Timing of the Middle-to-Upper Palaeolithic transition in the Iberian inland (Cardina-Salto do Boi, Côa Valley, Portugal)

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1 **Timing of Middle-to-Upper Palaeolithic transition in Iberian inland (Cardina-Salto do Boi,**
2 **Côa Valley, Portugal)**

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27 **Abstract**

28 The timing of the Neanderthal-associated Middle Palaeolithic demise and a possible overlap with
29 Anatomically Modern Humans (AMH) in some regions of Eurasia continues to be debated. The
30 Iberian Peninsula is considered a possible refuge zone for the last Neanderthals, but the chronology
31 of the later Middle Palaeolithic record has undergone revision and has increased the debate on the
32 timing of Neanderthal extinction. Here we report on a study of the 5-metre-thick archaeological
33 stratigraphy of the Cardina-Salto do Boi, an open-air site located in inland Iberia, from which
34 Optically Stimulated Luminescence (OSL) ages are obtained for Middle and Upper Palaeolithic
35 occupations preserved in overbank alluvial deposits. Geomorphology, archaeo-stratigraphy, stone-
36 tool evolution and OSL dating support the persistence of Neanderthals after 41 ka in central Iberia;
37 the transition between the Middle Paleolithic material culture to the Modern Human-associated
38 Aurignacian blade and bladelet production is estimated to lie between 34.0 ± 2.0 ka and 38.4 ± 1.9
39 ka. Our results demonstrate that investigations focusing on different geomorphological situations
40 are necessary to overcome the current limitations of the evidence and to establish more consistent
41 models for Neanderthal disappearance and AMH expansion in the Iberian Peninsula.

42
43 **Keywords:** Neanderthal, Modern Human, Middle-to-Upper Palaeolithic, Iberia

44 INTRODUCTION

45 Since the end of the 1980s, and based on ages of under 40,000 ^{14}C yr BP, it has been widely
46 accepted that southern Iberia represents a possible refuge zone for the last Neanderthal population
47 (Hublin et al., 1995; Zilhão, 2000), and that this population persisted until approximately 37,000 cal
48 yr BP (Zilhão, 2006a; Zilhão et al., 2010), or even as late as ~28,000 cal yr BP (Straus et al., 2000;
49 Finlayson et al., 2006). This hypothesis implies coexistence for several millennia with Anatomically
50 Modern Humans (AMH), established in northern Iberia from around 42,000 cal yr BP (Wood et al.,
51 2014; Hublin, 2017). It also implies the existence of a biogeographical frontier along the Ebro
52 Basin, functioning as a barrier to migration and diffusion between Neanderthals and AMH (Zilhão,
53 2000).

54 However, new radiocarbon data from several key Late Middle Palaeolithic European sites
55 (Higham et al., 2014), and direct radiocarbon dating of Neanderthal remains (Devièse et al., 2017)
56 using refined sample pre-treatment measures and suitable sample selection, have pushed back some
57 of the youngest radiocarbon ages for the Middle Palaeolithic to about 42,000 cal yr BP. The Iberian
58 peninsula, the westernmost part of Europe, has been subject to special attention in this research. The
59 association between dates from Sima de las Palomas, Carihuela and Gorham's Cave, and their
60 supposed archaeological context (Fig. 1, Zilhão and Pettitt, 2006; Wood et al., 2013), has been
61 questioned, and the dates from El Salt, Jarama VI and Zafarraya have been pushed back several
62 millennia (Fig. 1, Maroto et al., 2012; Wood et al., 2013; Galván et al., 2014; Kehl et al., 2013).
63 Nevertheless, the hypothesis of a persistent Neanderthal presence in southern Iberia has not been
64 invalidated; there remains evidence for a relatively late survival of Neanderthals (Zilhão et al.,
65 2017, Carrión et al., 2019), and more work is needed.

66 The current discussion on the Middle-to-Upper Palaeolithic transition in Iberia shows clear
67 shortcomings resulting directly from: 1) the lack of research in inland Iberia, when compared to the
68 coastal regions; 2) the difficulties of locating open-air sites that can expand the geographic and

69 temporal scope of the archaeological record; and 3) the challenges of dating (especially using ^{14}C)
70 (Aubry et al., 2002, Alcaraz-Castaño, 2015).

71 Our view of the importance of the open-air Cardina-Salto do Boi site discussed in this paper
72 is based on the above discussion. The site is located in Northeastern Portugal along the Côa River
73 (Fig. 1), halfway between the Central Portuguese and Asturias site clusters of Middle and Upper
74 Palaeolithic occupations. The site also presents a sequence of deposits containing artefacts from the
75 Middle Paleolithic through to the Upper Palaeolithic. These deposits have the potential to provide
76 an important new contribution to the ongoing debate concerning the chronological overlap between
77 Neanderthal and AMH populations in Western Eurasia and the geographical and
78 palaeoenvironmental context of such overlap.

79

80 **CARDINA-SALTO DO BOI SITE**

81 The Côa River is a Portuguese left-bank tributary of the Douro River, one of the major watercourses
82 that cross the NW Iberian Mountains from east to west (Fig. 1). The 120 km long river basin is
83 controlled by the tectonic structure of the SSW/NNE Manteigas-Vilarica-Bragança fault system,
84 separating the basin from the Portuguese Western Mountains (Ferreira, 1978, Aubry et al., 2012a).
85 The Côa river basin comprises two different geological sectors. Upstream, the river flows in a
86 deeply gorged valley, through Hercinian granites (Silva and Ribeiro, 1991). The last 17 km of the
87 Côa, before the confluence with the Douro, grades to a meandering pattern into intensely folded and
88 faulted metasedimentary rocks (phylite, greywacke and quartzite), ranging in age from the
89 Precambrian to the Ordovician (Silva and Ribeiro, 1991).

90 The last 22 km of the Côa river valley and its confluence with Douro are well known to
91 preserve the largest concentration of open-air Palaeolithic rock art, classified as a UNESCO World
92 Heritage site in 1998 (Zilhão, 1997). Since 1995, 22 open-air sites have been identified in an area of
93 less than 400 km², along the river's last nine kilometres (Fig. 2). These lie in a region where Upper
94 Palaeolithic settlement was previously unknown, and their existence partially contradicts the

95 accepted logistic hunting sites model for the Iberian inland's scarce occurrences ([Davidson, 1986](#)).
96 The sites are found both on the valley bottom and on the surrounding granite plateau, along the
97 eastern limit of the northern Meseta ([Zilhão et al., 1995](#); [Aubry, 2009](#); [Aubry et al., 2002](#)).

98 A relative chronology for the Côa Valley Upper Palaeolithic settlement phases was
99 established from the stratigraphic sequences identified at the sites, using a geoarchaeological
100 approach ([Aubry et al., 2010](#)). Thermoluminescence (TL) ages were obtained from heated quartz
101 and quartzite pebbles found at four Côa Valley sites, and optically stimulated luminescence (OSL)
102 ages from sediments at Cardina, Olga Grande 4, Quinta da Barca Sul and Fariseu ([Fig. 2, Valladas](#)
103 [et al., 2001](#); [Mercier et al., 2006](#), [Aubry et al., 2010](#)). From a radiocarbon perspective, the acid soils
104 developed on schist and granite do not favour the preservation of macro-organic remains. However,
105 bones and teeth fragments were recovered in the stratigraphic level 4 of Fariseu ([Aubry, 2009](#)). The
106 nitrogen (N) content tested on Cardina-Salto do Boi faunal remains from Gravettian layers has
107 revealed that collagen is not sufficiently preserved to be used for radiocarbon ages (Monge Soares,
108 A., personal communication, 2008). However, two radiocarbon ages from the Early Holocene,
109 10,405-10,240 Cal yr BP ($9,160 \pm 30$ ^{14}C yr BP [Beta-460528] and 10,496-10,266 Cal yr BP ($9,220$
110 ± 30 yr BP [Beta-460529]), (2σ) using the IntCal13 calibration curve ([Reimer et al., 2013](#)), were
111 obtained on cremated bones from the top of the layer 4 ([Aubry et al., 2017](#)) and from the Younger
112 Dryas stade, 12,601-12,244 cal yr BP ($10,510 \pm 40$ yr BP [Beta-213130]), 11,759-10,781 cal yr BP
113 ($9,830 \pm 130$ ^{14}C yr BP [Ua-32645]) for two bones of the layer 4 at Fariseu ([Aubry, 2009](#)). In
114 addition, a charcoal fragment from Fariseu's layer 9 was dated by AMS to 23,175-22,595 cal yr BP
115 ($19,020 \pm 80$ ^{14}C yr BP [GrA-40167]), demonstrating the potential conservation of last glacial
116 maximum macro-organic material in alluvial deposits.

117 Cardina-Salto do Boi was the first Upper Palaeolithic site discovered in the area, in 1995,
118 yielding the first Côa Valley rock art context ([Zilhão et al., 1995](#)). The 1-metre-thick sequence of
119 deposits revealed by excavation between 1995 and 2001 is preserved on the top of a left bank

120 meander, 166 metres above sea level, and 20 metres above the Côa riverbed level, just upstream of
121 a rhyolite dyke (Fig. 3). Four main lithostratigraphic units were defined during this first phase of
122 excavation (1995-2001) which did not reach the bedrock. The deposits of layers 1 to 4b are
123 interpreted as the result of slope processes initiated by surface runoff (Bergadà, 2009). The stone-
124 tool assemblage from layer 4b and 4a can be assigned from the Late Gravettian at the bottom,
125 through Solutrean, Magdalenian to the Azilian and Pre-Boreal at the top; this association is
126 supported by TL (Valladas et al., 2001) and radiocarbon dates (Aubry et al., 2017). Based on
127 ceramic fragments and flint bladelets (layer 3) and modern ceramic fragments (layer 1 and 2) the
128 top layers contain Neolithic to Bronze Age human occupations.

129 A second phase of archaeological excavation began in 2014, undertaken by the PALÆCOA
130 project, including tests in other areas, in order to define the extent of the site and to observe the
131 entire sequence of deposits (Fig. 3, Aubry et al., 2017). Ongoing work has revealed an open-air 5-
132 meter-thick stratigraphic succession, with remains of older human occupations. This has allowed a
133 comprehensive archaeostratigraphic study of the site, using integrated multi/pluridisciplinary
134 analyses, and aimed at a reconstruction of formation processes, spatial analysis, a study of stone-
135 tool remains, and dating of the archaeological/sedimentary records.

136

137 MATERIAL AND METHODS

138 Geoarchaeological approach

139 The data from the Cardina-Salto do Boi open-air archaeological site were collected using a standard
140 geoarchaeological approach, including a geomorphological and geological study of the site
141 surroundings, sedimentological description and stratigraphic correlation of the siliciclastic deposits
142 exposed during excavation, as well as a subsequent sampling program for grain-size and clay
143 mineralogy laboratory analyses. Fieldwork involved the systematic description of exposed cross-
144 sections and profiles to reconstruct stratigraphic events and their vertical and lateral variations.

145 In particular, due to the presence of a local stratigraphy with recurrent sedimentary features,
146 the field description of the Cardina-Salto do Boi siliciclastic succession was conducted using facies
147 analysis, which combines the physical characteristics displayed by a single layer or by a set of
148 layers linked to a well-defined sedimentary process (e.g., [Moore, 1949](#); [Ricci Lucchi, 1980](#)).
149 Therefore, to be able to use the facies concept in archaeology (see [Angelucci et al., 2013](#)), informal
150 Geoarchaeological Field Units (GFU) were identified based on sedimentological (lithostratigraphy),
151 pedological or archaeological criteria and used as field categories. These field units were later
152 grouped into Geoarchaeological Complexes (GC) taking into consideration major changes in the
153 depositional style, as well as major stratigraphic unconformities (details in [Angelucci, 2002](#)).

154 In order to complement the observations made in the field and to better recognise the natural
155 sedimentary processes and the anthropogenic inputs/disturbances for the siliciclastics deposits that
156 make up the 5 metre-thick Cardina-Salto do Boi stratigraphic succession, a total of 18 samples for
157 grain-size analysis and clay mineralogy determination were collected during 2018 fieldwork
158 seasons. The selection of samples focused on a satisfactory coverage of the different identified
159 facies and GFUs, as shown in the cross-section and in the composite stratigraphic log of [Fig. 4](#) and
160 [5](#), respectively. Basically, field and laboratory sediment descriptions were made using a
161 comprehensive form addressing the sedimentary, pedogenic and anthropogenic characteristics of the
162 deposits (e.g., [Keeley and Macphail, 1981](#); [FAO-Isric, 1990](#); [Brown, 1997](#); [Goldberg and Macphail,](#)
163 [2006](#)), to assess the deposition and formation processes at the site.

164

165 **Grain-size and clay mineralogy laboratory analyses**

166 For each sample, grain-size analysis was carried out using a Horiba LA-950 laser particle size
167 analyser (detection range from 0.01 μm to 3000 μm). After sieving with a 2 mm mesh to separate
168 the coarse fragments (gravel), sample pre-treatment included suspension in sodium
169 hexametaphosphate (5 g/L) and hydrogen peroxide (35%) for 12 h, as well as ultrasonic suspension

170 for 60 s in the analyser to achieve optimal dispersion. Full description of the methodology
171 implemented in the laser diffraction particle-size analysis is laid out in the supplementary
172 information of [Sitzia et al. \(2017\)](#).

173 Grain-size frequency-distribution curves obtained from laser diffraction were deconvoluted
174 (parametric curve fitting) to identify the main modes ([Qin et al., 2005](#)). All grain-size analysis and
175 measurements were processed at PACEA laboratory (University of Bordeaux, France).

176 Clay mineralogy was estimated by X-ray diffraction (XRD) on the $<2\ \mu\text{m}$ fraction, which
177 was extracted by settling according to Stokes's law ([Moore and Reynolds, 1997](#)). Oriented slides of
178 clay residue were obtained from sedimentation of clay suspensions on glass slide and run in a
179 Malvern PANalytical X-ray diffractometer AERIS, equipped with a $\text{CuK}\alpha$ X-ray tube and a detector
180 that operate at 40 kV voltage and 15 mA intensity (at the Earth Sciences Department of Coimbra
181 University). Three runs were performed for each sample to discriminate clay phases: (i) air-drying
182 (normal run); (ii) ethylene-glycol vapor saturation for 24 h (glycol run); and (iii) heating at 550°C
183 during 2 h (heating run), as recommended by [Moore and Reynolds \(1997\)](#). Continuous goniometer
184 scans from 2° to 29° (of 2θ) were executed for normal runs and from 2° to 15° (of 2θ) for glycol
185 and heating runs, with a step size of 0.02° (of 2θ). Clay minerals were identified using their main
186 diffraction (d_{001}) peak and by comparing the three diffractograms obtained for each sample.

187 Semi-quantitative abundance of clay minerals was determined through the peak areas of the
188 basal reflection for the main clay mineral groups present on glycolated diffractograms, weighted by
189 empirical factors. According to various authors (e.g., [Moore and Reynolds, 1997](#); [Kahle et al.,](#)
190 [2002](#)), this approach allows a rough estimate of actual mineral percentages.

191 To be able to better understand the sediment transportation pathway, the illite crystallinity
192 and the illite chemical index were measured on the XRD diffractograms. The illite crystallinity (or
193 Kübler index) was measured as the full width at half maximum of the illite $10\text{\AA}$ peak ([Diekmann et](#)
194 [al., 1996](#); [Kübler and Jaboyedoff, 2000](#)). Generally, low values (<0.4) of illite $10\text{\AA}$ peak width

195 indicate good crystallinities (relatively unaltered illite) and high values (>0.8) indicate poor
196 crystallinities (highly degraded illite). The illite chemical index (or Esquevin index) was estimated
197 using a ratio between the 5Å and 10Å peak intensities ([Esquevin, 1969](#); [Gingele, 1996](#)). Values of
198 5Å/10Å illite peak intensities >0.5 indicate Al-rich illite, interpreted as formed under strong
199 hydrolysis. Values of 5Å/10Å illite peak intensities <0.5 represent Fe/Mg-rich illite (biotite, mica),
200 which is characteristic of physical erosion ([Gingele, 1996](#)).

201

202 **Lithic analysis**

203 Since 1995, all the deposits from GFU 4 to 5 have been excavated according to lithostratigraphic
204 units, combined with 5 cm-thick artificial units (UA), used to constrain the horizontal and vertical
205 position of non-piece-plotted or remains recovered by water sieving with 2 mm grids. From the top
206 to bottom of each GFU, the 5 cm-thick units are numbered sequentially, per quarter of square metre
207 unit of the excavation grid. Stone fragments of more than 5 cm, recovered in layers 4a and 4b (GFU
208 4), as well as in GFU 5 have been drawn, the raw material determined, and, along with all the lithic
209 remains recovered during the excavation of GFU 6 to 8, three-dimensionally located.

210 Lithic raw material sources of stone-tools have been determined by macroscopical
211 comparison with samples collected in the Côa Valley region and Western Iberia, and the
212 characterization of non-local flint and silcrete was complemented by a systematic binocular
213 examination of the microfacies and examination of thin sections for selected archaeological pieces,
214 following the methodology discussed in previous publications ([Mangado Llach, 2002](#); [Aubry et al.,](#)
215 [2012b](#)).

216 The knapped lithic remains have been counted and studied using a technological approach to
217 assess reduction sequences, and to define the blank selected and retouched tool types ([Demars,](#)
218 [Laurent, 1992](#); [Boëda, 1993](#); [Dibble and Bar-Yosef, 1995](#); [Pelegrin, 1995](#); [Zilhão, 1997](#), [Mourre,](#)
219 [2003](#)). The assemblages have been analysed in terms of variation in mass ratio of cores and blanks,
220 blanks and tools, to demonstrate, by their technological and typological attributes, the integrity of

221 each assemblage and its technical and cultural affiliation.

222 Refitting of knapped and heated lithic remains used in fire structures to infer both anthropic
223 and sedimentary processes, and to assess palimpsest formation and stratigraphic integrity (Villa,
224 1982; Hofman and Enloe, 1992; Deschamps and Zilhão, 2018), has been applied systematically to
225 the lithic remains of the GFU 8 to 4.

226

227 **Age determination**

228 The chronological data were obtained using OSL on K-rich feldspar and quartz-rich extracts from
229 11 sediment samples (Table 1). Cleaned quartz and K-rich feldspar grains (180-250 μm) were
230 derived from the sediment by sieving, soaking in HCl, H_2O_2 , heavy liquid separation (2.58 g cm^{-3})
231 and finally etching in 40% HF (quartz) or 10% HF (feldspar) before a final wash in HCl (Aitken,
232 1985, 1998). Only very limited amounts of feldspar could be extracted from these samples.

233 All OSL signals were measured using automated Risø TL/OSL Risø DA-20 readers (Bøtter-
234 Jensen et al., 2010) equipped with arrays of blue ($470 \pm 30 \text{ nm}$) and infrared (IR, $870 \pm 40 \text{ nm}$)
235 LEDs providing stimulation powers at the sample position of approximately 80 and 130 mW/cm^2 ,
236 respectively. The post-IR blue quartz signals (8 mm aliquots) were detected in a UV window (Hoya
237 U-340), whereas IR feldspar signals (2 mm aliquots) were detected in a blue-violet window (Schott
238 BG3 and BG39).

239 The single-aliquot regenerative-dose (SAR) procedure (Murray and Wintle, 2000) was used
240 for equivalent dose determination. For quartz, a double SAR procedure (Banerjee et al., 2001)
241 employing IR stimulation (at 50°C for 40 s) prior to blue (at 125°C for 100 s) and a test dose of 20
242 Gy was used on all samples to minimize the effects of any feldspar contamination. A preheat
243 temperature of 260°C for 10 s and a cutheat temperature of 220°C was used for all dose
244 measurements. A high-temperature blue bleach at 280°C for 40 s was inserted in between each
245 SAR cycle to minimise potential recuperation effects (Murray and Wintle, 2003). The signal was
246 summed over the initial 0.5 s of stimulation and the background over the subsequent 0.5 s of

247 stimulation.

248 For feldspar, two post-IR IR SAR protocols (Thomsen et al., 2008; Buylaert et al., 2009;
249 Thiel et al., 2011) were used. The pIRIR(50,225) protocol used a preheat (held for 60 s) at 250 °C,
250 a first IR stimulation at 50 °C (200 s), a second stimulation (200 s) at 225 °C and a high-temperature
251 (280 °C) IR exposure (200 s) after each SAR cycle. The pIRIR(50,290) protocol used a preheat of
252 320 °C, 60 s, a first IR stimulation at 50 °C (200 s), a second stimulation (200 s) at 290 °C and a
253 high-temperature (320 °C) IR exposure (200 s) after each SAR cycle. For both protocols, a the test
254 dose (TD) was chosen to approximately match the size of the natural dose (De), i.e $TD/De \in$
255 $[0.7;1.2]$. Calculations were based on the signal derived from the initial 2 s of the post-IR IRSL
256 minus a background derived from the last 50 s. Age-Depth Modelling was performed using Bayesian
257 Statistics (Bacon script, Blaauw and Christen, 2011).

258 Dose rates were determined using high-resolution gamma spectrometry calibrated as
259 described in Murray et al. (1987; 2018) and the conversion factors of Guérin et al. (2011). Before
260 counting, crushed and homogenized samples were mixed with wax, cast in a fixed cup-shaped
261 geometry, and stored for a minimum of 21 days (>five ^{222}Rn half-lives) to ensure equilibrium
262 between ^{222}Rn and ^{226}Ra . For K-feldspar extracts the internal beta dose rate of ^{40}K was calculated
263 assuming an effective K concentration of $12.5 \pm 0.5\%$ (Huntley and Baril, 1997). We also assume
264 that the present-day burial depths represent the lifetime burial depths and cosmic ray contributions
265 are based on Prescott and Hutton (1994). Lifetime water contents are based on measured (field)
266 values.

267

268 RESULTS

269 Cardina-Salto do Boi site stratigraphy

270 The field description of the cross-section exposed in areas excavated between 1997 and 2018
271 revealed a 5 m-thick stratigraphic succession (on a phyllite bedrock), articulated into eight field

units (GFU 1 to 8) and grouped in two main geoarchaeological complexes (GC A and B), as shown in the Fig. 4 and 5. From top to base, GFU 1 and 2 are massive and bioturbated coarse units (slightly gravelly), with a poorly to very poorly sorted muddy sand fraction (sand 54-58%; silt 38-42%; and clay 4-5%) (Fig. 5, [Supplementaries Fig. 1, 2](#)). GFU 3 is separated from the previous uppermost units by an irregular bounding surface (d0). Both GFU 3 and 4 are distinguished from GFU 1 and 2 by relatively higher silt (44-50%) and clay (8-11%) contents, matched by a reduction in gravel content. The lower bounding surfaces of both GFU 3 and 4 are characterized by important anthropogenic processes (near d1 and d2), with a main erosive unconformity between GFU 4 and 5 (d2). The rest of the GFUs (from 5 to 8) consist of tabular fine-grained bodies with recurrent grain-size characteristics such as low gravel content (3-7%; very slightly gravelly) and a very poorly sorted sand mud fraction enriched in both silt (42-55%) and sand (33-47%), with only secondary amounts of clay (10-15%). A planar to irregular bounding surface, ranging from non-erosive to slightly erosive in nature, separates GFU 5 and 6 (d3). Some intercalation of apparent incipient pedogenetically altered horizons can be also inferred in the middle part of GFU 5, as well as along the GFU 6 and 7 boundary. GFU 6 to 8 also contain some lenticular layers of well-rounded coarse to very coarse gravel ([Fig. 5](#)). The contact between the local siliciclastic sedimentary infill and the bedrock is represented by a main erosive unconformity (d4).

Six grain-size components stand out ([Supplementary Fig. 1](#)), in decreasing order of contribution: (i) 41-55% medium to fine silt (24 μm to 14 μm ; mean 18 μm) in GFU 4 to 8, slightly lower in the GFU 1 to 3 (23-30%) and higher (58%) near the d1 unconformity (with anthropogenic accumulation of material, [Fig. 5](#)); (ii) 11-33% medium to fine sand (303 μm to 206 μm ; mean 241 μm) in GFU 1 to 7 and 7-9% in GFU 8; (iii) very variable amounts (8-43%) of very fine sand (98 μm to 82 μm ; mean 87 μm) in all GFUs; (iv) 2-8% coarse sand (986 μm to 574 μm ; mean 843 μm) in GFU 1 to 7, absent in the GFU 8; (v) 3-8% ultrafine particles (mean 0.4 μm) around the d2 main unconformity and in the middle part of GFU 5 (samples C5d-C5g), as well as in GFU 6 and 7; and

297 (vi) 2-4% clay (mean 3 μm) in the upper part of GFU 5 (first levels with Upper Palaeolithic
298 remains) and in GFU 8.

299 Illite is clearly dominant (73-94%) in all sampled sediments, with kaolinite only 3-23%.
300 However, clay mineralogy clearly differentiates the samples collected from the more superficial
301 field units from those from the deeper units (Fig. 5). GFU 1 and 2 contain more illite (73-87%) than
302 kaolinite (5-15%), small amounts of vermiculite (3%), chlorite (4-5%) and 10-14Å mixed-layer
303 clays (1-4%). The remaining samples collected in GFU 3 to 7 almost always contain vestiges of
304 vermiculite (2-4%), with few 10-14Å mixed-layer clays (5-7%) in the middle position of the GFU 5
305 (samples C5e and C5f; Fig. 5); the only exception is the set of samples from lowermost
306 stratigraphic position (GFU 8) containing moderate amounts of smectite (2-12%) in addition to the
307 usual illite and kaolinite. The illite to kaolinite ratio only varies slightly within all sampled
308 sediments, although the proportion of kaolinite increases stratigraphically upwards and thus tends to
309 be higher in the relatively coarser units (Fig. 5). In addition, kaolinite content is relatively higher
310 (23-15%) in the samples collected immediately below the obvious unconformities (i.e., present-day
311 surface, d0, d1 and d2; Fig. 5), as well in the sample C5d (12%).

312 All samples have 10Å illite peak widths of below 0.15, indicating that illite crystallinity is
313 extremely high. Eighty-nine percent of the sediments show a ratio of 5Å/10Å illite peak intensities
314 <0.5 (Fe/Mg-rich illite), implying little or non-chemical weathering (except in samples C5d and
315 C8b).

316

317 **Archaeostratigraphic and technological evidence**

318 The vertical distribution of lithic remains recovered in GFU 1 to 8 of the H'/I'-17/19 area (Fig. 3,
319 section A) reveals that the highest density is found in GFU 4 (Supplementary Table 1, Fig. 6, 7).
320 Using lithic raw material types, refitting of lithics from the base of GFU 4 to GFU 8 (recovered
321 during excavation of the H'/I'-17/19 area) has established several sets of lithic remains from layer 4b

322 and in the same or different UA of GFU 5 (Fig. 6). Few links at the interface between GFU 4 and
323 GFU 5 have been identified and vertical distribution of the refitting sets (Fig 6, 7) is consistent with
324 the main grain-size components (Fig 5, Supplementary Fig 1). Refit links show that the components
325 of each refit unit scatter vertically over distances < 20 cm (Fig. 6, 7); this pattern is considered
326 representative of the entire alluvial sequence (GFU 8 to 5).

327 Except for broken/altered heated stones used in fire structures in GFU 5/UA24 to UA29, we
328 have obtained a low refit ratio for all the lithic assemblages (Fig. 6). This could be explained by the
329 small area excavated (6 m², cf. total site area estimated as >1,000 m²) and by discard of flakes or
330 tools produced outside the excavated area, as suggested by a low core/blank ratio (Supplementary
331 Table 1).

332 The lithic assemblages from GFU 8, 7 and 6 are very similar in terms of raw materials and
333 reduction method. The lithic assemblages are composed only of well preserved, fresh-edged pieces.
334 Varieties of the local milky, translucent and smoky quartz, rhyolite and quartzite pebbles have been
335 used (Supplementary Fig. 3). Technological study and refitting sets reveal two main different
336 productions: (i) Rhyolitic fragments and a refitted flake could correspond to the preparation of a
337 Levallois centripetal core (Supplementary Fig. 3, no. 3, Supplementary Table 1). Cores are under-
338 represented, but most of the blanks correspond to a Levallois recurrent centripetal method of flake
339 production (Boëda, 1993). Few of the flakes have been retouched into notches, denticulates or
340 single side-scrapers (Supplementary Table 1, Supplementary Fig. 3, no. 8). Two flake-cleavers were
341 found in GFU 7 (Supplementary Fig. 3, no. 4, 7). (ii) The second technological component
342 comprises flakes produced by Discoid centripetal methods (Boëda, 1993; Mourre, 2003; Thiébaud,
343 2007). A single quartz prismatic core, from GFU 6, indicates a possible production of elongated
344 flakes (Supplementary Fig. 3, no. 2).

345 Lithic assemblages from GFU 5/UA38 to UA11 are also composed of well preserved, non-
346 patinated, fresh-edged lithic remains. However, both faces of most pieces present concretions, with

347 magnesium (Mg) on the upper face, and silicon (Si) on the lower. Varieties of the local milky,
348 translucent quartz, rhyolite, quartzite pebbles and regional rock crystal have been used (Fig. 7). The
349 lithic assemblage reveals two different methods of reduction. The most frequent corresponds to
350 pseudo-Levallois triangular and centripetal flakes, produced by Discoid centripetal unifacial to
351 polyhedral methods (Fig. 8). A few blanks were retouched into single, double or convergent side-
352 scrapers, notches and denticulates (Fig. 8, Supplementary Table 1). The second component, found
353 in fine-grained milky quartz between GFU 5/UA29 to UA24 and in rock crystal in GFU 5/UA16-18
354 corresponds to the production of small quadrangular flakes and possibly bladelets, on prismatic
355 cores (Supplementary Fig. 4). One flake produced by this reduction method has been truncated
356 (Supplementary Fig. 4, no. 5).

357 Lithic remains from GFU 5/UA10 to GFU 5/UA-1 show a radical change, in both
358 technology and raw material. This assemblage was made from regional and local quartz, quartzite
359 and rock crystal, as well as flint and silcrete from distant sources in Central Iberia (Northern
360 Meseta) and Central Portugal, found throughout the Upper Palaeolithic in the Côa Valley (Fig. 6,
361 Aubry et al., 2012b). GFU 5/UA10 to UA2 contain both blades, produced on prismatic unipolar
362 cores and prepared by a central cresting (Fig. 9, no. 19, 20, 21), and bladelets, produced on
363 carenated or burin type cores (Fig. 9, no. 1, 2, 6, 7, 8, 15, 16, 17). This lithic assemblage set is
364 defined by the use of a specific regional filonian brown jasper (Fig. 9, no. 15-21, Fig. 8), absent in
365 all the other stratigraphic units (although a single blade fragment, probably intrusive, has been
366 recovered in the GFU 5/UA14, Fig. 9, no. 20) and confirmed by the vertical distribution of the
367 refitting set (Fig. 7). None of the fragmented jasper blades was transformed into a tool. However,
368 some bladelets of this raw material exhibit the technological characteristics of burin and carinated
369 nose scraper core reduction strategy on blade fragment, the latter being absent from the assemblage
370 (Fig. 9, no. 15-17). Some flint and silcrete bladelets were transformed into Dufour bladelets of the
371 subtype Dufour (Fig. 9, no. 13), Font-Yves bladelets (Fig. 9, no. 12; Demars, Laurent, 1992) and a

372 Caminade endscraper (Fig. 9, no. 14, Sonnevile-Bordes and Mortureux, 1956).

373 The first 20 cm of GFU 5 (UA1 to UA4) have yielded retouched bladelets, micro-*gravette*
374 point fragments (Supplementary Fig. 5, no. 27) and several Noailles burins (Demars, Laurent,
375 1992), made from long-distant flint and silcrete sources and from regional rock crystal (Fig. 6,
376 Supplementary Fig. 5, no. 28, 29, 31).

377 Layer 4b is represented by a large circular-shaped structure of stone fragments, mostly
378 heated (Fig. 4), and associated with a lithic assemblage of micro-*gravette* points and retouched
379 bladelet fragments (Supplementary Fig. 5, no. 1-26). Flint and silcrete long-distant sources are also
380 represented (Aubry et al., 2012b). Bladelet reduction comprises prismatic, burin core and bipolar
381 strategies.

382

383 **Luminescence dating**

384 The eleven sediment samples dated by luminescence (172206 to 172215 and 172219, Table 1) were
385 collected in metal tubes from the cross-section A of the H'I-17/19 test area (Fig. 3), in the GFU 5,
386 under a large circular stone structure defining the layer 4b (Fig. 4). The GFU 6, 7 and 8 were not
387 sampled, because they were not exposed until excavation in 2018, after sampling in April 2017.

388 Initial quartz measurements showed that the OSL signals were not fast-component
389 dominated and that a significant number (ranging between ~15 and 100%) of sensitivity-corrected
390 natural OSL signals (L_n/T_n) appeared to be in saturation on the laboratory dose response curve.
391 When fitting the dose response curves with a saturating exponential function (of the form
392 $L_x/T_x = a[1 - \exp(-x/D_0)]$ where x is the laboratory dose, and a and D_0 are constants) the average D_0
393 value is 65 ± 2 Gy. Except for the youngest four samples (i.e. 172212-15) all quartz dose estimates
394 are considerably above $2 \times D_0$ and thus not likely to be accurate estimates of the burial dose; this is
395 particularly true for samples 172206-11,-19.

396 On the other hand, the signals from the K-rich feldspar extracts are well-behaved with an
397 average D_0 value of 392 ± 6 Gy ($n=91$, pIRIR(50,225)). All feldspar dose estimates are well below
398 $2 \times D_0$ and thus likely to be accurate estimates of the burial dose (at least from the perspective of
399 dose estimation). A pIRIR (50,225) dose recovery experiment on sample 172209, where the aliquots
400 were first bleached for 2 h in a solar simulator and subsequently given a beta dose of 300 Gy, gave a
401 satisfactory dose recovery ratio of 0.96 ± 0.03 ($n=6$, using a test dose of 300 Gy). A similar
402 experiment using the pIRIR(50,290) protocol gave an unsatisfactory dose recovery ratio of
403 0.78 ± 0.02 ($n=6$). Thus, based on the dose recovery results, the pIRIR(50,225) protocol is more likely
404 to give accurate dose estimates. Nonetheless, it is informative to investigate the dose correlations
405 between the doses measured for the different feldspar signals, bearing in mind the order of the
406 signals IR(50) > pIRIR(50,225) > pIRIR(50, 290), in terms of both anomalous fading and
407 bleachability (e.g. [Buylaert et al., 2012](#)). In Figure 10a, the equivalent doses measured for IR(50)
408 and pIRIR(50,290) are plotted against those from pIRIR(50,225), together with the linear
409 regressions of the data, $y=0.77x-0.7$ Gy and $y=1.11x+32$ Gy, where x is the pIRIR(50,225) dose,
410 and y is the IR(50) and pIRIR(50,290) dose, respectively. It is expected that the IR(50) doses will
411 fall below the 1:1 line and the pIRIR(50,290) doses above due to anomalous fading of both the
412 IR(50) and pIRIR(50,225) signals. The intercept of the IR(50) fit is consistent with zero, showing
413 that the pIRIR(50,225) signal is likely to be well-bleached ([Murray et al., 2012](#)). The pIRIR(50,290)
414 data has an intercept of ~ 30 Gy, implying that this signal has a small residual dose arising because
415 this signal is more difficult to bleach than the other two., and because of this these ages are not
416 considered further.

417 Standard fading rate measurements ([Auclair et al., 2003](#)) gave a g -value of 3.29 ± 0.15 and
418 1.30 ± 0.16 %/decade normalised to 2 days ($n=6$) for IR(50) and pIRIR(50,225), respectively.
419 Fading correction using these g -values increases the age estimates by ~ 36 and $\sim 12\%$, respectively.
420 The average ratio of the fading corrected IR(50) to pIRIR(50,225) ages is 0.92 ± 0.01 ($n=11$). Given

421 the smaller fading correction for the pIRIR(50,225) signal, we regard these ages as the most
422 reliable.

423 A synthesis of luminescence data obtained for the GFU 5 is presented in [Table 1](#). For the
424 younger ages the quartz and the corrected pIRIR(50,225) ages are consistent with each other; for
425 older ages quartz tends to underestimate, presumably because of saturation effects in quartz.
426 Although the larger quartz uncertainties limit the value of this comparison, this agreement also
427 suggests the pIRIR(50,225) signals were sufficiently bleached at the time of deposition (as also
428 supported by the proportional relationship between IR(50) and pIRIR(50,225) doses in [Fig. 10a](#)).

429 [Fig. 10b](#) shows the fading-corrected pIRIR(50,225) ages as a function of depth. Bayesian
430 age-depth modelling was performed using the Bacon code ([Blaauw, M. & Christen, 2001](#)) The
431 stratigraphic boundary between the Middle and Upper Paleolithic lithic technology was discussed
432 above as lying between 153 cm and 161 cm ([Fig. 4, 6](#)). Age-Depth modelling quantitatively
433 constrains the timing of this Middle to Upper Paleolithic transition to between 34.0 ± 1.4 ka (153
434 cm) and 38.4 ± 1.1 ka (161 cm, see [Fig. 10b](#); random uncertainties only). As is standard in
435 luminescence dating, the uncertainties in the ages are given at the 68% confidence interval. The
436 uncertainties derived from Bayesian modelling only include the random component; typical
437 systematic uncertainties are ~4% and so the age of the Middle-to-Upper Palaeolithic boundary
438 (including all known sources of uncertainty) lies between 34.0 ± 2.0 ka and 38.4 ± 1.9 ka.

439

440

441 **DISCUSSION**

442 **Sedimentary processes and depositional environments**

443 Facies analysis, coupled with grain-size and clay mineralogy results, allow the interpretation of
444 sedimentary processes and provide a better understanding of changes in depositional environment
445 of the Cardina-Salto do Boi stratigraphic succession; they can also explain some dating results.

446 The presence of several modes in clastic sediments from hydraulic continental environments
447 can reflect either multiple sedimentary sources or different transport mechanisms (Sun et al., 2002;
448 Liu et al., 2018; among others). This understanding helps in the interpretation of the results of
449 grain-size polymodal decomposition. The first (i), third (iii) and last (vi) grain-size components,
450 consisting of medium to fine silt, very fine sand, and clay, respectively, represent accumulation
451 from suspension load after fluvial sediment input. This, of course, depends on the available source
452 material and water-energy (Torres et al., 2005; Xiao et al., 2015). In contrast, the coarse particles
453 (from ~200 µm to 1000 µm) from the second (ii) and fourth (iv) grain-size components would
454 indicate a transport by traction-current from proximal sources (Sun et al., 2002). In addition, the
455 ultrafine particles from the fifth (v) grain-size component (<1 µm) can be related to chemical-
456 weathering and pedogenesis (e.g., Paton, 1978; Bronger and Heinkele, 1990).

457 The illite-dominated clay fraction is mainly of very high crystallinity and is Fe/Mg-rich; this
458 indicates relatively unaltered clay mineralogy, largely determined by the geology of the sourced
459 areas (Keller, 1970; Chamley, 1989). Here, this can be explained by the proximity to rapidly
460 eroding mica-rich Precambrian-Palaeozoic metasedimentary rocks.

461 The observed slight increase in the kaolinite/illite ratio with position upwards in the studied
462 stratigraphic succession may suggest an evolution with time towards relatively more humid
463 conditions, but still within a generally cold context. The presence of smectite (limited to the lower
464 part of the succession) is also compatible with climate with contrasting seasons (Singer, 1980, 1984;
465 Chamley, 1989) during the deposition of GFU 7 and 8.

466 In addition, the presence of some post-depositional overprinting of the clay minerals must be
467 also considered. This includes: (i) enrichment of vermiculite and the 10-14Å mixed-layer clays
468 close to present-day land surface (GFU 1 and 2), and in the upper levels containing the last Middle
469 Palaeolithic remains (in the GFU 5), presumably due to the deterioration of mica-type minerals
470 under low pH conditions, e.g. by pedogenetic processes (Singer, 1980; Chamley, 1989; Braga et al.,

2002; Pe-Piper et al., 2005); (ii) alteration of muscovite/biotite and/or feldspar to chlorite in the GFU 1 and 2, also linked to pedogenesis; (iii) meteoric water infiltration and flushing, during sub-aerial exposure of the sediments, with kaolinite increasing near erosive unconformities (with anthropogenic inputs and disturbances), as well as just below an inferred non-depositional unconformity (hiatus, with no evident erosion in the GFU 5) at the archaeologically attested Middle-Upper Palaeolithic transition (Fig. 5, 6). This is confirmed by the relatively higher content of the ultrafine grain-size fraction (Supplementary Fig. 1).

In summary, in terms of formation processes at the site, the Cardina-Salto do Boi sedimentary infill started with accumulation in a fluvial environment, between 5 m and 3.5 m below the present-day surface (GFU 8 to 6), under low energy diffusive water-flow conditions with the settling of suspended fine sediments dominant over bedload deposition (overbank sedimentation). This occurred relatively closer to the palaeo-channel, where the decrease in water-flow energy (dominated by low-water vertical accretion) is most rapid. In the 3.5 m to 1 m interval (GFU 5) vertical sedimentary accretion continues, now relatively more distant from the paleo-fluvial channel; this deposition is interrupted by environmental stabilization phases with no evident erosion. A new phase of overbank sedimentation then took place before an important erosive phase (d2) and anthropogenic accumulation of material (Fig. 5). The uppermost ~1 m of sedimentary thickness (GFU 1 to 4) reflects slope deposition, under the control of gravity-driven processes, accumulating with the concurrent action of water (though with some evidence of pedogenesis) and anthropogenic inputs/disturbances and redepositions.

Thus, the two local geoarchaeological complexes identified here are interpreted in terms of depositional environment, as follows (from bottom to top): (i) GCB = a relatively stable floodplain sequence with some nuisance flooding caused either by overbank floods or by rising groundwater levels, linked to generally continuous and low intensity meteoric precipitation initially under more temperate and humid climate (with some seasonality), that evolved to colder conditions; GCA = a

496 subsequent period of progressive increase in humid conditions and chemical-weathering attested by
497 the more superficial disturbed slope sequence (colluvium), driven by gravity processes and shallow
498 surface waters flow.

499 Lithic remains refit links show a vertical distribution pattern over distances < 20cm in GFU
500 5 to 7 (Fig. 6) that should result from reworking related to the rapid decrease in water-flow energy
501 at the end of the alluvial floodplain process of sedimentation. The 3D distribution and orientation of
502 refitting links pieces indicate that lithic remains were affected by low magnitude post depositional
503 non-anthropic alluvial displacement in conformity with an accumulation in a fluvial environment
504 under low energy diffuse water-flow conditions (Fig. 7).

505

506 **Cultural attribution of lithic assemblages**

507 Technological study of Middle Palaeolithic lithic assemblages of Portugal and the Iberian inland is
508 incipient and well-dated archaeostratigraphic sequences giving information on the techno-cultural
509 evolution patterns of Neanderthal technology are sparse (Raposo, 1995; Zilhão, 2001; Cardoso,
510 2006; Zilhão et al., 2011). The Gruta da Oliveira (Fig. 1) archaeostratigraphical succession, dated by
511 U/Th, has been studied using a taphonomical/technical approach. The study shows a shift, during
512 late MIS 5 or early MIS 4, from the centripetal Levallois reduction, associated with rare bifaces and
513 flake-cleavers to Discoid and Kombewa debitage (Deschamps and Zilhão, 2018). Despite the small
514 area excavated, the lithic assemblages of GFU 8 to 6 at the Cardina-Salto do Boi site have
515 characteristics in common with layers 15 to 27 of the Gruta da Oliveira archaeostratigraphy.

516 Discoid reduction methods found throughout GFU 5/UA38 to UA11 are widespread in
517 Iberian Middle Palaeolithic assemblages dated to MIS 5 and MIS 4 (Deschamps and Zilhão, 2018).
518 Despite some variation along the GFU 5 stratigraphy of Cardina-Salto do Boi, and possible
519 production of small flakes and bladelets, the selection of local raw-materials and the technology
520 used to produce flakes are similar, with no indication of the bidirectional blade reduction sequence

521 or bifacial technology that characterize the Middle-to-Upper transitional lithic assemblages.

522 The GFU 5/UA10 to UA1 lithic assemblages are distinct and can be assigned by their
523 typology and technology to the Upper Palaeolithic. Different lithic assemblages can be defined
524 based on raw materials, reduction strategies and tool-types. The lithic assemblage recovered from
525 GFU 5/UA10, defined by the use of brown jasper (Fig. 8), comprises blade debitage, several
526 examples of the Roc-de-Combe subtype Dufour and Font-Yves bladelets and a Caminade
527 endscraper. These are typical index fossils of the Evolved Aurignacian (Rigaud, 1982; Demars,
528 Laurent, 1992; Morala et al., 2005; Michel 2010). In Portugal, the lithic assemblages from a cluster
529 of open-air sites in the Rio Maior basin and the Lower Mondego valley, and caves in the Alentejo
530 and Estremadura regions, exhibit a blade debitage on prismatic unipolar core, prepared by cresting
531 and bladelets produced on carinated or burin cores. These assemblages have previously been
532 assigned to the Final or Evolved Aurignacian (Zilhão, 1997; 2006b; Aubry et al., 2006). The end of
533 the Aurignacian in southern France has been dated by radiocarbon to approximately 32,000 cal yr BP
534 (Michel, 2010; Higham et al., 2011; Rigaud et al., 2016), and the Brignol (Lot-et-Garonne, France)
535 open-air occupation, yielding Caminade endscrapers and Roc-de-Combe Dufour bladelets, has been
536 dated by OSL to 33-34 ka (Anderson et al., 2016).

537 The Noailles burins of the top of GFU 5 is a diagnostic stone-tool type only known in the
538 Early and Middle Gravettian contexts of France, Northern Spain and Italy. Gravettian occupation
539 with Noailles burins have provided ¹⁴C ages covering a wide period between 28,000 and 32,000 cal
540 yr BP (Klaric, 2007; Peña Alonso, 2010; Foucher et al., 2011; Rigaud et al., 2016).

541

542 **New data for the timing of the Middle-to-Upper Palaeolithic transition in Iberia**

543 Different models have been proposed for the timing and nature of the Middle-to-Upper Palaeolithic
544 transition in Iberia, based on radiometric dating of archaeological layers and lithic assemblage
545 technology. The reevaluation of the stratigraphical contexts and the application of new dating

546 procedures have led some authors to consider that Neanderthal populations did not survive much
547 longer in the Iberian Peninsula than in the rest of Europe (Maroto et al., 2012; Wood et al., 2013;
548 Higham, et al., 2014; Alcaraz-Castano et al., 2017). Based on luminescence dating of loess deposits
549 from the Upper Tagus Basin, it has been suggested that the abandonment of the interior of Iberia by
550 Neanderthals occurred 42 ka ago, and that, as a direct consequence of a pronounced environmental
551 aridity, inner territories were uninhabited until 28 or 25.5 ka. In this model, any persistence of
552 Neanderthals until 37 ka was restricted to coastal areas (Wolf et al., 2018). Others have accepted a
553 late survival of Neanderthals in Iberia and proposed possible isolation and survival of residual
554 Neanderthal groups more recently than 30 ka in ecological refuge zones in marginal mountain areas
555 of the Cantabrian region (Baena et al., 2018) or in the south-western Iberian Peninsula (Finlayson et
556 al., 2008; Jennings et al., 2011).

557 After the recent revisions of Middle-to-Upper Palaeolithic sites, improvements in pre-
558 treatment used for samples dated by ^{14}C or by other dating methods, and the discovery of new sites,
559 few Middle Palaeolithic occupation sites have provided unquestionable ages younger than 40 ka
560 and little reliable evidence for such young existence of Aurignacian lithic technology in southern
561 Iberia.

562 At the Cova de les Cendres site near Alicante (Fig. 1), level XVI, corresponding to the lower
563 part of the Early Upper Palaeolithic sequence, has been assigned to the Evolved Aurignacian
564 (Villaverde et al., 2019), based on the lithic assemblage and a radiocarbon date of 35,379-34614 cal
565 yr BP (31.080 $\pm$ 170 Cal yr BP [Beta-458,3469]) (2 σ) using the IntCal13 calibration curve (Reimer et
566 al., 2013).

567 Archeostratigraphy, radiocarbon and luminescence dating at Cueva Antón, located in the
568 Mula basin of Murcia (Fig. 1, south-eastern Spain (Zilhão et al., 2016), have shown that the
569 Mousterian layer I-k cannot be older than 37,100 cal yr BP and at the nearby rock-shelter at La
570 Boja, the basal Aurignacian cannot be younger than 36,500 cal yr BP (Zilhão et al., 2017).

571 In Portugal, one bovid and two horse tooth enamel samples have been used to date the
572 Middle Palaeolithic occupation at the open-air site of Foz do Enxarrique to 33.6 ± 0.5 ka by U-
573 series (Fig. 1, Raposo, 1995), and the alluvial deposit containing the faunal remains and lithic
574 assemblage provided an age of 38.5 ± 1.6 ka, using fading-corrected IRSL (Cunha et al., 2008).
575 However, using the pIRIR dating protocol applied at Cardina-Salto do Boi, the same archaeological
576 level provided dates of 44 ± 3 ka, 43 ± 4 ka and 37 ± 2 ka. The U-series and conventional IRSL
577 ages are now considered as underestimates, when compared to pIRIR ages (Cunha et al., 2019) and
578 do not provide reliable evidence of Neanderthal persistence after 40 ka.

579 The existence of Aurignacian occupation in South-western Iberia has been debated (Zilhão,
580 1997; Straus et al., 2000; Zilhão and Trinkaus, 2002; Trinkaus et al., 2007; Zilhão et al., 2010; Peña
581 Alonso and Vega Toscano, 2013; Bicho et al., 2017). Recently, the Bj-13-12 layer lithic assemblage
582 of the Bajondillo Cave (Fig. 1) has been attributed to the Early Aurignacian or Proto-Aurignacian,
583 based on the presence of blades and bladelet cores and the 43-41 cal yr BP dates (Cortés-Sánchez et
584 al., 2019). However, the lead author has previously considered the same assemblage as minimal and
585 impracticable for a reliable techno-typological analysis (Cortés Sánchez, 2007, p.141-142), it
586 cannot be clearly attributed to the Proto-Aurignacian or Early Aurignacian, and rather than assign it
587 to chrono-cultural phase it would be wiser to consider it a mixed assemblage (Peña Alonso, 2019;
588 Anderson et al., 2019). Nevertheless, at Cardina-Salto do Boi, lithic assemblages, stratigraphy and
589 dating indicate that other reduction strategies than Discoid or Levallois flake production are already
590 present from 80 to 50 ka cal BP, attesting to reduction scheme diversity at early stages
591 (Supplementary Fig. 4).

592 Several hypotheses based on ecological factors have been put forward to explain the
593 apparent late survival of Neanderthal populations in the southern and western regions of the Iberian
594 Peninsula (Finlayson et al., 2004; 2006, D'Errico and Sanchez Goñi, 2004; Zilhão, 2006a; Jiménez-
595 Espejo et al. 2013; Zilhão et al., 2017, Carrión et al., 2019). The first of these hypotheses suggests

596 that AMH populations bearing an Aurignacian technology may not have expanded south of the Ebro
597 River during Interstadial 9, which occurred just prior to Heinrich Event 4 (H4, 39 ka). Based on the
598 ages obtained in the Mula region, the spread of the Evolved Aurignacian into Southern and Western
599 Iberia and the replacement of Iberian late-persisting Mousterian (~36.5-37.1 ka) has been
600 interpreted as a response to the global climatic transition from Greenland Interstadial 8 to Greenland
601 Stadial 8 (Rasmussen et al., 2014; Zilhão et al. 2017). This lack of expansion to the south may have
602 been because these regions were significantly more wooded and thus less favourable, since the large
603 mammals on which their subsistence systems were focused preferred open landscapes (Sepulchre et
604 al., 2007).

605 The Greenland Interstadial 8, which followed Heinrich Stadial (HS) 4, lasted from ~ 38.2 to
606 ~36.6 ka (Wolff et al., 2010). This period is associated with a strongly expressed vegetation gradient
607 which developed ~40° N, with temperate (deciduous oaks) and warm-temperate (Mediterranean
608 taxa) elements undergoing a very significant expansion to the south (Fletcher et al., 2010). The
609 persistence of the frontier effect over several millennia has been explained by extreme aridity in the
610 northern slopes of the Iberian Range during HS 4 and because of temperate forest expansion in its
611 southern slopes during the interstadials that bracket it (Daura et al., 2012).

612 The new data obtained at Cardina-Salto do Boi in Northeastern Portugal, at the eastern limit
613 of the northern Meseta, show clearly that the absence of evidence can not be interpreted as evidence
614 of absence. The lithic assemblages defined, refitting set links (Fig. 6), sedimentological data (Fig. 5)
615 indicate that the transition between Discoid reduction method technology and blade and bladelet
616 production using non-local flint and silcrete sources can be placed between the GFU 5/UA12 and
617 GFU 5/UA10. The blade fragment in fine-grained jasper found in GFU 5/UA 14 (Fig. 9, no. 20) is
618 the unique piece made of non local source recovered under the GFU 5/UA 12 (Fig. 6).

619 The ages obtained for the samples 17208 (43.9 ± 2.1) and 17209 (42.9 ± 1.9) confirm the
620 persistence of Middle Palaeolithic discoidal reduction strategy during the temporal range of the

621 Chatelperronian technocomplexe attested in France and Northern Spain ([Higham et al., 2014](#),
622 [Marín-Arroyo et al., 2018](#)). Considering that AMH associated with Early Aurignacian technology is
623 established in northern Iberia from around 42,000 cal yr BP ([Wood et al., 2014](#)) the age obtained for
624 the sample 17210 and lithic assemblage raw material and reduction strategies support the
625 coexistence model and that Neanderthal and AMH overlapped in geographical areas at north and
626 west of the Iberian Plateau ([Fig. 1](#)).

627 The boundary between the Middle and Upper Paleolithic has been identified as lying
628 between 153 cm and 161 cm ([Fig. 4, 6](#)). From the Age-Depth modelling of the luminescence dates,
629 the age of the Middle-to-Upper Palaeolithic boundary lies between 34.0 ± 2.0 ka and 38.4 ± 1.9 ka.

630 Moreover, the reconstruction of the sedimentary processes and related palaeoenvironmental
631 conditions show that like in cave and rockshelter Iberian sites ([Aubry et al., 2011](#); [Mallol et al.,](#)
632 [2012](#)) the Middle-to-Upper technological transition occurred during a stratigraphic disconformity
633 ([Fig. 5, supplementary Fig. 1, 2](#)) preventing a precise characterization of the Neanderthal or AMH
634 occupations that could have occurred during this hiatus and hampering evaluations of the continuity
635 or discontinuity of human occupation.

636 The Upper Palaeolithic technology, constrained by the distribution of 28 pieces of regional
637 filonian fine-grained jasper ([Fig. 7, 9](#)) that yielded a lithic remains assemblage featuring diagnostic
638 Evolved Aurignacian blade, carenated core reduction strategies and stone-tools ([Fig. 9](#)) is dated
639 from 33.6 ± 2 ka (172211, GFU 5/UA10). Lithic assemblage attribution to the Aurignacian is
640 supported by the Bayesian radiocarbon age model obtained for the end of the Aurignacian in the
641 Cantabrian region ([Marín-Arroyo et al., 2018](#)) and for the Abri Pataud sequence in southern France
642 ([Higham et al., 2011](#)).

643 The age obtained for the sample 172212 (31.5 ± 1.6 ka) could be related to the Middle
644 Gravettian occupation associated with the Noailles burins from the top of GFU 5 in agreement with
645 radiocarbon ages obtained for Middle Gravettian contexts ([Klaric, 2007](#); [Peña Alonso, 2010](#)). The

ages from the samples 172213 to 172215 (28.7 ± 1.6 , 25.6 ± 1.4 , 27.5 ± 2.5 , [Table 1](#), [Fig. 10](#)), are statistically indistinguishable from the results obtained by TL for the base of GFU 4 (27.8 ± 1.5 , 28 ± 2.1 , 27 ± 1.8 , 26.5 ± 1.8 , 30.1 ± 1.5 ka) in the area excavated between 1995 and 2001 ([Fig. 3](#), [Valladas et al., 2001](#)). The ages indicate an Upper or Late Gravettian chronology, probably related to a pit detected all around the excavated portion of the large circular stone structure (and corresponding to the layer 4b, [Fig. 4](#)).

652

653

654 CONCLUSION

655 The results obtained at Cardina-Salto do Boi since 1995 show that, in contrast to the largely
656 accepted model for the Upper Pleistocene settlement of Iberia, the Côa Valley and the eastern limit
657 of northern Meseta were occupied throughout the Middle and Upper Palaeolithic.

658 The Cardina-Salto do Boi archaeostratigraphy and OSL dating indicate that a Neanderthal-
659 associated Middle Palaeolithic culture live in the Côa valley through the MIS 4 and 3. The OSL
660 ages obtained for the samples 17208 and 17209 (43.9 ± 2.1 , 42.9 ± 1.9 ka) confirm the persistence
661 of Middle Palaeolithic technology in Central Iberia during the development of ‘transitional’
662 industries in Northern Spain, France and Italy. The lithic assemblage and the luminescence age
663 obtained for the sample 172210 (39.5 ± 1.8 ka) provides new evidence of the persistence of
664 Neanderthal-associated Middle Palaeolithic material culture in some regions of Iberia after they
665 were replaced by AMH in the rest of Europe.

666 Correlatively, the Late Aurignacian affinities of the lithic assemblage recovered under GFU
667 5/UA10 and the OSL age obtained for sample 172211 (33.6 ± 2 ka) provide new evidence
668 contradicting the hypothesis that AMH dispersal in southern and central Iberia only occurred during
669 the Gravettian.

670 Interpretation of the evolution of the depositional environment and luminescence ages reveal
671 that the Middle-to-Upper stone-tool technology change coincides with a minor non-depositional

672 unconformity (hiatus, with no evident erosion). Further work is needed to establish if this
673 disconformity of several millenia could be related to drastic change in climatic conditions attested
674 in Atlantic marine record and to characterized and establish the precise chronology of human
675 occupation during the sedimentary hiatus.

676 Even 25 years after the identification of the significance of the Côa Valley it is still
677 necessary to emphasise that the Iberian inland was not a human void during the Middle and Upper
678 Palaeolithic, and that the several colonizations, either earlier or later, were not confined to the
679 coastline. Cardina-Salto do Boi proves that it is possible to find, in the Iberian inland, a well
680 preserved and significant open-air sequence of datable deposits recording the Middle-to-Upper
681 transition.

682 Our results confirm that additional dating methods and the development of surveys focusing
683 on different geomorphological settings can be used to overcome the current evidential limitations of
684 cave and rockshelter record and to establish more consistent models for the timing of Neanderthal
685 disappearance and AMH expansion in the different regions of Iberian Peninsula.

686

687

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697

698 **AUTHOR CONTRIBUTIONS**

699 A.T. and D.L. conceived the research; A.T. designed the research; A.T., B.A.F., L.L., S.A.T., S.M.
700 performed the archaeological fieldwork; A.T., L.L. and S.A.T performed and interpreted
701 archaeological data; D.L. performed the facies analysis and interpreted all the sedimentological
702 field/laboratory data (including grain-size, and XRD data with the technical help of Mr. Carlos
703 Maia); K.T., E.R., M.A. and A.S.M. conducted the OSL analysis. A.T. and D.L. wrote the paper;
704 and all the authors reviewed and edited the manuscript. Furthermore, all the authors have read and
705 approved the manuscript, declaring no conflict of interest.

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Figure and table captions

Table 1. Summary of OSL data for the Cardina-Salto do Boi reference section. Q is quartz and KF is K-rich feldspar extracts. De is the equivalent dose estimate, n_x and N_x is the number of accepted and measured aliquots, respectively. De KF has been derived from pIRIR(50,225) measurements. The fading corrected KF ages (Age KFcorr) has been derived by correction for fading (measured to be 1.30 ± 0.15 %/decade, Auclair et al., 2003) and these ages are expected to be the most accurate estimates of burial ages for these samples.

Figure 1. Location of Middle Palaeolithic and Aurignacian sites in the Iberian Peninsula, and sites mentioned in the text.

Figure 2. Location map of the Palaeolithic sites in the Côa valley.

Figure 3. Topographic map and photography of the Cardina site (from southwest). Excavated area at the end of the 2018 field season and location of the cross-section A in the excavation grid.

Figure 4. Stratigraphic sequence, field units and samples location in the reference cross-section A.

Figure 5. Cardina-Salto do Boi synthetic log showing the studied stratigraphic succession, including the location of the sampled siliciclastic sediments, the chronometric data, the grain-size and clay mineralogy results, the inferred sedimentary processes and the respective depositional environment interpretations.

Figure 6. Stratigraphical position of the radiometric luminescence data, Artificial Units by Geoarchaeological Field Unit (GFU), raw material proportions of knapped lithic remains and vertical distribution of the refitting sets.

Figure 7. 3D plot of the all lithic remains over 5 cm in the layer 4b (grey dots) and in the GFU 5 (red dots) and refitting links of knapped and heated fracture lithic remains (lines). In GFU 6 (orange dots) and GFU 7 (yellow dots), only refitted material is presented. Jasper lithics in GFU 5

1096 are represented in blue and dating samples in black.

1097 **Figure 8.** Lithic industries from the GFU 5/UA38 to UA10 and stratigraphical position.

1098 **Figure 9.** Lithic industries from the GFU 5/UA14 (no. 20), UA10 (no. 19), UA8 (no. 3), UA7 (no.
1099 18), UA6 (no. 1, 12, 17, 21), UA5 (no. 7, 14, 15, 16), UA4 (no. 4, 5, 6, 9, 10, 11), UA3 (no. 8, 13),
1100 UA2 (no. 2). Bladelets produced on carenated or burin type cores (no.1, 2, 6, 7, 8, 15, 16, 17),
1101 retouched bladelets (no. 3, 4, 5, 9, 10, 11, 18) and Dufour bladelets of the subtype Dufour (no. 13),
1102 Font-Yves bladelets (no. 12), Caminade endscraper (no. 14.) and blades fragments (no. 19, 20, 21).

1103 **Figure 10.** a) K-feldspar doses: IR(50) (squares) and pIRIR(50,290) (circles) as a function of
1104 pIRIR(50,225) doses. Also shown are the linear fits to the data. b) Fading corrected pIRIR(50,225)
1105 ages. A g-value of 1.30 ± 0.16 %/decade (n=6) were used to correct for fading. The uncertainties
1106 quoted on these ages are at 68%. Also shown is Age-Depth Modelling using Bayesian Statistics
1107 (Bacon script; [Blaauw, M. & Christen, 2001](#)). The dotted lines represent the 68% confidence
1108 interval. Also shown (red dashed lines) is the transition from the Middle to the Upper Paleolithic
1109 occurring in the depth range between 153 cm ($34.0 - \pm 1.4$ ka) and 161 cm (38.4 ± 1.1 ka)

Table 1

Sample	Depth (cm)	w.c. (%)	Dose rate Q (Gy/ka)	D _e Q (Gy)	n _Q	N _Q
172219	270	0	4.90 ± 0.24	-	0	6
172206	193	4	4.96 ± 0.26	172 ± 21	4	6
172207	190	4	4.37 ± 0.22	161 ± 27	3	6
172208	179	4	4.91 ± 0.23	177 ± 15	5	6
172209	170	4	4.65 ± 0.22	171 ± 23	6	6
172210	161	2	4.82 ± 0.25	189 ± 40	5	6
172211	153	3	4.80 ± 0.25	217 ± 33	6	6
172212	145	3	4.85 ± 0.24	129 ± 10	5	6
172213	136	2	4.64 ± 0.23	136 ± 27	6	6
172214	130	1	4.75 ± 0.23	143 ± 11	6	6
172215	118	2	4.91 ± 0.24	134 ± 24	6	6

Dose rate KF (Gy/ka)	D _e KF (Gy)	n _{KF}	N _{KF}	Age Q (ka)	Age KF _{uncorr} (ka)	Age KF _{corr} (ka)
5.83 ± 0.25	417 ± 7	8	8	-	71.4 ± 3.2	80.3 ± 3.6
5.89 ± 0.27	267 ± 4	8	8	35 ± 5	45.4 ± 2.1	51.0 ± 2.4
5.30 ± 0.23	235 ± 7	6	6	37 ± 6	44.4 ± 2.4	49.9 ± 2.7
5.85 ± 0.24	229 ± 6	8	8	36 ± 3	39.1 ± 1.9	43.9 ± 2.1
5.59 ± 0.23	214 ± 3	18	18	37 ± 5	38.2 ± 1.6	42.9 ± 1.9
5.76 ± 0.25	203 ± 2	7	8	39 ± 8	35.2 ± 1.6	39.5 ± 1.8
5.74 ± 0.26	172 ± 7	6	6	45 ± 7	29.9 ± 1.8	33.6 ± 2.0
5.79 ± 0.24	163 ± 5	7	8	27 ± 3	28.1 ± 1.5	31.5 ± 1.6
5.58 ± 0.24	143 ± 5	6	6	29 ± 6	25.6 ± 1.5	28.7 ± 1.6
5.69 ± 0.24	130 ± 5	11	11	30 ± 3	22.8 ± 1.3	25.6 ± 1.4
5.84 ± 0.25	143 ± 11	6	6	27 ± 5	24.5 ± 2.2	27.5 ± 2.5

Figure 1

[Click here to access/download;Figure;Fig. 1.jpg](#)

Figure 2

[Click here to access/download;Figure;Fig. 2.tif](#)

- ☐ First excavated before 2014
- ☒ First excavated after 2014

Approximate photo viewpoint location

Figure 4

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Figure 5

[Click here to access/download;Figure;Fig. 5 def.tif](#)

Figure 6

Figure 7

Figure 8

Figure 9

Supplementary Material

Timing of Middle-to-Upper transition in Iberian inland (Cardina-Salto do Boi, Ca Valley, Portugal)

Thierry AUBRY, Luca Antonio DIMUCCIO, Antnio Fernando BARBOSA, Lus LUS, Andr Toms SANTOS, Marcelo SILVESTRE, Kristina Jrkov THOMSEN, Eike RADES, Martin AUTZEN, Andrew Sean MURRAY

Supplementary Figure 1. Representative grain-size frequency-distribution curves of the sampled siliciclastic sediments from the Cardina-Salto do Boi stratigraphic succession. The location of the samples is shown in Fig. 4 and 5.

Timing of Middle-to-Upper transition in Iberian inland (Cardina-Salto do Boi, Côa Valley, Portugal)

Thierry AUBRY, Luca Antonio DIMUCCIO, António Fernando BARBOSA, Luís LUÍS, André Tomás SANTOS, Marcelo SILVESTRE, Kristina Jørgkov THOMSEN, Eike RADES, Martin AUTZEN, Andrew Sean MURRAY

Supplementary Figure 3. Lithic industries from the GFU 6 (no. 1, 2) and GFU 7 (no. 3-8).

Timing of Middle-to-Upper transition in Iberian inland (Cardina-Salto do Boi, Côa Valley, Portugal)

Thierry AUBRY, Luca Antonio DIMUCCIO, António Fernando BARBOSA, Luís LUÍS, André Tomás SANTOS, Marcelo SILVESTRE, Kristina Jørkov THOMSEN, Eike RADES, Martin AUTZEN, Andrew Sean MURRAY

Supplementary Figure 4. Quadrangular flakes, truncated bladelet and bladelets produced on prismatic cores from GFU 5/UA24 (no. 2, 3), UA25 (no. 6, 8, 12), UA26 (no. 4, 7), UA28 (no. 1) UA30 (no. 5), UA18 (no. 9) and UA16 (no. 10, 11).

Timing of Middle-to-Upper transition in Iberian inland (Cardina-Salto do Boi, Côa Valley, Portugal)

Thierry AUBRY, Luca Antonio DIMUCCIO, António Fernando BARBOSA, Luís LUÍS, André Tomás SANTOS, Marcelo SILVESTRE, Kristina Jørgov THOMSEN, Eike RADES, Martin AUTZEN, Andrew Sean MURRAY

Supplementary Figure 5. Lithic industries from the layer 4b (no. 1-26) and GFU 5/UA4 to UA1 (no. 27-31).

Timing of Middle-to-Upper transition in Iberian inland (Cardina-Salto do Boi, Côa Valley, Portugal)

Thierry AUBRY, Luca Antonio DIMUCCIO, António Fernando BARBOSA, Luís LUÍS, André Tomás SANTOS, Marcelo SILVESTRE, Kristina Jørkov THOMSEN, Eike RADES, Martin AUTZEN, Andrew Sean MURRAY

H/I'-17/19	Tools	Cores	Rock fragment	Pebbles	Flakes	Siret flake	Blanks Blade	Bladelet	Burin bladelet	Chips	Heated fracture	Total
1	-	-	-	-	1	-	-	-	-	-	-	1
2	-	-	2	-	14	-	-	-	-	6	7	29
3	10	13	11	2	395	-	2	5	-	225	185	848
4_1	4	19	9	-	283	-	1	4	-	312	220	852
4_2	14	19	16	2	494	-	2	10	-	352	387	1 296
4_3	13	18	16	-	493	-	2	20	-	487	328	1 377
4_4	12	13	13	-	571	-	1	18	-	517	256	1 401
4_5	10	13	8	-	309	-	3	15	-	346	146	850
4_6	2	3	1	-	101	-	-	6	-	123	25	261
4B_1	23	18	8	7	353	68	2	23	1	483	300	1 286
4B_2	16	25	3	10	322	101	7	44	-	572	304	1 404
4B_3	20	24	3	9	345	101	3	52	-	763	167	1 487
4B_4	6	8	-	2	150	33	3	22	-	495	61	780
4B_5	-	4	-	-	36	-	-	7	-	70	2	119
5_01	6	2	2	1	68	17	-	19	-	327	34	476
5_02	11	9	1	2	173	40	-	34	-	766	71	1 107
5_03	14	10	-	4	152	33	2	40	2	720	51	1 028
5_04	8	9	1	1	112	16	-	33	1	547	68	796
5_05	6	5	-	-	79	23	1	32	-	438	62	646
5_06	10	4	1	1	68	17	-	19	1	377	47	545
5_07	2	3	-	-	75	12	-	10	-	328	45	475
5_08	3	1	-	-	56	7	-	7	1	282	30	387
5_09	3	1	-	-	81	13	-	6	-	282	21	407
5_10	3	1	-	-	82	22	1	5	-	225	13	352
5_11	3	1	-	-	75	10	-	1	-	258	50	398
5_12	3	2	1	-	112	28	2	6	-	511	120	785
5_13	2	1	-	-	40	9	-	6	-	113	40	211
5_14	-	-	-	-	47	5	1	1	-	213	28	295
5_15	2	-	-	-	41	3	-	1	-	168	68	283
5_16	4	1	1	-	69	12	-	-	-	177	107	371
5_17	2	1	1	-	49	5	-	-	-	181	86	325
5_18	1	2	1	-	72	8	-	1	-	233	103	421
5_19	2	1	-	-	95	11	-	2	-	174	92	377
5_20	-	2	4	-	71	10	-	-	-	180	62	329
5_21	4	2	3	-	55	3	-	-	-	126	57	250
5_22	1	2	-	-	52	14	-	1	-	276	35	381
5_23	2	2	1	1	75	10	-	1	-	145	15	252

Timing of Middle-to-Upper transition in Iberian inland (Cardina-Salto do Boi, Côa Valley, Portugal)

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H'/I'-17/19	Tools	Cores	Rock fragment	Pebbles	Flakes	Siret flake	Blanks Blade	Bladelet	Burin bladelet	Chips	Heated fracture	Total
5_24	-	1	1	1	73	15	-	4	-	238	32	365
5_25	7	4	-	-	72	18	-	8	-	208	29	346
5_26	-	1	-	1	69	17	-	5	-	273	26	392
5_27	2	1	1	-	46	16	-	4	-	259	14	343
5_28	1	3	-	-	53	17	-	5	-	192	18	289
5_29	2	-	-	-	42	16	-	3	-	199	7	269
5_30	1	1	-	-	36	10	-	3	-	192	21	264
5_31	1	1	-	-	28	3	-	3	-	150	8	194
5_32	-	1	-	-	27	6	-	-	-	125	7	166
5_33	-	-	-	-	22	6	-	1	-	93	-	122
5_34	-	-	-	-	9	7	-	1	-	95	1	113
5_35	-	1	-	1	19	2	-	-	-	73	-	96
5_36	-	-	-	-	17	2	-	-	-	44	3	66
5_37	-	1	1	1	12	4	-	-	-	50	2	71
5_38	-	-	-	-	9	2	-	-	-	29	5	45
6_01	-	-	-	-	3	1	-	-	-	-	1	5
6_02	-	1	-	-	-	-	-	-	-	-	1	2
6_05	-	-	1	-	2	-	-	-	-	-	-	3
6_06	-	-	-	-	1	1	-	-	-	-	-	2
7_01	-	-	-	-	1	-	-	-	-	-	-	1
7_02	2	-	-	-	1	1	-	-	-	-	-	4
7_03	-	-	-	1	8	1	-	-	-	-	1	11
7_04	-	-	-	-	7	1	-	-	-	-	-	8
7_05	1	-	3	-	13	1	-	-	-	-	-	18
7_06	3	-	-	-	8	-	-	-	-	-	-	11
7_07	-	-	1	-	6	-	-	-	-	-	-	7
7_08	-	1	-	-	5	2	-	-	-	-	-	8
7_09	1	-	1	-	2	-	-	-	-	-	-	4
7_10	1	-	-	-	3	-	-	-	-	-	-	4
7_11	-	-	-	-	5	-	-	-	-	-	-	5
TOTAL	244	256	116	47	6 265	780	33	488	6	14 018	3 869	26 122

Supplementary Table 1. Techno-typology composition of the lithic industries from Geoarchaeological Field Unit (GFU) 8 to 4 of the H'/I'-17/19 squares.