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1 Original Article - Stratigraphy, Sedimentology

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3 **A cryptotephra from the Upper Pleistocene volcanism of the Bas-Vivarais in the**
4 **sedimentary infilling of the Chauvet-Pont d'Arc cave (Ardèche, France)**

5

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34

35 **Abstract**

36
37 A cryptotephra belonging to the Upper Pleistocene volcanism of the Bas-Vivarais was
38 identified for the first time in the sedimentary infilling of the entrance area of the Chauvet-Pont
39 d’Arc cave. This slightly reworked tephra fall is characterized by its heavy minerals
40 assemblage, among which magnesian olivine, enstatite, and chromian diopside issued from
41 peridotites and olivine and diopside of basaltic origin. This composition likely refers to a
42 phreatomagmatic eruption of a maar-crater. The ^{14}C datings of the cryptotephra beds are
43 contemporaneous with the Aurignacian settlement and paintings, that is, an age slightly older
44 or close to 36 ka. Among the maar-craters from the Bas-Vivarais, the Ray-Pic maar have the
45 closest $^{40}\text{Ar}/^{39}\text{Ar}$ age ($36.2 \pm 11.3 / 32.2 \pm 11.1$ ka). By contrast, the Vestide-du-Pal, the biggest
46 maar-crater of this country, seems to have a younger age, but the $^{40}\text{Ar}/^{39}\text{Ar}$ dating was measured
47 on a basalt which could have occurred later and been the source of the tephra-fall, since its
48 tephra contain the same minerals of unknown origin as those found in Chauvet Cave. This
49 discovery strengthens the previous hypothesis according to which the humans living in the
50 Chauvet-Pont d’Arc area during the Upper Paleolithic have witnessed eruptions from the Bas-
51 Vivarais volcanic field and other phenomena.

52
53 Keywords. Chauvet-Pont d’Arc cave, Cryptotephra, Phreatomagmatism, Bas-Vivarais
54 volcanism, Upper Pleistocene.

55
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57 58 **1. Introduction**

59
60 The Chauvet-Pont d’Arc cave is situated in France in the Ardèche valley near Vallon-Pont-
61 d’Arc ($44^{\circ} 23' 14''$ N, $4^{\circ} 25' 07''$ E, Figure 1A, B, D). Discovered in 1994, it is universally
62 known for the richness and the age of its Paleolithic paintings (Clottes, 2001; Clottes and
63 Geneste, 2007, Delannoy and Geneste, 2020). The ^{14}C datings of charcoal and paintings
64 indicate two periods of occupation attributed to the Aurignacian and to the Gravettian (from
65 37.5 to 33.5 ka cal BP and from 31 to 28 ka cal BP; Clottes et al., 1995; Cuzange et al., 2007;
66 Quiles et al., 2016; Valladas et al., 2005). These dates coincide with one of the activity phases
67 of the Bas-Vivarais volcanism. Several recent $^{40}\text{Ar}/^{39}\text{Ar}$ datings have actually dated these
68 eruptions between 29 ± 10 ka and 35 ± 8 ka (95% probability uncertainty Nomade et al., 2016,
69 Sasco, 2015, Sasco et al., 2017). These dates fully cover the ^{14}C AMS datings (Quiles et al.,

70 2016) and the thermoluminescence (TL) datings (Guibert et al., 2015) which correspond to the
71 human settlements responsible for numerous parietal representations in the cave. Among them,
72 spray-shape signs (Figure 1C) were hypothetically ascribed to depiction of strombolian
73 volcanic eruptions (Nomade et al., 2016).

74 In the context of the pluridisciplinary study of the cave financed by the French Culture Ministry
75 the analysis of the heavy minerals of the sediments was undertaken. This study led to the
76 discovery of volcanic minerals attributed to a cryptotephra subcontemporaneous with the
77 sedimentary infilling of the entrance area of the cave. These results, presented here, corroborate
78 the contemporaneity of the recent volcanism of the Bas-Vivarais with the history of the cave
79 during a period close to its occupation by Aurignacians.

80

81 **2. Stratigraphical and sedimentological context**

82 The volcanic minerals were identified in the sediments of a limited archeological pit located at
83 about twenty meters from the old entrances which are now filled by deposits related to several
84 processes (Figure 2). Four phases were distinguished in the clogging of the entrance (Debard
85 et al., 2016):

86 - The first one constitutes the origin of a gravity scree (= lower scree) mainly due to the
87 gelifraction of the porch and entry area, to the mechanical expansion of the vaults as well as to
88 the reworking of old superficial deposits. The spreading of the deposits on about forty meters
89 up to the entrance of the Chamber of the Bear Hollows (“Salle des Bauges”) is attributed to
90 mobilization by creep and solifluction.

91 - The second one also corresponds to a gravity scree (intermediate scree) less expanded than
92 the lower one. Their very similar components suggest a same origin.

93 - The third phase corresponds to blocks generated by the collapse of the cliff. This collapse
94 mainly occurred in two main phases determined by ^{36}Cl cosmogenic dating ($23\,500 \pm 1\,200$
95 and $21\,500 \pm 1\,000$ years – Sadier et al., 2012) and gave rise to the definitive cave closure. This
96 set was later covered by fine brown sediments originating from reworking of superficial
97 deposits.

98 - After the closing of the porch, the ultimate registered events correspond to the desquamation
99 of the equilibrium vaults resulting in small sedimentary clasts, to water runoff, to recent
100 concretions growth, to the settling down of the scree.

101 The archeological pit (named GE1) carried out between 2006 and 2010 (Gély and Maksud,
102 2009; Gély et al., 2012) is located in a small gallery connecting the old porch to the Chamber
103 of the Bear Hollows (“Salle des Bauges”) and corresponding to one of the natural paths used

104 by large vertebrates and prehistoric humans (Figure 2). Of small dimensions (50 x 50 cm), 80
105 cm deep, the pit intersected the lower scree and, near the surface, a gravel of clasts issued from
106 the desquamation of the vault.

107 Six beds have been defined (Figure 3a, b):

- 108 - Bed 1: near the surface, this layer is mainly composed of small plates of desquamation
109 (c.1a). Underneath is found dry gravel of elements righted in counterslope (c.1b).
110 Among the clasts of the first level was a fistulous concretion which was dated by U/Th
111 to $13,315 \pm 79$ years (Genty, 2008). This dating as well as the one obtained on the
112 stalagmite Chau-stm 8 which seals the scree near the archaeological pit and whose basis
113 is dated at $11,500 \pm 170$ years (Genty et al., 2005) allow to date this bed between the
114 Bølling-Allerød warming and the beginning of the Holocene (Lateglacial). Level c.1b
115 supplied a flint attributed to the Upper Palaeolithic, a trace of the last human incursion
116 before the porch was finally clogged up and attributed to the Gravettian (31,000-28,000
117 cal BP; Quiles et al., 2016).
- 118 - Bed 2: this bed is a small gravel secondarily packed in a sandy-silty reddish matrix.
119 Some clasts show a soft surface identified as bears' polish. Bed 2b corresponds to the
120 reworking of the uppermost part of bed 3.
- 121 - Bed 3: this bed is about 10 cm thick, it is less gravely, with a sandy and micaceous
122 matrix very rich in charcoals responsible of its dark color. This layer contrasts with the
123 reddish color of the remaining part of the sequence. It corresponds to the reworking of
124 hearths probably at the origin of the significant thermal impacts observed close to the
125 archeological pit on the ceiling and the walls (Ferrier et al., 2014). Rubefied clasts or
126 with blackish marks have been found in this bed. Dating of several charcoals (i.e.
127 ranging from 36,000-37,000 cal BP; Quiles et al., 2016) attributes these hearths to the
128 Aurignacian occupancy.
- 129 - Bed 4: this bed is divided in two, the upper part corresponding to a small dense gravel
130 with angular granules due to run-off, while its lower part is coarser. The matrix is sandy-
131 silty reddish brown becoming more yellow towards the bottom.
- 132 - Bed 5: this bed is made of an angular gravel packed in a red sandy sediment, more silty
133 towards the base. At its base, a charcoal dated from between 36,361 and 34,797 cal. BP
134 (Quiles et al., 2016) is contemporaneous to the first Aurignacian occupation of the cave.
- 135 - Bed 6: also, coarse, contains wall elements (one block and clasts) polished by bears.
136 The matrix is more sandy, brownish.

137 - In beds 2 to 5, the presence of sorted lamellar microstructures and occasionally layered
138 caps at the surface of the clasts shows the role of cold weather (mainly frost periods) in
139 this part of the scree and its spreading by solifluction towards the Chamber of the Bear
140 Hollows.

141 The volcanic minerals characterizing the Chauvet cryptotephra were identified in the beds 6 to
142 1b, indicating a reworking of the initial tephra fall from the outside.

143

144 **3. Material and methods**

145

146 The mineralogical study was carried out on the 63 μ m-2mm sand fraction separated by wet
147 sieving in an aqueous solution of sodium hexametaphosphate (dispersant) and removing of
148 carbonates (post-deposition calcite coatings) by HCl 1N/2 hours treatment. Results are based
149 on the study of ten samples distributed in the various beds of the archeological pit. The
150 percentages between the silty-clayey fraction and the clayey fraction characterize clayey-silty
151 sands and clayey-sandy silts. The examination of the light sandy fraction reveals quartz-rich
152 sands (angular or slightly blunt quartz) poor in feldspars, issued from the regional granitic and
153 metamorphic basement. Heavy minerals were separated with bromoform (samples CHAU 1-4
154 = beds 1b, 2, 3, 4) or with sodium polytungstate (samples CHAU 8-9 = beds 5a and 6, samples
155 ARD 25-28 = beds 3, 4, 5, 6). Thus, they represent the heavy fraction ($d > 2.8$), including some
156 minerals of the basement and all the volcanic minerals potentially present, except possible
157 plagioclases of basaltic origin, not analyzed. These volcanic minerals either correspond to
158 minerals typical of basaltic magma or to mantellic minerals issued from ultramafic xenoliths
159 (peridotites/lherzolites). The percentages of heavy minerals vary between 0.85 and 3% of the
160 sand fraction. The minerals have been identified with a polarization microscope and a binocular
161 lens. In order to establish their frequency, which is slightly variable due to the grain-size of the
162 samples, several samples were counted on a squared grid. To specify their respective
163 characterizations and origins, the various minerals identified by optical study were then
164 analyzed with an electron microprobe. The handpicked minerals were included in epoxy resin
165 and polished with abrasive papers and diamond powders. They were then analyzed with a WDS
166 Cameca SX 100 microprobe at the Camparis center (Sorbonne University, Paris VI/CNRS)
167 with column conditions 15 keV, 10 nA. These results were then compared to those of the
168 analysis performed on minerals issued from tephtras or peridotitic nodules from the Upper
169 Pleistocene volcanism of Bas-Vivarais (Ardèche).

170

171 4. Mineralogy and characterization of the cryptotephra

172

173 The results of the heavy minerals counting of six samples are reported in Table 1 and Figure 4.
174 They make it possible to appraise the frequencies of the various species and possibly to link
175 them to the modal composition of the original host-rocks. All the samples are largely dominated
176 by olivine (73.8 to 89.7%). This one is mainly composed of xenomorph grains which can result
177 from the mechanical fragmentation of peridotites nodules or from basaltic magma. Some
178 automorphic specimens clearly originate from the last. The orthopyroxenes (xenomorph
179 enstatite 3.9-7.6%) and the green clinopyroxenes (xenomorph chromiferous diopside, 2.5-
180 6.6%) then represent minerals characteristic of peridotites xenoliths (e.g. Berger, 1981). The
181 brown clinopyroxene (diopside) only plays a minor role (0.7-2%). It probably originates from
182 a basaltic magma together with other pyroxenes such as those occurring in the alkali basalts
183 from the Massif Central. The brown amphiboles, also little abundant (0.2-2%) are probably
184 peridotites amphiboles as those described by Berger (1981).

185 These minerals are attributable to a basaltic volcanism rich in peridotites nodules (lherzolites)
186 as well as lower crustal material which can only correspond to the Upper Pleistocene volcanism
187 of the Bas-Vivarais located about 35 km away (e.g. Berger, 1973, 1981, Sasco et al., 2017).
188 They come from a tephra brought by the wind at the probable origin of most of the other drifts
189 (basement silts and sands) and scattered in the cave environment. The homogeneity of the
190 minerals assemblage and the freshness of the minerals (e.g. automorphic olivine) lead one to
191 think that this slightly reworked tephra is subcontemporaneous with the sediments including
192 the latter. Thus, it can be defined as a cryptotephra. This fall probably results from a
193 phreatomagmatic eruption associated with formation of a maar. The explosive products (base-
194 surges and falls) are actually usually rich in peridotites minerals (see discussion). The origin of
195 the fall from a strombolian eruption is much less probable. In fact, this type of eruption
196 effectively produces basaltic ashes and scoriae which are not present in the Chauvet samples
197 and are also generally poor in minerals.

198 The other heavy silicates are basement minerals which play only a minor role (Table 1). These
199 include garnets (0.7 to 5.9%), andalusite, sillimanite-fibrolite, tourmaline and rutile. They could
200 be alluvial minerals from the Ardèche river, coming from the Massif Central and reworked
201 from old fluvial terraces by run-off or gravity process. But they were more probably brought
202 by the wind. Some could also come from the cryptotephra, the explosive products of the maars
203 being mainly rich in basement minerals. The opaque minerals, little represented (2.5 to 3.6%),
204 correspond either to Fe-Ti oxides issued from the regional basaltic volcanism (magnetite,

205 titanomagnetite), or to silicates and oxides of unknown origin (work in progress), or to rare
206 chromium spinels (about 23% of Cr₂O₃) probably issued from peridotites.

207

208 **5. Microprobe geochemical study of minerals**

209

210 In order to precisely characterize the mineralogy and chemical composition of the minerals, a
211 mineralogical study using an electron microprobe was undertaken and compared with the
212 available analyses (Berger, 1981) and new analyses of proximal volcanic falls (base-surges) as
213 well as peridotites from the Ardèche volcanism. Various characteristic analyses are reproduced
214 on Table 2.

215 Olivines are mainly characterized by the variation of their MgO contents. The analysis of
216 automorphic grains reveals compositions comprised between 43.67 and 46.30% of MgO (Fo =
217 83.1-86.6%). Such compositions, poor in Mg, are typical of basaltic phenocrystals as confirmed
218 by their automorphic habitus. After all the cross-checking we have done, it seems that the limit
219 of composition between basaltic and peridotite olivines is at about 47% MgO. The lowering of
220 magnesium in these basaltic olivines (e.g. Table 2, OL1-2) results in their iron enrichment (FeOt
221 = 12.65-15.39% for the most ones) as shown by the diagram of the figure 5. Except for visibly
222 broken specimens from basaltic origin with MgO contents < 47%, the other xenomorphic
223 olivines are more magnesian (MgO = 47.40–48.96%) and characterize olivines from peridotites
224 (e.g. Table 2, OL3-4, Figure 3). However, these olivines are slightly less magnesian than the
225 olivine from peridotites of the Vestide du Pal and Chambon maars analysed by Berger (1981)
226 which mostly exceed 49% of MgO (48.71-49.82%); but based on six analyses performed on
227 the phreatomagmatic tuff of Vestide. We have noticed that they were less magnesian and
228 compatible with the compositions of the Chauvet cryptotephra (44.57 – 44.98 – 45.37 – 47.08
229 – 47.44 – 48.02% MgO). For comparison, the olivines from the Ray-Pic maar peridotites have
230 compositions varying between 47.89 and 49.50% MgO. The olivines of micro-peridotite
231 enclaves found within the strombolian tuff of Gravenne de Montpezat, were also analyzed. They
232 are slightly more magnesian and mainly exceed 49% MgO. Although small, these variations
233 seem to indicate significant slight differences of composition for the olivines of peridotites
234 xenoliths from the Ardèche volcanism.

235 The orthopyroxenes necessarily come from peridotites of which they are one of the
236 characteristic minerals with MgO contents near 32-33%. These are enstatites En_{87.8-89.8}, Wo<sub>0.93-
237 1.27</sub> (Figure 6). Their analytical results (e.g. Table 2, EN1-2) are close to those of Berger (1981)
238 concerning the orthopyroxenes of peridotites from the Vestide du Pal and Chambon maars. Like

239 them, they are slightly chromiferous ($\text{Cr}_2\text{O}_3 = 0.22\text{-}0.34\%$). The other orthopyroxenes we
240 analyzed (Ray-Pic maar, Borée maar, Gravenne de Montpezat scoria cone, Moula rockshelter
241 tephra) showed relatively similar compositions.

242 The green clinopyroxene corresponds to the common clinopyroxene of peridotites (Berger,
243 1981). This is chromiferous diopside (calcic clinopyroxene $\text{Wo}_{45\text{-}48}$, Figure 5). The results of
244 the ten analyses performed (e.g. Table 2, CD1-2) show slightly less chromium-rich pyroxenes
245 than those analysed by Berger (1981) for peridotites of the Vestide du Pal and Chambon maars:
246 $0.54\text{-}0.81\%$ compared to $0.75\text{-}1.36\%$. This difference is not explained. Only one sample differs
247 with $1.34/1.48\%$ Cr_2O_3 .

248 The brown clinopyroxenes correspond to diopsides $\text{Wo}_{44.97\text{-}48.30} - \text{En}_{40.01\text{-}42.34} - \text{Fs}_{10.68\text{-}13.87}$ (e.g.
249 Table 2 BD1-2, Figure 6). These are basaltic pyroxenes common in the alkali basalts from the
250 Massif Central and attributed to the basaltic magma pulverized by the phreatomagmatic
251 eruption. They show typical amounts of Al_2O_3 ($8.51\text{-}9.46\%$), TiO_2 ($2.15\text{-}2.53\%$) and FeOt
252 ($6.14\text{-}7.86\%$).

253 Analysis of some opaque minerals revealed the existence of several minerals of unspecified
254 origin. The first one presents a chemical composition with $27\text{-}34.5\%$ SiO_2 , $5\text{-}7\%$ K_2O , 15.4-
255 20.3% FeOt, $13.9\text{-}17.7\%$ Al_2O_3 , $5.8\text{-}8.8\%$ MgO, $3.8\text{-}4.5\%$ TiO_2 . The second one is mainly
256 composed of FeO ($67\text{-}75\%$ FeOt), but contains low percentages of SiO_2 , Al_2O_3 , CaO, MnO and
257 P_2O_5 and cannot be ascribed to a true oxide.

258

259 **6. Discussion, origin and possible age of the cryptotephra**

260

261 As previously seen the mantellic minerals (peridotites minerals = magnesian olivine +
262 orthopyroxene + chromiferous diopside) and the basaltic minerals (olivine + brown diopside)
263 characterizing the cryptotephra of the Chauvet-Pont-d'Arc cave can be ascribed without any
264 doubt to a phreatomagmatic eruption related to a maar of the Upper Pleistocene volcanism of
265 the Bas-Vivarais. They were pulverized and mixed by the phreatomagmatic explosions. The
266 absence of basaltic ash (microscoriae) attributable to a strombolian eruption, the mixing of
267 mantellic and basaltic minerals and the lower explosivity of this type of eruption led us to
268 exclude a strombolian eruption at the origin of the cryptotephra.

269 The volcanism of the Bas-Vivarais is known since the work of Faujas de Saint-Fond (1778). Its
270 volcanic products are mainly alkaline basalts derived from a unique enriched mantle source
271 (Chauvel and Jahn, 1984; Downes, 1987). It benefited in particular from the works of Berger
272 (e.g. Berger, 1973, 1981, 2007) and is distinguished by the frequency of its ultramafic xenoliths

273 (Berger, 1981; Berger and Forette, 1975). It comprises 17 eruptive centers. Its activity is
274 characterized by phreatomagmatic eruptions (maars) preceded or generally followed by a
275 strombolian activity associated with the emission of basaltic flows filling pre-existing valleys.
276 The karst of the Bas-Vivarais, situated to the southeast, is characterized by the importance of
277 its Upper Pleistocene infillings (Debard, 1988, 1997). The signature of volcanic eruptions from
278 the Bas-Vivarais was evidenced in three of these karstic infillings: the Moula rockshelter in
279 Soyons (Debard and Pastre, 2008; Pastre et al., 1994), the Marzal II aven (or Flahault aven) and
280 the Devès du Reynaud aven in Saint-Remèze (Debard and Pastre, 2008). Among them, the in-
281 situ tephra found in Soyons is the more representative example of a phreatomagmatic fall
282 comparable to that detected in Chauvet. Among the recent maars of the Bas-Vivarais four
283 present an explosive activity and can be at the origin of the cryptotephra we described above:
284 the Ray-Pic, the Vestide du Pal, the Chambon and the Sapède (Berger, 1981). This last
285 explosion crater can a priori be excluded, due to its essentially basaltic type (Berger, 1981) as
286 confirmed by our own observations and analyses. Derived tephtras are therefore mainly
287 composed of basalt clasts and their olivines are mainly basaltic in composition with 44.01-
288 46.55% MgO (Fo = 86.3-87%). The Chambon maar emitted a base-surge and lahars visible in
289 the Fau valley above the hamlet. The mineralogical and microchemical study shows that these
290 products both contain peridotite and basaltic minerals similar to Chauvet' ones. The peridotites
291 olivines (48.43-48.97% MgO) are however more abundant than the basaltic ones in the sample
292 we analyzed. This maar cut in the basement could have been large enough to disperse
293 widespreadly its products, but, due to little extended dispersal in the proximal area, it was
294 probably less extended than those of the following maars. Among the following eruptions, the
295 Vestide du Pal maar constitutes one of the largest explosive craters in the Massif Central
296 (diameter = 1700 m, Berger, 1973, 1981). It emitted important surges visible in its eastern and
297 southern parts (Suc du Pal). The mineralogical study of these products rich in basement
298 minerals pulverized by explosions, show that they content both peridotite and basaltic minerals.
299 These ones however comprise peridotite olivines (47.05-50% MgO) and peridotite pyroxenes.
300 The basaltic olivines (44.57-45.37% MgO) are rare. However, this composition makes them
301 compatible with the composition of Chauvet cryptotephra ones. The Ray-Pic maar also emitted
302 large surges visible along the road D 215 to the east of the Ray-Pic cascade. The mineralogical
303 study of these tephtras also rich in basement minerals shows that they contain basaltic and
304 peridotite minerals. The olivine shows a composition varying between 44.63 and 49.78% MgO
305 (Fo = 85.2-90.9%) which clearly argues for these two origins and compositions close to those
306 of Chauvet.

307 The cryptotephra-bearing beds are well dated due to the presence of micro-charcoals ascribed
308 to frequenting of the site by Aurignacians. ^{14}C AMS datings gave ages comprised between 36,
309 361-34,797 (bed c5) and 36,100-34,880 (bed c2a) years cal. BP (Quiles et al., 2016). Thus, the
310 cryptotephra must have an age greater than or close to 36 ka. The Bas-Vivarais volcanism
311 benefited from ^{14}C datings (Berger, 1973, Berger et al., 1975, Berger, 2007), from
312 thermoluminescence datings (Guérin, 1983, Guérin and Gillot, 2007, Sanzelle et al., 2000),
313 from paleomagnetism measurements (Rochette et al., 1993, Sasco, 2015, Sasco et al., 2017)
314 and from K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ datings (Sasco, 2015, Sasco et al., 2017). Among them, the
315 $^{40}\text{Ar}/^{39}\text{Ar}$ datings (ibid.) seem to be the most accurate. The $^{40}\text{Ar}/^{39}\text{Ar}$ age of the Vestide du Pal
316 maar would thus be comprised between 25.8 ± 7.7 and 27.2 ± 8.2 ka (ibid.). It would thus
317 belong to the recent phase of the Ardèche volcanism. This age seems too young to fit with the
318 potential age of the Chauvet cryptotephra. Nevertheless, it was performed on a basalt following
319 the phreatomagmatic eruption and not on the tephtras coming from the maar explosions. It is
320 also the same for the age of the Chambon maar dated at 18.8 ± 9.6 ka (ibid.). On the other hand
321 the age of the Ray-Pic maar comprised between 36.2 ± 11.3 and 32.2 ± 11.1 ka (ibid) is well
322 compatible with the ^{14}C datings of the beds containing the minerals of the Chauvet cave. This
323 maar belonging to the middle phase of the Bas-Vivarais volcanism could be at the origin of the
324 cryptotephra we discovered. Nevertheless, its products do not contain the peculiar minerals
325 which are currently studied to define their origin (terrestrial or extraterrestrial).

326 The correlation with the other tephtras identified in the karstic infillings of the region can be
327 examined. The tephtra of the Devès du Reynaud aven (Debard and Pastre, 2008) is characterized
328 by the presence of basaltic glass and its richness in biotite to which a peculiar provenance can
329 be attributed. This composition is clearly different from the Chauvet cryptotephra. In the Marzal
330 II (or Flahault) the basaltic and mantellic minerals reworked in set 5 (Debard and Pastre, 2008)
331 can also be attributable to a phreatomagmatic emission of the Upper Pleistocene volcanism of
332 Ardèche. The data obtained by biochronology suggest that this fall could belong to the recent
333 or middle phase of Ardèche volcanism. The minerals of this infilling could originate from the
334 same fall as the minerals of the Chauvet cave's cryptotephra or originate from another eruption
335 like those of Vestide du Pal or Chambon. The tephtra identified in the Moula rockshelter
336 corresponds to a beautiful in situ phreatomagmatic fall (Debard and Pastre, 2008, Pastre et al.,
337 1994). Rich in basement minerals, it contains both peridotite and basaltic minerals as illustrated
338 by the composition of its olivines varying between 43.97 and 48.87% MgO. Its initial dating
339 around 40 ka (Pastre et al., 1994) was contested according to a TL dating of 72 ± 12 ka (Sanzelle
340 et al., 2000). It is indeed worth noticing that this older age is hardly reconcilable with the

341 sedimentological and paleoclimatic data suggesting a periglacial context rather than a temperate
342 one such as the Saint-Germain 2 episode (Debard and Pastre, 2008). In the hypothesis of an age
343 close to 40 ka, its correlation with the phreatomagmatic eruption of the Ray-Pic maar is
344 possible. This hypothesis is in any case compatible with the composition of the products
345 identified in these two entities.

346

347 **7. Conclusion**

348

349 The cryptotephra from the Chauvet-Pont d'Arc cave provides a new example of tephra-fall
350 from the Upper Pleistocene volcanism of the Bas-Vivarais, trapped in the karst of this area. Its
351 possible attribution to the phreatomagmatic eruption of the Ray-Pic maar could be supported
352 by the mineralogical and geochemical compositions of its products containing mantellic and
353 basaltic minerals. It is also in agreement with the recent $^{40}\text{Ar}/^{39}\text{Ar}$ datings of the Ardèche
354 volcanism (Sasco, 2015; Sasco et al., 2017), giving an age subcontemporaneous with the beds
355 containing the charcoals well dated by ^{14}C (Quiles et al., 2016) and contemporaneous with the
356 Aurignacian occupation and art, that is slightly older than or close to 36 ka. In the other hand,
357 the cryptotephra could also originate from the Vestide du Pal maar, as it also contains peculiar
358 minerals whose origin is still unknown and which were also found in sedimentary infilling of
359 the Chauvet cave. The discovery of this slightly reworked tephra in this remarkable Paleolithic
360 cave provides an additional evidence of the contemporaneity of the Ardèche volcanism with
361 the Aurignacian occupation of this region. Our findings are however not the bulletproof that
362 will legitimate the hypothesis according which the spray-shape signs of the cave can be ascribed
363 to the first depiction of a volcanic eruption (Nomade et al., 2016), but they surely reinforced
364 the hypothesis that Aurignacians have been the witnesses of volcanic activity in the Ardèche
365 region and that volcanic derived material did fall in the vicinity of Chauvet-Pont d'Arc cave
366 about 36 ka ago.

367

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369

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376

377

378 **References**

379

380 Berger, E. (1973). Le volcanisme r ecent de l'Ard eche, PhD thesis, Univ. Orsay, 402 p.

381 Berger, E. (1981). Enclaves ultramafiques, m egacristaux et leurs basaltes-h otes en contexte
 382 oc anique (Pacifique sud) et continental (Massif central fran ais). Th ese d'Etat, Univ. Paris-
 383 sud, Orsay, 470 p.

384 Berger, E. (2007). Les jeunes volcans d'Ard eche. Sud-Ouest  ditions. 2879018293, 187 p.

385 Berger, E. and Forette, M.C. (1975). R eactions des basaltes alcalins des Causses, du Vivarais
 386 et du Velay (France) avec les x enocristaux et les min eraux des enclaves hom og enes. *Bull. Soc.*
 387 *Fr. Mineral. Cristal.*, 98 : 366-373.

388 Berger, E., Brousse, R. and Maury, R.C. (1975). Age r ecent ($11\ 770 \pm 270$ ans BP) des derni eres
 389  ruptions du Vivarais. *C. R. Acad. Sci., Paris*, Ser.D 280 : 419-422.

390 Chauvel, C. and Jahn, B.M. (1984). Nd-St isotope and REE geochemistry of alkali basalts from
 391 the Massif Central, France. *Geochim., Cosmochim. Acta.*, 48 : 93-110.

392 Clottes, J. (2001). La Grotte Chauvet. L'art des origines, Paris, Seuil Edition, 224 p.

393 Clottes, J., Chauvet, J.-M., Brunel-Deschamps,  ., Hillaire, Ch., Daugas, J.-P., Arnold, M.,
 394 Cachier, H.,  vin, J., Fortin, Ph., Oberlin, C., Tisnerat, N. and Valladas, H. (1995). Les
 395 peintures pr ehistoriques de la Grotte Chauvet-Pont d'Arc (Ard eche, France) : datations directes
 396 et indirectes par la m ethode du radiocarbone. *C. R. Acad. Sci., Paris*, Ser. IIa 320 : 1133-1140.

397 Cuzange, M.T., Delqu -Kolic, E., Goslar R., Meiert Grootes, P., Higham, T., Kaltnecker, E.,
 398 Nadau, M.-J., Oberlin, C., Paterne, M., Plicht, J. van der, Bronk Ramsey, Ch., Valladas, H.,
 399 Clottes, J. and Geneste, J.-M. (2007). Radiocarbon intercomparaison program for Chauvet
 400 Cave. *Radiocarbon*, 49(2) : 339-347.

401 Debard,  . (1988). Le Quaternaire du Bas-Vivarais d'apr es l' tude des remplissages d'avens,
 402 de porches de grottes et d'abris sous-roche. Dynamique s dimentaire, pal oclimatologie et
 403 chronologie. Th ese d'Etat. *Doc. Labo. g ol. Lyon*, 103, 317 p.

404 Debard,  . (1997). Les remplissages karstiques du Bas-Vivarais : karstog n se,
 405 s dimentog n se et arch ologie. *Quaternaire*, 8 : 305-317.

- 406 Debard, É., Ferrier, C. and Kervazo, B. (2016). Grotte Chauvet-Pont d'Arc (Ardèche) :
407 évolution morphosédimentaire de l'entrée. Implication sur les occupations et sur la
408 conservation des vestiges. *Quaternaire*, 27 (1) : p. 3-14.
- 409 Debard, É. and Pastre, J.F. (2008). Nouvelles données sur les téphras pléistocènes piégés dans
410 les remplissages karstiques ardéchois (S-E France). *Quaternaire*, 19 (2) : 107-116.
- 411 Downes, H. (1987). Relationship between geochemistry and textural type in spinel peridotite
412 xenoliths, Massif Central, France. *Earth Planet. Sci. Lett.*, 82: 121-135.
- 413 Faujas de Saint-Fond, B. (1778). Recherches sur les volcans éteints du Vivarais et du Velay.
414 Joseph Cuchet Édition, Grenoble.
- 415 Ferrier, C., Debard, É., Kervazo, B., Brodard, A., Guibert, P., Baffier, D., Feruglio, V., Gély,
416 B., Geneste, J.-M. and Maksud, F. (2014). Les parois chauffées de la grotte Chauvet-Pont d'Arc
417 (Ardèche, France) : caractérisation et chronologie. *Paleo*, 25 : 59-78.
- 418 Gély, B., Boche, E. and Maksud, F. (2012). Rapport triennal 2010-2012. In : Études
419 pluridisciplinaires à la grotte Chauvet-Pont d'Arc (Ardèche). Rapports d'activités 2010-2012
420 (coordinateur J.-M. Geneste) : 215-242.
- 421 Gély, B. and Maksud, F. (2009). Sondage GE-1 dans la galerie d'entrée - Travaux 2009 et
422 synthèse des résultats 2006-2009. In : Études pluridisciplinaires à la grotte Chauvet-Pont d'Arc
423 (Ardèche). Rapports d'activités triennaux 2007-2009 et Perspectives 2010-2012 (coordinateur
424 J.-M. Geneste) : 211-233.
- 425 Genty, D. (2008). Datations et analyses isotopiques des stalagmites de la grotte Chauvet du
426 Secteur Rouge. In : Geneste, J.M. (dir.), La grotte Chauvet à Vallon Pont d'Arc (Ardèche).
427 Rapports d'activités 2008 : 155-160.
- 428 Genty, D., Blamart, D. and Ghaleb, B. (2005). Apport des stalagmites pour l'étude de la grotte
429 Chauvet: datations absolues U/Th (TIMS) et reconstitution paléoclimatique par les isotopes
430 stables de la calcite. In : Geneste, J.M. (dir.), La grotte Chauvet à Vallon-Pont d'Arc : un bilan
431 des recherches pluridisciplinaires. Actes de la séance de la Société préhistorique française,
432 Lyon, 2003. *Bull. Soc. Prehist.Fr.*, 102 (1) : 45-62.
- 433 Guérin, G. (1983). La thermoluminescence des plagioclases. Méthode de datation du
434 volcanisme, applications au domaine volcanique français : Chaîne des Puys, Mont-Dore et
435 Cézallier, Bas Vivarais. Thèse d'Etat. Université Pierre et Marie Curie, 258 p.
- 436 Guérin, G. and Gillot, P.Y. (2007). Nouveaux éléments de chronologie du volcanisme
437 pléistocène du Bas-Vivarais, (Ardèche, France) par thermoluminescence. *C.R. Geoscience*, 339
438 : 40-49.

- 439 Guibert, P., Brodard, A., Quiles, A., Geneste, J.-M., Baffier, D., Debard, É. and Ferrier, C.
440 (2015). When were the walls of the Chauvet Cave heated? A chronological approach by
441 thermoluminescence. *Quat. Geochronol.*, 29: 36-47, doi 10.1016/j.quageo.2015.04.007.
- 442 Nomade, S., Genty, D., Sasco, R., Scao, V., Feruglio, V., Baffier, D., Guillou, H., Bourdier, C.,
443 Valladas, H., Reigner, E., Debard, É., Pastre, J.F. and Geneste, J.M. (2016). A 36,000-Year-
444 Old Volcanic Eruption Depicted in the Chauvet-Pont d'Arc Cave (Ardèche, France)? *Plos One*
445 11(1): e0146621. Doi:10.1371/journal.pone.0146621.
- 446 Pastre, J.F., Debard, É., Chennaoui, K. (1994). Un téphra-repère du volcanisme
447 phréatomagmatique du Vivarais dans la séquence Pléistocène supérieur de l'abri Moula
448 (Soyons, Ardèche, France). *C.R. Acad. Sci. Paris, Ser. II* 319 : 937-943.
- 449 Quiles, A., Valladas, H., Bocherens H., Delqué-Kolic, E., Kaltnecker, E., van der Plicht J.,
450 Delannoy, J.J., Feruglio, V., Fritz, C., Monney, J., Philippe M., Tosello, G., Clottes, J. and
451 Geneste, J.M. (2016). A high-precision chronological model for the decorated Upper Paleolithic
452 cave of Chauvet-Pont d'Arc, Ardèche, France. *PNAS.org/cgi/doi/10,1073/Pnas.1523158113.*, 6
453 p.
- 454 Rochette, P., Bertrand, H., Braun, C. and Berger, E. (1993). La province volcanique Pléistocène
455 Supérieur du Bas-Vivarais (Ardèche, France) : propagation de fentes crustales en échelons ?.
456 *C.R. Acad. Sci. Paris, Ser. II* 316 : 913-920.
- 457 Sadier, B., Delannoy, J.J., Benedetti, L., Bourlès, D.L., Jaillet, S., Geneste, J.M., Lebatard,
458 A.E. and Arnold, M. (2012). Further constraints on the Chauvet cave artwork elaboration. *Proc.*
459 *Nat. Acad. Sci. USA*, 109 (21): 8002-8006.
- 460 Sanzelle, S., Pilleyre, T., Montert, M., Fain, J., Miallier, D., Camus, G. Goër H. de and Defleur,
461 A. (2000). Datation par thermoluminescence : étude d'une corrélation possible entre le maar de
462 la Vestide-du-Pal et un niveau de téphra de la Baume-Moula-Guercy (Ardèche, France). *C.R.*
463 *Acad. Sci. Paris, Ser. II*, 330 : 541-546.
- 464 Sasco, R. (2015). Développement d'un outil chronostratigraphique pour les archives
465 climatiques : datations absolues (K/Ar, $^{40}\text{Ar}/^{39}\text{Ar}$) et paléomagnétisme appliqués aux laves.
466 Thèse de doctorat, Université Paris-sud.
- 467 Sasco, R., Guillou, H., Nomade, S., Scao, V., Maury R.C., Kissel, C. and Wandres, C. (2017).
468 $^{40}\text{Ar}/^{39}\text{Ar}$ and unspiked ^{40}K - ^{40}Ar dating of upper Pleistocene volcanic activity in the Bas-
469 Vivarais (Ardèche, France). *J. Volcanol. Geotherm. Res.*, 341: 301-314.
- 470 Valladas, H., Tisnerat-Laborde, N., Cachier, H., Kaltnecker, E., Arnold, M., Oberlin, C. and
471 Evin J. (2005). Bilan des datations carbone 14 effectuées sur des charbons de bois de la grotte
472 Chauvet. *Bull. Soc. Préhist. Fr.*, 102 (1) : 109-113.

473

474 **Figures and tables captions**

475

476 Fig. 1. A) Location of the Chauvet cave in France, B) Location of the Chauvet cave in
477 Ardèche area, C) Example of spray-shape sign, D) Perspective view of the Bas-Vivarais
478 volcanism seen from Chauvet cave.

479

480 Fig. 2. Location of the archeological pit GE1 located about twenty meters from the
481 Palaeolithic entrances. Équipe Grotte Chauvet (Ministère de la Culture, CNRS, Universités).

482

483 Fig. 3a. Archeological pit GE1: view of the southern and western sections and dating
484 elements. Picture by C. Ferrier (Equipe Grotte Chauvet – Ministère de la Culture, CNRS,
485 Universités).

486 Fig. 3b. Log of the archeological pit GE1.

487

488 Fig. 4. Heavy minerals composition of the beds containing the cryptotephra.

489

490 Fig. 5. MgO/total FeO diagram of the olivines of Chauvet cryptotephra.

491

492 Fig. 6. Wo-En-Fs diagram of the pyroxenes of Chauvet cryptotephra.

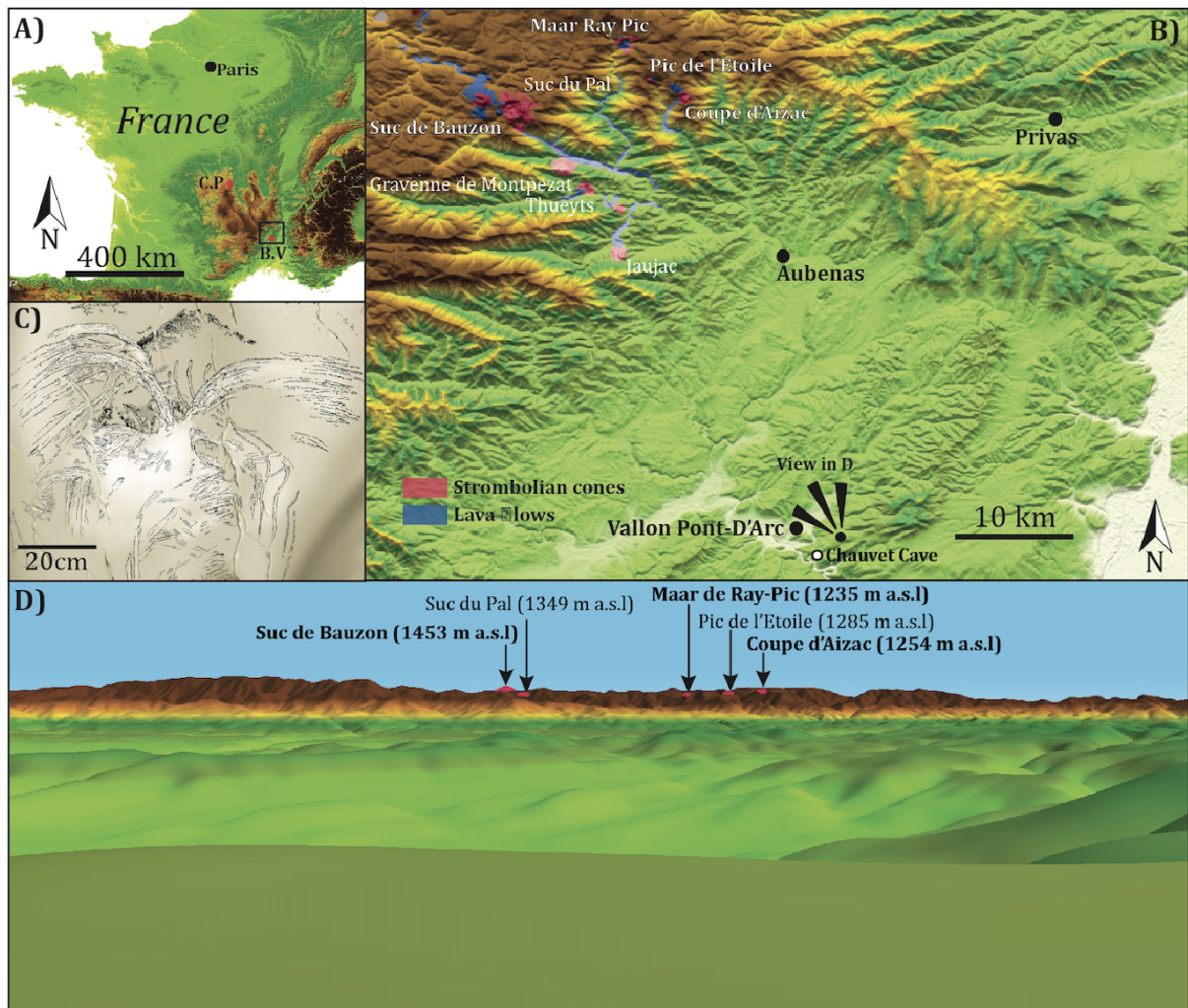
493

494 Tab. 1. Heavy minerals spectras of samples containing Chauvet cryptotephra.

495

496 Tab. 2. Selected microprobe analyses of minerals issued from Chauvet cryptotephra (sample
497 CHAU 4, bed 4). OL1-2: basaltic olivine – OL3-4: peridotite olivine – EN1-2: enstatite –
498 CD1-2: chromiferous diopside – BD1-2: brown diopside. Olivines: numbers of ions on the
499 basis of 4 O, pyroxenes: numbers of ions on the basis of 6 O.

500



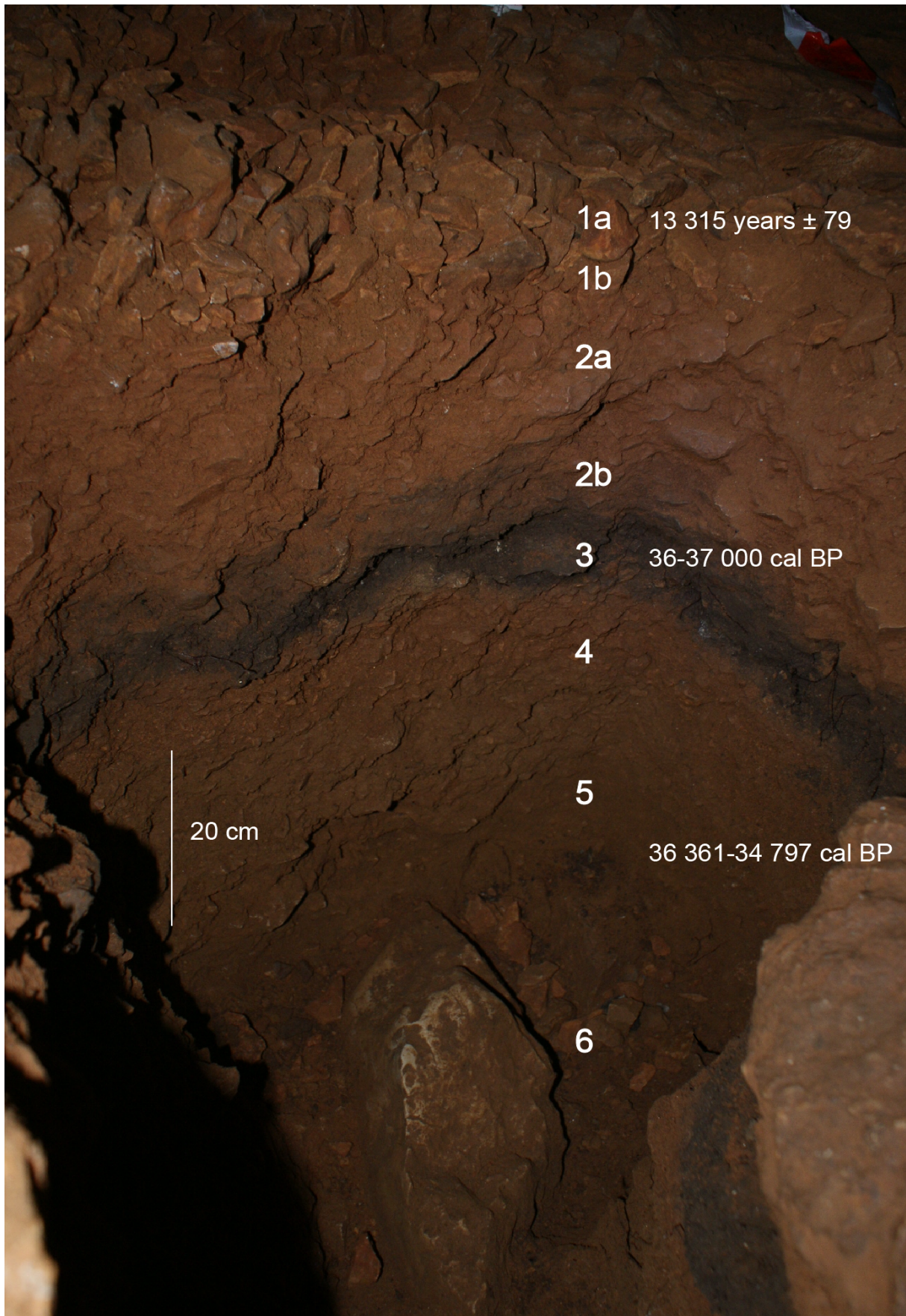
501

502 Fig. 1



503

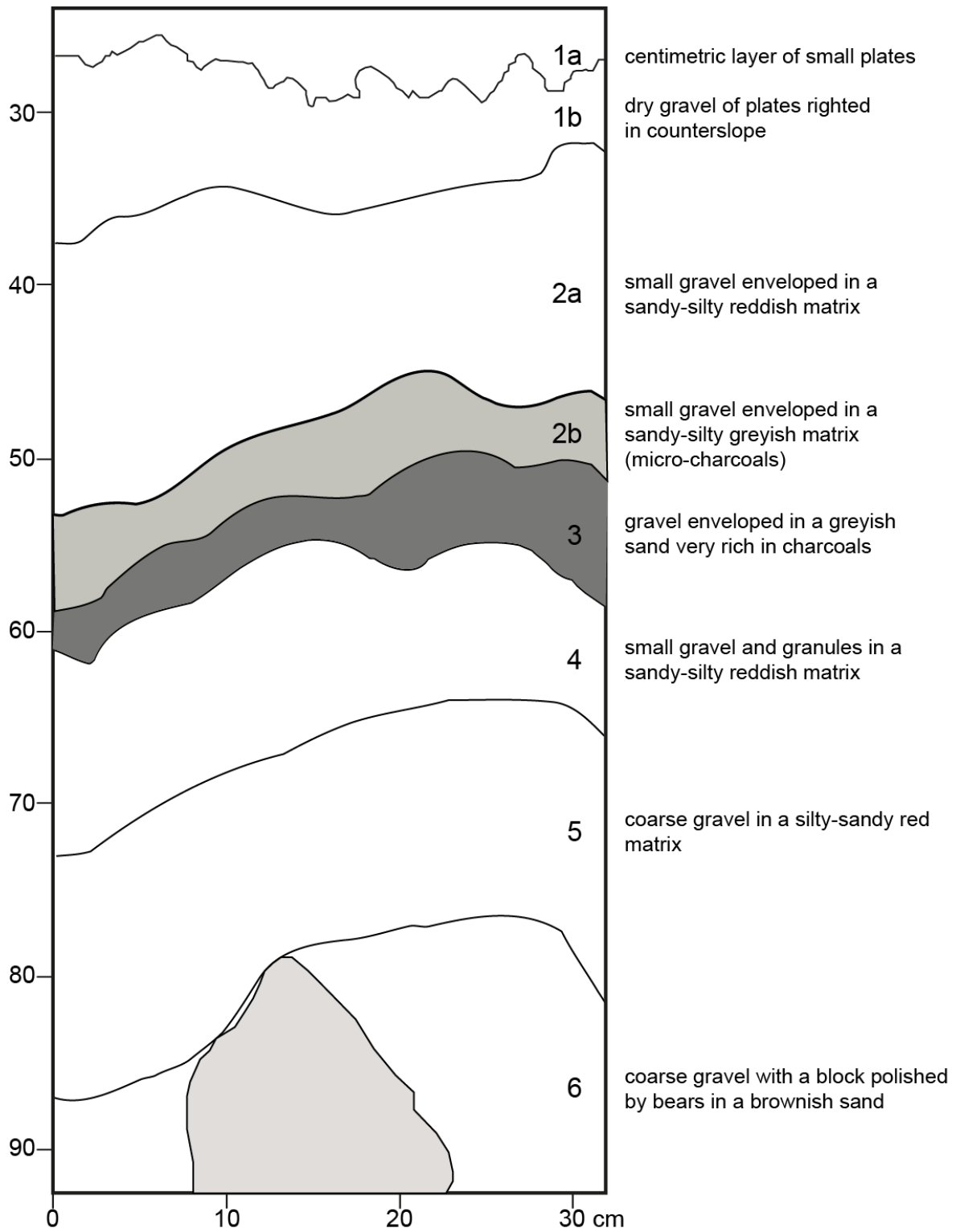
504 Fig. 2



505

506 Fig. 3a

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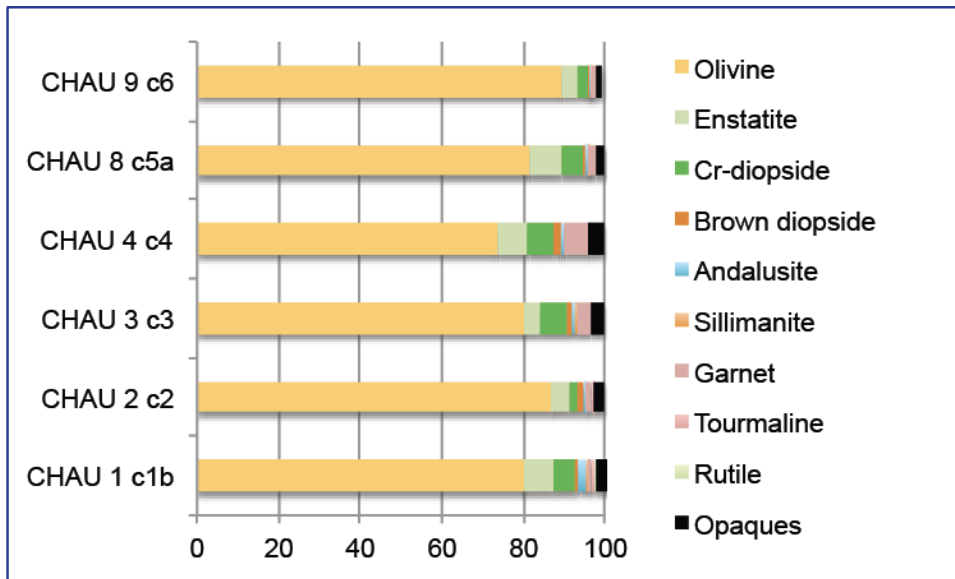


508

509 Fig. 3b

510

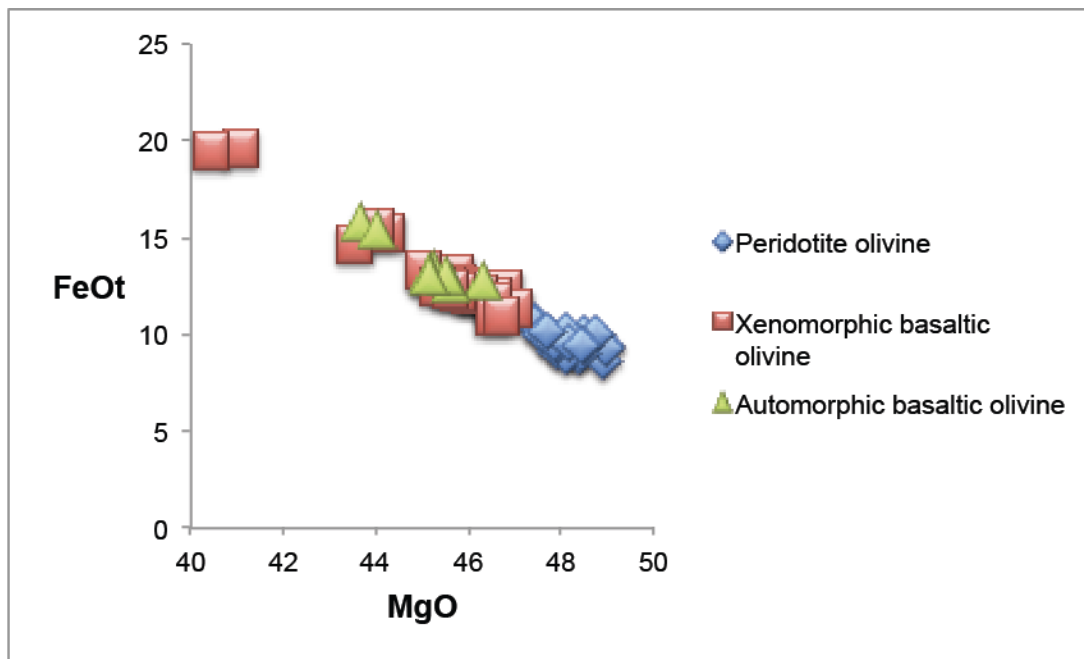
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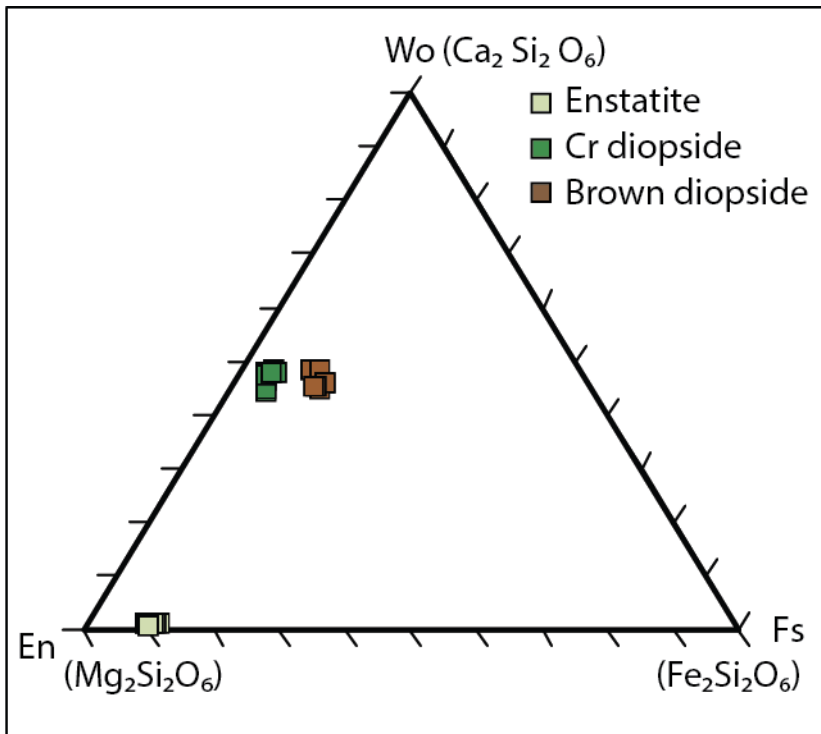
513 Fig.4

514



515

516 Fig. 5



517

518 Fig. 6

519

Sample Bed	CHAU 1 1b	CHAU 2 2	CHAU 3 3	CHAU 4 4	CHAU 8 5a	CHAU 9 6
Brown amphibole	2.01	0.25	0.39	0.28	0.99	0.51
Enstatite	7.38	4.28	3.9	7.26	7.58	3.78
Chromiferous diopside	5.37	2.52	6.64	6.14	5.58	2.41
Brown diopside	0.67	1.26	1.17	1.95	0.39	0.34
Olivine	77.18	86.64	80.07	73.74	80.43	89.5
Andalusite	2.01	0.75	0.78	0.83	0.59	0.34
Sillimanite-fibrolite	0.67		0.39		0.39	0.17
Garnet	0.67	1.26	3.51	5.86	1.79	1.37
Tourmaline	0.67	0.5		0.28		
Rutile	0.67					
Opagues	2.68	2.52	3.12	3.63	2.19	1.37

520 Tab. 1

521

	OL1	OL2	OL3	OL4	EN1	EN2	CD1	CD2	BD1	BD2
SiO ₂	39.99	40.15	40.96	40.62	56.04	55.48	52.49	52.88	46.68	45.86
Al ₂ O ₃	0.03	0.01	0.10	0.01	3.30	3.40	4.30	4.88	8.80	8.88
TiO ₂	0.00	0.03	0.00	0.04	0.04	0.08	0.33	0.24	2.18	2.53
Cr ₂ O ₃	0.00	0.03	0.02	0.02	0.19	0.29	0.81	0.65	0.05	0.07
FeO _t	12.72	13.08	9.95	9.38	7.37	6.21	2.71	2.34	6.14	7.86
MnO	0.18	0.13	0.18	0.14	0.16	0.09	0.02	0.02	0.13	0.20
MgO	46.30	45.74	48.50	48.96	32.69	32.22	16.47	15.77	13.28	12.83
CaO	0.18	0.19	0.03	0.07	0.55	0.63	21.75	21.65	21.62	20.23

Na ₂ O	0.05	0.00	0.02	0.00	0.08	0.06	1.04	1.37	0.75	0.98
NiO	0.33	0.24	0.29	0.34	0.02	0.07	0.02	0.02	0.01	0.05
Total	99.84	99.65	100.12	99.61	100.48	99.58	99.98	99.85	99.71	99.53
Si	0.997	1.003	1.003	0.998	1.933	1.923	1.905	1.916	1.736	1.721
Al	0.001	0.000	0.003	0.000	0.134	0.139	0.181	0.208	0.386	0.392
Ti	0.000	0.000	0.000	0.000	0.001	0.002	0.009	0.006	0.061	0.071
Cr	0.000	0.000	0.000	0.000	0.005	0.008	0.023	0.018	0.001	0.002
Fe	0.265	0.273	0.203	0.192	0.212	0.180	0.082	0.071	0.191	0.246
Mn	0.003	0.002	0.003	0.002	0.004	0.002	0.000	0.000	0.004	0.006
Mg	1.720	1.703	1.77	1.794	1.680	1.716	0.891	0.852	0.736	0.718
Ca	0.004	0.005	0.000	0.002	0.020	0.023	0.846	0.840	0.862	0.813
Na	0.002	0.000	0.001	0.000	0.005	0.004	0.073	0.096	0.054	0.071
Ni	0.006	0.005	0.005	0.006	0.000	0.002	0.000	0.000	0.000	0.001
Total	3.003	2.995	2.995	2.999	3.999	4.002	4.018	4.011	4.035	4.045
Fo	86.6	86.2	89.7	90.3						
Wo					1.06	1.22	46.49	47.65	48.17	45.74
En					87.81	89.4	48.98	48.31	41.14	40.38
Fs					11.11	9.37	4.52	4.02	10.68	13.87

522 Tab. 2