

LA-ICP-MS U/Pb zircon timescale constraints of the Pleistocene latest magmatic activity in the Sancy stratovolcano (French Massif Central)

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1	LA-ICP-MS U/Pb zircon timescale constraints of the Pleistocene latest
2	magmatic activity in the Sancy stratovolcano (French Massif Central).
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11	
12	Abstract
13	It has been demonstrated for several years that the U-Pb zircon system can provide
14	useful dating information for understanding the time-evolution of the volcanic systems. In
15	addition, in situ techniques were successfully used for determining the formation age of
16	young Pliocene and Pleistocene volcanic rocks and to record the spatial and temporal
17	distribution and the lifetime evolution of the magma chambers, generally in the case of large
18	volcanic domains.
19	Here we show that it is possible to obtain a precision at the percent level on zircon
20	from a short-size and late volcanic event from the Sancy stratovolcano (French Massif
21	Central). LA-ICP-MS dating of Pleistocene magmatic zircons allow to distinguish the
22	timescale of these late magmatic events within the complex volcanic activity of this large
23	stratovolcano. A syenite xenolith enclosed into a trachyte pumice flow were dated at 277.6 \pm
24	3.2 ka and 260.1 \pm 3.6 ka, respectively, whereas an earlier trachyandesite dome was emplaced

25 at 284.4 \pm 4.2 ka. These different ages allow to propose a minimum evolution time of about

26 24 ± 8 kyrs for a differentiated magma chamber, which corresponds to a short lifetime 27 associated with low magma volumes. The duration of this discrete volcanic event should be 28 compared to the hundreds of thousands of years reported for the large volcanic systems. 29 Interestingly, the zircon crystals from the pumices were embedded into a thin layer of glass of 30 trachytic composition, demonstrating that these zircons crystallized into the melt only a short 31 time before eruption.

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Keywords: U-Pb zircon geochronology; LA-ICP-MS dating; Sancy Massif; French Massif
Central; Pleistocene volcanism; ignimbrites.

35

36 1 - Introduction

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38 Analytical improvements along more than four decades makes U-Pb zircon dating by 39 CA-ID-TIMS a very high precision geochronological technique illustrated by analytical 40 uncertainties better than 0.05 % of the age (Schmitz and Kuiper, 2013; Schoene et al., 2013; 41 Schaltegger et al., 2015). The numerous analysed single zircons allowed to decipher the evolution of magma chambers and plutons construction in many intrusive complexes (e.g. 42 43 Matzel et al., 2006; Miller et al., 2007; Michel et al., 2008; Schaltegger et al., 2009; Leuthold 44 et al., 2012; Schoene et al., 2012; Wotzlaw et al., 2012; Barboni et al., 2013; Zeh et al., 2015). 45 Such small age uncertainties cannot be achieved by in situ techniques because matrix 46 matching standardization cannot challenge isotope dilution in terms of analytical precision. 47 Consequently, the best levels obtained by high spatial resolution analyses by SIMS or LA-48 ICP-MS remains close to 1-2% of the age (Nemchin et al., 2013). Nevertheless, such a 49 precision can be maintained up to very young mineral ages, lower than 1 Ma, by increasing 50 the radiogenic Pb vs. common Pb ratio to preserve concordant analytical points. When zircon 51 crystals containing common Pb-enriched inclusions are discarded, then common Pb mostly 52 corresponds to the blank level of the analytical system, itself composed of many parameters 53 such as epoxy resin, gasses, nylon and metal tubes, mass flow controllers, plastic connectors, 54 ablation cell, introduction device, etc. This can be achieved by simply enlarging the spot-size which automatically raises the signal level of radiogenic Pb and allows a precise measurement 55 of the ²³⁸U/²⁰⁶Pb ratio. The ability of LA-ICP-MS or SIMS to date very young zircons was 56 57 already demonstrated in several recent studies (e.g. Brown and Fletcher, 1999; Dalrymple et 58 al., 1999; Bacon et al., 2000; Reid and Coath, 2000; Sano et al., 2002; Schmitt et al., 2003; 59 Brown and Smith, 2004; Bachmann et al., 2007; Wilson et al., 2008; Simon et al., 2009; 60 Storm et al., 2011; Shane et al., 2012; Guillong et al., 2014; Ito, 2014; Ickert et al., 2015; 61 Sakata et al., 2017). Obtaining a decent precision for Pleistocene zircon crystals is not a target 62 itself, but such an analytical age uncertainty may be strongly significant compared to the 63 timescale of magma chamber activity during volcanic events. Thus, given sufficient analytical 64 precision, multiple pulses of magma input can be resolved. Indeed, a few percent of the age of 65 so young zircon grains only corresponds to a few thousand years, which is a very short time at the geological scale, basically able to constraint the lifetime of a magma chamber. Here, we 66 67 tested this concept on the youngest volcanic activity of the Sancy stratovolcano in Central 68 France.

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70 2 - Geological setting

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The investigated area is part of the Mont-Dore massif, a 35 x 16 km (500 km²) and 200 km³ composite edifice formed by two stratovolcanoes (Baubron and Cantagrel, 1980; Nehlig et al., 2001). These stratovolcanoes belong to the French Massif Central Province, one of the volcanic provinces associated with the European Cenozoic Rift System. The European 76 Cenozoic Rift System results from widespread lithospheric extension in the Alpine foreland, 77 following the formation of the Alps (Michon and Merle 2001, Michon et al. 2003). Large intraplate alkaline provinces (French Massif Central, Eifel, Vogelsberg, Eger graben...) are 78 79 associated with the later stages of rifting. In the French Massif Central, most of the volcanism 80 occurred in the last 14 Ma, with large stratovolcanoes active until about 250 ka (Cantagrel and 81 Baubron 1983), and monogenetic edifices forming as late as 6,700 years BP (Juvigné and 82 Miallier 2016). Alkaline magmas in the French Massif Central are associated with mantle 83 upwelling, which triggered melting of asthenospheric and lithospheric sources previously 84 metasomatized during the Variscan orogeny (e.g., Wilson and Downes 1991, Martin et al. 2017). 85

86 To the north of the Mont-Dore massif, the Guéry stratovolcano represents the oldest 87 volcanic center, dated between 3.85 and 1.47 Ma (Cantagrel and Baubron, 1983; Pastre and 88 Cantagrel, 2001; Nomade et al., 2014). The activity of the younger Sancy stratovolcano (Fig. 89 1) started 1.1 Ma ago and its products form the southern part of the Mont-Dore massif 90 (Nomade et al., 2012, Cantagrel and Baubron, 1983). According to Cantagrel and Baubron 91 (1983), the most recent eruptive activity of the Sancy stratovolcano is located in three areas 92 near the center of the stratovolcano: the Puy de Cliergues area, the Montagne de la Platte area 93 and the Roc de Cuzeau area (Fig. 1). Existing K/Ar ages for the youngest lava flows and 94 domes in these areas vary between 0.24 and 0.22 Ma with two sigma age uncertainties 95 between 0.04 and 0.10 Ma (Cantagrel and Baubron, 1983). The most recent known 96 pyroclastic unit is a distal Plinian deposit sampled in the Bouchet and Praclaux maars and dated by ${}^{40}\text{Ar}/{}^{39}\text{Ar}$ at 0.279 ± 0.011 Ma (Roger et al., 1999, as recalibrated by Nomade et al., 97 98 2012). Recent fieldwork in the Puy de Cliergues area has revealed the existence of a 99 previously unknown young pyroclastic unit and has highlighted discrepancies between the

volcanic stratigraphy observed in the field, and existing K/Ar ages, and was the incentive forthe present study.

102 The field area includes the Roc de Cuzeau itself (1737 m a.s.l.), one of the main 103 summits of the Sancy stratovolcano, and the area extending to the north down to the "Col de 104 la Croix Saint Robert" pass (Fig. 1). Detailed field mapping has been combined with previous 105 existing geological maps to provide an accurate map and stratigraphy of the field area 106 (Francomme, 2014). At the bottom of the sequence, the Plateau de Durbise is formed by the 107 superposition of three lava flows. The first flow is a 60 m thick heterogeneous trachytic 108 coulee that originates from the Puy de Cliergues to the west (Latutrie et al., 2017), and is 109 dated at 0.32 ± 0.06 Ma (Lavina, 1985). It is overlaid by two basaltic trachyandesitic flows, 110 each about 20-30 m thick, with the surface of the upper flow making the Plateau de Durbise. 111 The Roc de Cuzeau itself (0.23 ± 0.04 Ma, Cantagrel and Baubron, 1983) is a trachyandesitic 112 dome, possibly emplaced through the basaltic trachyandesitic flows.

113 A fourth basaltic trachyandesite flow crops out in the central part of the Durbise 114 plateau. This blocky lava flow has very fresh features, including surface ogives and a steep 115 flow front, and is dated at 0.25 ± 0.10 Ma (Cantagrel and Baubron, 1983). It will be referred 116 to as the "Upper Durbise Flow" in the following. Field observation and petrology suggest that 117 it is correlated to another basaltic trachyandesitic outcrop on the eastern flank of Roc de 118 Cuzeau and is stratigraphically on top of the Roc de Cuzeau dome (Francomme, 2014). This 119 stratigraphy disagrees with existing K/Ar ages (Cantagrel and Baubron, 1983), but the two 120 ages largely overlap within a one sigma error. The presence of a basaltic trachyandesite dyke 121 crosscutting the Roc de Cuzeau dome near its south edge confirms that basaltic 122 trachyandesites where emplaced after the dome.

Finally, a light-colored pyroclastic unit is visible in a 20 m long and 1 m high outcrop on the northeastern edge of the dome (45° 33.040' N, 2° 49.987 E, 1653 m a.s.l., Fig. 2). This

125 unit may have a higher extent but most of the area is covered with dense grass. This 126 previously unknown pyroclastic unit is stratigraphically on top of the dome, and on top of the 127 Upper Durbise Flow. It likely represents the product of the latest eruption in the Roc de 128 Cuzeau area (and possibly the latest eruption of the Sancy stratovolcano). This deposit is 129 composed of rounded pumices (5 to 30 cm diameter) and angular plutonic blocks (5 to 40 cm 130 diameter) in an ash matrix and can be characterized as a pumice-and-ash flow. It will be 131 referred thereafter as the "Cuzeau Pumice Flow". Similar pumices and plutonic blocks have 132 also been observed 1300 m to the south, on a ridge above the Valley de Chaudefour (Fig. 1), 133 suggesting a larger extent for this unit.

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135 3 - Analytical techniques

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137 3.1. U-Pb dating
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139 Zircons were separated at the Laboratoire Magmas et Volcans (LMV) using standard 140 techniques of crushing and sieving, followed by Wilfley table, magnetic separation and heavy 141 liquids before handpicking under binocular microscope. They were mounted in epoxy disks (EPO-TEK[®] 301 from Epoxy Technology Inc.) and ground and polished at 0.25µm to expose 142 143 crystal interiors. Cathodoluminescence (CL) and EDS imaging were conducted at LMV using 144 a JEOL JSM-5910LV SEM. U-Th-Pb isotopic data on zircons were obtained by laser ablation 145 inductively coupled plasma spectrometry (LA-ICP-MS) at the LMV (Clermont-Ferrand, 146 France) and reported in Table 1. The analyses involved the ablation of minerals with a 147 Resonetics M-50 laser system operating at a wavelength of 193 nm. Spot diameters of 73 µm 148 were associated to repetition rates of 3 Hz and fluency of 3.5 J/cm² resulting in a spot depth of 149 12-15 µm. This set up allows to significantly improve the signal intensity with a large spot-

150 size since the increase of the spot-size from 20 µm to 73 µm multiplies the signal intensity by 151 a factor of ten, while laser-induced elemental fractionation effects are minimized by using low 152 fluency and repetition rate. The ablated material was carried into helium and then mixed with 153 nitrogen and argon before injection into the plasma source of a Thermo Element XR Sector 154 Field high-resolution ICP-MS. The alignment of the instrument and mass calibration were 155 performed before every analytical session using the NIST SRM 612 reference glass, by inspecting the signals of ²³⁸U, ²³²Th and ²⁰⁸Pb and by minimising the ThO⁺/Th⁺ ratio. The 156 157 analytical method for isotope dating with laser ablation ICPMS (see Supplemental Data SD1 158 for details) is basically similar to that reported in Hurai et al. (2010), Paquette et al. (2014) and Mullen et al. (2018). The ²³⁵U signal is calculated from ²³⁸U on the basis of the ratio 159 238 U/ 235 U = 137.818 (Hiess et al., 2012). Single analyses consisted of 30 seconds of 160 161 background integration with laser off followed by 1 minute integration with the laser firing 162 and a 30 seconds delay to wash out the previous sample and prepare the next analysis.

163 Data are corrected for U-Pb fractionation occurring during laser sampling and for 164 instrumental mass bias by standard bracketing with repeated measurements of GJ-1 zircon 165 standards (Jackson et al., 2004). Repeated analyses of 91500 zircon reference material 166 (Wiedenbeck et al., 1995) during each analytical session and treated as unknown, 167 independently control the reproducibility and accuracy of the corrections. Data reduction was carried out with the software package GLITTER® from Macquarie Research Ltd (van 168 Achterbergh et al., 2001; Jackson et al., 2004). Common Pb and initial disequilibria caused by 169 ²³⁰Th/²³⁸U and ²³¹Pa/²³⁵U fractionation in the zircon/melt system were corrected according to 170 171 Sakata et al. (2015) and Sakata (2018) method and related Microsoft Excel spreadsheet. 172 Whole-rock Th and U contents and calculated Th/U_{melt} values of the studied samples (Table 173 2) were determined following the technique described in Vlastelic et al. (2015). The concentrations in U-Th-Pb were calibrated relative to the certified contents of GJ-1 zircon 174

175 (Jackson et al., 2004) reference material. The available fractionation factor of Pa/U in a 176 zircon-melt system of rhyolitic composition roughly shows agreement with a value of $2.9 \pm$ 177 1.0 (Sakata, 2018). This value and related uncertainty is propagated into the calculations for 178 the three samples. The isotopic ratios and ages together with all of the uncertainties were 179 corrected from elemental and isotopic fractionation, common Pb contribution and Th/U 180 disequilibria correction. Weighted mean 206 Pb/ 238 U ages and Concordia diagrams were 181 generated using Isoplot/Ex v. 2.49 software package by Ludwig (2001).

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183 3.2. Whole rocks major and trace element compositions

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Whole rock major element compositions were obtained by Inductively Coupled Plasma
Atomic Emission Spectroscopy (ICP – AES). Samples were fused using a LiBO₂ flux and
dissolved in HNO₃. Calibration was performed using reference materials GH (for Si, Na and
K) and BR (for other elements), both from CRPG, Nancy, France (Centre de Recherches
Petrographiques et Geochimiques), prepared in the same way as the unknown samples.

Whole-rock U and Th concentrations were obtained by Inductively Coupled Plasma Mass Spectrometry (Agilent Technologies ICP-MS 7500 Series) at LMV (see Vlastelic et al. 2015). The signal was calibrated against international standards BHVO-2 and BEN. The external reproducibility and the accuracy, estimated from repeated measurements of the standards, are lower than 10 %. The U and Th values obtained for the three investigated samples are shown in Table 2.

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197 4 – Sample description and petrography

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199 4.1. Roc de Cuzeau trachyandesitic dome (sample RC-03)

201 The Roc de Cuzeau dome is composed of a mesocratic to leucocratic trachyandesite, with 202 a porphytic microlitic texture. Large (up to 5 cm) sanidine megacrysts and amphibole, 203 clinopyroxene and plagioclase phenocrysts are set in a groundmass that also contains biotite, 204 magnetite, apatite and zircons. At the outcrop scale, the trachyandesite is heterogeneous, and 205 contains numerous quenched mafic enclaves, indicative of magma mixing, which is a widespread 206 phenomenon in the eruptive history of the Sancy stratovolcano (Gourgaud and Maury, 1984). 207 Evidence of magma mixing is also present at the thin section scale, including partial resorption of 208 the sanidine megacrysts which have rounded edges. The selected sample comes from the Western 209 end of the Roc de Cuzeau (45° 32.972' N, 2° 49.730 E, 1725 m a.s.l.), and is the one that shows 210 the least evidence of magma mixing. 211 212 4.2. Juvenile pumices from the Cuzeau Pumice Flow pyroclastic unit (sample RC-09a) 213 214 Juvenile pumices have a hyaline porphyritic texture, with phenocrysts of biotite, green 215 clinopyroxenes, sanidine, plagioclase, and minor apatite, zircon and magnetite in a glassy 216 matrix (Fig. 3a). Most phenocrysts are euhedral and unzoned, although inclusion of rounded 217 plagioclase crystals in sanidine phenocrysts may be indicative of some amount of magma 218 mixing. 219 220 4.3. Syenite xenolith from the Cuzeau Pumice Flow (sample RC-09b1) 221 222 Numerous angular syenitic fragments are present in the pumice deposit. Their size 223 vary from a few cm to about 40 cm. The representative sample investigated here is a quartz-224 syenite with a holocrystalline granular texture. Mafic and accessory minerals (clinopyroxene, 225 amphibole, magnetite, titanite, biotite, apatite, zircon) are mostly grouped in clusters (~9 % of 226 the sample, Fig. 3b), surrounded by mm-sized crystals of sanidine (~56 %) and plagioclase

(~27 %,). A small number of interstitial quartz crystals (~8 %) are present around mafic
mineral clusters.

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230 5. LA-ICP-MS zircon dating

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232 The zircon crystals from RC-09b1 syenite and RC-03 trachyandesite are large, 233 medium elongated, colourless and display a continuous euhedral growth (Fig. 4a). The large 234 size and their apparent textural consistency all along the growth of the zircon crystals confirm 235 that using large spot-size is a valuable strategy in this case. Cathodo-luminescence images are 236 poorly contrasted and display a fine oscillatory zoning (Fig. 4a) with some dark melt 237 inclusions, mostly sub-spherical blobs. In few grains from the syenite, dark centre domains 238 are evidenced that can be interpreted as a U and Th-enriched early growth phase. In the 239 syenite, most Th and U content are ranging from 200 to 400 ppm with maximum values of 240 2800 and 1600 ppm respectively. In the trachyandesite, Th and U content are lower, generally 241 ranging from 100 to 300 ppm. In the three dated samples, Th/U ratios yield constant 242 magmatic values of 1.1 ± 0.2 . In the RC-09a trachyte pumice, the zircon morphology looks 243 similar than in the two other samples, nevertheless under binocular microscope the crystals 244 appear less translucent, milkier with an irregular surface. In cathodo-luminescence (Fig. 4b), 245 oscillatory and sector zoning are combined. The same zircon grain imaged in backscattered 246 electrons mode (Fig. 4c) clearly shows that the light grey crystal faces are embedded by an 247 irregular darker phase. We performed EDS chemical mapping of both phases (Fig. 4h). 248 Unsurprisingly, the zircon crystal in the middle is enriched in Zr, Hf and Si (Fig. 4d and 4e). 249 The irregular overgrowth obviously contains more silica than zircon (Fig. 4e), as well as 250 significant amounts of Al, K and Na (Fig. 4f and 4g), which approximately corresponds to the 251 composition of the melt. This demonstrates that the zircons were already crystallized into the

liquid and, at the vicinity of the eruption time, this latter quenched rapidly and irregularly at
the zircon surface producing this trachyte glass mantle. Similar features have already been
reported in volcanic zircons (Miller and Wooden, 2004; McCormack, 2009; Schmitt et al.,
2011).

256 The analytical results are reported in the Table 1. 59 spots were performed on the 257 zircon grains from the RC-09b1 syenite and 56 common Pb and Th/U disequilibria-corrected zircon analyses yield a weighted mean 206 Pb/ 238 U concordant age of 277.6 ± 3.2 ka (Fig. 5a). 258 259 This age is interpreted as the crystallization age of the zircons in the magma chamber. In the 260 RC-03 trachyandesite, 41 spots were performed on individual zircons and 25 analyses yield a weighted mean ${}^{206}\text{Pb}/{}^{238}\text{U}$ concordant age of 284.4 ± 4.2 ka (Fig. 5b) taking into account the 261 262 common Pb and Th/U disequilibria correction. This age, equivalent within error limits to the 263 former one, is also interpreted as the crystallization age of the zircons. Analytical points of the 264 trachyandesite are often more discordant than those of the syenite owing to their lower U 265 content, producing lower radiogenic Pb content. Consequently, this low radiogenic Pb vs. 266 common Pb ratio moves the points toward the common Pb upper intercept and increase the 267 correction, discarding some points from the age calculation. For the RC-09a trachyte pumice, 32 analyses on 37 zircon spots yield a weighted mean 206 Pb/ 238 U concordant age of 260.1 ± 268 269 3.6 ka (Fig. 5c), taking into account the common Pb and Th/U disequilibria correction. Owing 270 to the peculiar character of the zircon morphology developed in the former paragraph, this age 271 characterizes the crystallization of the zircon, which should be very close to the eruption time. 272 In the three studied samples, no xenocrystic zircons and related inherited ages were 273 evidenced. The lack of zircon xenocryst may reflect limited assimilation of the basement or 274 resorption of zircon by Zr-undersaturated magma.

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276 6. Discussion

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278 6.1. Dating the latest magmatic activity of the Sancy stratovolcano

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This new precise dating is well integrated to the rare dataset of geochronological informations about the final activity of the Sancy stratovolcano (Cantagrel and Baubron, 1983; Lavina, 1985; Nomade et al., 2012; Pastre and Cantagrel, 2001). These new dates improve the precision on the ages of the latest eruptive activity by a factor of ten and resolve significant inconsistencies between field observation and the existing inaccurate age data.

285 The age of 260.1 ± 3.6 ka for the Cuzeau Pumice Flow is significantly younger than 286 existing ages for silicic pyroclastic activity from the Sancy stratovolcano. The latest 287 pyroclastic cycle of the Sancy stratovolcano (phase III of Pastre and Cantagrel, 2001, cycle IV 288 of Nomade et al., 2012) is characterized by trachytic products with phenocrysts of green 289 clinopyroxene, biotite, two feldspars and titanite (Pastre and Cantagrel, 2001), very similar to 290 the pyroclastic unit investigated here. There are only two recent accurate ages for this pyroclastic cycle, both obtained by ${}^{40}\text{Ar}/{}^{39}\text{Ar}$ dating of sanidine crystals: 392 ± 14 ka for the 291 292 Barbier unit (Nomade et al., 2012), and 279 ± 11 ka for a distal Plinian deposit sampled in the 293 Lac du Bouchet and Praclaux maars (Roger et al., 1999, as recalibrated by Nomade et al., 294 2012). Pastre and Cantagrel (2001), however, list a few poorly dated units around 0.3 Ma. The 295 260.1 ka - old Cuzeau Pumice Flow is thus the youngest pyroclastic deposit of the Sancy 296 stratovolcano and marks the end of the pyroclastic cycle IV of Nomade et al. (2012), which 297 lasted at least 144 ka.

Field evidence (Francomme, 2014) indicates that the Cuzeau Pumice Flow is younger than the Upper Durbise Flow that was so far considered the youngest volcanic activity in this area (Cantagrel and Baubron, 1983). This lava flow is dated at 0.25 ± 0.10 Ma by K/Ar (Cantagrel and Baubron, 1983). Due to the significant error on this value, the two ages of the 302 Cuzeau Pumice Flow and the Upper Durbise Flow largely overlap. According to our new 303 results and taking into account their respective uncertainties, the Upper Durbise flow is 304 younger than 288.6 ka (oldest possible age of the Cuzeau dome) and older than 256.5 ka 305 (youngest possible age of the Cuzeau Pumice Flow), giving a more likely age of 273 ± 16 ka. 306 Other young mafic lava flows in the Sancy stratovolcano have been dated at 0.24 ± 0.06 Ma 307 (Puv de Cliergues, Cantagrel and Baubron, 1983) and 0.22 ± 0.04 Ma (Montagne de la Platte, 308 Cantagrel in Lavina 1985), all within error of the ages of the Upper Durbise Flow. Those 309 three mafic flows crop out on the upper slopes of the volcano, but the Upper Durbise flow has 310 fresher morphologies than the two other flows. Given the fact that ages are indistinguishable 311 within error, and that all three flows have similar chemistries, it is reasonable to assume that 312 all three flows have almost the same age, and that the Upper Durbise Flow is slightly younger 313 than the other two because of its fresher morphologies. This would indicate that silicic and 314 mafic magmas were both emplaced near the end of the stratovolcano activity, and that activity 315 ended around 260.1 ± 3.6 ka, after a lifetime of about 950 ka for the Sancy stratovolcano.

316 The zircon age of 284.4 \pm 4.2 ka places an upper limit on the age of the Roc de 317 Cuzeau dome emplacement. There is no constraint to establish if the zircon crystallization 318 began significantly before the eruption. This age is older but in reasonable agreement with the 319 230 ± 40 Ma K/Ar age determined by Cantagrel in Lavina (1985). The new age of the Roc de 320 Cuzeau dome is also within 2σ error of the 279 ± 11 ka age of the distal fall deposits reported 321 from sedimentary sequences in the Bouchet and Praclaux maars (Roger et al., 1999). Given 322 their age range and mineralogy, these tephras are very likely to originate from the Sancy 323 stratovolcano but no proximal deposit of this age has been found so far. It is possible that 324 these distal fall deposits correspond to an early Plinian magmatic phase of the Roc de Cuzeau 325 system, before dome emplacement, whose proximal deposits are hidden by the dome and 326 have not been sampled yet.

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328 6.2. Dating of the timescale of a small chamber producing discrete batches of magma.

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Magma storage timescale vary from 10^2 to 10^6 years in silicic systems due to the age, 330 331 composition and structural characteristics of the host region (Brown and Smith, 2004; 332 McCormack et al., 2009). Storage timescales can be constrained using the crystallization age 333 of zircon and later crystallizing minerals. Complicated and discontinuous age spectra indicate 334 phenocrysts, antecrysts and xenocrysts present in a single eruption (Charlier et al., 2005). It is 335 assumed that this difference between zircon age spectra is the results of different geological 336 conditions. The Roc de Cuzeau is a small-volume dome associated to pyroclastic units. It is 337 characterized by a different temporal evolution of magmatic processes compared to large-338 volume silicic volcanic systems.

339 All the investigated samples plot in the general differentiation trend of the Sancy 340 stratovolcano. The trachyandesitic lava of the Roc de Cuzeau dome is already differentiated 341 (56.0 wt% SiO₂, Mg# 36.4, Table 2). However, significant additional differentiation occurred 342 between the trachyandesite and the trachytic pumice (61.4 wt% SiO₂, Mg# 27.3, Table 2). 343 The bulk composition of the syenite is difficult to interpret: it may have crystallized "en-344 masse" and its bulk composition is the composition of a liquid, but since it is coarse grained, 345 melt extraction and/or crystal accumulation cannot be excluded. Its bulk composition is, 346 however, close to the bulk composition of the trachytic pumice (62.9 wt% SiO₂, Mg# 32.0, 347 Table 2). It thus cannot be a cumulate counterpart to either the trachyandesite or the trachyte, 348 and most likely represent a plutonic equivalent of the trachyte, possibly crystallized on the 349 edges of the magma chamber after the dome-forming eruption. Similar compositions, close 350 geographic association, and closely spaced ages strongly suggest all three samples belong to 351 the same magmatic system.

352 Syenite xenoliths and the neighbouring trachyandesitic lava were dated at 277.6 ± 3.2 353 ka and 284.4 \pm 4.2 ka, respectively. Both magmatic events cannot be distinguished within 354 uncertainties. A late trachytic pumice was emplaced at 260.1 ± 3.6 ka. Considering the ages 355 and related analytical precision obtained on the three different samples, the timescale of the 356 magmatic activity is estimated at 24 ± 8 ka, which is a minimum evolution time for a small 357 magma chamber associated to a low volume of magma for this late volcanic event. Such a 358 duration is obviously not related to an accumulation of large amounts of rhyolitic magmas 359 over slightly longer timescales. Similar age within error limits for the syenite and the 360 trachyandesite demonstrates a non-resolvable residence time of the zircon in the magma 361 chamber between crystallization and eruption. Nevertheless, the syenite does not represent the 362 cumulate counterpart of the synchronous trachyandesite. Consequently, this 24 ka duration 363 should be considered as a minimum estimate because older rocks from this magmatic system 364 may be present at depth. We do not observe any remobilization of xenocrystic zircon from the magma chamber and/or the volcanic and plutonic basement. No complex growth history of 365 366 the zircon crystals characterized by the older cores-younger rims evolution frequently 367 observed in the large volcanic systems was recorded here. The lack of any inherited zircon is 368 in agreement with a lithospheric mantle source without significant crustal contamination 369 (Briot, 1990).

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371 7. Conclusion

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We performed U-Pb zircon dating on one of the latest volcanic event from the Sancy stratovolcano located in the French Massif Central. Precise LA-ICP-MS dating of Pleistocene magmatic zircons was obtained with uncertainties of 3-4 ka and allow to clearly distinguish the evolution of these late magmatic events within the complex volcanic activity of this large 377 stratovolcano. Syenite xenoliths and the neighbouring trachytic lava were dated at 277.6 \pm 3.2 378 ka and 284.4 \pm 4.2 ka, respectively, whereas a late trachyandesitic pumice was emplaced at 379 260.1 \pm 3.6 ka.

380 Comparison between the ages of a series of trachyandesitic lava, trachytic pumice and 381 cognate syenitic cumulates allows to determine a minimum evolution time of about 24 ± 8 ka 382 for a small magma chamber. It corresponds to the lifetime of a reduced magma chamber 383 associated to a low volume of magma for this late volcanic event, which should be compared 384 to the hundreds of thousands of years reported for large volcanic systems. These data also 385 constrain the latest activity of the Sancy stratovolcano, one of the largest and youngest 386 stratovolcano in the Western European Rift System, with the last eruptive phases around 250 387 ka.

388

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396	This is L	aboratory	of Excel	lence (ClerVol	c contribution	1 number	332.
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590 Figure Captions:

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592 Figure 1. Geographic extension of the deposits of the Sancy stratovolcano (redrawn after 593 Brousse et al. 1989, 1990, Cantagrel and Baubron 1983, Nomade et al. 2017). The three 594 youngest flow are drawn in grey: 1. Highest flow in the Puy de Cliergues area dated at 0.24 \pm 595 0.06 Ma (Cantagrel and Baubron, 1983); 2. Upper Durbise Flow dated at 0.25 \pm 0.10 Ma 596 (Cantagrel and Baubron, 1983) or 258 ± 13 ka (this study); 3. Cinder cone and flow of 597 Montagne de la Platte dated at 0.22 ± 0.04 Ma (Cantagrel in Lavina, 1985). An enlarged 598 topographic map of the Durbise-Cuzeau area shows the location of the investigated samples 599 (RC30 marks the second outcrop of the Cuzeau Pumice Flow) on the 10-m DEM of France 600 (IGN).

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Figure 2. Main outcrop of the Cuzeau Pumice Flow (outcrop RC-09, picture taken September2015).

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Figure 3. (a, b) Texture and mineralogy of sample RC-09b1 (syenite xenolith) seen in planepolarized light (a) and cross-polarized light (b). (c) Texture and mineralogy of sample RC-09a
(trachytic pumice) seen in plane-polarized light.

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Figure 4. Scanning Electron Microscope images of the zircon crystals. a) cathodoluminescence (CL) image of a zircon crystal from the RC-09b1 syenite showing an oscillatory zoning and an U and Th-enriched dark inner domain. b) CL image of a zircon crystal from the RC09a trachyte pumice showing an oscillatory zoning and the laser spot. c) Backscattered (BSE) image of the former zircon crystal. An irregular dark grey rim covering the zircon crystal is evidenced with a thin white outline. d-e-f-g) Zr, Si, Al and K chemical maps of the

615	zircon crystal and its outer irregular rim obtained by energy dispersive X-ray spectroscopy
616	(EDS). h) Cumulative chemical map showing a Zr-Si purple euhedral zircon crystal
617	surrounded by a Si-Al-K orange rim of volcanic glass. The thin outline appears Al-enriched.
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619	Figure 5. Concordia diagrams of the dated samples are plotted on the left column. Individual
620	uncorrected analyses are represented by error ellipses and common Pb and U-Th disequilibria
621	corrected weighted means are represented by red squares on the Concordia curve.
622	Corresponding detailed diagrams of individual ²⁰⁶ Pb/ ²³⁸ U corrected ages are represented on
623	the right column.
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627	Tables content:
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629	Table 1. Zircon U-Th-Pb data from the dated samples obtained by in situ Laser Ablation ICP-
630	MS.
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632	Table 2. Whole rock major elements and concentrations of U and Th in the investigated
633	trachyandesite (RC-03), trachytic pumice (RC-09a) and syenite (RC-09b1) of the Sancy
634	volcano.
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