of
296 analyses allowed to create the longest and continuous European speleothem-
297 based palaeoclimate record for the last glacial period (Comas-Bru et al. 2020). In
298 fact, PC stalagmite continuously grew from $106.0^{+2.8}/_{-2.7}$ to $26.6^{+0.8}/_{-0.9}$ ka
299 (Columbu et al. 2020).

300



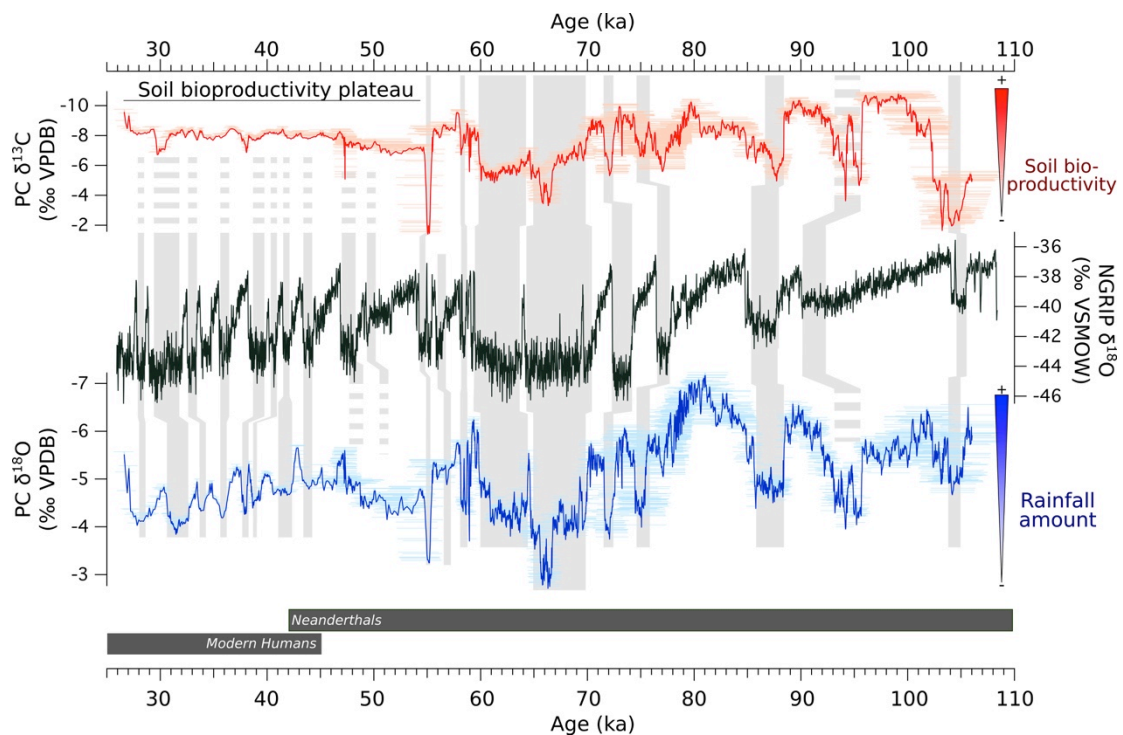
301

302 **Figure 3.** *The PC stalagmite. A) The sample as it was found in the cave. Note the*
303 *remains of big mammals scattered on the ground, a loose surface where possibly*
304 *the stalagmite originally grew. B) The PC stalagmite slice used for dating (black*
305 *lines and IDs) and stable isotopes analyses (blue vertical line). On the right there is*
306 *the age depth model, showing that the stalagmite continuously grew from ~106 to*
307 *~27 ka (dots and bars are respectively the obtained U-Th ages and the*
308 *uncertainties, while the envelope is the calculated age model. After Columbu et al.*
309 *(2020)*

310

311 It resulted as a rare, possibly unique, specimen in the European and
312 Mediterranean context. In fact, in this macro region, the prolonged deposition of
313 cave calcite in colder-than-now climate regimes is impeded because of the drier
314 and colder conditions. PC record is an ideal candidate to become a “reference
315 record” to which new Mediterranean, European and even global palaeoclimate
316 reconstruction will be compared to, considering that the $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ variations
317 demonstrated a strong global signal (i.e. the climate was controlled by climate
318 variations occurring in Greenland and the Atlantic Ocean), but modulated by a
319 regional signal (i.e. climate influenced by variations occurring within the
320 Mediterranean basin). Most importantly, the interpretation of PC $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$
321 timeseries sheds light on the climate status during: 1) the late settlement of
322 Neanderthal in Apulia (~106 to ~42 ka); 2) the arrival of Sapiens in Apulia (~45
323 ka); 3) the 3000 years long cohabitation of the two human species; 4), the
324 Neanderthal extinction (~42 ka). The Sapiens-Neanderthal turnover is the most
325 important cultural transition in Human history, yet there is no leading theory
326 explaining this interchange. Climate variations, particularly the occurrence of
327 frequent very harsh periods during the last glacial, have often been invoked as
328 primary triggers of the Neanderthal demise in other localities (Finlayson and
329 Carrion 2007; Wolf et al. 2018; Staubwasser et al. 2018; Melchionna et al. 2018).
330 However, the PC record gave another view to this topic, attesting that during the
331 Sapiens-Neanderthal turnover, climate in Apulia was never affected by dramatic
332 cold and dry periods and relative environmental modifications that could have
333 caused the extinction of Neanderthal in this region. Accordingly, Apulia has been
334 defined as a “climate niche” in that period. Because of PC record, it is now clear

335 that in Apulia-like areas, i.e. mid-latitude regions where global climatic variations
 336 during the last glacial were attenuated by latitudinal, orographic and/or
 337 geographical factors, climate cannot be considered as the primary factor in
 338 Neanderthal demise (Columbu et al. 2020) and the consequent territorial
 339 supremacy of modern humans. Accordingly, the PC record indirectly reinforces
 340 the theories that see the advanced hunting technology of Sapiens groups
 341 compared to that of Neanderthals since their migration to Europe as a possible
 342 explanation for their turnover (Sano et al. 2019; Marciani et al. 2020).



343
 344 **Figure 4.** PC stable isotope timeseries ($\delta^{13}C$ on the top, $\delta^{18}O$ on the bottom)
 345 compared to palaeoclimate reconstruction from Greenland ice core (NGRIP project
 346 members (2004), black curve in the centre). Bars on the bottom indicate
 347 Neanderthal and Modern Human (Sapiens) turnover. Grey vertical bars are the
 348 proposed correlation with NGRIP. The soil bioproductivity plateau ($\delta^{13}C$) and the
 349 moderate rainfall variation ($\delta^{18}O$) attest to stable environmental conditions during
 350 Neanderthal demise and Sapiens territorial predominance. After Columbu et al.
 351 (2020).

352

353 **The museumization approach**

354 We here propose a plan for the museumization of the PC stalagmite, which has
 355 been agreed with the Castellana Cave society. The latter greatly contributed for

356 the PC scientific venture, both from a financial and logistic aspect, and it is now
357 participating in this new phase. Indeed, the institution selected for the display, to
358 which the sample will be donated, is the Franco Anelli Speleological Museum.
359 The museum is in Castellana Grotte, and belongs to the facilities of the Castellana
360 Show Cave, which is supervised by the Castellana Society. All visitors accessing
361 the show cave have free access to the Franco Anelli Museum, hence the
362 exposition is visited frequently throughout the year. Notwithstanding, the aim of
363 selecting this institution is to bring back the stalagmite to its original region,
364 considering the vicinity between Castellana and Pozzo Cucù. By extension, we
365 suggest to all scientists willing to adopt the museumization approach to donate
366 the speleothem to the closest available institution with respect to the cave where
367 the speleothem has been collected. Before the donation, it is good practice to
368 make a full photographic documentation of the sample and compile a personal
369 database with the most important characteristics of the specimen. This might
370 turn useful to the next generation of scientists that could be willing to work on
371 the same speleothem (Fairchild and Baker 2012).

372 The museumization requires the creation of two items: 1) the showcase where
373 the stalagmite will be exhibited; 2) a didactic panel, which will be disclosed
374 besides the case itself. The first, together with finding the appropriate collocation
375 in the museum collection as well as planning the most suitable lighting,
376 necessitates of the expertise and skills of the museum superintendent and
377 his/her crew. Scientists should instead provide the contents of the second. We
378 have thus created a didactic panel that will complete the exposition of the PC
379 stalagmite. This represents the principal “supporting element” in scientific
380 museums (Miglietta et al. 2011). Its layout is of key importance because the
381 visitor should be able to identify the most important information and the level of
382 details he is interested in. Besides the informative function, the panel often gives
383 physical support to the object, becoming an integral part of the specimen itself
384 (Bartoli et al. 1996). In this way, it captures the visitors’ attention, which is
385 attracted by its shape, colours and schematism. Indeed, the fruition by the visitor
386 strictly depends on the interaction between text and graphic. These components
387 should not be taken separately when planning the composition of a panel
388 (Merzagora and Rodari 2007), in order to enhance the communicative power.

389 The latter is favoured by taking into consideration the readability of the text and
390 emphasis in the message delivered by the text, balance and coherence between
391 elements and equilibrium between text and background. For example, text
392 blocks are a useful expedient to fragment a long text, and visitors more easily
393 remember the panel contents if text is proposed in short isolated paragraphs
394 rather than a long continuous one (Appiano 1998). Additionally, it is important
395 to avoid as much as possible scientific jargon, which could result hard to
396 understand by the average public, while lexicon should be simple, non-
397 redundant, captivating and supported by images. From a general perspective, the
398 hierarchical order of the information must be straightforward in order to
399 facilitate the comprehension and memorization, as well as to highlight a logical
400 and easy-to-follow reading path.

401 The proposed panel is currently under evaluation by the Franco Anelli Museum
402 superintendent. The chosen font is Verdana, because of its great readability even
403 for smaller dimension text. The panel is bilingual (Italian and English), and the
404 two languages are reported with two different text colours in order to better
405 delineate the reading path. The Gulpease index (Lucisano and Piemontese, 1988)
406 was used to test the text readability, making contents fully comprehensible for
407 the younger public (targeting middle school average students). The title and
408 subtitle of the panel are characterised by vivid colour, in order to capture the
409 public's attention immediately. The title itself is captivating, already stimulating
410 the curiosity of the reader. The sub-title, instead, proposes a super condensed
411 summary of the panel content, still procuring a sort of gap of information that the
412 visitor can only fill by continuing the exploration of the panel. In the top corners
413 there is a brief explanation about the genesis of stalagmites and their potential
414 for scientific applications. On the left, on the bottom part, there is instead a one-
415 line message recalling the importance of the cave environment protection, which
416 clearly establishes that removing cave deposits is allowed for scientific purpose
417 only. Three short paragraphs compose the main reading path. They are
418 numbered and connected by an arrow, extending from the left to the right of the
419 panel. In this way, the visitor is invited to observe the panel in its whole. The
420 path starts with a question about the importance of the stalagmite, which
421 intrigues the reader and tempts to continue reading. The three blocks highlight

422 the uniqueness of the sample (i.e. one of the few last glacial European stalagmite
423 ever found) and the outcome of the scientific application (i.e. climate was not the
424 main trigger of Neanderthal extinction in southern Italy). The central part is
425 instead dedicated to the stalagmite itself. The intent of the big picture of the
426 sample is to straightforwardly declare what the panel is about, and this can be
427 noticed from distance (i.e. even at distance where text is non readable). Visitors
428 are thus attracted by this expedient and conveyed toward the showcase. The two
429 paragraphs beside the picture are a slightly detailed explanation on the
430 geochemical analyses carried out on the stalagmite; the visitor might decide their
431 reading according to the level of detail he/she is interested in. The panel also
432 includes other two images: 1) on the left portion there is a picture taken in Pozzo
433 Cucù Cave, which shows a scientist inspecting stalagmites for their sampling; 2)
434 on the bottom right corner there is a proposed reconstruction of the Neanderthal
435 and Sapiens appearance. This is the last component of the panel that the visitor
436 should theoretically look at, as a take-home message that the exposed item (the
437 stalagmite) is in someway telling a story about ancient populations. This is a
438 powerful expedient for enhancing the possibilities that the visitors will
439 remember the panel, and its main content, in the future. However, aimed to
440 visitors wishing more information, a QR code placed in this same portion of the
441 panel connects to the scientific paper upon which the panel is based (Columbu et
442 al. 2020).

443 The proposed museumization approach takes also into account an evaluation
444 strategy (Economou 2004), which will help the museum superintendent to
445 understand the audience appreciation and feelings toward the new exposition. A
446 survey will assess how intriguing the content of the proposed panel is and how
447 much the informative expedients enhance the visitors' memory. Experts in
448 museum management will conceive the survey; the results will give the
449 possibility to modify the panel if needed. In fact, the characteristics of the real or
450 even potential public must be considered to clarify or adapt a cultural project
451 (MacDonald 1992). The analysis of the survey information permits to increase
452 the value of the cultural offer, making it more readable and attractive for a range
453 of different types of visitors (Tobelen 2003). This will also allow to comprehend
454 if this approach can be applied to other Italian and/or non-Italian museums,

455 similar in contents and public. This is because the knowledge of the demography
 456 and social characteristics of the various kind of public, as well as their
 457 motivations and expectations, are essential elements for the effectiveness of
 458 cultural management (Merzagora and Rodari 2007). Indeed, while in the past
 459 visitors were considered only figures to be counted, in the last few years they
 460 have become attentive users (Kotler and Kotler 1999); curators must focus on
 461 them if the final aim is to achieve the main goals of modern museums, which are
 462 primarily to inform and educate (Posi et al. 2010).

463 Last but not least, the final step of the museumization should be the advertising
 464 by authorities. Indeed, *“for an object to be considered as heritage, it is necessary to
 465 recognise value on it; if only one person recognises it as such, it is not enough, since
 466 heritage is necessarily a collective concept”* (de Lima & de Souza Carvalho 2020).
 467 In our opinion, this process should be boosted by local authorities by a detailed
 468 and precise project of social and cultural enhancement of the represented
 469 heritage. This would gradually educate people on the importance of a single item
 470 as a record of a small slice of the ancient history and culture of a specific area.

471



472

473 **Figure 5.** The didactic panel created for the museumization of the PC stalagmite
 474 (see text for details). The final size will be decided according to the space available
 475 in the exposition room and its characteristics.

476

477

478 **Conclusions**

479 Speleothems used for palaeoclimate research are generally disassembled by the
 480 multiple geochemical and petrographic analyses required for their full scientific
 481 exploitation. Generally, one half of the speleothem is spared, acting as a reference
 482 model for the exact location of samples, hiatuses, and petrographic changes, as

483 well as for future researches. This work proposed the museumization of a
484 speleothem after scientific application. To this aim we have selected the PC
485 stalagmite that, in previous studies, has allowed the reconstruction of the
486 changing climate conditions when Modern Humans gradually substituted
487 Neanderthal groups in Apulia. This stalagmite, with its intriguing story, is a
488 perfect sample to be displayed in a museum considering its scenic and scientific
489 value. Indeed, the polished half of the speleothem is ideal for exhibition
490 purposes, attracting the interest of visitors because of its aesthetic aspect. A
491 panel has been designed to accompany this sample in a museum exhibition close
492 to its original finding. The panel intends to highlight the scientific value of the
493 sample, as well as to procure a didactic mean for visitors. This important
494 stalagmite is a good example of how these samples, which are normally stored in
495 collections of research institutions and are often lost or forgotten, can help in
496 promoting the knowledge on palaeoclimate research in general, and of cave
497 speleothems as palaeoclimate archives in the specific, becoming a useful tool for
498 the karst geosites valorisation.

499

500

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516

517

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