Multiple sources for tephra from AD 1259 volcanic signal in Antarctic ice cores

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Biancamaria Narcisi, Jean Robert Petit, Barbara Delmonte, Valentina Batanova, Joel Savarino. Multiple sources for tephra from AD 1259 volcanic signal in Antarctic ice cores. *Quaternary Science Reviews*, 2019, 210, pp.164-174. 10.1016/j.quascirev.2019.03.005 . hal-02350371

HAL Id: hal-02350371

<https://hal.science/hal-02350371>

Submitted on 25 Nov 2020

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Manuscript Details

Manuscript number JQSR_2019_21

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Strong volcanic signals simultaneously recorded in polar ice sheets are commonly assigned to major low-latitude eruptions that dispersed large quantities of aerosols in the global atmosphere with the potential of inducing climate perturbations. Parent eruptions responsible for specific events are typically deduced from matching to a known volcanic eruption having coincidental date. However, more robust source linkage can be achieved only through geochemical characterisation of the airborne volcanic glass products (tephra) sometimes preserved in the polar strata. We analysed fine-grained tephra particles extracted from layers of the AD 1259 major bipolar volcanic signal in four East Antarctic ice cores drilled in different widely-spaced locations of the Plateau. The very large database of glass-shard geochemistry combined with grain size analyses consistently indicate that the material was sourced from multiple distinct eruptions. These are the AD 1257 mega-eruption of Samalas volcano in Indonesia, recently proposed to be the single event responsible for the polar signal, as well as a newly-identified Antarctic eruption occurred in AD 1259. Finally, a further eruption that took place somewhere outside Antarctica has contributed to tephra deposition. Our high-resolution, multiple-site approach was critical to reveal spatial heterogeneity of tephra at the continental scale. Evidence from ice-core tephra indicates recurrent explosive activity at the Antarctic volcanoes and could have implications for improved reconstruction of post-volcanic effects on climate from proxy polar records.

Submission Files Included in this PDF

File Name [File Type]

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Fig1_sample position_dic18.pdf [Figure]

figura 2_v3.JPG [Figure]

Fig3_micro foto dic 2018.pdf [Figure]

Fig4_TAS_AD1259_thin+ comp.pdf [Figure]

Fig5_TASthin_trend TD.pdf [Figure]

Supplementary_AD1259_rev2019.docx [MethodsX]

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Microprobe single-grain data are given as Supplementary Material along with details of analytical conditions

MULTIPLE SOURCES FOR TEPHRA FROM AD 1259 VOLCANIC SIGNAL IN ANTARCTIC ICE CORES

Biancamaria Narcisi¹, Jean Robert Petit², Barbara Delmonte³, Valentina Batanova⁴, Joël Savarino²

(1) ENEA, C.R. Casaccia, 00123 Roma, Italy, biancamaria.narcisi@enea.it

(2) Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, 38000 Grenoble, France

(3) Department of Earth and Environmental Sciences (DISAT), Univ. Milano-Bicocca, Piazza della Scienza, 20126 Milano, Italy

(4) Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France

Abstract

Strong volcanic signals simultaneously recorded in polar ice sheets are commonly assigned to major low-latitude eruptions that dispersed large quantities of aerosols in the global atmosphere with the potential of inducing climate perturbations. Parent eruptions responsible for specific events are typically deduced from matching to a known volcanic eruption having coincidental date. However, more robust source linkage can be achieved only through geochemical characterisation of the airborne volcanic glass products (tephra) sometimes preserved in the polar strata. We analysed fine-grained tephra particles extracted from layers of the AD 1259 major bipolar volcanic signal in four East Antarctic ice cores drilled in different widely-spaced locations of the Plateau. The very large database of glass-shard geochemistry combined with grain size analyses consistently indicate that the material was sourced from multiple distinct eruptions. These are the AD 1257 mega-eruption of Samalas volcano in Indonesia, recently proposed to be the single event responsible for the polar signal, as well as a newly-identified Antarctic eruption occurred in AD 1259. Finally, a further eruption that took place somewhere outside Antarctica has contributed to tephra deposition. Our high-resolution, multiple-site approach was critical to reveal spatial heterogeneity of tephra at the continental scale. Evidence from ice-core tephra indicates recurrent explosive activity at the Antarctic volcanoes and could have implications for improved reconstruction of post-volcanic effects on climate from proxy polar records.

35 **Highlights**

- 36 • Significant tephra concentration in AD 1259 volcanic signal from four Antarctic ice cores
37 • Compositional heterogeneity of tephra suggests sourcing from multiple distinct eruptions
38 • Linkage of the Antarctic ice signal with the Samalas AD 1257 eruption confirmed
39 • A new Antarctic eruption that occurred in AD 1259 has been also identified
40 • Antarctic regional-scale effects of local volcanic activity conceivable

41 **Key words:** Cryptotephra; Antarctica; Ice Cores; Volcanic isochron; Glass shard
42 microanalysis; Antarctic rifting volcanism; Samalas AD 1257 eruption

1. Introduction

As ~~it is~~ documented in the vast literature produced during the last four decades, continuous volcanic profiles from polar ice sheets reconstructed by electric conductivity (ECM) and sulphate measurements are punctuated by prominent spikes recording explosive eruptions of the past (e.g., Hammer, 1980; Delmas et al., 1992; Langway et al., 1995; Severi et al., 2012; Sigl et al., 2014, 2015). These signals can be used both as reference horizons to provide independent age constraints for the ice core series, and to reconstruct the history of explosive volcanism and its relationship with climate. Volcanic events with bipolar occurrence are particularly interesting in this respect. These are typically interpreted as related to massive low-latitude events capable to produce sulphuric acidic deposition all over the world with the potential of forcing global climate (e.g., Langway et al., 1995; Sigl et al., 2015). Their record in both polar regions also enables direct north-south synchronisation of ice stratigraphies, which is of crucial importance to reconstruct the phasing of climatic events and understanding underlying mechanisms (Svensson et al., 2013).

Among the most outstanding volcanic deposition events of the last 2 millennia (Sigl et al., 2014), peak fallout of volcanic aerosols over the poles dated ~~AD~~ 1259 represents a fundamental age marker for ice chronologies. Its signal is recorded in several Greenland and Antarctic ice cores, and was initially identified by Langway et al. (1988), who suggested that the parent volcano could be probably located in the Northern Hemisphere close to Equator. Since then, numerous papers have considered various aspects of this event (e.g. Delmas et al., 1992; Zielinski, 1995; Stothers, 2000). Particularly, its source has been a matter of debate as until recently no record of large volcanic eruption around that date was known. On the basis of analysis of tiny glass shards, Palais et al. (1992) suggested that the material from Greenland and South Pole (SP) ice levels is indeed from the same volcano, and identified El Chichón, Mexico, as the probable source, despite the chemical match was not perfect in detail. Oppenheimer (2003) presented the hypothesis of a super-eruption of global significance or a smaller eruption enriched in sulphur. Baroni et al. (2008) used sulphur isotope analysis to indicate a stratospheric nature for the volcanic signals at the Antarctic Dome C and SP sites. More recently, a major caldera explosive event was identified at Samalas volcano, on Lombok Island, Indonesia (Lavigne et al., 2013, Vidal et al., 2015, 2016; Alloway et al., 2017). Based upon chronostratigraphic and geochemical studies nearby the source, and the analysis of historical texts, this eruption of exceptional size was dated at AD 1257, placed at the end of the Medieval Warm Period (ca. 900-1250 A.D., Mann et al., 2009). It has been inferred to be the single counterpart of the AD 1259 bipolar spike. In particular, according to a recent reconstruction of Antarctic continental-scale volcanic aerosol deposition, the sulphate injection greatly exceeded that of the AD 1815 cataclysmic Tambora eruption (Sigl et al., 2014).

When strong explosive volcanic eruptions occur, large quantities of solid particles (tephra) and gases penetrate the tropopause and rise to altitudes well within the stratosphere, where they can be distributed all around the globe. Tephra fallout can affect vast regions, and small particles can be deposited thousands of kilometres from active sources forming invisible horizons (e.g., Lowe, 2011; Ponomareva et al., 2015, and references therein). The fingerprint of volcanic material preserved in distant sites can univocally identify source areas and could be employed to disentangle the origin of volcanic glacio-chemical signals in polar ice cores

(e.g., Yalcin et al., 2006; Dunbar et al., 2017), that otherwise is conjectured from the record of documented eruptions. However, especially for tropical-equatorial eruptions the amount of tephra that could be dispersed towards the poles is typically very small and the material very fine-grained, making such tephra study very challenging.

A preliminary exploratory investigation of a shallow Antarctic ice core from the Concordia-Dome C site revealed evidence of an appreciable concentration of cryptotephra in connection with the AD 1259 sulphate peak (Petit et al., 2016). This intriguing observation prompted us to carry out a detailed tephra study in order to make inferences about source(s) that produced the tephra and to discuss the related atmospheric implications. In this work we describe the characteristics of the glassy volcanic material associated with the AD 1259 signal in different sectors of the East Antarctic Plateau (EAP). We took advantage of having access to various good-quality ice cores covering the last millennium to apply a multiple core approach that allows highlighting the spatial distribution of volcanic products. Note that while attempts to identify the parent eruption of major polar signals through a tephra study often rely on few shards (e.g., Zielinski et al., 1997; Barbante et al., 2013), here we obtained a large dataset based on a considerable amount of electron probe microanalyses that allows recognizing compositional heterogeneities within tephra, in association with ash grain size measurements. We also considered an inventory of candidate source volcanoes more extended than that employed in previous studies.

2. Materials and Methods

In this study we used 4 EAP ice cores located at elevations between 1950 and 3488 m (Figure 1 and Table S1). Two core sites, Dome C-Concordia (DC) and Vostok (VK), are located ~ 600 km apart in the central, inner sector of the Plateau, and two, Talos Dome-TALDICE (TD) and GV7, are ~ 200 km apart in peripheral position facing the Ross Sea. They show different modern climate and atmospheric characteristics (e.g., Masson-Delmotte et al., 2011) as well as distance from the Quaternary volcanoes of the Antarctic rift provinces. All the cores used have an undisturbed stratigraphy and are provided with a detailed volcanic aerosol profile, either as sulphate or ECM measurements. They all show the broad and pronounced signal unambiguously related to the AD 1259 event that occurs at variable depth depending on the accumulation rate of the site (between 29.6 m at VK and 181.9 m at GV7, Figure 1a).

Since at the visual core inspection no macroscopic evidence for the presence of tephra was detected, the core depth intervals corresponding to the volcanic spike were sub-sampled continuously, albeit with different resolution (5 to 15 cm) depending on the local accumulation rate. Processing of subsamples for laboratory measurements was carried out under clean conditions. To reduce contamination of samples to a minimum, the outer portion of porous firn samples was removed with a clean ceramic knife while ice pieces were washed thrice in ultrapure water. The resulting decontaminated samples were then melted and an aliquot was used for quantitative measurements of dust concentration and size distribution using a Coulter Counter set up in a class 100 clean room (Delmonte et al., 2002). The only exception relates to the GV7 core, where presence of abundant drilling fluid prevented accurate Coulter Counter measurements. A separate aliquot of meltwater from levels showing unusually high concentration of particles with respect to the local background was filtered (nucleopore polycarbonate membranes) for tephra recovery. Filters were examined using light and scanning electron microscopes, and typical tephra grains were

132 photographed (Figure 2). To investigate the source for the recovered material, we
133 determined the major element composition of individual shards using the electron
134 microprobe set up at the Institut des Sciences de la Terre (ISTerre) of Grenoble. The
135 operating details are given in the Supplementary Material.

136 From the initial geochemical dataset (over 900 analyses) collected during different sessions,
137 we cautiously discarded analytical data showing total oxide sums $\leq 60\%$ and those obviously
138 related to pure minerals (quartz, plagioclase, metals, etc.). The rest, consisting of ~ 320
139 measurements generally made on very small individual glass particles, was normalised to
140 100% total oxide values for subsequent interpretation. We expect a decrease of precision but
141 after normalisation all the elements with oxide contents $> 1\%$ can be considered robust
142 enough for interpretation (Iverson et al., 2017).

143 3. Results

144 EAP core samples selected at the culmination of the volcanic spike show microparticle
145 concentrations well above background levels for each site (Fig. 2). Central Plateau samples
146 show concentrations higher (a factor 6 to 10) than background levels for firn (~ 8 ppb,
147 Delmonte et al., 2013) and mass size distributions well-defined around modal values smaller
148 than background (~ 2 μm on average during Holocene, Delmonte et al., 2005). For DC, the
149 mode is around 1.7 μm , while for VK it is between 1.3 μm and 1.9 μm respectively for samples
150 VK-16 and VK-14, although some very large particles up to ~ 20 μm were included in the
151 latter.

152 TD sample 87-1 from the base of the volcanic sulphate peak shows very large particles with
153 mass modal values as high as ~ 6 μm , associated with concentration levels higher than ~ 10
154 times background levels for firn (~ 12 ppb, Delmonte et al., 2013). From the lowermost to the
155 uppermost part of the volcanic spike (see Figure 1a for stratigraphic position of the samples),
156 a progressive decrease in microparticle concentration and size can be observed. A
157 population of particles larger than ~ 5 μm is present in the two deepest samples (TD 87-1 and
158 86-4), while the relative abundance of particles smaller than 2 μm increases upward within
159 the peak. We note that sample 86-4 shows a bimodal distribution with a first mode smaller
160 than 2 μm and a larger mode around 4-6 μm .

161 At the microscopic inspection, glass particles generally display well-preserved textures with
162 no traces of abrasion strongly suggesting that the material was not subject to reworking
163 (Figure 3). Among the examined samples, TD 87-1 and 86-4 contain pumice particles with
164 elongated vesicles up to ca. 40-50 μm long along with fine-size shards remnants of thin
165 vesicle walls. Particles in the filters from the inner EAP cores are typically represented by tiny
166 curved and platy-like shards. Material from sample VK-14 contains glass particles up to 15-20
167 μm in size. Microscopic observations coupled with grain size analysis exclude that the
168 volcanic material belongs to background dust, and instead provide compelling evidence of
169 primary tephra deposition at levels within the AD 1259 acidity peak.

170 Results of grain-specific geochemical analysis are illustrated in Figs 4-5, where the data are
171 plotted on the total alkali-silica (TAS) diagram. Silica co-variations with K_2O , CaO , FeO and
172 Al_2O_3 , not shown here, are coherent in providing the same chemical pattern. Representative
173 analyses of individual glass shards are presented in Table S3, along with biplot comparisons

174 of selected major-oxide ratios in the present data and in published literature for further
175 potential source volcanoes and equivalents (Supplementary Material).

176 The analysed glass shards, taken altogether, display variable silica contents, from
177 intermediate to evolved compositions ($\text{SiO}_2 > 52$ wt %). No basic and ultrabasic
178 geochemistries are represented. Within the glass heterogeneous composition spreading over
179 three TAS fields, we identify two main separate clusters of data, one trachytic falling in the
180 alkaline field, $\sim 63\text{--}65$ wt %, and the other showing sub-alkaline affinity and straddling the
181 trachyte-dacite-rhyolite boundaries (for brevity referred to hereafter as 'dacitic'), ~ 70 wt %. A
182 third subpopulation, subordinate in terms of frequency, shows a siliceous rhyolitic
183 composition ($\text{SiO}_2 > 74$ wt %).

184 Volcanic glass composition also varies spatially (Figure 4a). Ice core shards from the Central
185 EAP sites are predominantly sub-alkaline in composition. However, the three analysed
186 samples display different characteristics. The very fine-grained DC sample and sample VK-14
187 also dominantly dacitic. Sample VK-16 displays two clusters of geochemical data. The main
188 glass population is dacitic in composition and appears comparable with that in sample VK-14
189 and in DC, the subordinate population is a siliceous rhyolite. Sparse analyses from both VK
190 samples fall within the trachytic glass group.

191
192 In all six ice sections from the two peripheral EAP sites trachytic tephra particles are
193 dominating, but with occurrence of subordinate glass with different signature (Fig. 4a). At TD,
194 we observe an interesting compositional variation with respect to the time-stratigraphic
195 position of the samples (Figure 5). Volcanic ash on the TD 87-1 filter, situated at the very
196 beginning of the sulphate fallout (Figure 1) and containing coarse particles, is mainly
197 trachytic in composition. The adjacent TD 86-4 from the acme of the sulphate volcanic signal
198 shows two main coexisting glass populations. This is consistent with the striking bimodal
199 grain size distribution of this sample (Figure 2). According to scanning electron microscopic
200 check during microprobe analysis, coarser particles correspond to trachyte, finer particles
201 are mostly dacitic. Glass from the upper TD 86 samples -3 and -2, stratigraphically located at
202 the later part of the spike and populated by fine particles, is trachytic. GV7 ice shows co-
203 existing trachytic and dacitic geochemistries (Figure 4a). The two analysed samples are
204 equally heterogeneous (not shown). In all samples from the peripheral cores, only one shard
205 from TD falls within the rhyolite cluster identified in VK-16 (Figure 4a).

206

207 **4. Interpretation and discussion**

208

209 *4.1 Identification of tephra sources*

210

211 Filters from all studied cores contain significant volcanic glass that appears heterogeneous
212 both in grain size and geochemistry and present variable spatial characteristics.

213 Taken as a whole, the composition of glass shards allows two prevailing and a third
214 subsidiary populations to be distinguished. Trachytic shards are more abundant in the
215 samples from peripheral EAP sites, which are characterised by coarser grain size. Dacitic
216 shards occur in all sites but are dominating in the Central EAP samples, typically
217 characterised by smaller particle size. This pattern ~~already~~ suggests that tephra transport

218 and deposition could be controlled by different atmospheric dynamics over the Plateau.
219 Although tephra transport is very different from background dust input onto the EAP (Narcisi
220 et al., 2005), mineral dust investigations highlighted that the periphery of the ice sheet ~~in fact~~
221 is influenced by regional atmospheric circulation dynamics of the Western Ross Sea, while
222 sites from the inner part of the EAP are more sensitive to long-range high-altitude transport
223 above Antarctica (e.g., Delmonte et al., 2013).

224 Focusing on the geochemical signature of volcanic glass as a major criterion for source
225 identification, we first point out that compositional heterogeneity in a tephra horizon could
226 be related to magmatic differentiation during a single parent explosive episode or to coeval
227 deposition from separate events. Several examples of both types of tephra are known in
228 Antarctic ice (e.g., Narcisi et al., 2016). Since alkaline (i.e. trachytic) composition and sub-
229 alkaline (i.e. dacitic) composition typically pertain to different tectonic settings, here we
230 interpret co-existing trachytic and dacitic tephtras in the studied samples as related to
231 contemporaneous eruptions from independent sources.

232 Alkaline trachytic compositions are characteristic of Antarctic volcanoes, belonging to one of
233 the largest active alkali rift systems of the world (Werner, 1989). Indeed, the identified
234 trachytic glass shards, particularly copious in the filters from peripheral cores that are
235 adjacent to Victoria Land volcanic provinces, **is chemically very consistent with compositions**
236 **of the tephra layers in the TALDICE core originated from local sources during the last climatic**
237 **cycle** (Narcisi et al., 2012, 2016, 2017) (Figure 4b). We therefore deduce that the trachytic
238 glass in the studied samples was produced by a local Antarctic explosive eruption ~~occurred~~ at
239 AD 1259. The coarse particle size observed at TD which is ~ 200 km distant from **the inferred**
240 **source area**, further supports this interpretation. This event dispersed material mostly over
241 **the adjacent ice sheet region**, but the ash deposition involved also more inland areas of the
242 EAP, as the occurrence of sporadic trachytic shards in the VK samples demonstrates.
243 Infrequent ash layers of Antarctic derivation in long cores from the EAP have been already
244 observed within the last four glacial-interglacial cycle ice series (e.g., Narcisi et al., 2010). We
245 infer that the Antarctic volcanic plume entered into the polar vortex circulation and then
246 rapidly reached the inner sectors of the Plateau. Based on the available data, it is unclear
247 whether the plume from the AD 1259 Antarctic eruption dispersed particulate material onto
248 the SP area. In the early tephra investigation by Palais et al. (1992), no trace of trachytic glass
249 is reported for the Antarctic ice core. That tephra study however, was based upon the
250 analysis of a handful of volcanic particles, representing a limitation for the detection of
251 compositional heterogeneity and multiple fingerprints within individual horizons. Finally,
252 similarly to other local eruptions, this Antarctic event likely delivered sulphate aerosols, but
253 this is difficult to detect as it is combined with the coincidental broad signal peaking at AD
254 1259 related to long-range stratospheric transport and deposition of aerosols and generated
255 during an extra-Antarctic source event (see discussion below). Note that examples of circa-
256 coeval multiple eruptions manifesting as a single volcanic signal are known in the Antarctic
257 ice record (Cole-Dai and Mosley-Thompson, 1999; Cole-Dai et al., 2000). They represent tricky
258 case studies for estimation of atmospheric aerosol loadings by related eruptions, with
259 implications for assessment of the real impact on climate (e.g., Timmreck et al., 2009).

260 Our discovery of Antarctic-sourced tephra associated with the AD 1259 acidic deposition is
261 remarkable given the postulated tropical source of the eruption responsible for this polar

262 signal (e.g., Sigl et al., 2015). Nevertheless it is not particularly surprising considering that
263 Antarctic volcanoes from Victoria Land and Marie Byrd Land show evidence of Holocene-
264 historical activity and ice cores drilled adjacent to volcanoes contain numerous locally
265 derived discrete tephra layers, sometimes in the form of invisible horizons, as a result of
266 persistent explosive activity (e.g., Kurbatov et al., 2006; Narcisi et al., 2012). In this respect,
267 we point out that the local eruption identified here does not correspond to the Antarctic
268 event dated 1254 ± 2 AD that produced widespread tephra deposition over most of the
269 Pacific-facing sector of Antarctica (Narcisi and Petit, 2018, and references therein). At TD and
270 GV7 in fact this eruption occurs as both coarse visible ash and a sharp sulphate spike
271 standing well above the background values and clearly preceding the AD 1259 volcanic peak
272 (e.g., Narcisi et al., 2001; Severi et al., 2012). The newly identified event neither corresponds
273 to the local eruption at AD 1261 detected as both volcanic sulphate deposition and a large
274 particle concentration peak in the West Antarctic Ice Sheet (WAIS) Divide ice core (Koffman et
275 al., 2013) that clearly follows the AD 1259 signal. Therefore, within a decade three distinct
276 local events took place in the Antarctic mainland that left tangible fallout traces in the ice
277 sheet. Such rapid succession of eruptions could be overlooked in low time resolution studies
278 and instead needs to be carefully considered when addressing the attribution of Antarctic
279 ice-core signals, as having implications for reconstructions of volcanic forcing.

280 The main sub-alkaline component of dacitic composition is genetically linked to subduction-
281 related volcanism. Differently from the trachytic glass, it is not straightforward to identify the
282 source responsible for this tephra. The distant geographic location of the EAP with respect to
283 subduction provinces provides no clues, and the tiny particle size of the volcanic material in
284 the Central EAP ice suggests long-distance transport, thus enlarging the suite of potential
285 source areas to be considered to the whole Southern Hemisphere and even beyond the
286 Equator. Note in this respect that although not very frequently, ash produced in equatorial-
287 tropical volcanoes could have reached Antarctica during past eruptions, as in the case of
288 Pinatubo ($15^{\circ}14'N$) tephra ($2\text{--}10\text{ }\mu\text{m}$) identified in the 1993-94 snow layers at South Pole after
289 the 1991 eruption (Cole-Dai et al., 1997). In the search for possible sources for the dacitic
290 tephra, we therefore considered an extended inventory of volcanoes. A thorough discussion
291 of this piece of our work is presented in Supplementary Material.

292 The recently discovered volcanic eruption of Samalas in the Indonesian Archipelago ($8^{\circ}33'S$)
293 was suggested as the most probable source for the AD 1259 polar spike, due to its
294 exceptional size (estimated VEI and maximum plume height 7 and 43 km, respectively) and
295 appropriate date (e.g., Lavigne et al., 2013; Vidal et al., 2015, 2016; Alloway et al., 2017).
296 Indeed, we found ~~no~~ positive chemical match with Samalas products over all constituent
297 elements considered (Figure 4b). Thus, the striking geochemical similarities between the
298 Samalas glass and the ice core dacitic glass population along with the significant differences
299 between the ice core glass and products from other potential sources (Figure S2) led us to
300 conclude that our dacitic glass material was sourced from the Samalas AD 1257 eruption.
301 Note that this volcanic material is also chemically coherent with glass shards formerly found
302 in Greenland and SP ice cores (Palais et al., 1992) suggesting a common source eruption
303 (Figure 4b). The cataclysmic AD 1257 Samalas explosive eruption clearly ranks among the
304 greatest volcanic events of the Holocene. Once injected into the stratosphere up to about 40
305 km (Vidal et al., 2015), the Samalas tephra particles must have been transported poleward.
306 Volcanic particles are supposed to settle in the lower stratosphere and accumulate just

307 above the tropopause, similarly to ^{10}Be and sulphate. Then, when stratosphere/troposphere
308 exchange of mass and chemical species occurs above Antarctica, sedimentation of volcanic
309 aerosols proceeds within the troposphere at the ice sheet surface. The whole process
310 likely occurred on a timescale of 1-2 years, as indicated by the time shift between the
311 eruption and deposition. Evidence for stratospheric transport of volcanic ash to Central EAP
312 in association with strong explosive eruptions is not new. At Vostok, it has been observed
313 (Delmonte et al., 2004) that small particles with modal values around 1.5-1.7 μm are
314 generally associated stratospheric ash entering the troposphere during
315 stratosphere/troposphere folding, jointly with sulphate and likely ^{10}Be . We believe that in
316 case of injection of large quantities of volcanic ash to great heights in the stratosphere also
317 some relatively large particles can be transported in the stratosphere at great distance from
318 the source, as suggested by presence of some large dacitic glasses in VK-14 sample.

319 A limited subset of glass analyses from a Vostok sample indicate distinctive high-silica
320 rhyolitic composition with sub-alkaline affinity (Figure 4a). In the TAS diagram, this evolved
321 component appears separated from the two main glass populations previously discussed,
322 suggesting a different source. Note that this rhyolitic glass was not detected in the samples
323 from the peripheral sites characterised by conspicuous deposition of locally-originated
324 trachytic ash, suggesting that it is likely unrelated to the newly identified Antarctic eruption.
325 Indeed, no such composition is known in the recent volcanic record from Antarctic centres
326 (Dunbar et al., 2008; Narcisi et al., 2012) and neither in the Samalas products (Vidal et al.
327 2015; Alloway et al., 2017). We therefore infer that this glass could be originated from a
328 further distant event that contributed to the ice-core tephra. Interestingly, this interpretation
329 could be in accordance with previous investigations in the WAIS Divide ice core that show
330 that the stratospheric microparticle deposition during the year 1258 occurred in two pulses
331 (Koffman et al., 2013), thus hinting for the possible contribution of two quasi-coeval tropical
332 volcanic eruptions.

333 In the Southern Hemisphere, rhyolitic products related to subduction processes occur at
334 some active Andean volcanoes and especially in the volcanic centres of New Zealand ($\sim 39^\circ\text{S}$,
335 ca. 6000 km from the Vostok site in direct line), whereas rarely were erupted from West
336 Antarctic intraplate volcanoes . The rhyolitic ice-core glass shards display higher K_2O contents
337 compared to glasses of American contemporary volcanoes; they are also characterised by
338 CaO and FeO contents $< 1 \text{ wt}\%$, more typical of New Zealand rhyolitic glasses than of the
339 Antarctic (Marie Byrd Land) ones found in the marine realm (Shane and Froggatt, 1992)
340 (Figure S3). Although we are aware that some Andean centres may have been more
341 geochemically evolved than ~~it is currently represented in literature data~~ , none of the
342 considered volcanoes appear compositionally ~~coherent with~~ our ice-core tephra sub-
343 population (Figure S3).

344 Considering the recent tephra record of New Zealand volcanoes, we observe that ice-core
345 glass mimics the chemical composition of Kaharoa Tephra, which represents the only
346 rhyolitic deposit during the last 1000 years in the region (Nairn et al., 2004, Lowe et al., 2013)
347 (Figure S3). This plinian eruption however is precisely dated to $\text{AD } 1314 \pm 12$ (Lowe et al.,
348 2013, and references therein), thus is ca. 50 years younger than the polar spike (Lowe and
349 Higham, 1998). Therefore, despite the geochemical similarities, the significant age difference
350 prevents this correlation. We conclude that the source for the identified rhyolitic glass, likely

located outside the Antarctic continent, remains undecided. Nevertheless, the New Zealand volcanic province represents the most frequently active rhyolitic zone on Earth (e.g., Smith et al., 2005) and is a suitable source of tephra in Antarctica, despite only one New Zealand tephra layer in Antarctic ice has been identified so far (Dunbar et al., 2017). Our intriguing finding could hopefully provide a hint for future investigations.

4.2 Implications

Volcanic eruptions are drivers of transient weather and climate disturbances (e.g., Robock, 2000). The possible climate-forcing produced by the Samalas event, the most powerful eruption of the last millennium, has been addressed in several papers using various proxy archives and historical documents, along with estimate of the release of gas during the eruption based upon an independent geochemical approach. The volatile emissions standing as the greatest volcanogenic gas injection of the last few millennia were enough to produce global cooling (Vidal et al., 2016). Indeed, considerable environmental and social post-volcanic effects were reconstructed that along the Central Indonesian archipelago affected also vast regions of Europe (Guillet et al., 2107; Alloway et al., 2017). According to Gennaretti et al. (2014), tree-ring-based temperature reconstruction from northeastern North America displays an abrupt cooling regime shift that chronologically coincides with the occurrence of a series of eruptions centred around the AD 1257 Samalas event suggesting volcanic impact on the local forests and ice-caps. Moreover, indirect geological sources show occurrence of an El Niño-like event in the Americas and SE Asia in the year after the mega-eruption that suggests causal connection between the volcanic event and the climate anomaly (Emile-Geay et al., 2008; Alloway et al., 2017). In the Antarctic record, the 13th century appears exceptionally rich in conspicuous volcanic signals, with the AD 1259 being the most prominent (e.g., Cole-Dai et al., 2000). Possible effects of volcanic activity around the date of 1259 have been invoked also for high southern latitudes, but the data are still very sparse. Using a combination of firn/ice core records, Frezzotti et al. (2013) identified middle 13th century as the onset of a 50yrs-long period of negative surface mass balance of the Antarctic ice sheet at the continental scale. This pattern could be related to solar irradiance with other factors, as volcanic forcing, superimposing (Frezzotti et al., 2013).

Results of ice-core tephra studies presented here and elsewhere (Koffman et al., 2013; Narcisi and Petit, 2018, and references therein) collectively have shown for the first time that three distinct Antarctic eruptions took place in the time span of a decade between AD 1254 ± 2 and AD 1261. These eruptions produced deposition of tephra blanket and atmospheric sulphate aerosols onto the polar ice sheet. In the ice volcanic record local eruptions typically emitting only tropospheric sulphate are represented by strong but short-lived residence times of aerosols in the atmosphere (e.g., Castellano et al., 2005). This pattern suggests that such individual events most likely are incapable of significant large-scale climatic impact. However, here we raise question about the potential consequences of this closely spaced local eruption sequence occurred in association with the tropical Samalas eruption, on the Antarctic climate and environment. Note that owing to the close proximity to the source region the local forcing would be exerted through both the radiative impacts of gas and particulate aerosols and the reduction in ice surface albedo produced by repeated extensive tephra deposition. With respect to the latter factor, recent estimations have shown the significance of volcanic ash deposition onto snow/ice even from mid-sized eruptions at high-

latitudes to alter surface reflectivity and enhance glacier melting (e.g., Dadic et al., 2013; Young et al., 2014; Muschitiello et al., 2017). Given the continuous sustained explosive activity of the Antarctic volcanoes with related large production of tephra and consequent dispersal over the Plateau due to favourable atmospheric conditions (e.g., Scarchilli et al., 2011), we believe that the potential role of forcing caused by locally-derived ash deposits should not be neglected in Antarctic palaeoclimate reconstructions. This factor deserves further more specific investigation in future research.

With respect to sulphate emission, unfortunately the available data currently do not permit to distinguish between the contribution to the aerosol deposition from the Samalas event and the AD 1259 local Antarctic eruption. These limitations notwithstanding, at this stage we can remark that in Antarctica two distinct volcanic forcings (one tropical and the other of high southern-latitude) may be superimposed around the date of 1259. In conclusion, our results add complexity to interpretation of volcanic aerosol yields from polar records and could have implications for more reliable climate model simulations for the pre-instrumental period (Schneider et al., 2009; Stoffel et al., 2015, and references therein).

5. Conclusions

Non-visible tephra deposits trapped within polar snow and ice represent precious chronostratigraphic tools. When the material is found associated with a prominent acidic signal, firm attribution to specific eruptions can be given with implications for climate forcing reconstructions. However, tephra detection and fingerprinting at such remote locations is often problematic. We successfully used four cores collected from different sites in the EAP to demonstrate extensive deposition of volcanic dust on the ice sheet coeval with the large acidity peak at AD 1259, a key time stratigraphic horizon of inter-hemispheric significance. Our compelling data show that the material displays different characteristics from site to site. Geochemical fingerprinting of tephra, obtained with a grain-specific methodology, indicates that altogether multiple distinct explosive events have contributed to the ice core ash deposition, i.e. a newly-identified Antarctic eruption in AD 1259, the great AD 1257 eruption of Samalas, and a further eruption likely occurred somewhere outside Antarctica. Indeed, spatial variations reflecting different atmospheric circulation patterns over the EAP were significant in the volcanic deposition on the ice sheet and should not be discounted in order to obtain sound source attribution of volcanic signals in polar sequences. We therefore underline the need of detailed studies based upon a multi-site and parameter approach as well as a large number of chemical analyses for capturing complexities inside tephra. Our results of the chemical composition of hundreds of microscopic particles confirm the inferred linkage of the Antarctic ice signal with the Samalas tropical eruption occurred in AD 1257, but also provide evidence for a coincidental cluster of local explosive events, so far not adequately considered in climate reconstructions derived by ice-core volcanic aerosol records. Local activity instead was important in shaping the Antarctic volcanic record and should be regarded as an agent of potential regional disturbances, not least through dispersion of ash over large areas with consequent radiative impact. We emphasise the potential of tephra investigations with respect to traditional measurements of aerosol concentrations in ice also for identifying superimposition of distinct contemporary events at a single site. Our findings also contribute to a more complete reconstruction of the history of volcanic activity in the Antarctic region.

Aknowledgements

We thank D.J. Lowe (University of Waikato) for his useful advice on New Zealand tephrochronology, N. Metrich and J.-C. Komorowski (Institut de Physique du Globe de Paris) for providing tephra samples from the Samalas deposits, C. Rado for drilling operations at Vostok, and E. Gautier (IGE, Grenoble) for DC ice sample selection. The Vostok ice core was obtained during 1991-92 field season through the Russian US French collaboration on ice cores with the support from the Soviet-Russian Antarctic Expedition, the National Science Foundation and the French Polar Institute. This works contributes to TALos Dome Ice CorE (TALDICE), a joint European programme lead by Italy and funded by national contributions from Italy, France, Germany, Switzerland and the United Kingdom, that was aimed at retrieving an ice core reaching back through the previous two interglacials (about 250,000 years). This is TALDICE publication no. xxx.. The GV7 drilling project, carried out in cooperation with KOPRI (Korea Polar Research Institute), was financially supported by the MIUR (Italian Ministry of University and Research)-PNRA (Italian Antarctic Research Programme) program through the IPICS-2kyr-It project. Author Contributions: B.N. and J.R.P. conceived this study. J.R.P. conducted ice-core sample processing grain-size analysis, and preliminary microprobe work. B.N. conducted tephra analysis, interpreted the results, and wrote most of the manuscript. V.B. was responsible for microprobe work. B.D. interpreted grain-size data and significantly contributed to the writing of the text. J.S. collaborated in the discussion of the experimental results.

462 **Figure captions**

463 Figure 1. (a) AD 1259 signal (as sulphate in mg/L, or electrical conductivity, ECM, in arbitrary
464 units) in the studied Antarctic cores. TALDICE sulphate profile redrawn from Severi et al.
465 (2012), GV7 sulphate profile courtesy of R. Nardin. Also shown is the position of samples
466 analysed for grain size and geochemistry (grey shaded blocks). The dashed line indicates
467 ‘bag’ section limit and/or core break. (b) Map of Antarctica with location of the ice cores and
468 main Quaternary volcanoes in Victoria Land (e.g., Mt. Erebus, Mt. Melbourne and The
469 Pleiades) and in Marie Byrd Land, West Antarctica (e.g., Mt. Takahe and Mt. Berlin).

470 Figure 2. Mass-size distributions (Relative Units, R.U., %) of samples analysed for
471 geochemistry. (A): Central EAP samples from Dome C (DC 71-a) and Vostok BH6 (VK-30-14 and
472 VK-30-16) ice cores. (B): TD samples 87-1, 86-4, 86-3, 86-2 from the base to the top of the
473 volcanic sulphate spike.

474
475 Figure 3. Scanning electron microphotographs of volcanic glass particles from a, DC-71a; b-c,
476 VK-14; d-e, TD-87-1; f, TD-86-4.

477 Figure 4. (a) Total alkali-silica (TAS) classification diagram and alkaline/sub-alkaline division
478 line (Rickwood, 1989, and references therein) showing the normalised analyses of ice-core
479 shards. Ph= Phonolite, An = Andesite, T = Trachyte, D = Dacite, Rh = Rhyolite. In the inset the
480 TAS diagram with envelopes for the three glass compositional sub-populations is illustrated.
481 (b) The TAS classification diagram as above showing the whole data set (in grey-scale)
482 compared with glass geochemical analyses for the most likely correlatives (data from
483 Alloway et al., 2017; Narcisi et al., 2012, 2016, 2017; Palais et al., 1992). Geochemical
484 comparison with further potential sources is provided in Supplementary Material.

485 Figure 5. Total alkali-silica (TAS) classification diagram and alkaline/sub-alkaline division line
486 (Rickwood, 1989, and references therein) for the normalised analyses of ice-core shards in
487 the four TD samples. Data of pertinent samples are superimposed upon the whole data set
488 (in grey-scale) for comparative purposes. Ph = Phonolite, An = Andesite, T = Trachyte, D =
489 Dacite, Rh = Rhyolite. For the stratigraphic position of samples with respect to the AD 1259
490 ice-core volcanic signal see Fig. 1.

491
492 **Captions for Supplementary Tables and Figures**

493 Table S1. Location and characteristics of the studied ice cores.

494 Table S2. Composition of reference glasses and Samalas samples measured at different
495 analytical conditions.

496
497 Table S3. Representative major element composition of individual glass shards determined
498 by electron microprobe analysis. Values are given in weight % oxide and are normalised to
499 100%. Total iron is expressed as FeO. MnO not determined. Glass populations as defined in
500 the main text.

501
502 Figure S1. World map showing the location of Antarctic ice core sites (blue dots) and of

503 selected volcanic sources considered in the text (red triangles). Letters for sources are as
504 follows. CH, Chaitén; EC, El Chichón; HU, Hudson; MBL, Marie Byrd Land; NZ, New Zealand;
505 PCC, Puyehue-Cordon Caulle; QU, Quilotoa; SM, Samalas; SSh, South Shetland Islands; SSL,
506 South Sandwich Islands; VL, Victoria Land.

507 Figure S2. Monte Carlo simulation of the interaction and emission volumes of X-rays at 10kV
508 for Na-K α in Na-Si rich glass considered as A) common polished sample and B) small 1x1 μ m
509 particle placed on the C-glue. The blue lines show the electron trajectory outside the particle.

510
511 Figure S3. Major element biplots for the analysed ice-core shards (in grey-scale) compared
512 with glass geochemical analyses for selected potential sources and counterparts (data from
513 Moreno et al., 2015; Fontijn et al., 2016; Nairn et al., 2004; Kratzmann et al., 2009; Moreno et
514 al., 2015; Nooren et al., 2017; Stewart and Castro, 2016; Shane and Froggatt, 1992). Location
515 of considered source volcanoes is shown in Supplementary Figure S1.

516 **References**

- 517
518 Alloway, B.V., Andreastuti, S., Setiawan, R., Miksic, J., Hua, Q. (2017). Archaeological implications of a
519 widespread 13th Century tephra marker across the central Indonesian Archipelago. *Quaternary Science Reviews*
520 155, 86-99, <https://doi.org/10.1016/j.quascirev.2016.11.020>
- 521 Barbante, C., Kehrwald, N. M., Marianelli, P., Vinther, B. M., Steffensen, J. P., Cozzi, G., Hammer, C. U., Clausen, H.
522 B., Siggaard-Andersen, M.-L. (2013). Greenland ice core evidence of the 79 AD Vesuvius eruption. *Climate of the*
523 *Past* 9, 1221-1232, <https://doi.org/10.5194/cp-9-1221-2013>
- 524 Baroni, M., Savarino, J., Cole-Dai, J., Rai, V.K., Thiemens, M. H. (2008). Anomalous sulfur isotope compositions of
525 volcanic sulfate over the last millennium in Antarctic ice cores. *Journal of Geophysical Research: Atmospheres*
526 113, D20, 2156-2202, DOI: 10.1029/2008JD010185
- 527 Castellano, E., Becagli S., Hansson M., Hutterli M., Petit J.R., Rampino M.R., Severi M., Steffensen J.P., Traversi R.,
528 Udisti R. (2005). Holocene volcanic history as recorded in the sulfate stratigraphy of the European Project for Ice
529 Coring in Antarctica Dome C (EDC96) ice core. *Journal of Geophysical Research* 110, D06114,
530 [doi:10.1029/2004JD005259](https://doi.org/10.1029/2004JD005259)
- 531 Cole-Dai, J., Mosley-Thompson, E., Thompson, L.G. (1997). Quantifying the Pinatubo volcanic signal in south
532 polar snow. *Geophysical Research Letters* 24, 2679–2682.
- 533 Cole-Dai, J., Mosley-Thompson, E. (1999). The Pinatubo eruption in South Pole snow and its potential value to
534 ice-core paleovolcanic records. *Annals of Glaciology* 29, 99-105. [doi:10.3189/172756499781821319](https://doi.org/10.3189/172756499781821319)
- 535 Cole-Dai, J., Mosley-Thompson, E., Wight, S. P., Thompson, L.G. (2000). A 4100-year record of explosive
536 volcanism from an East Antarctica ice core. *Journal of Geophysical Research* 105(D19), 24431–24441,
537 [doi:10.1029/2000JD900254](https://doi.org/10.1029/2000JD900254)
- 538 Dadic, R., Mullen, P.C., Schneebeil, M., Brandt, R.E., Warren, S.G. (2013). Effects of bubbles, cracks, and volcanic
539 tephra on the spectral albedo of bare ice near the Transantarctic Mountains: Implications for sea glaciers on
540 Snowball Earth. *Journal of Geophysical Research: Earth Surface*, 118, 1658-1676, [doi:10.1002/jgrf.20098](https://doi.org/10.1002/jgrf.20098)
- 541 Delmas, R.J., Kirchner, S., Palais, J.M., Petit, J.R. (1992). 1000 years of explosive volcanism recorded at the South
542 Pole. *Tellus* 44B, 335-350.
- 543 Delmonte, B., Petit, J.R., Maggi, V. (2002). Glacial to Holocene implications of the new 27000-year dust record
544 from the EPICA Dome C (East Antarctica) ice core. *Climate Dynamics* 18, 647-660, DOI 10.1007/s00382-001-0193-
545 9
- 546 Delmonte, B., Petit, J.R., Andersen, K.K., Basile-Doelsch, I., Maggi, V., Lipenkov, V.Ya (2004). Dust size evidence
547 for opposite regional atmospheric circulation changes over east Antarctica during the last climatic transition.
548 *Climate Dynamics* 23 (3-4), 427-438.
- 549 Delmonte, B., Petit, J.R., Krinner, G., Maggi, V., Jouzel, J., Udisti, R. (2005). Ice core evidence for secular
550 variability and 200-year dipolar oscillations in atmospheric circulation over East Antarctica during the Holocene.
551 *Climate Dynamics*, 24 (6), 641-654.
- 552 Delmonte, B., Baroni, C., Andersson, P.S., Narcisi, B., Salvatore, M.C., Petit, J.R., Scarchilli, C., Frezzotti, M.,
553 Albani, S., Maggi, V. (2013). Modern and Holocene aeolian dust variability from Talos Dome (Northern Victoria
554 Land) to the interior of the Antarctic ice sheet. *Quaternary Science Reviews* 64, 76-89,
555 <http://dx.doi.org/10.1016/j.quascirev.2012.11.033>
- 556 Dunbar, N.W., McIntosh, W.C., Esser, R.P. (2008). Physical setting and tephrochronology of the summit caldera
557 ice record at Mount Moulton, West Antarctica. *Geological Society of America Bulletin* 120, 796–812, [doi:](https://doi.org/10.1130/B26140.1)
558 <https://doi.org/10.1130/B26140.1>

559 Dunbar, N.W., Iverson, N.A., Van Eaton, A.R., Sigl, M., Alloway, B.V., Kurbatov, A.V., Mastin, L.G., Mc Donnell, J.R.,
560 Wilson, C.J.N., (2017). New Zealand supereruption provides time marker for the Last Glacial Maximum in
561 Antarctica. *Scientific Reports* 7, Article number: 12238, doi: 10.1038/s41598-017-11758-0

562 Emile-Geay, J., Seager, R., Cane, M.A., Cook, E.R., Haug, G.H. (2008). Volcanoes and ENSO over the past
563 millennium. *Journal of Climate* 21, 3134-3148.

564 Frezzotti, M., Scarchilli, C., Becagli, S., Proposito, M., Urbini, S. (2013). A synthesis of the Antarctic surface mass
565 balance during the last 800 yr. *The Cryosphere* 7, 303-319, <https://doi.org/10.5194/tc-7-303-2013>

566 Gennaretti, F., Arseneault, D., Nicault, A., Luc Perreault L., Bégin, Y. (2014). Volcano-induced regime shifts in
567 millennial tree-ring chronologies from northeastern North America. *Proceedings of the National Academy of*
568 *Sciences* 111 (28) 10077-10082; <https://doi.org/10.1073/pnas.1324220111>

569 Guillet, S., Corona, C., Stoffel, M., Khodri, M., Lavigne, F., Ortega, P. et al. (2017). Climate response to the
570 Samalas volcanic eruption in 1257 revealed by proxy records. *Nature Geoscience* 10,123–128.
571

572 Hammer, C.U. (1980). Acidity of polar ice cores in relation to absolute dating, past volcanism, and radio–echoes.
573 *Journal of Glaciology* 25, 359-372, <https://doi.org/10.3189/S0022143000015227>
574

575 Koffman, B.G. Kreutz K.J., Kurbatov, A.V., Dunbar, N.W. (2013). Impact of known local and tropical volcanic
576 eruptions of the past millennium on the WAIS Divide microparticle record. *Geophysical Research Letters* 40, 1–5,
577 doi:10.1002/grl.50822

578 Kurbatov, A.V., Zielinski, G.A., Dunbar, N.W., Mayewski, P.A., Meyerson, E.A., Sneed, S.B., Taylor, K.C. (2006). A
579 12,000 year record of explosive volcanism in the Siple Dome Ice Core, West Antarctica. *Journal of Geophysical*
580 *Research* 111, D12307, doi:10.1029/2005JD006072

581 Iverson, N.A., Kalteyer, D., Dunbar, N.W., Kurbatov, A.V., Yates, M. (2017). Advancements and best practices for
582 analysis and correlation of tephra and cryptotephra in ice. *Quaternary Geochronology* 40, 45-55,
583 <https://doi.org/10.1016/j.quageo.2016.09.008>
584

585 Langway, C.C., Clausen, H., Hammer, C. (1988). An inter-hemispheric volcanic time-marker in ice cores from
586 Greenland and Antarctica. *Annals of Glaciology* 10, 102–108.

587 Langway, C.C. Jr., Osada, K., Clausen, H.B., Hammer, C.U., Shoji, H. (1995). A 10-century comparison of
588 prominent bipolar volcanic events in ice cores. *Journal of Geophysical Research* 100 (D8), 16241–16247.

589 Lavigne, F., Degeai, J.-P., Komorowski, J.-C., Guillet, S., Robert, V., Lahitte, P., Oppenheimer, C., Stoffel, M., Vidal,
590 C.M., Surono, Pratomo, I., Wassmer, P., Hajdas, I., Sri Hadmoko, D., de Belizal, D. (2013). Source of the great A.D.
591 1257 mystery eruption unveiled, Salamas volcano, Rinjani Volcanic Complex, Indonesia. *Proceedings of the*
592 *National Academy of Sciences* 110 (42) 16742-16747, <https://doi.org/10.1073/pnas.1307520110>

593 Lowe, D.J., 2011. Tephrochronology and its application: a review. *Quaternary Geochronology* 6,107–153,
594 <http://dx.doi.org/10.1016/j.quageo.2010.08.003>

595 Lowe, D.J., Blaauw, M., Hogg, A.G., Newnham, R.M. (2013). Ages of 24 widespread tephras erupted since 30,000
596 years ago in New Zealand, with re-evaluation of the timing and palaeoclimatic implications of the Lateglacial
597 cool episode recorded at Kaipo bog. *Quaternary Science Reviews* 74, 170-194.

598 Lowe, D.J., Higham, T.F.G. (1998). Hit-or-myth? Linking a 1259 AD acid spike with an Okataina eruption.
599 *Antiquity* 72, 427-431.

600 Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G., Ni, F.
601 (2009). Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. *Science* 326,
602 1256–1260, DOI: 10.1126/science.1177303

603 Masson-Delmotte, V., Buiron, D., Ekaykin, A., Frezzotti, M., Gallée, H., Jouzel, J., Krinner, G., Landais, A.,
 604 Motoyama, H., Oerter, H., Pol, K., Pollard, D., Ritz, C., Schlosser, E., Sime, L.C., Sodemann, H., Stenni, B., Uemura,
 605 R., Vimeux, F. (2011). A comparison of the present and last interglacial periods in six Antarctic ice cores. *Climate*
 606 *of the Past* 7, 397–423.

607 Muschitiello, F., Pausata, F.S.R., Lea, J.M., Mair, D.W.F., Wohlfarth, B. (2017). Enhanced ice sheet melting driven
 608 by volcanic eruptions during the last deglaciation. *Nature Communications* 8, Article number: 1020, DOI:
 609 10.1038/s41467-017-01273-1
 610

611 Nairn, I.A., Shane, P.R., Cole, J.W., Leonard, G.J., Self, S., Pearson, N. (2004). Rhyolite magma processes of the ~AD
 612 1315 Kaharoa eruption episode, Tarawera volcano, New Zealand. *Journal of Volcanology and Geothermal*
 613 *Research* 131, 265–294, [https://doi.org/10.1016/S0377-0273\(03\)00381-0](https://doi.org/10.1016/S0377-0273(03)00381-0)

614 Narcisi, B., Proposito, M., Frezzotti, M. (2001). Ice record of a 13th century explosive volcanic eruption in northern
 615 Victoria Land, East Antarctica. *Antarctic Science* 13, 174–181.

616 Narcisi, B., Petit, J.R., Delmonte, B., Basile-Doelsch, I., Maggi, V. (2005). Characteristics and sources of tephra
 617 layers in the EPICA-Dome C ice record (East Antarctica): implications for past atmospheric circulation and ice
 618 core stratigraphic correlations. *Earth and Planetary Science Letters* 239, 253–265.
 619

620 Narcisi, B., Petit, J.R., Delmonte, B. (2010). Extended East Antarctic ice core tephrostratigraphy. *Quaternary*
 621 *Science Reviews* 29, 21–27.

622 Narcisi, B., Petit, J.R., Delmonte, B., Scarchilli, C., Stenni, B. (2012). A 16,000-yr tephra framework for the
 623 Antarctic ice sheet: a contribution from the new Talos Dome core. *Quaternary Science Reviews* 49, 52–63.

624 Narcisi, B., Petit, J.R., Langone, A., Stenni, B. (2016). A new Eemian record of Antarctic tephra layers retrieved
 625 from the Talos Dome ice core (Northern Victoria Land). *Global and Planetary Change* 137, 69–78,
 626 <http://dx.doi.org/10.1016/j.gloplacha.2015.12.016>

627 Narcisi, B., Petit, J.R., Langone, A., 2017. Last glacial tephra layers in the Talos Dome ice core (peripheral East
 628 Antarctic Plateau), with implications for chronostratigraphic correlations and regional volcanic history.
 629 *Quaternary Science Reviews*, 165, 111–126.
 630

631 Narcisi, B., Petit, J.R. (2018). Englacial tephra of East Antarctica. In J. Smellie, K. Panter, A. Geyer (eds),
 632 *Volcanism in Antarctica: 200 Million Years of Subduction, Rifting and Continental Break-Up*. Geological Society,
 633 London, Memoirs, in press.

634 Oppenheimer, C. (2003). Ice core and palaeoclimatic evidence for the timing and nature of the great mid-13th
 635 century volcanic eruption. *International Journal of Climatology* 23, 417–426, doi:10.1002/joc.891
 636

637 Palais, J.M., Germani, M.S., Zielinski, G.A. (1992). Interhemispheric transport of volcanic ash from a 1259 A.D.
 638 volcanic eruption to the Greenland and Antarctic ice sheets. *Geophysical Research Letters* 19(8), 801–804.

639 Petit, J.R., Narcisi, B., Batanova, V.G., Savarino, J., Komorowski, J.C., Michel, A., Metrich, N., Besson, P., Vidal, C.,
 640 Sobolev, A.V. (2016). Identifying the AD 1257 Salamas volcanic event from micron-size tephra composition in
 641 two East Antarctic ice cores. *Geophysical Research Abstracts*, 18, EGU2016-5191.

642 Ponomareva, V., Portnyagin, M., Davies, S.M. (2015). Tephra without borders: far-reaching clues into past
 643 explosive eruptions. *Frontiers in Earth Science* 3 (83), doi:10.3389/feart.2015.00083

644 Rickwood, P.C. (1989). Boundary lines within petrologic diagrams which uses oxides of major and minor
 645 elements, *Lithos* 22, 247–263.
 646

647 Robock, A. (2000). Volcanic eruptions and climate. *Reviews of Geophysics* 38, 191–219,
 648 doi:10.1029/1998RG000054

649 Scarchilli, C., Frezzotti, M., Ruti, P.M. (2011). Snow precipitation at four ice core sites in East Antarctica:
650 provenance, seasonality and blocking factors. *Climate Dynamics* 37, 2107-2125,
651 <http://dx.doi.org/10.1007/s00382-010-0946-4>.

652 Schneider, D. P., Ammann C. M., Otto-Bliesner B.L., Kaufman, D.S. (2009). Climate response to large, high-
653 latitude and low-latitude volcanic eruptions in the Community Climate System Model. *Journal of Geophysical*
654 *Research* 114, D15101, doi:10.1029/2008JD011222

655 Severi, M., Udisti, R., Becagli, S., Stenni, B., Traversi, R. (2012). Volcanic synchronisation of the EPICA-DC and
656 TALDICE ice cores for the last 42 kyr BP. *Climate of the Past* 8, 509-517.

657 Shane, P.A.R., Froggatt, P.C. (1992). Composition of widespread volcanic glass in deep-sea sediments of the
658 Southern Pacific Ocean: an Antarctic source inferred. *Bulletin of Volcanology* 54, 595-601.

659
660 Sigl, M., McConnell, J.R., Toohey, M., Curran, M., Das, S.B., Isaksson, E., Kawamura, K., Kipfstuhl, S., Krüger, K.,
661 Layman, L., Maselli, O.J., Motizuki, Y., Motoyama, H., Pasteris, D.R., Severi, M., (2014). Insights from Antarctica on
662 volcanic forcing during the Common Era. *Nature Climate Change* 4, 693-697,
663 <http://dx.doi.org/10.1038/nclimate2293>
664

665 Sigl, M., Winstrup, M., McConnell, J.R., Welten, K.C., Plunkett, G., Ludlow, F., Büntgen, U., Caffee, M., Chellman,
666 N., Dahl-Jensen, D., Fischer, H., Kipfstuhl, S., Kostick, C., Maselli, O.J., Mekhaldi, F., Mulvaney, R., Muscheler, R.,
667 Pasteris, D.R., Pilcher, J.R., Salzer, M., Schüpbach, S., Steffensen, J.P., Vinther, B.M., Woodruff, T.E. (2015).
668 Timing and climate forcing of volcanic eruptions for the past 2,500 years. *Nature* 523, 543-549.
669 doi:10.1038/nature14565

670 Smith, V.C., Shane, P., Nairn, I.A. (2005). Trends in rhyolite geochemistry, mineralogy, and magma storage
671 during the last 50 kyr at Okataina and Taupo volcanic centres, Taupo Volcanic Zone, New Zealand. *Journal of*
672 *Volcanology and Geothermal Research* 148 (3-4), 372-406, <https://doi.org/10.1016/j.jvolgeores.2005.05.005>

673 Stoffel, M., Khodri, M., Corona, C., Guillet, S., Poulain, V. Bekki, S., Guiot J., Luckman B.H., Oppenheimer C.,
674 Lebas, N., Beniston M., Masson-Delmotte V. (2015). Estimates of volcanic-induced cooling in the Northern
675 Hemisphere over the past 1,500 years. *Nature Geoscience* 8, 784-788, DOI: 10.1038/NGEO2526

676 Stothers, R.B. (2000). Climatic and demographic consequences of the massive volcanic eruption of 1258.
677 *Climatic Change* 45, 361-374.

678 Svensson, A., Bigler, M., Blunier, T., Clausen, H. B., Dahl-Jensen, D., Fischer, H., Fujita, S., Goto-Azuma, K.,
679 Johnsen, S. J., Kawamura, K., Kipfstuhl, S., Kohno, M., Parrenin, F., Popp, T., Rasmussen, S. O., Schwander, J.,
680 Seierstad, I., Severi, M., Steffensen, J. P., Udisti, R., Uemura, R., Vallenga, P., Vinther, B. M., Wegner, A.,
681 Wilhelms, F., Winstrup, M. (2013). Direct linking of Greenland and Antarctic ice cores at the Toba eruption (74 ka
682 BP). *Climate of the Past* 9, 749-766, <https://doi.org/10.5194/cp-9-749-2013>

683 Timmreck, C., Lorenz S.J., Crowley T.J., Kinne S., Raddatz T.J., Thomas M.A., Jungclaus J.H. (2009). Limited
684 temperature response to the very large AD 1258 volcanic eruption. *Geophysical Research Letters* 36, L21708,
685 doi:10.1029/2009GL040083

686 Vidal, C.M., Komorowski, J.-C., Metrich, N., Pratomo, I., Kartadinata, N., Prambada, O., Michel, A., Carazzo, G.,
687 Lavigne, F., Rodysill, J., Fontijn, K., Surono, 2015. Dynamics of the major plinian eruption of Samalas in 1257 A.D.
688 (Lombok, Indonesia). *Bulletin of Volcanology* 77, 73. <http://dx.doi.org/10.1007/s00445-015-0960-9>

689 Vidal, C.M., Metrich, N., Komorowski, J.-C., Indyo Pratomo, Michel, A., Kartadinata, N., Robert, V., Lavigne, F.
690 (2016). The 1257 Samalas eruption (Lombok, Indonesia): the single greatest stratospheric gas release of the
691 Common Era. *Scientific Reports* 6, Article number: 34868, DOI: 10.1038/srep34868

692 Wörner, G. (1999). Lithospheric dynamics and mantle sources of alkaline magmatism of the Cenozoic West
693 Antarctic rift system. *Global and Planetary Change* 23, 61-77.

694 Yalcin, K., Wake, C.P., Kreutz, K.J., Germani, M.S., Whitlow, S.I. (2006). Ice core evidence for a second volcanic
695 eruption around 1809 in the Northern Hemisphere. *Geophysical Research Letters* 33, L14706,
696 doi:10.1029/2006GL026013

697 Young, C. L., Sokolik, I.N., Flanner, M.G., Dufek, J. (2014). Surface radiative impacts of ash deposits from the 2009
698 eruption of Redoubt volcano, *Journal of Geophysical Research Atmosphere* 119, 11387–11397,
699 doi:10.1002/2014JD021949

700 Zielinski, G.A. (1995). Stratospheric loading and optical depth estimates of explosive volcanism over the last
701 2100 years derived from the GISP2 Greenland ice core. *Journal of Geophysical Research* 100, 20937-20955. DOI:
702 10.1029/95JD01751

703 Zielinski, G.A., Dibb, J.E., Yang, Q., Mayewski, P.A., Whitlow, S., Twickler, M.S., Germani, M.S. (1997). Assessment
704 of the record of the 1982 El Chichón eruption as preserved in Greenland snow. *Journal of Geophysical*
705 *Research* 102 (D25), 30,031–30,045, doi:10.1029/97JD01574

(a)

Central Plateau

Peripheral Plateau

(b)

Fig. 3. Scanning electron microphotographs of volcanic glass particles from a, DC-71a; b-c, VK-14; d-e, TD87-1; f, TD86-4.

toward the upper part of the AD 1259 volcanic spike

1 Supplementary Material for

2

3 MULTIPLE SOURCES FOR TEPHRA FROM AD 1259 VOLCANIC SIGNAL IN ANTARCTIC ICE CORES

4

5 Biancamaria Narcisi¹, Jean Robert Petit², Barbara Delmonte³, Valentina Batanova⁴, Joël
6 Savarino²

7

8 (1) ENEA, C.R. Casaccia, 00123 Roma, Italy, biancamaria.narcisi@enea.it

9

10 (2) Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, 38000 Grenoble, France

11 (3) Department of Earth and Environmental Sciences (DISAT), Univ. Milano-Bicocca, Piazza della Scienza, 20126
12 Milano, Italy

13 (4) Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France

Drilling Site/Ice core	Short name	Location, elevation a.s.l.	Accumulation rate (mm we year ⁻¹)	Drilling period	Reference	Present sample resolution (cm)
Concordia Station at Dome C	DC	75°06'S, 123°20'E, 3220 m	~25	2013-14	Schwander et al. (2001)	7
Vostok/BH6	VK	78°28'S, 106°48'E, 3488 m	~20	1991- 92	Osipov et al. (2014)	5
Talos Dome/TALDICE	TD	72°49'S, 159°11'E, 2315 m	~80	2004-05	Severi et al. (2012)	5
GV7	GV7	70°41'S, 158°52'E, 1950 m	~240	2013-14	Frezzotti et al. (2007) Caiazzo et al. (2017)	15

Table S1. Location and characteristics of the studied ice cores

Figure S1. World map showing the location of Antarctic ice core sites (blue dots) and of selected volcanic sources considered in the text (red triangles). Letters for sources are as follows. CH, Chaitén; EC, El Chichón; HU, Hudson; MBL, Marie Byrd Land; NZ, New Zealand; PCC, Puyehue-Cordon Caulle; QU, Quilotoa; SM, Samalas; SSh, South Shetland Islands; SSI, South Sandwich Islands; VL, Victoria Land

Details of microprobe analysis

Although tephra embedding and polishing should be preferred for microprobe analysis, this was not possible here due to the small amount of material and its very fine grain size. Therefore, single-grain geochemical analysis was carried out on unpolished samples using a JEOL JXA-8230 electron microprobe set up at the Institut des Sciences de Terre (ISTerre) of Grenoble. For analysis of small (1-3 μm) and thin (< 2 μm) unpolished tephra shards the analytical protocol with simultaneous WDS/EDS signal acquisition has been applied. We run Ti, Na, Mg, K, and Fe on WD spectrometers and Si, Ca, Al, on ED spectrometers. The following analytical conditions have been used: accelerating voltage 10kV, probe beam current 2 nA and beam diameter 1 μm . The low accelerating voltage was selected to reduce X-ray excitation volume. Natural and synthetic minerals and glasses were used for standardisation: StHs6/80-G (Si, Al, Ca) and GOR132-G (Fe) synthetic glasses (Jochum et al, 2000 and GEOREM database), pure synthetic MgO (Mg), synthetic rutile (Ti), albite (Na), orthoclase (K). During analytical sessions the reference materials StHs6/80-G, ATHO-G (Jochum et al., 2000) and KE-12 (Metrich and Rutherford, 1992) ran as unknowns after each 40-50 analytical points to evaluate analytical accuracy and precision. Even at current as low as 2 nA the migration of sodium could be significant if the diameter of the electron beam is small (1 μm). The results of analysis of reference glasses and polished tephra samples analysed at traditional (Acc. voltage 15kV, probe current 5nA, beam diameter 5 μm , e.g. Narcisi et al., 2016) and non-traditional (Acc. voltage 10kV, beam current 2nA, probe diameter 1 μm , this study) are in Table S2. We estimate that Na loss for polished samples analysed by 1 μm beam and non-traditional analytical conditions described above corresponds to 25% relative for samples with 4-7 wt% of Na_2O and 67-75 wt% of SiO_2 (ATHO-G, KE-12, and samples RIN1392E and RIN1392A related to the AD 1257 Samalas medial tephra, Vidal et al., 2015) (Table S2). As it has been shown in several studies (e.g. Nielsen and Sigurdsson, 1981; Spray and Rae, 1995; Morgan and London, 1996) sodium migration from the excitation volume is a result of heating of the area of analysis by electron beam. According to Spray and Rae (1995) sodium migrates downward to space-charge layer within the sample. Figure S2 shows Monte Carlo electron trajectory simulation of the interaction volume as well as Na-K α generation and emission volumes for 10kV in common polished sample and unpolished 1x1 μm particle on filter. These figures demonstrated how electron beam penetrates the samples of the different morphology. As follows from the modelling in case of analysis of small shards the Na migration does not take place because of small sample size. Analysis of small tephra shards often displayed low analytical total (30-60 %). Low and variable totals of analysis are result of small size of analytical area (smaller than excitation volume) (Figure S2-B). The analytical precision for the selected analytical conditions is in Table S2. While the analytical precision at 10 kV and 2 nA for the most analysed oxides is significantly lower than for traditional conditions it is still within reasonable error (5-15%).

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B

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Figure S2. Monte Carlo simulation of the interaction and emission volumes of X-rays at 10kV for Na-K α in Na-Si rich glass considered as A) common polished sample and B) small 1x1 μm particle placed on the C-glue. The blue lines show the electron trajectory outside the particle.

Table S2. Composition of reference glasses and Samalas tephra samples measured at different analytical conditions

Sample	Reference	Analytical conditions	N	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MnO	MgO	CaO	Na ₂ O	K ₂ O	Total
StHs6/80-G	this work	10kV, 2nA, 1 µm	15	63,56	0,69	17,61	4,46		1,95	5,38	4,33	1,29	99,28
±				0,45	0,10	0,33	0,26		0,11	0,33	0,30	0,04	
StHs6/80-G	this work	15kV, 5nA, 5 µm	15	63,73	0,69	17,86	4,29	0,08	1,94	5,26	4,62	1,28	99,75
±				0,21	0,01	0,18	0,08	0,03	0,04	0,06	0,12	0,03	
StHs6/80-G	Jochum et al. (2000) (a)			63,70	0,70	17,80	4,37	0,08	1,97	5,28	4,44	1,29	99,63
95%CL				0,50	0,02	0,20	0,07	0,00	0,04	0,09	0,14	0,02	
ATHO-G	this work	10kV, 2nA, 1 µm	12	75,64	0,26	11,95	3,14		0,09	1,72	2,79	2,61	98,20
±				0,59	0,04	0,21	0,27		0,03	0,25	0,47	0,08	
ATHO-G	this work	15kV, 5nA, 5 µm	12	75,88	0,24	12,30	3,14	0,11	0,09	1,71	3,98	2,64	100,08
±				0,32	0,02	0,21	0,06	0,03	0,01	0,03	0,10	0,04	
ATHO-G	Jochum et al. (2000) (a)			75,60	0,26	12,20	3,27	0,11	0,10	1,70	3,75	2,64	99,62
95%CL				0,70	0,02	0,20	0,10	0,01	0,01	0,03	0,31	0,09	
KE-12	this work	10kV, 2nA, 1 µm	12	71,56	0,32	7,92	8,93		0,01	0,39	5,36	4,09	98,60
±				0,45	0,08	0,20	0,45		0,02	0,20	0,23	0,09	
KE-12	this work	15kV, 5nA, 5 µm	12	71,01	0,30	7,84	8,30	0,26	0,03	0,37	7,01	4,23	99,35
±				0,33	0,01	0,11	0,08	0,03	0,02	0,01	0,17	0,04	
KE-12	Metrich and Rutherford (1992) (b)			70,30	0,33	7,60	8,36	0,26	nd	0,35	7,28	4,27	98,75
KE-12	Vidal et al. (2015) (c)		5	69,93	0,33	7,64	8,47	0,31	0,03	0,37	6,91	4,26	98,25
±				0,38	0,05	0,22	0,20	0,08	0,01	0,03	0,34	0,04	
RIN1392E	this work	10kV, 2nA, 1 µm	41	68,25	0,45	15,19	2,43		0,58	1,67	2,90	4,10	96,29
±				0,93	0,06	0,38	0,25		0,11	0,28	0,50	0,24	
RIN1392E	this work	15kV, 5nA, 5 µm	26	68,38	0,45	15,41	2,40	0,12	0,58	1,67	4,52	4,45	97,97
±				0,48	0,01	0,27	0,09	0,02	0,09	0,09	0,29	0,11	
RIN1392E	Vidal et al. (2015) (c)		10	70,09	0,47	15,65	2,51	0,14	0,60	1,80	3,52	4,39	99,17
±				0,69	0,07	0,28	0,10	0,07	0,05	0,21	0,47	0,22	
RIN1392A	this work	10kV, 2nA, 1 µm	48	67,95	0,45	16,05	2,81		0,74	2,22	3,59	3,99	98,68
±				0,65	0,07	0,26	0,22		0,07	0,25	0,35	0,10	
RIN1392A	this work	15kV, 5nA, 5 µm	48	67,67	0,45	16,16	2,66	0,12	0,72	2,18	4,73	4,11	98,81
±				0,49	0,02	0,21	0,07	0,02	0,02	0,05	0,19	0,06	
RIN1392A	Vidal et al. (2015) (c)		16	68,24	0,46	16,11	2,70	0,11	0,73	2,22	4,69	4,16	99,42
±				0,77	0,07	0,31	0,12	0,05	0,04	0,13	0,19	0,11	

Notes: Oxides reported in wt%. N - number of analyses. Reproducibility (±) is shown as 1 standard deviation of average.

(a) reference values; (b) whole rock data; (c) EPMA data.

Table S2. Composition of reference glasses and Samalas tephra samples measured at different analytical conditions.

Potential sources for the ice-core dacitic glass population

Our attempt at source identification was based upon comparison with bibliographic information for volcanoes that have been active during post-glacial times. We considered as constraining features the chronostratigraphy of the deposits, the character of volcanic activity and the chemical signature of the material. However, a matching source depends on the data available in the literature. Inaccessible volcanoes may be ~~provided with~~ stratigraphic records that are still incomplete or poorly age constrained. The possibility that our tephra may represent a hitherto unknown eruption in the proximal sequence cannot be entirely excluded. As for chemical features of deposits from proximal contexts, in order to avoid misleading correlations we took into account only sources for which single-shard microprobe data are available. We consider in fact bulk-rock analyses of near-vent samples, often affected by the presence of minerals on xenoliths, unsuitable for comparison with the present shard-specific dataset. However, we are aware that proximal and distal tephra components of the same eruption may have slightly different compositions and this may represent a further problem of our approach. On the other hand, here we considered a large set of possible volcanic sources within and surrounding the Antarctic continent, more extended than that employed in previous studies. This strategy, requiring scrutiny of a high number of relevant published papers, allowed us to confidently rule out clearly dissimilar sources and to ascribe the investigated ice-core tephra to the parent eruption.

Figure S1 illustrates location of a few volcanoes considered in this discussion. Graphical comparison of the composition of individual ice-core shards with glass analyses from proximal source deposits (Figure S3) supports the following considerations.

Regardless of age of proximal activity, we could readily exclude volcanism of South Sandwich Islands (SSI) in the Southern Atlantic Ocean, producing several tephtras preserved in Central EAP (e.g., Narcisi et al., 2010, and references therein), because of its low-K tholeiitic nature (e.g., Nielsen et al., 2007), as well as volcanoes in the South Shetland Islands (Antarctic Peninsula region) that display predominantly basaltic and basaltic andesitic compositions (Kraus et al., 2013; Antoniadou et al., 2018). Both provinces are clearly dissimilar in composition with the ice-core glass.

Careful attention was paid to post-glacial volcanoes of the Andean belt representing very efficient producers of sub-alkaline (calc-alkaline) tephra. These could be eligible candidates considering that the westerly atmospheric circulation penetrating the EAP favours the rapid transport and deposition of dust and tephra from South America to Antarctica (e.g., Pitts and Thomason, 1993; Delmonte et al., 2008; Narcisi et al., 2012; Koffman et al., 2017). On the basis of numerous studies over the last decades, the eruptive chronologies of many of these volcanic centres are well constrained, thus helping us to rule out a number of them.

In particular, in the Southern and Austral Volcanic Zones of the Andes (latitudes between 33 to 55°S) about 20 volcanoes produced explosive eruptions with significant regional or even hemispheric impact (Fontijn et al., 2014). However, the largest Holocene explosive eruptions of volcanoes in the southernmost Andes producing regionally widespread tephra layers are dated back at least to 3 ka (Stern, 2008) and so are too old to be related with the studied tephra. Other volcanoes of the Southern Volcanic Zone that either are too old or do not show geological

117 evidence of energetic explosive activity in mid-13th century to be considered as likely sources are
118 Calbuco (41°33'S, Watts et al., 2011), Mocho-Choshuencho (39°55'S, Rawson et al., 2015),
119 Quetrupillán (39°30' S, Fontijn et al., 2016), Sollipulli (38°58'S; Naranjo et al., 1993), Lonquimay
120 (38°22'S, Gilbert et al., 2014), Quizapu–Cerro Azul (35°39'S, Ruprecht et al., 2012) San Pedro
121 (36°S, Singer et al., 1997). Similarly, we can exclude volcanoes of the Central Volcanic Zone of
122 the Andes (latitudes between 14° and 29°S) characterised by high-K calc-alkaline compositions.
123 Here, the two last major explosive events were the 2-ka BP plinian eruption of El Misti volcano
124 (Thouret et al., 2001) and the AD 1600 eruption of Huaynaputina volcano (e.g., Lavallée et al.,
125 2006), both inconsistent with age of the ice tephra sample. The remaining explosive activity was
126 small to moderate, so most likely not capable of dispersing ash onto the Antarctic ice sheet.
127 Farther north, also at the Andean volcanoes of Chimborazo (1°28'S, Barba et al., 2008) and
128 Cotopaxi (0°38'S, Hall and Mothes, 2008) the recorded activity is not appropriate as either age or
129 character to suggest a linkage with our tephra. In the Northern Hemisphere, according to marine
130 tephrostratigraphy offshore the southern Central American Volcanic Arc (7-9 °N) documenting
131 explosive activity of Costa Rica and Nicaragua volcanoes, the most recent marker is 3.5 ka old
132 (Schindlbeck et al., 2016), thus much older than our ice-core tephra. Terrestrial
133 volcanostratigraphies of Irazú (9°58'N, Benjamin et al., 2007), Apoyeque (12°14'N, Kutterolf et al.,
134 2011) and Ilopango (13°67'N, Mehringer et al., 2005) do not show any suitable tephra deposit of
135 appropriate age. The voluminous eruption of El Metate (19°32'N, Mexico) dated at ~ AD 1250 was
136 purely effusive (Chevrel et al., 2015), making it an unlikely candidate.

137 We carried out a comparison between our glass-shard microprobe data and the composition of
138 selected calc-alkaline tephra sources active in the last millennium (Figure S3). In particular, we
139 considered recent explosive products of the American volcanoes of Chaitén (42°49'S, Moreno et
140 al., 2015), Puyehue-Cordon Caulle (40°59'S, Mil Hojas tephra, modelled age 0.84 ± 0.18 cal ka BP,
141 Fontijn et al., 2016), Hudson (45°54'S, Kratzmann et al., 2009), Quilotoa (~ AD 1280, 0°51'S,
142 Stewart and Castro, 2016), El Chichón (6th-century deposits, 17°22'N, Nooren et al., 2017) along
143 with tephra erupted during the Kaharoa event in New Zealand (AD 1314 ± 12 ; e.g., Nairn et al.,
144 2004) and from Marie Byrd Land volcanoes found in the marine realm (Shane and Froggatt,
145 1992). It can be seen that none of these satisfactorily fit the dacitic chemistry of the ice-core
146 tephra component and consequently cannot be likely counterparts. Note that El Chichón
147 volcano was previously suggested as a probable source for the polar tephra in the South Pole
148 (SP) and Greenland ice cores (Palais et al., 1992). Although the El Chichón historic volcanic
149 record does not preclude this possibility (Espíndola et al., 2000), the present comparison
150 highlights appreciable compositional differences between the studied dacitic tephra and the
151 proximal volcanic deposits, thus excluding the former attribution.

152
153 We finally found a positive chemical match between dacitic glass shards trapped within ice and
154 products of AD 1257 Samalas volcanic eruption, the cataclysmic event that occurred in the
155 Indonesian Archipelago (8°33'S) and ranking among the greatest volcanic events of the
156 Holocene (e.g., Lavigne et al., 2013; Vidal et al., 2015, 2016; Alloway et al., 2017) (Figure 4b, main
157 text). Note that our chemical results are also consistent with microprobe data of Samalas samples
158 analysed within this work (Table S2).

○ Central Plateau ◇ Peripheral Plateau △ Chaitén * Puyehue-C. Caulle
 ◆ El Chichon ■ Hudson ● Quilotoa ■ NZ-Kaharoa ✕ West Antarctic marine tephra

159
 160 Figure S3. Major element biplots for the analysed ice-core shards (in grey-scale) compared with glass geochemical
 161 analyses for selected potential sources and counterparts (data from Moreno et al., 2015; Fontijn et al., 2016; Nairn et
 162 al., 2004; Kratzmann et al., 2009; Nooren et al., 2017; Stewart and Castro, 2016; Shane and Froggatt, 1992). Location
 163 of considered source volcanoes is shown in Supplementary Figure S1.

Table S3. Representative major element composition of individual glass shards determined by electron microprobe analysis. Values are given in weight % oxide and are normalised to 100%. Total iron is expressed as FeO. MnO not determined. Glass populations as defined in the main text

Analytical session	DC 71-a	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
May 2015											
	1259_1-p3	67.57	0.60	15.68	4.41	0.94	2.65	4.24	3.91	60.66	diacitic
	1259_1-p6	67.27	0.56	15.31	4.33	0.68	2.27	5.16	4.42	64.67	diacitic
	1259_1-p10	69.07	0.37	15.87	2.05	0.82	1.71	5.41	4.71	77.55	diacitic
	1259_1-p14	68.86	0.55	15.72	2.82	0.68	1.90	4.75	4.71	67.51	diacitic
	1259_1-p16	68.37	0.47	15.52	3.22	0.98	2.13	4.68	4.62	67.86	diacitic
December 2015											
	1259_p6	69.33	0.51	15.68	3.44	0.77	2.02	4.44	3.81	77.58	diacitic
	1259_p13	67.32	0.59	15.59	3.29	0.90	2.69	5.21	4.41	72.66	diacitic
	1259_p16	70.90	0.44	15.43	2.81	0.76	1.56	3.67	4.43	90.67	diacitic
	1259_p19	68.41	0.62	16.05	3.44	0.94	2.25	4.19	4.09	72.85	diacitic
	1259_p20	67.47	0.53	16.78	3.17	0.84	2.52	4.69	4.01	91.60	diacitic
	1259_p31	69.65	0.52	15.56	3.16	0.60	1.54	4.25	4.75	71.40	diacitic
	1259_p40	68.47	0.51	14.76	3.78	1.05	2.29	4.65	4.49	61.73	diacitic
	1259_p42	69.05	0.39	15.07	3.64	0.89	2.16	4.68	4.12	67.41	diacitic
	1259_p44	69.61	0.49	15.83	2.08	0.85	1.61	4.92	4.61	66.34	diacitic
Analytical session	VK_14	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
October 2016											
	BH6-30-14_p7	69.38	0.50	15.05	2.62	0.59	1.10	5.51	5.25	76.31	diacitic
	BH6-30-14_p8	70.33	0.43	15.96	2.56	0.65	1.81	4.04	4.22	90.59	diacitic
	BH6-30-14_p17	68.72	0.44	15.61	2.80	0.79	2.43	4.96	4.24	77.77	diacitic
	BH6-30-14_p26	67.09	0.60	15.33	3.65	0.95	2.51	4.91	4.96	79.05	diacitic
	BH6-30-14_p27	68.17	0.50	16.29	2.89	0.86	2.31	4.97	4.01	95.16	diacitic
	BH6-30-14_p50	69.78	0.66	16.13	2.46	0.70	1.57	4.36	4.33	95.08	diacitic
	BH6-30-14_p75	69.21	0.53	16.56	2.96	0.71	2.02	4.02	4.00	93.55	diacitic
	BH6-30-14_p89	63.54	0.47	16.04	6.18	0.09	0.72	8.07	4.89	95.72	trachytic
	BH6-30-14_p90	63.78	0.48	17.30	6.17	0.14	0.86	6.59	4.69	91.31	trachytic
	BH6-30-14_p91	68.00	0.83	15.48	3.59	0.77	2.34	4.83	4.18	66.61	diacitic
	BH6-30-14_p92	67.92	0.55	15.67	3.21	0.89	2.02	5.13	4.61	84.58	diacitic
	BH6-30-14_p110	71.16	0.41	16.44	1.40	0.48	1.37	4.29	4.44	96.57	diacitic
	BH6-30-14_p120	70.58	0.49	16.17	2.00	0.79	1.64	4.32	4.02	97.06	diacitic
	BH6-30-14_p146	68.56	0.56	16.12	2.79	1.15	2.17	4.46	4.19	90.30	diacitic
	BH6-30-14_p153	69.21	0.45	16.04	2.54	0.65	2.50	4.54	4.07	87.56	diacitic
Analytical session	VK_16	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
October 2016											
	BH6-30-16_p10	69.40	0.50	16.29	2.37	0.75	1.70	4.88	4.11	68.11	diacitic
	BH6-30-16_p22	76.15	0.00	13.81	0.53	0.30	0.94	2.70	3.48	90.33	trachytic
	BH6-30-16_p29	69.38	0.43	16.10	2.46	0.60	2.72	4.25	4.06	76.28	diacitic
	BH6-30-16_p63	77.19	0.18	12.70	0.43	0.02	0.68	3.43	5.38	69.81	trachytic
	BH6-30-16_p68	77.07	0.19	12.36	0.26	0.13	0.55	4.30	5.15	82.58	trachytic
	BH6-30-16_p76	68.53	0.48	15.22	3.64	0.91	1.82	5.21	4.19	68.17	diacitic
	BH6-30-16_p77	68.86	0.50	16.19	3.50	0.66	1.08	5.05	4.16	80.05	diacitic
	BH6-30-16_p82	68.34	0.62	16.28	3.11	0.82	1.48	4.62	4.52	71.11	diacitic
	BH6-30-16_p83	65.26	0.39	14.21	8.55	0.62	0.76	5.04	5.17	63.35	trachytic
	BH6-30-16_p87	70.24	0.47	15.16	2.98	0.67	1.57	4.59	4.32	70.77	diacitic
	BH6-30-16_p91	69.11	0.42	16.28	2.99	0.75	1.92	4.51	4.02	89.56	diacitic
	BH6-30-16_p95	67.53	0.42	15.97	2.78	0.76	2.78	5.27	4.39	76.03	diacitic
	BH6-30-16_p99	68.93	0.54	15.49	3.49	0.67	1.20	5.03	4.65	63.47	diacitic
	BH6-30-16_p117	69.85	0.59	15.54	3.09	0.54	1.07	4.53	4.79	60.37	diacitic
	BH6-30-16_p130	77.72	0.05	12.77	0.37	0.00	1.01	3.38	4.69	68.34	trachytic
	BH6-30-16_p134	67.55	0.61	15.51	3.85	0.70	2.28	5.23	4.26	73.56	diacitic
	BH6-30-16_p140	77.64	0.19	12.44	0.98	0.13	0.56	2.50	5.55	88.98	trachytic
	BH6-30-16_p160	68.33	0.40	15.91	3.45	0.84	2.14	4.78	4.15	79.73	diacitic
Analytical session	TD 87-1	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
December 2015											
	87-1-p27	63.69	0.24	17.06	4.07	0.06	1.42	7.63	5.82	90.22	trachytic
	87-1-p37	64.03	0.34	16.21	5.08	0.20	1.41	6.98	5.75	94.07	trachytic
	87-1-p42	62.06	0.49	16.03	7.97	0.12	1.43	6.74	5.14	68.65	trachytic
	87-1-p45	61.97	0.44	16.46	7.54	0.19	1.37	7.09	4.94	89.66	trachytic
	87-1-p47	61.35	0.61	15.99	6.23	0.34	3.09	7.75	4.63	95.15	trachytic
	87-1-p50	63.32	0.43	16.57	6.80	0.07	0.79	6.52	5.50	91.35	trachytic
Analytical session	TD 86-4	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
December 2015											
	86-4A-14	69.18	0.46	15.87	2.75	0.89	2.20	4.56	4.28	86.15	diacitic
	86-4A-15	76.72	0.53	12.22	0.93	0.04	0.57	2.83	4.37	90.99	trachytic
	86-4A-30	69.51	0.45	16.07	2.57	0.58	2.14	4.25	4.37	92.92	diacitic
	86-4A-34	68.83	0.48	16.33	3.31	0.75	2.20	4.11	3.98	89.23	diacitic
	86-4A-38	64.29	0.53	14.92	7.44	0.13	0.24	7.26	5.19	79.68	trachytic
	86-4A-51	68.56	0.49	15.70	2.97	0.76	2.18	4.75	4.59	83.72	diacitic
	86-4A-60	63.26	0.45	15.88	7.63	0.13	1.23	6.26	5.16	77.80	trachytic
	86-4A-61	62.52	0.43	15.99	8.23	0.12	0.98	6.23	5.50	71.52	trachytic
	86-4A-65	69.54	0.46	15.69	2.89	0.75	2.21	4.27	4.19	92.31	diacitic
	86-4A-66	64.18	0.41	16.36	7.36	0.14	0.88	6.09	4.57	85.33	trachytic
	86-4A-67	68.78	0.62	16.94	2.35	0.85	2.32	4.06	4.10	88.71	diacitic
	86-4A-89	64.13	0.41	16.37	6.20	0.10	0.80	6.76	5.23	75.48	trachytic
	86-4A-90	64.61	0.44	15.50	6.93	0.17	0.65	6.18	5.53	83.29	trachytic
	86-4A-99	69.29	0.43	16.23	3.18	0.68	1.82	4.03	4.34	88.59	diacitic
Analytical session	TD 86-3	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
December 2015											
	86-3a-25	62.66	0.27	16.70	7.11	0.12	0.64	7.32	5.18	95.57	trachytic
	86-3a-27	62.04	0.33	16.28	7.05	0.16	0.98	8.31	4.85	91.91	trachytic
	86-3a-30	62.07	0.36	16.37	6.76	0.08	0.76	8.60	5.00	86.71	trachytic
	86-3a-38	61.39	0.57	13.81	8.41	0.20	1.58	8.77	5.26	89.03	trachytic
	86-3a-66	63.06	0.37	16.00	7.78	0.03	0.86	7.48	4.42	67.57	trachytic
	86-3a-72	62.31	0.50	16.07	7.53	0.06	0.83	7.83	4.87	81.62	trachytic
	86-3a-76	64.04	0.34	16.86	6.72	0.14	0.92	6.41	4.67	92.06	trachytic
Analytical session	TD 86-2	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
December 2015											
	86-2A-7	61.79	0.47	15.64	8.34	0.14	0.63	7.21	5.79	63.85	trachytic
	86-2A-12	64.54	0.41	16.68	5.52	0.19	0.65	7.18	4.82	95.52	trachytic
	86-2A-13	69.21	0.68	15.23	3.06	0.77	1.20	5.32	4.54	62.11	diacitic
	86-2A-14	65.09	0.43	17.62	6.62	0.05	0.85	5.32	4.02	95.45	trachytic
	86-2A-20	63.38	0.45	16.38	6.28	0.29	0.75	7.58	5.39	91.46	trachytic
Analytical session	GV7 295-1	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
February 2016											
	295-1-p12	68.43	0.45	16.67	3.05	0.86	2.20	4.43	3.91	98.29	diacitic
	295-1-p24	64.92	0.46	17.70	6.21	0.07	0.73	5.40	4.50	100.14	trachytic
June 2016											
	295-1-p127	62.78	0.48	16.50	6.18	0.11	0.64	8.21	5.08	91.29	trachytic
	295-1-p131	65.06	0.22	17.96	4.77	0.00	1.39	5.46	5.12	68.02	trachytic
	295-1-p156	64.57	0.11	16.83	5.50	0.07	1.00	7.01	4.92	89.80	trachytic
	295-1-p166	66.40	0.41	16.68	2.10	0.00	0.54	7.75	6.11	97.83	trachytic
	295-1-p167	70.93	0.59	15.66	2.95	0.68	1.61	3.38	4.21	88.51	diacitic
Analytical session	GV7 294-4	SiO ₂	TiO ₂	Al ₂ O ₃	FeO _{tot}	MgO	CaO	Na ₂ O	K ₂ O	Original Total	Glass pop.
February 2016											
	294-4-p2	63.78	0.38	16.40	7.22	0.19	1.72	5.75	4.55	83.47	trachytic
	294-4-p3	61.46	0.36	16.52	8.11	0.02	0.66	4.49	4.39	93.18	trachytic
	294-4-p10	67.92	0.48	16.29	3.15	0.87	2.82	4.34	4.12	92.97	diacitic
	294-4-p14	60.43	0.35	15.66	8.91	0.14	0.81	8.49	5.22	68.57	trachytic
June 2016											
	294-4A-p6	64.65	0.48	16.94	6.10	0.08	1.26	5.77	4.73	96.13	trachytic
	294-4A-p15	6									

168 **References for Supplementary Material**

- 169
- 170 Alloway, B.V., Supriyati Andreastuti, Ruly Setiawan, John Miksic, Quan Hua (2017). Archaeological implications of a
171 widespread 13th Century tephra marker across the central Indonesian Archipelago. *Quaternary Science Reviews*
172 155, 86-99. <https://doi.org/10.1016/j.quascirev.2016.11.020>
- 173 Antoniades, D., Giralt, S., Geyer, A., Álvarez-Valero, A.M., Pla-Rabes, S., Granados, I., Liu, E.J., Toro, M., Smellie, J.L.,
174 Oliva, M. (2018). The timing and widespread effects of the largest Holocene volcanic eruption in Antarctica.
175 *Scientific Reports* 8, 1–11, DOI:10.1038/s41598-018-35460-x
- 176 Barba, D., Robin, C., Samaniego, P., Eissen, J.-P. (2008). Holocene recurrent explosive activity at Chimborazo
177 volcano (Ecuador). *Journal of Volcanology and Geothermal Research* 176 (1), 27-35,
178 <https://doi.org/10.1016/j.jvolgeores.2008.05.004>
- 179 Benjamin, E.R., Plank, T., Wade, J.A., Kelley, K.A., Hauri, E.H., Alvarado, G.E. (2007). High water contents in basaltic
180 magmas from Irazú Volcano, Costa Rica. *Journal of Volcanology and Geothermal Research* 168, 68–92,
181 <https://doi.org/10.1016/j.jvolgeores.2007.08.008>
- 182 Caiazza, L., Baccolo, G., Barbante, C., Becagli, S., Bertò, M., Ciardini, V., Crotti, I., Delmonte, B., Dreossi, G., Frezzotti,
183 M. et al. (2017). Prominent features in isotopic, chemical and dust stratigraphies from coastal East Antarctic ice
184 sheet (Eastern Wilkes Land). *Chemosphere* 176, 273-287, <https://doi.org/10.1016/j.chemosphere.2017.02.115>
- 185 Chevrel, M., Siebe, C. Guilbaud, M.N. Salinas, S. (2015). The AD 1250 El Metate shield volcano (Michoacán): Mexico's
186 most voluminous Holocene eruption and its significance for archaeology and hazards. *The Holocene* 26, 471-488,
187 DOI: 10.1177/0959683615609757
- 188 Delmonte, B., Andersson, P.S., Hansson, M., Schöberg, H., Petit, J.R., Basile-Doelsch, I., Maggi, V. (2008). Aeolian dust
189 in East Antarctica (EPICA-Dome C and Vostok): Provenance during glacial ages over the last 800 kyr. *Geophysical*
190 *Research Letters* 35 L07703, doi:10.1029/2008GL033382
- 191 Espíndola, J.M., Macías, J.L., Tilling, R.I., Sheridan M.F. (2000). Volcanic history of El Chichón Volcano (Chiapas,
192 Mexico) during the Holocene, and its impact on human activity. *Bulletin of Volcanology* 62, 90-104.
- 193 Fontijn, K., Lachowycz, S.M., Rawson, H., Pyle, D.M., Mather, T.A., Naranjo, J.A., Moreno- Roa, H. (2014). Late
194 Quaternary tephrostratigraphy of southern Chile and Argentina. *Quaternary Science Reviews* 89, 70–84.
- 195 Fontijn, K., Rawson, H., Van Daele, M., Moernaut, J., Abarzúa, A.M., Heirman, K., Bertrand, S., Pyle, D.M. et al. (2016).
196 Synchronisation of sedimentary records using tephra: A postglacial tephrochronological model for the Chilean Lake
197 District. *Quaternary Science Reviews* 137, 234-254, <https://doi.org/10.1016/j.quascirev.2016.02.015>
- 198 Frezzotti, M., Urbini, S., Proposito, M., Scarchilli, C., Gandolfi, S. (2007). Spatial and temporal variability of surface
199 mass balance near Talos Dome, East Antarctica. *Journal of Geophysical Research* 112, F02032.
- 200 Gilbert, D., Freundt, A., Kutterolf, S. et al. (2014) Post-glacial time series of explosive eruptions and associated
201 changes in the magma plumbing system of Lonquimay volcano, south central Chile. *International Journal of Earth*
202 *Sciences* 103, 2043–2062, <https://doi.org/10.1007/s00531-012-0796-x>
- 203 Jochum, K.P., Dingwell, D.B., Rocholl, A., Stoll, B., Hofmann, A.W., Becker, S., Besmehn, A., Bessette, D., Dietze, H.,
204 Dulski, P., Erzinger, J., Hellebrand, E., Hoppe, P., Horn, I., Janssens, K., Jenner, G., Klein, M., McDonough, W. Maetz,
205 M., Mezger, K., Mürer, C., Nikogosian, I., Pickhardt, C., Raczek, I., Rhede, D., Seufert, H., Simakin, S., Sobolev, A.,
206 Spettel, B., Straub, S., Vincze, L., Wallianos, A., Weckwerth, G., Weyer, S., Wolf, D., Zimmer, M. (2000). The
207 Preparation and Preliminary Characterisation of Eight Geological MPI-DING Reference Glasses for In-Situ
208 Microanalysis. *Geostandards Newsletter* 24: 87-133, doi:10.1111/j.1751-908X.2000.tb00590.x
- 209
- 210 Hall, M., Mothes, P. (2008). The rhyolitic-andesitic eruptive history of Cotopaxi volcano, Ecuador. *Bulletin of*
211 *Volcanology* 70, 675-702.

212 Koffman, B.G., Dowd, E.G., Osterberg, E.C., Ferris, D.G., Hartman, L.H., Wheatley, S.D., et al. (2017). Rapid transport
213 of ash and sulfate from the 2011 Puyehue-Cordón Caulle (Chile) eruption to West Antarctica. *Journal of Geophysical*
214 *Research: Atmospheres* 122, 8908-8920, <https://doi.org/10.1002/2017JD026893>

215 Kratzmann, D.J., Carey, S., Scasso, R., Naranjo, J.A. (2009). Compositional variations and magma mixing in the 1991
216 eruptions of Hudson volcano, Chile. *Bulletin of Volcanology* 71, 419-439, doi:10.1007/s00445-008-0234

217 Kraus, S., Kurbatov, A., Yates, M. (2013). Geochemical signatures of tephras from Quaternary Antarctic Peninsula
218 volcanoes: *Andean Geology* 40 (1), 1-40, doi:<http://dx.doi.org/10.5027/andgeoV40n1-a01>

219 Kutterolf, S., Freundt, A. & Burkert, C. (2011). Eruptive history and magmatic evolution of the 1.9 kyr Plinian dacitic
220 Chiltepe Tephra from Apoyeque volcano in west-central Nicaragua. *Bulletin of Volcanology* 73, 811-831,
221 doi:10.1007/s00445-011-0457-0

222 Lavallée, Y., de Silva, S.L., Salas, G., Byrnes, J.M. (2006). Explosive volcanism (VEI 6) without caldera formation:
223 insight from Huaynaputina volcano, southern Peru. *Bulletin of Volcanology* 68, 333-348, DOI 10.1007/s00445-005-
224 0010-0

225 Lavigne, F., Degeai, J.-P., Komorowski, J.-C., Guillet, S., Robert, V., Lahitte, P., Oppenheimer, C., Stoffel, M., Vidal,
226 C.M., Surono, Pratomo, I., Wassmer, P., Hajdas, I., Sri Hadmoko, D., de Belizal, D., (2013). Source of the great A.D.
227 1257 mystery eruption unveiled, Salamas volcano, Rinjani Volcanic Complex, Indonesia. *Proceedings of the*
228 *National Academy of Sciences* Sep 2013, 201307520; DOI: 10.1073/pnas.1307520110

229 Mehringer, P.J. Jr., Sarna-Wojcicki, A.M., Wollwage, L.K., Sheets, P. (2005). Age and extent of the Ilopango TBJ
230 Tephra inferred from a Holocene chronostratigraphic reference section, Lago De Yojoa, Honduras. *Quaternary*
231 *Research* 63(2), 199-205, <https://doi.org/10.1016/j.yqres.2004.09.011>

232 Metrich, N., Rutherford, M.J. (1992). Experimental study of chlorine behavior in hydrous silicic melts. *Geochimica et*
233 *Cosmochimica Acta*, 56 (2), 607-616, [https://doi.org/10.1016/0016-7037\(92\)90085-W](https://doi.org/10.1016/0016-7037(92)90085-W)

234 Moreno, P.I., Alloway, B.V., Villarosa, G., Outes, V., Henríquez, W.I., De Pol-Holz, R., Pearce, N.J.G. (2015). A past-
235 millennium maximum in postglacial activity from Volcán Chaitén, southern Chile. *Geology* 43, 47-50,
236 doi:10.1130/G36248.1

237 Morgan, G.B., London, D. (1996). Optimizing the electron microprobe analysis of hydrous alkali aluminosilicate
238 glasses. *American Mineralogist* 81 (9-10), 1176-1185, DOI: <https://doi.org/10.2138/am-1996-9-1016>

239 Nairn, I.A, Shane, P.R, Cole, J.W, Leonard, G.J., Self, S., Pearson, N. (2004). Rhyolite magma processes of the ~AD
240 1315 Kaharoa eruption episode, Tarawera volcano, New Zealand. *Journal of Volcanology and Geothermal Research*
241 131 (3-4), 265-294, [https://doi.org/10.1016/S0377-0273\(03\)00381-0](https://doi.org/10.1016/S0377-0273(03)00381-0)

242 Naranjo, J., Moreno, H., Emparan, C., Murphy, M. (1993). Volcanismo explosivo reciente en la caldera del volcan
243 Sollipulli, Andes del Sur (39°S). *Revista Geológica de Chile* 20 (2), 167-191,
244 doi:<http://dx.doi.org/10.5027/andgeoV20n2-a03>

245 Narcisi, B., Petit, J.R., Delmonte, B. (2010). Extended East Antarctic ice core tephrostratigraphy. *Quaternary Science*
246 *Reviews* 29, 21-27.

247 Narcisi, B., Petit, J.R., Delmonte, B., Scarchilli, C., Stenni, B. (2012). A 16,000-yr tephra framework for the Antarctic
248 ice sheet: a contribution from the new Talos Dome core. *Quaternary Science Reviews* 49, 52-63.

249 Narcisi, B., Petit, J.R., Langone, A., Stenni, B. (2016). A new Eemian record of Antarctic tephra layers retrieved from
250 the Talos Dome ice core (Northern Victoria Land). *Global and Planetary Change* 137, 69-78,
251 <http://dx.doi.org/10.1016/j.gloplacha.2015.12.016>

252 Nielsen, S.H.H., Hodell, D.A., Kamenov, G., Guilderson, T., Perfit, M.R. (2007). Origin and significance of ice-rafted
253 detritus in the Atlantic sector of the Southern Ocean, *Geochemistry, Geophysics, Geosystems* 8, Q12005,
254
255

258 doi:10.1029/2007GC001618

259 Nielsen, C.H., Sigurdsson, H. (1981). Quantitative methods for electron micro-probe analysis of sodium in natural
260 and synthetic glasses. *American Mineralogist* 66, 547-552.

261
262 Nooren, K., Hoek, W.Z., van der Plicht, H., Sigl, M., van Bergen, M.J., Galop, D., Torrescano-Valle, N. et al. (2017).
263 Explosive eruption of El Chichón volcano (Mexico) disrupted 6th century Maya civilization and contributed to global
264 cooling. *Geology* 45, 175-178, doi:10.1130/G38739.1

265
266 Osipov, E.Y., Khodzher, T.V., Golobokova, L.P., Onischuk, N.A., Lipenkov, V.Y., Ekaykin, A.A., Shibaev, Y.A., Osipova,
267 O.P. (2014). High-resolution 900 year volcanic and climatic record from the Vostok area, East Antarctica. *The*
268 *Cryosphere* 8, 843-851.

269 Palais, J.M., Germani, M.S., Zielinski, G.A. (1992). Interhemispheric transport of volcanic ash from a 1259 A.D.
270 volcanic eruption to the Greenland and Antarctic ice sheets. *Geophysical Research Letters* 19(8), 801-804.

271 Pitts, M.C., Thomason L.W. (1993). The impact of the eruptions of Mount Pinatubo and Cerro Hudson on Antarctic
272 aerosol levels during the 1991 austral spring. *Geophysical Research Letters* 20, 2451-2454,
273 <https://doi.org/10.1029/93GL02160>

274 Rawson, H., Naranjo, J.A., Smith, V.C. Fontijn, K., Pyle, D.M., Mather, T.A., Moreno, H. (2015). The frequency and
275 magnitude of post-glacial explosive eruptions at Volcán Mocho-Choshuencho, southern Chile. *Journal of*
276 *Volcanology and Geothermal Research* 299, 103-129.

277 Ruprecht P., Bergantz, G.W., Cooper, K.M., Hildreth, W. (2012). The Crustal Magma Storage System of Volcán
278 Quizapu, Chile, and the Effects of Magma Mixing on Magma Diversity. *Journal of Petrology* 53 (4), 801-840,
279 <https://doi.org/10.1093/petrology/egs002>

280 Shane, P.A.R., Froggatt, P.C. (1992). Composition of widespread volcanic glass in deep-sea sediments of the
281 Southern Pacific Ocean: an Antarctic source inferred. *Bulletin of Volcanology* 54, 595-601.

282
283 Schindlbeck, J.C., Kutterolf, S., Freundt, A., Alvarado, G.E., Wang, K.-L., Straub, S.M., Hemming, S.R., Frische, M.,
284 Woodhead J.D. (2016). Late Cenozoic tephrostratigraphy offshore the southern Central American Volcanic Arc: 1.
285 Tephra ages and provenance, *Geochemistry, Geophysics, Geosystems* 17, 4641-4668, doi:10.1002/2016GC006503

286 Schwander, J., Jouzel, J., Hammer, C.U., Petit, J.R., Udisti, R., Wolff, E. (2001). A tentative chronology for the EPICA
287 Dome Concordia ice core. *Geophysical Research Letters* 28 (22), 4243-4246.

288 Severi, M., Udisti, R., Becagli, S., Stenni, B., Traversi, R. (2012). Volcanic synchronisation of the EPICA-DC and
289 TALDICE ice cores for the last 42 kyr BP. *Climate of the Past* 8, 509-517.

290 Singer, B.S., Thompson, R.A. Dungan, M.A., Feeley, T.C., Nelson S.T., Pickens, J.C., Brown, L.L., Wulff, A.W., Davidson,
291 J.P., Metzger, J. (1997). Volcanism and erosion during the past 930 k.y. at the Tatara-San Pedro complex, Chilean
292 Andes. *Geological Society of America Bulletin* 109 (2), 127-142.

293
294 Spray, J.G., Rae, D.A. (1995). Quantitative electron-microprobe analysis of alkali silicate-glasses: A review and user
295 guide. *Canadian Mineralogist* 33, 323-332.

296
297 Stern, C.R. (2008). Holocene tephrochronology record of large explosive eruptions in the southernmost Patagonian
298 Andes. *Bulletin of Volcanology* 70, 435-454.

299 Stewart A.-M., Castro J.M. (2016). P-T-X evolution of the 1280 AD Quilotoa dacite. *Journal of Volcanology and*
300 *Geothermal Research* 313, 29-43, <https://doi.org/10.1016/j.jvolgeores.2015.11.024>

301 Thouret, J.-C., Finizola, A., Fornari, M., Legeley-Padovani, A., Suni, J., Frechen, M. (2001). Geology of El Misti volcano
302 near the city of Arequipa, Peru. *Geological Society of America Bulletin* 113, 1593-1610.

- 303 Vidal, C.M., Komorowski, J.-C., Metrich, N., Pratomo, I., Kartadinata, N., Prambada, O., Michel, A., Carazzo, G.,
304 Lavigne, F., Rodysill, J., Fontijn, K., Surono (2015). Dynamics of the major plinian eruption of Samalas in 1257 A.D.
305 (Lombok, Indonesia). *Bulletin of Volcanology* 77, 73. DOI 10.1007/s00445-015-0960-9
- 306 Vidal, C.M., Metrich, N., Komorowski, J.-C., Pratomo, I., Michel, A., Kartadinata N., Vincent R., Lavigne, F. (2016). The
307 1257 Samalas eruption (Lombok, Indonesia): the single greatest stratospheric gas release of the Common Era.
308 *Scientific Reports* 6, Article number: 34868, DOI: 10.1038/srep34868
- 309 Watt, S.F.L., Pyle, D.M., Naranjo, J., Rosqvist, G., Mella, M., Mather, T.A., Moreno, H. (2011). Holocene
310 tephrochronology of the Hualaihue region (Andean southern volcanic zone, ~ 42°S), southern Chile. *Quaternary*
311 *International* 246, 324-343, <http://dx.doi.org/10.1016/j.quaint.2011.05.029>