

1 Simultaneous eruptions from multiple vents at Campi
2 Flegrei (Italy) highlight new eruption processes at calderas

3 **Marco Pistolesi¹, Roberto Isaia², Paola Marianelli³, Antonella Bertagnini⁴, Céline**
4 **Fourmentraux³, Paul G. Albert⁵, Emma L. Tomlinson⁶, Martin A. Menzies⁷, Mauro**
5 **Rosi³ and Alessandro Sbrana³**

6 *¹Dipartimento di Scienze della Terra, Università di Firenze, via G. La Pira 4, Florence,*
7 *Italy*

8 *²Istituto Nazionale di Geofisica e Vulcanologia, via Diocleziano 328, Naples, Italy*

9 *³Dipartimento di Scienze della Terra, Università di Pisa, via S. Maria 53, Pisa, Italy*

10 *⁴Istituto Nazionale di Geofisica e Vulcanologia, via della Faggiola 32, Pisa, Italy*

11 *⁵Research Laboratory for Archaeology and the History of Art, University of Oxford,*
12 *Dyson Perrins Building, South Parks Road, Oxford, OX1 3QY, UK*

13 *⁶Department of Geology, Trinity College Dublin, Dublin 2, Ireland*

14 *⁷Department of Earth Sciences, Royal Holloway University of London, Egham, Surrey,*
15 *TW20 0EX, UK*

16 **ABSTRACT**

17 Volcanic eruptions are typically characterized by the rise and discharge of magma
18 at the surface through a single conduit/vent system. However, in some cases, the rise of
19 magma can be triggered by the activation of eruptive fissures and/or vents located several
20 kilometers apart. Simultaneous eruptions from multiple vents at calderas, not related to
21 caldera collapse (e.g., ring faults) are traditionally regarded as an unusual phenomenon,
22 the only historically reported examples occurring at Rabaul caldera, Papua New Guinea.

23 Multiple venting within a caldera system is inherently difficult to demonstrate, owing
24 partly to the infrequency of such eruptions and to the difficulty of documenting them in
25 time and space.

26 We present the first geological evidence that at 4.3 kyr ago the Solfatara and
27 Averno vents, 5.4 km apart, erupted simultaneously in what is now the densely populated
28 Campi Flegrei caldera (Southern Italy). Using tephrostratigraphy and geochemical
29 fingerprinting of tephra, we demonstrate that the eruptions began almost at the same
30 time and alternated with phases of variable intensity and magnitude. The results of this
31 study demonstrate that multi-vent activity at calderas could be more frequent than
32 previously thought and volcanic hazards could be greater than previously evaluated.
33 More generally we infer that the simultaneous rise of magma and gas along different
34 pathways (multiple decrepitation of chamber/s) could result in a sudden pressure rise
35 within sub-caldera magmatic system.

36 **INTRODUCTION**

37 The forecasting of future eruptive vent locations is a challenging goal in
38 volcanology and an important element in the volcanic emergency arrangements. Most
39 calderas have produced highly explosive and effusive eruptions from widespread vents
40 that are difficult to reconcile to any regular spatio-temporal pattern (Bosworth et al.,
41 2003; Acocella, 2007; Cashman and Giordano, 2014). Although multi-vent activity has
42 been described at several volcanic centers worldwide during fissure-fed eruptions (e.g.,
43 Walker et al., 1984; Smith et al., 2006), the possibility of simultaneous, or quasi-
44 contemporaneous, eruptions from independent vents within caldera systems has rarely
45 been reported. To date, Rabaul caldera (Papua New Guinea) showed this phenomenon on

46 three occasions - 1878, 1937, 1994 (Roggensack et al., 1996). This raises a question as to
47 whether multi-vent activity is a peculiarity of this specific volcanic system, or if such
48 behavior has occurred at other calderas worldwide. The twin eruptions of 1994 at Rabaul
49 caldera were preceded by volcano-seismic and deformation crises in 1983 and 1985
50 (McKee et al., 1984). At Campi Flegrei caldera (Southern Italy), a very similar crisis
51 occurred in the mid-1980's but has not yet resulted in an explosive event. During detailed
52 mapping for the new geological map of Naples 446–447 sheets (ISPRA CAR.G Project,
53 Italy), interlayered pyroclastic deposits of the Averno and Solfatara volcanoes were
54 reported within the Campi Flegrei caldera (Isaia et al., 2009). This paper presents a
55 detailed stratigraphic reconstruction and geochemical study of the juvenile component of
56 these pyroclastic deposits and aims to unravel and document the relative timing of the
57 “simultaneous” eruptions from the Solfatara and Averno volcanoes at 4.3 ka BP. The
58 robust documentation of the coeval Averno and Solfatara eruptions can shed light on the
59 potential eruptive behavior of calderas worldwide. Multi-vent activity could actually be
60 more common than previously envisaged even for lower intensity eruptions unrelated to
61 caldera formation.

62 **THE AVERNO 2 AND SOLFATARA ERUPTIONS**

63 The Campi Flegrei caldera (CFc) is one of the most active caldera systems on
64 Earth. In recent decades, CFc has exhibited significant deformation in its central sector,
65 with uplift of several meters centered on the town of Pozzuoli (Del Gaudio et al., 2010).
66 In January 2013, based on very recent ground uplift episodes and gas chemistry data, the
67 Dipartimento della Protezione Civile (Italy) raised the state of CFc from the green (quiet)
68 to the yellow (scientific attention) level. The dense urbanization of the region, where

69 more than three hundred thousand people live within the caldera, makes the volcanic risk
70 at CFc one of the highest in the world.

71 The present structure of the CFc (Vitale and Isaia, 2014) results from a main
72 collapse related to the eruption of the Campanian Ignimbrite (CI) at ca. 40 ka (Rosi and
73 Sbrana, 1987; Orsi et al., 1996) and from minor collapses linked to the Neapolitan
74 Yellow Tuff (NYT) eruption at ca. 15 ka (Orsi et al., 1992).

75 The Averno 2 eruption (4181 – 4386 yr B.P.; Isaia et al., 2009; Smith et al.,
76 2011), or simply the Averno eruption according to the nomenclature introduced by the
77 recent geological map (ISPRA CAR.G Project), occurred in the western sector of the
78 CFc. It was characterized by repeated episodes of sustained and collapsing columns that
79 generated a complex sequence of pumice fall and pyroclastic density currents (PDCs)
80 deposits with a total volume of 0.07 km³. The tephra sequence has been divided (Di Vito
81 et al., 2011) into three members, from base to top, A, B and C. Member A has been
82 subdivided into six fallout sub-members (A0 to A5) interlayered with thin, fine-grained
83 surge deposits. Members B and C consist mainly of surge bedsets intercalated with minor
84 fallout deposits. The whole nomenclature of tephra layers is detailed in the Data
85 Repository. According to Di Vito et al. (2011), the highest intensity of the eruption was
86 reached during emplacement of the A2 sub-Member, with an estimated column height of
87 10 km. The Averno 2 eruption was fed by two trachytic and shallow (<4 km) magma
88 batches with slightly differing degrees of evolution and geochemical signature (Di Vito et
89 al., 2011; Fourmentraux et al., 2012). The most evolved end-member was discharged
90 during the initial phase (A0) and the least evolved in the final part of the eruption (C).
91 Systematic analyses of matrix glass of juvenile pumice fragments show that glasses of the

92 upper part of the fallout deposit A2 (A2t) and of the member B (Bt) are strongly
93 heterogeneous (mingled) with compositions covering the entire compositional range
94 between the two endmembers A0 and C (Fourmentraux et al., 2012). Hereafter, for
95 simplicity, we divide the Averno 2 eruption into three main phases: i) opening phase
96 (corresponding to Member A0 of Di Vito et al., 2011), fed by a more evolved
97 compositional end-member; ii) intermediate phase, which includes the peak fallout
98 deposit (A2t) followed by PDC and minor fallout deposits (member B); iii) final phase
99 (PDC and minor fallout deposits of Member C), containing the less evolved
100 compositional end-member.

101 The Solfatara eruption (4181 - 4386 yr B.P.; Isaia et al., 2009; Smith et al., 2011;
102 Isaia et al., 2015) occurred in the central-eastern sector of the CFc, 5.4 km from Averno
103 lake (Figs. DR1 and DR2). The tephra sequence consists of an opening, mainly phreatic
104 phase. This comprises massive to crudely stratified, fine to coarse ash and block deposits
105 containing scarce juvenile material and minor stratified PDC deposits with limited
106 dispersal. Later in the eruption, shallow discrete Vulcanian explosions produced low
107 eruption columns emplacing accretionary lapilli-bearing ash fallout deposits and PDCs
108 distributed around the Solfatara crater. This phase of the Solfatara eruption was fed by a
109 homogeneous trachytic magma batch stored at shallow (<3 km) level (Cipriani et al.,
110 2008).

111 **STRATIGRAPHY AND SEDIMENTOLOGY**

112 We present data for a well-preserved, key stratigraphic section where deposits of
113 two eruptions are interlayered (Isaia et al., 2009). The outcrop is ~2 km northwest of
114 Solfatara crater and 4 km northeast of Averno lake (Fig. DR1). The section is separated

115 by a thick (>15 cm) paleosol from the underlying deposits of the Agnano Monte Spina
116 eruption (4482 – 4625 yr B.P.; Smith et al., 2011) and by an upper, 3-cm-thick humified
117 horizon from ash beds belonging to the Astroni volcano (4098 – 4297 yr B.P.; Isaia et al.,
118 2004) (Fig. 1a, b).

119 The succession is 100 cm-thick and consists of alternating greenish to light gray
120 ash beds containing accretionary lapilli (Fig. 1). Light colored and white coarser ash beds
121 with scattered pumice clasts are interlayered at various heights. The section has been
122 subdivided into 5 main units, mainly based on tephra sedimentological characteristics
123 (color and grain-size variations), consisting of an alternation of accretionary lapilli-
124 bearing, ash layers with scattered pumice fragments. Each unit is presented and described
125 in detail in Figure DR3. The stratigraphic log, sample location and results of grain-size
126 analyses are presented in Figure DR4, and all the analytical methodologies are detailed in
127 the Data Repository.

128 **MAJOR AND TRACE ELEMENT GLASS COMPOSITIONS**

129 About 140 juvenile clasts were analyzed from the tephra sequence (Table DR1).
130 Glass analyses were obtained for 13 lapilli-sized clasts (from 2 to 6 cm) and one bomb
131 (10 cm) at the base of Unit 1 (sample SA1), pumice fragments from light colored tephra
132 beds of Units 2 (SA3), 4 (SA17), and 5 (SA19), fine white ash from accretionary lapilli in
133 Unit 3 (SA11) and 4 (SA12) and pumice fragments from the greenish deposits of Unit 3
134 (SA5, SA9) and 4 (SA18). The data were compared to those already obtained by Cipriani
135 et al. (2008) for the products of Solfatara and by Fourmentraux et al. (2012) for those of
136 Averno 2.

137 Glassy groundmass pumice collected in the green ash layers of Units 3 and 4
138 (SA5, SA9 and SA18) show a fairly homogeneous trachytic composition ($\text{SiO}_2 = 59.3\text{--}$
139 60.8 wt.%, $\text{CaO} = 2.1\text{--}3.0$ wt.%, $\text{Na}_2\text{O} 3.9\text{--}5.4$ wt.%, $\text{K}_2\text{O} = 8.0\text{--}9.0$ wt.%) perfectly
140 matching the composition of the Solfatara products (Cipriani et al., 2008). Samples
141 belonging to the light colored layers show a wider compositional range ($\text{SiO}_2 = 59.0\text{--}63.3$
142 wt.%, $\text{CaO} = 1.5\text{--}2.5$ wt.%, $\text{Na}_2\text{O} 4.6\text{--}6.8$ wt.%, $\text{K}_2\text{O} = 6.6\text{--}8.7$ wt.%). This range
143 encompasses all the variability of Averno 2 glasses and extends to compositions clearly
144 distinct from Solfatara samples, which have higher contents of CaO , Al_2O_3 , FeO and K_2O
145 and lower contents of SiO_2 and Na_2O . Glassy groundmass pumice clasts from Units 1
146 (SA1), 2 and 3 and the base of Unit 4 (SA3, SA11 and SA12) have heterogeneous
147 compositions covering the entire range of the Averno 2 sequence, essentially comparable
148 to those of the intermediate phase (Fig. 2) (Fourmentraux et al., 2012). In contrast,
149 glasses from the top of the sequence (SA17 and SA19 from Units 4 and 5) show a more
150 homogeneous and less evolved composition ($\text{K}_2\text{O} = 8.1 \pm 0.2$ wt.%) (Fig. 2 and Table
151 DR1), similar to the less evolved trachytic end member emitted during the final phase of
152 Averno 2 eruption. Accretionary lapilli from the upper part of Unit 3 have cores formed
153 by white ash chemically identical to the Averno compositions and green ash coatings
154 with the composition of Solfatara juvenile fraction.

155 To further constrain the major element geochemistry, a total of 70 trace element
156 analyses were performed on 8 selected samples (SA1, SA3, SA5, SA9, SA12, SA17,
157 SA18, SA19). Representative samples of Solfatara (SF12_4) and of the two end-members
158 emitted during the opening (A0) and final (Cmb) phase of Averno eruptions were also
159 analyzed for comparison (Table DR2). Despite the overlap of some incompatible trace

160 elements with the final phase products of the Averno 2 eruption (e.g., Th, Nb, Zr),
161 Solfatara glasses clearly differ from Averno glasses by having markedly higher Ba and Sr
162 contents (Fig. 3, Table DR2). Only one clast of Solfatara shows lower Sr and Ba contents
163 possibly due to K-feldspar crystallization in the matrix glass. Trace elements confirm the
164 heterogeneous compositions of Units 1, 2, and the base of Unit 4 (SA12) and more
165 homogeneous compositions close to the final phase of Averno 2 eruption in Units 4
166 (SA17 and SA19) (Fig. 3).

167 **TEPHRA CORRELATIONS**

168 Detailed sedimentological and chemical analyses performed on the key tephra
169 sequence allow us to attribute the green ash beds to Solfatara and the light colored beds to
170 the Averno 2 eruption. Dispersal and grain-size analyses of greenish deposits are
171 consistent with a medial deposit which recorded the main stages of the Solfatara eruption.
172 In particular, Unit 1, including a scarce juvenile component, represents the basal Solfatara
173 stratified deposits emplaced during the opening phase. The fairly homogeneous
174 composition of the juvenile glassy groundmass from Units 3 and 4 matches that of
175 Solfatara products, thus indicating a correlation to the second phase of the Solfatara
176 eruption.

177 The light colored ash to lapilli-size clasts and whitish to pink layers intercalated
178 within the green ash sequence reveal a larger, more evolved compositional range that
179 matches the different phases of the Averno 2 eruption. Major and trace element contents
180 of lapilli and bomb-sized clasts embedded within Unit 1 (SA1 sample) agree with the
181 composition of the top of A2 fallout deposit, corresponding to the climax of Averno 2.
182 The whole of Unit 2 (SA3), and lapilli from the upper part of the Unit 3 (SA11), and from

183 Unit 4 (SA12) record the PDC-dominated phase of the Averno 2 eruption (intermediate
184 phase). Finally, the chemical composition of lapilli from the upper part of Unit 4 (SA17)
185 and Unit 5 (SA19) correlate well with the glass chemistry of the final phase of Averno 2.

186 **TIMING AND ERUPTIVE DYNAMICS**

187 The correlation of the deposits in the key section with the different phases of the
188 two eruptions allows us to make inferences about the timing of the two contemporaneous
189 eruptive events (Table DR3). Unit 1 records the beginning of the Solfatara eruption; ash
190 deposits are thin at the studied site and thicken toward the Solfatara crater, where phreatic
191 breccias are present at the crater rim. Also at this stage, magmatic explosions and
192 sustained eruptive columns started at the Averno 2 vent; pumice bombs and lapilli
193 produced during the sub-Plinian climactic phase are interlayered within Unit 1.

194 Stratigraphic studies of other outcrops indicate that the pumice clast size and thickness of
195 the fallout deposit increase toward the Averno 2 crater. Unit 2 probably records either a
196 pause in the Solfatara activity or a shift in wind direction, during which time the Averno
197 2 eruptive plume, characterized by ash-laden plumes related to PDCs during its
198 intermediate phase, drifted northeastward. Afterward, a new wind shift or a resumption of
199 the Solfatara activity with magmatic and possibly phreatomagmatic, Vulcanian-type
200 explosions, emplaced breccia deposits and roughly stratified ashes (Unit 3). In the basal
201 part of Unit 3, the Averno 2 products are recorded only by the light ash coatings on the
202 green accretionary lapilli. In the upper part of Unit 3, “inverse” accretionary lapilli, with
203 cores of light ash chemically identical to Averno 2 and coatings of green ash with the
204 composition of Solfatara juvenile clasts occur. The alternation of normal and “inverse”
205 accretionary lapilli suggest either a downturn in activity from one vent and/or a higher

206 sedimentation rate of ash from the other, which forms the cores of the accretionary lapilli.
207 In addition, the cores of accretionary lapilli possibly formed higher in the atmosphere,
208 where only Solfatara or Averno 2 ashes was present, and then fell into an eruptive cloud
209 dominated by ash from the other eruption. If so, the zoning in the accretionary lapilli
210 (both the normal and the “inverse” zoning) may reflect relative heights of the ash cloud
211 from the two synchronous eruptions. Unit 4 is characterized by a close interlayering of
212 green and light-colored ash beds related to ash fallout from Solfatara and to minor
213 pumice fallout associated with PDCs in the final phase of Averno 2. This activity
214 produced a rapid series of short-lived explosions, as shown by the proximal deposits of
215 Averno 2 (Di Vito et al., 2011). Finally, the uppermost Unit 5 records only Averno 2
216 activity.

217 **CONCLUDING REMARKS**

218 This detailed study of the stratigraphy and geochemistry of an intra-caldera tephra
219 sequence reveals that the two eruptions of Solfatara and Averno 2 evolved in parallel,
220 despite coming from vents 5 km apart and located in sectors of the CFc characterised by
221 different magma compositions, structural alignments and eruptive styles.

222 The compositional features of erupted products suggest the involvement of
223 magmas tapped from different shallow portions of the whole Campi Flegrei magmatic
224 system which evolved independently; however, the simultaneity of eruptive activity
225 implies some form of connectivity to a common source at a deeper level. We speculate
226 that the perturbation to the system triggering the two eruptions originated from this
227 common deep reservoir. Since no evidence of arrival of mafic magmas have been
228 detected, we also speculate that the trigger consisted in a sudden pressure increase within

229 the magmatic system possibly due to volatiles saturation (Stock et al., 2016), which in
230 turn caused the multiple decrepitation of its shallowest apophyses. It is worth noticing
231 that most of the activity driven by phreatic/ash emission occurred at Solfatara, which is
232 still the preferential path for gas emission of the caldera. This behaviour of contrasting
233 activity remarkably resembles that of Rabaul 1994 eruption, which was mostly
234 characterized by magma-driven explosivity (Vulcan) with contemporaneous emission of
235 hydrothermally-altered material (Tavurvur) (Global Volcanism Program, 1994).
236 Moreover, the 1994 Rabaul eruption was preceded by a general uplift started years
237 before, but the short-term precursory activity escalated only tens of hours before, with
238 strong and shallow earthquakes, implying a rapid rise of gas and magma. If we assume a
239 similar mechanism, we potentially expect the same scenario for the Averno-Solfatara
240 event. The activation at both Rabaul and Campi Flegrei of the area of higher fluids
241 discharge of the calderas (Tavurvur and Solfatara) also suggests that the destabilization of
242 the magmatic reservoir could be promoted by the sudden rise of high-pressure gas
243 masses, along the plumbing system feeding the shallow magma chamber/s.
244 Finally, the past occurrence of such eruptive dynamics has to be taken into account when
245 assessing future volcanic hazards and considering a realistic eruptive scenario in case of
246 future reactivation of calderas. This is particularly true for densely urbanized areas like
247 CFe, which encompasses large parts of the cities of Pozzuoli and Naples.

248 **ACKNOWLEDGMENTS**

249 Financial support was provided by the projects “V1” and “Speed” funded by
250 Dipartimento della Protezione Civile (Italy) and Regione Campania, and by ISPRA
251 Regione Campania CAR.G Project 446–447 Napoli sheets. This research was partially

252 funded by the NERC “RESET” consortium (NE/E015905/1) and forms “RHOXTOR”
253 contribution 047. D. Swanson, K. Cashman and S. de Silva are greatly acknowledged for
254 their insightful comments.

255 **REFERENCES CITED**

256 Acocella, V., 2007, Understanding caldera structure and development: An overview of
257 analogue models compared to natural calderas: *Earth-Science Reviews*, v. 85,
258 p. 125–160, doi:10.1016/j.earscirev.2007.08.004.

259 Bosworth, W., Burke, K., and Strecker, M., 2003, Effect of stress fields on magma
260 chamber stability and the formation of collapse calderas: *Tectonics*, v. 22, p. n/a,
261 doi:10.1029/2002TC001369.

262 Cashman, K.V., and Giordano, G., 2014, Calderas and Magma Reservoirs: *Journal of*
263 *Volcanology and Geothermal Research*, v. 288, p. 28–45,
264 doi:10.1016/j.jvolgeores.2014.09.007.

265 Cipriani, F., Marianelli, P., and Sbrana, A., 2008, Studio di una sequenza piroclastica del
266 vulcano della Solfatara (Campi Flegrei): *Atti Società Toscana Scienze Naturali*
267 *Memorie, Serie A*, v. 113, p. 1–6.

268 Del Gaudio, C., Aquino, I., Ricciardi, G.P., Ricco, C., and Scandone, R., 2010, Unrest
269 episodes at Campi Flegrei: A reconstruction of vertical ground movements during
270 1905–2009: *Journal of Volcanology and Geothermal Research*, v. 195, p. 48–56,
271 doi:10.1016/j.jvolgeores.2010.05.014.

272 Di Vito, M.A., Arienzo, I., Braia, G., Civetta, L., D’Antonio, M., Di Renzo, V., and Orsi,
273 G., 2011, The Averno 2 fissure eruption: a recent small-size explosive event at the

- 274 Campi Flegrei Caldera (Italy): *Bulletin of Volcanology*, v. 73, p. 295–320,
275 doi:10.1007/s00445-010-0417-0.
- 276 Fourmentraux, C., Métrich, N., Bertagnini, A., and Rosi, M., 2012, Crystal fractionation,
277 magma step ascent, and syn-eruptive mingling: The Averno 2 eruption (Campi
278 Flegrei, Italy): *Contributions to Mineralogy and Petrology*, v. 163, p. 1121–1137,
279 doi:10.1007/s00410-012-0720-1.
- 280 Global Volcanism Program, 1994, Report on Rabaul (Papua New Guinea). In: Venzke, E
281 (ed.), *Bulletin of the Global Volcanism Network*, 19:9. Smithsonian Institution.
282 <http://dx.doi.org/10.5479/si.GVP.BGVN199409-252140>.
- 283 Isaia, R., D’Antonio, M., Dell’Erba, F., Di Vito, M., and Orsi, G., 2004, The Astroni
284 volcano: The only example of closely spaced eruptions in the same vent area during
285 the recent history of the Campi Flegrei caldera (Italy): *Journal of Volcanology and
286 Geothermal Research*, v. 133, p. 171–192, doi:10.1016/S0377-0273(03)00397-4.
- 287 Isaia, R., Marianelli, P., and Sbrana, S., 2009, Caldera unrest prior to intense volcanism
288 in Campi Flegrei (Italy) at 4.0 ka B.P: implications for caldera dynamics and future
289 eruptive scenarios: *Geophysical Research Letters*, v. 36, p. L21303,
290 doi:10.1029/2009GL040513.
- 291 Isaia, R., Vitale, S., Di Giuseppe, M.G., Iannuzzi, E., Tramparulo, F., and Troiano, A.,
292 2015, Stratigraphy, structure and volcano-tectonic evolution of Solfatara maar-
293 diatreme (Campi Flegrei, Italy): *Geological Society of America Bulletin*, v. 127,
294 p. 1485–1504, doi:10.1130/B31183.1.

- 295 McKee, C.O., Lowenstein, P.L., de Saint Ours, P., Talai, B., Itikarai, I., and Mori, J.J.,
296 1984, Seismic and ground deformation crises at Rabaul caldera: Prelude to an
297 eruption?: *Bulletin of Volcanology*, v. 47, p. 397–411, doi:10.1007/BF01961569.
- 298 Orsi, G., D'Antonio, M., De Vita, S., and Gallo, G., 1992, The Neapolitan Yellow Tuff, a
299 large-magnitude trachytic phreatoplinian eruption; eruptive dynamics, magma
300 withdrawal and caldera collapse: *Journal of Volcanology and Geothermal Research*,
301 v. 53, p. 275–287, doi:10.1016/0377-0273(92)90086-S.
- 302 Orsi, G., de Vita, S., and Di Vito, M., 1996, The restless, resurgent Campi Flegrei nested
303 caldera (Italy): Constraints on its evolution and configuration: *Journal of*
304 *Volcanology and Geothermal Research*, v. 74, p. 179–214, doi:10.1016/S0377-
305 0273(96)00063-7.
- 306 Roggensack, K., Williams, S.N., Schaefer, S.J., and Parnell, R.A., 1996, Volatiles from
307 the 1994 eruptions of Rabaul: Understanding large caldera systems: *Science*, v. 273,
308 p. 490–493, doi:10.1126/science.273.5274.490.
- 309 Rosi, M., and Sbrana, A., 1987, The Phlegraean fields: CNR, *Quaderni Ricerca*
310 *Scientifica*, v. 114, 175 p.
- 311 Smith, V.C., Shane, P., Nairn, I.A., and Williams, C.M., 2006, Geochemistry and
312 magmatic properties of eruption episodes from Haroharo linear vent zone, Okataina
313 Volcanic Centre, New Zealand during the last 10 kyr: *Bulletin of Volcanology*, v. 69,
314 p. 57–88, doi:10.1007/s00445-006-0056-7.
- 315 Smith, V.C., Isaia, R., and Pearce, N.J.G., 2011, Tephrostratigraphy and glass
316 compositions of post-15 kyr Campi Flegrei eruptions: implications for eruption

317 history and chronostratigraphic markers: *Quaternary Science Reviews*, v. 30,
318 p. 3638–3660, doi:10.1016/j.quascirev.2011.07.012.

319 Stock, M.J., Humphreys, M.C.S., Smith, V.C., Isaia, R. and Pyle, D.M., 2016, Late-stage
320 volatile saturation as a potential trigger for explosive volcanic eruptions. *Nature*
321 *Geoscience*, v. 9, p. 249-254, doi:10.1038/ngeo2639.

322 Vitale, S., and Isaia, R., 2014, Fractures and faults in volcanic rocks (Campi Flegrei,
323 southern Italy): Insight into volcano-tectonic processes: *International Journal of*
324 *Earth Sciences*, v. 103, p. 801–819, doi:10.1007/s00531-013-0979-0.

325 Walker, G.P.L., Self, S., and Wilson, L., 1984, Tarawera, 1886, New Zealand: A basaltic
326 plinian fissure eruption: *Journal of Volcanology and Geothermal Research*, v. 21,
327 p. 61–78, doi:10.1016/0377-0273(84)90016-7.

328

329 FIGURE CAPTIONS

330

331 Figure 1. (A) Key section where Solfatara and Averno 2 deposits are interlayered; (B)
332 Unit 1: thin yellowish ash laminae intercalated with Solfatara tephra (greenish in color);
333 (C) pisolitic ash layer from Unit 3; note that pisolites have a greenish core and yellowish
334 rim; (D) pisolitic ash layer from the top of Unit 3 (sample SA11); note that pisolites have
335 a yellowish core and a greenish rim; (E) detail of Unit 4. Locations of C-E shown in A.

336

337 Figure 2. Stratigraphic section of the Solfatara deposits showing plots of K_2O versus
338 Na_2O (black diamonds, Solfatara samples; squares, circles, crosses and triangles refer to
339 Averno 2 samples. Same symbols for Averno 2 refer to the same stratigraphic unit). The

340 Solfatara field is from Cipriani et al. (2008); the three variability fields of Averno 2 are
341 from Fourmentaux et al. (2012).

342

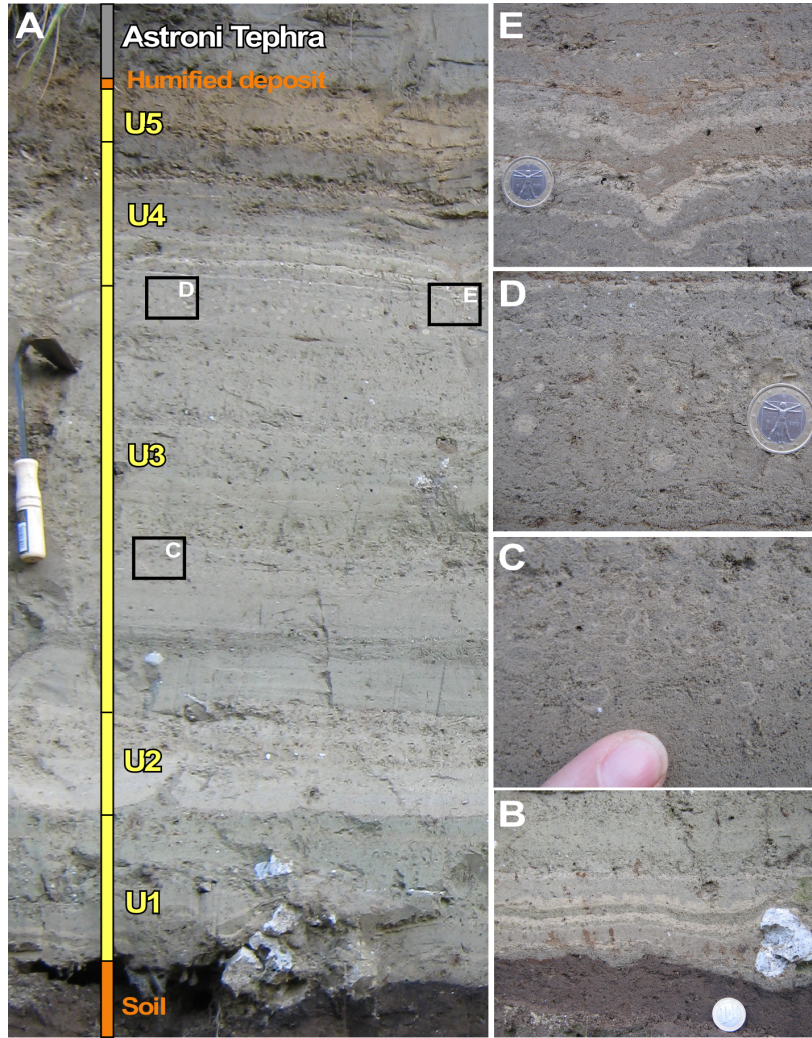
343 Figure 3. Ba/Th, Sr/Th and Th/Zr plots. Full colored symbols (stars, squares and
344 triangles) refer to the reference clasts from Solfatara (SF12_4, green stars) and Averno 2
345 eruptions (A0 and Cmb, yellow triangles and squares, respectively). Analyses from the
346 Averno 2 glasses represent the two compositional end-members of the opening (A0) and
347 final (Cmb) phases. Error bars are within the symbols.

348

349 1GSA Data Repository item 2015xxx, xxxxxxxx, is available online at
350 www.geosociety.org/pubs/ft2015.htm, or on request from editing@geosociety.org or

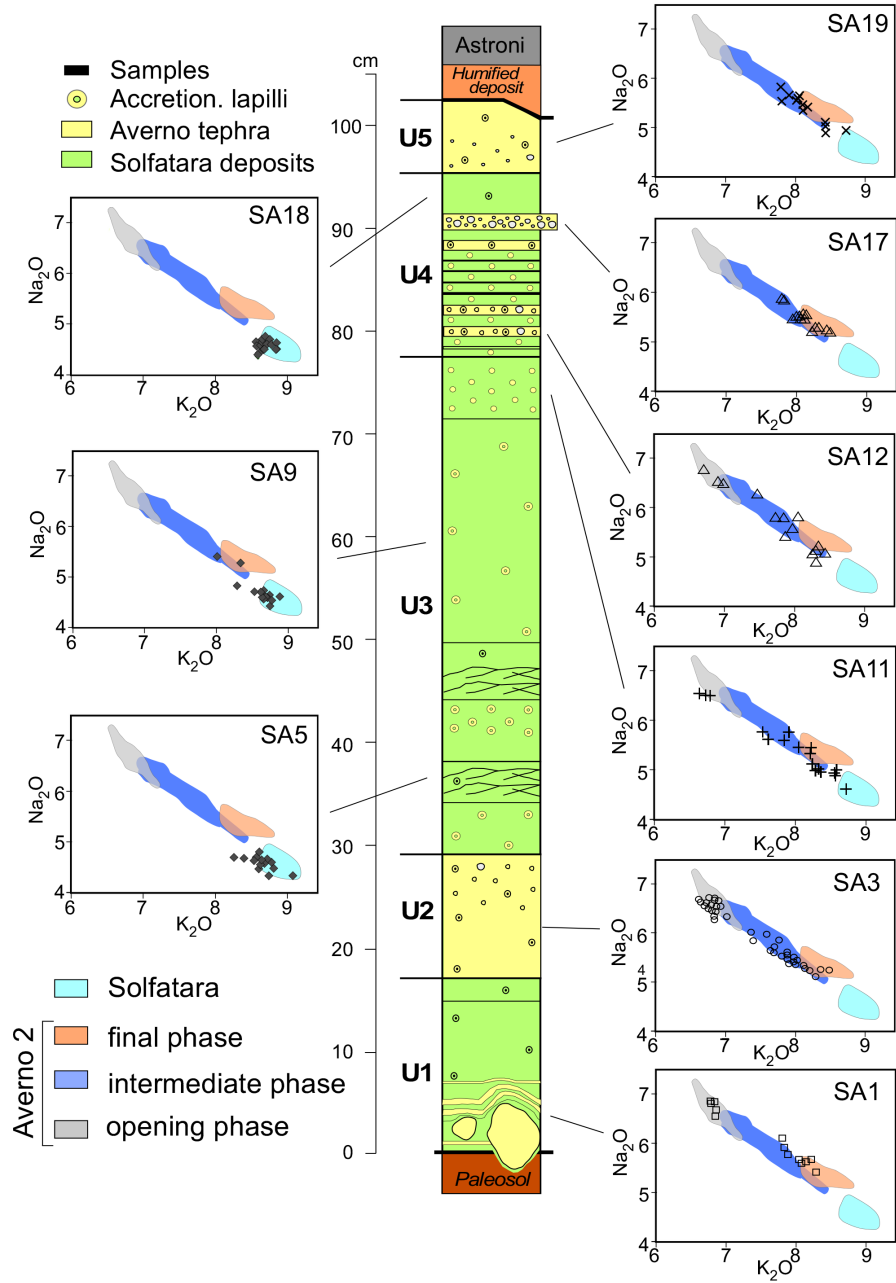
351 Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

352



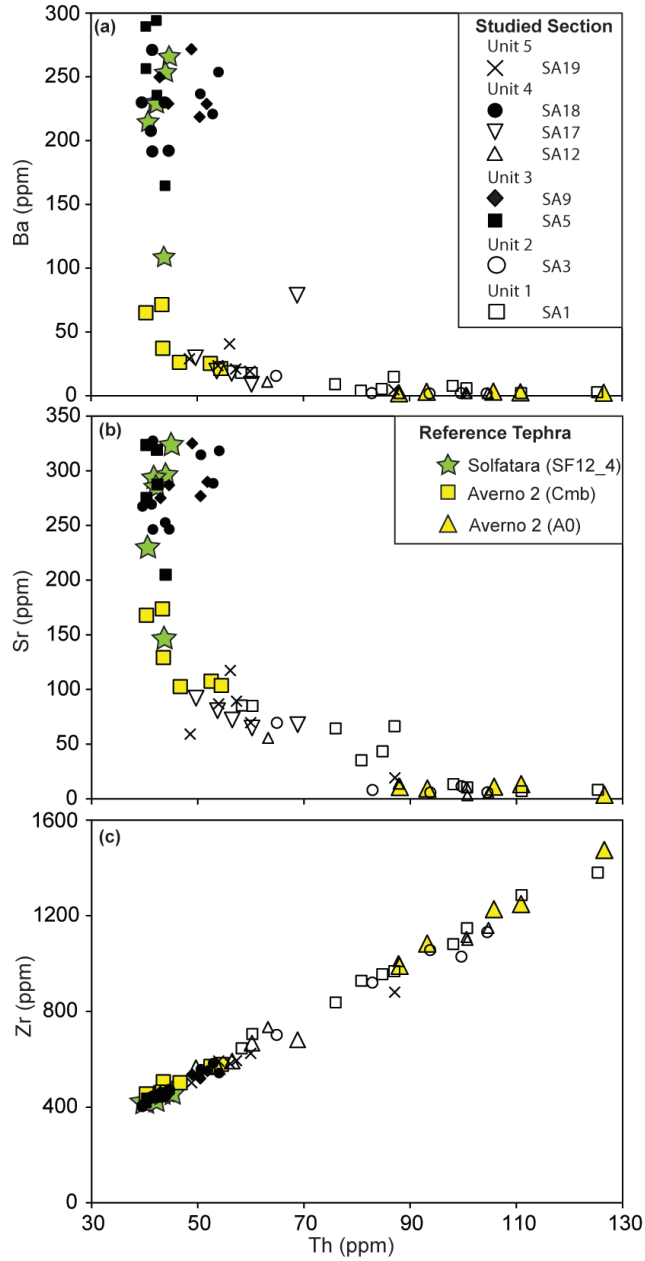
353

354



355

356



357