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Espín

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1 **Geochronological evolution of the potentially active Iliniza Volcano (Ecuador) based on**
2 **new K-Ar ages**

3 Santiago Santamaria ^{a*}, Xavier Quidelleur ^a, Silvana Hidalgo ^b, Pablo Samaniego ^c,
4 Jean-Luc Le Pennec ^{d,e}, Céline Liorzou ^d, Pierre Lahitte ^a, Marco Córdova ^b, Pedro Espín ^b

5
6 ^a GEOPS, Université Paris-Saclay, CNRS, Rue du Belvédère, 91405 Orsay, France

7 ^b Instituto Geofísico, Escuela Politécnica Nacional, Ap. 17-01-2759, Quito, Ecuador

8 ^c Laboratoire Magmas et Volcans, Université Clermont Auvergne, CNRS, IRD, OPGC, F-
9 63000 Clermont-Ferrand, France

10 ^d Geo-Ocean, Institut Universitaire Européen de la Mer, Université de Bretagne Occidentale,
11 CNRS-UBO-Ifremer-UBS, Rue Dumont d'Urville, 29280 Plouzané, France

12 ^e IRD – Délégation Ouest, Technopôle Brest-Iroise, CS10070, 29280 Plouzané, France

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14 *Corresponding author. santiago.santamaria@universite-paris-saclay.fr,
15 sdsantiago@gmail.com

16

17 Keywords:

- 18 - Iliniza volcano
19 - Ecuador
20 - K-Ar dating
21 - Geomorphology
22 - Volcanic hazards

23

24 Highlights:

- 25 - Iliniza volcano is formed by two late-Pleistocene edifices and their satellite vents.
26 - The North Iliniza edifice started growing at ~123 ka and ended at ~116 ka.
27 - The South Iliniza edifice was built from ~46 to ~25 ka and produced a VEI 5 event.
28 - Effusive eruptions took place during the Holocene from 2 southern satellite vents.
29 - Iliniza volcano should be considered as a potentially active volcano.

30

31

32 **ABSTRACT**

33 The youngest volcanism of the Ecuadorian Volcanic Front (Western Cordillera) is mainly
34 dominated by highly explosive events, including the growth and violent destruction of lava domes, and
35 the formation of thick pyroclastic sequences. Deposits associated with such eruptive dynamics have
36 been identified at Iliniza, a compound volcano located in the Western Cordillera with a poorly defined
37 evolutionary history. We present the first K-Ar ages of Iliniza volcano combined with stratigraphic data,
38 numerical reconstructions, and geochemical analyses, providing a new perspective on its evolution. Our
39 results show that Iliniza volcano is much younger than previously proposed. The Iliniza twin-peaked
40 shape is the result of the superposition of two andesitic to dacitic stratovolcanoes. (1) The North Iliniza
41 (NI) edifice was constructed by two lava successions and an intermediate satellite vent, showing a short
42 range of mainly effusive activity between 123 ± 6 and 116 ± 2 ka. (2) The South Iliniza (SI) edifice
43 began its construction through the Lower SI stage when massive lavas dated at ~ 45 ka formed a basal
44 cone. During the Upper SI stage, the uppermost part of this edifice was destroyed by the highly
45 explosive Jatuncama phase (VEI 5) leaving a 30-40 m-thick ignimbrite sequence. The subsequent
46 extrusion of several dacitic lava domes reconstructed the South Iliniza summit at around 35 ka. The
47 Terminal SI stage corresponds to the emission of several andesitic lavas between 31 ± 4 and 25 ± 3 ka.
48 The Iliniza eruptive activity extended into the Late Pleistocene and Holocene with the extrusion of the
49 Tishigcuchi lava dome, and the emission of the Pongo lava flow dated at 6 ± 4 ka. Based on the proposed
50 eruptive history, we suggest that a revised volcanic hazard assessment of the potentially active Iliniza
51 volcano is required.

52

53 1. INTRODUCTION

54 Magmatism in subduction zones archetypically creates volcanic arcs formed by large composite
55 volcanoes whose erupted volumes reaches several tens of cubic kilometers (de Silva and Lindsay,
56 2015). After several geochronological studies, it seems that arc volcanoes grow in “spurts”, i.e.,
57 relatively short-term construction stages separated by long-term quiescence periods. Inside these
58 constructional periods, there are frequent “instantaneous” destruction events, such as sector collapses
59 and caldera-forming eruptions (e.g., Esser et al., 2004; Hildreth, 2007; Conway et al., 2016; Pure et al.,
60 2020). Indeed, several case studies worldwide attest the potential for eruptive activity to occur even
61 after long-term quiescence periods (e.g., García-Palomo et al., 2002; Hora et al., 2007; Mariño et al.,
62 2021). The study of the temporal, morphological and compositional records during the growth of a
63 volcano provides insights into magmatic processes and eruptive behavior at various time scales, and
64 thus represents a key issue for hazard assessment (Gamble et al., 2003; Capra et al., 2008; Brenna et
65 al., 2012).

66 Although several suitable examples are found in the North and South American arcs, for
67 instance, most studies are focused on recent time scales, leaving the oldest eruptive history poorly
68 studied. Along the Ecuadorian Andes, at least 84 Quaternary volcanoes have been identified (Bernard
69 and Andrade, 2011). These volcanic centers are arranged in north-south alignments, described from east
70 to west as the Volcanic Front, the Main Arc, and the Back-Arc (Fig. 1; Hall and Beate, 1991; Hall et
71 al., 2008). Each alignment shows distinctive characteristics in terms of magma composition, volcanic
72 edifice morphology and eruptive dynamics. In particular, the Volcanic Front includes the edifices
73 located on the Western Cordillera, with 15-20 km-wide composite volcanoes which showed several
74 cone-building stages and major sector collapses (e.g., Pichincha volcanic complex; Robin et al., 2010).
75 The formation of lava dome complexes is also recurrent, and often appears during the final eruptive
76 stages following the transition from high-silica andesites to dacites (e.g., Hidalgo, 2006; Robin et al.,
77 2010; Almeida et al., 2019; Bellver-Baca et al., 2020). Moreover, these stages also involve highly
78 explosive eruptions (e.g., Hidalgo et al., 2008; Robin et al., 2008; Andrade et al., 2021), directed blast
79 events (e.g., Bernard et al., 2014), and the formation of two 3 km-wide calderas (i.e., Cuicocha and

80 Quilotoa calderas; von Hillebrandt, 1989; Mothes and Hall, 2008; Sierra et al., 2020). Notably, large
81 explosive eruptions occurred during the Holocene in the northern and central segments of the Volcanic
82 Front (Fig. 1), where large urban areas such as Quito (Ecuador's capital city) are nowadays surrounded
83 by a high number of volcanoes.

84 Iliniza is a twin-peaked compound volcano (5125 m asl) located 50 km south of Quito, in the
85 central segment of the Ecuadorian Volcanic Front (Fig. 1a). Iliniza volcano exhibits volcanological
86 characteristics that are similar to other Volcanic Front edifices, including the presence of dacite lava
87 domes and a thick pyroclastic density current (PDC) deposit, both associated with its late eruptive stages
88 (Hidalgo et al., 2007). Although the geochemistry of the Iliniza volcano's magmas was previously
89 investigated (e.g., Hidalgo et al., 2007, 2012; Schiano et al., 2010; Georgatou et al., 2018), its eruptive
90 chronology remained uncertain due to the lack of radioisotopic ages. Based on erosional
91 geomorphology compared to other volcanoes in the Ecuadorian arc, Hidalgo et al. (2007) suggested
92 that the earliest Iliniza activity might be as old as ~1 Ma, and Hall and Beate (1991) inferred an
93 Holocene age for the Tishigcuchi satellite lava dome. Despite the lack of reliable chronological data,
94 Iliniza volcano was classified as potentially active (Bernard and Andrade, 2011). If confirmed, a
95 relatively young activity would increase the probability of a future reactivation and, consequently,
96 increase the threat that this volcano may represent for the populations living in the Inter-Andean valley.

97 Here, we define the main geomorphologic and volcanological units of Iliniza volcano and
98 present its first geochronological data, combined with new field observations and geomorphological
99 reconstructions. We aim to constrain the eruptive stages of Iliniza volcano through time, as well as its
100 growth and erosion patterns. In addition, geochemical data are used to describe the compositional
101 evolution of its eruptive products over time. Our results show that the construction period of Iliniza
102 volcano is shorter and younger than expected.

103

104 2. GEOLOGICAL CONTEXT

105 Iliniza volcano is part of the Northern Andean Volcanic Zone, which results from the
106 subduction of the Nazca plate beneath the South American plate (Fig. 1a). The tectonic processes related
107 to the active margin in Ecuador caused the formation of two N-S mountain ranges separated by a
108 tectonic depression known as the Inter-Andean Valley (e.g., Tibaldi and Ferrari, 1992; Spikings et al.,
109 2005; Winkler et al., 2005; Alvarado et al., 2016). Iliniza volcano (0°39.8'S, 78°43.0'W) is constructed
110 on the boundary between the Western Cordillera and the Inter-Andean Valley. The Western Cordillera
111 mainly consists of deformed oceanic mafic rocks accreted to the continental margin during the Late
112 Cretaceous to Paleocene, which are covered by Paleogene sedimentary and volcano-sedimentary
113 sequences (Jaillard et al., 2004; Vallejo et al., 2009, 2019). These units are in turn overlain by the Silante
114 Formation, which is exposed to the northwest of Iliniza volcano. It is composed of volcanoclastic
115 sandstones, conglomerates and red mudstones derived from the erosion of the San Juan de Lachas
116 volcanic island arc, of Early Miocene age (Boland et al., 2000; Vallejo, 2007; Vallejo et al., 2020).
117 Towards the southwest, the Zumbahua Formation constitutes an extensive volcanic and volcano-
118 sedimentary sequence deposited in lacustrine and fluvial basins during the Late Miocene-Pliocene
119 (Barberi et al., 1988; Hughes and Bermúdez, 1997; Vallejo et al., 2019). Although no radioisotopic ages
120 are reported, a Pliocene age is inferred for the volcanoclastic series forming the plains gullied by the
121 Jatuncama River, to the west of Iliniza (Hughes and Bermúdez, 1997).

122 The northern Andean geodynamics are dominated by the northeastward decoupling of the North
123 Andean Sliver from the continental margin of South America (Freymueller et al., 1993; Witt et al.,
124 2006; Egbue and Kellogg, 2010; Nocquet et al., 2014). Alvarado et al. (2016) observed that deformation
125 in Ecuador has progressively migrated eastward to its current location on the Chingual-Cosanga-
126 Pallatanga-Puna (CCPP) fault system creating the Quito-Latacunga Microblock (QL-M). Iliniza
127 volcano is located along the NE-SW alignment created by the Machachi right-lateral strike-slip fault
128 (M-f; Soulas et al., 1991; Egüez et al., 2003), and is close to the northern extension of the Latacunga
129 reverse Fault System (Lavenue et al., 1995; Egüez et al., 2003). The M-fs is considered part of the Quito-
130 Latacunga fault system which delineates the western boundary of the QL-M (Alvarado et al., 2016).

131

132 **3. METHODS**

133 **3.1. Sampling strategy**

134 Field work and sampling were carried out in 2019 and 2020 with the purpose to identify and
135 describe the main volcanic units, to establish their stratigraphic relationships, and to collect new fresh
136 rock samples for K-Ar dating and whole-rock geochemical analyses. In addition, in order to gather a
137 comprehensive stratigraphic record, we used previous field data, petrographic descriptions, and samples
138 from Hidalgo (2001, 2006) and Hidalgo et al. (2007). As a result, we completed a dataset of 113 whole-
139 rock analyses that cover the entire stratigraphic succession. Sample locations are shown in Figure 2. All
140 maps and locations are projected using the Universal Transverse Mercator (UTM) coordinate system
141 (Zone 17).

142 From the whole dataset, a total of nineteen new samples were selected for K-Ar dating from
143 lava flows, monolithological breccias, and juvenile blocks from PDC deposits. Six samples belong to
144 the North Iliniza edifice, of which two correspond to monolithological breccias located at the base of
145 the northern flank (ILI 11, ILI 20), three to intermediate height lavas (ILI 16B, ILI 18, 19EQ17), and
146 one to a summit lava (19EQ24). Four lavas of South Iliniza edifice were sampled from the northern
147 (19EQ18, 19EQ25), eastern (19EQ02), southern (20EQ72) and southwestern (19EQ20, 20EQ75)
148 flanks, as along with a lava dome sample (19EQ23b) and a massive lava block (ILI 29A, 20EQ79b)
149 from the summit area. Three juvenile blocks were sampled from PDC's deposits on the northern flank
150 of Iliniza (19EQ16), Jatuncama river valley (19EQ19a) and Santa Rosa area (20EQ81a). Lastly, four
151 dacitic blocks were collected from the Pilongo (ILI 25) and Tishigcuchi (19EQ22, 19EQ70, 20EQ74)
152 satellite lava domes. In addition, three samples of the nearby Santa Cruz volcano were taken from its
153 southern (19EQ44) and northern (19EQ03, 20EQ69) flanks.

154

155 **3.2. K-Ar dating**

156 Eighteen samples were carefully selected based on their low weathering appraised from thin
157 section examination (Appendix A). High groundmass abundance (relative to phenocrysts content), and

158 low vesicle content were also considered. Samples were dated by applying the K-Ar method on
159 groundmass, using the unspiked Cassinol-Gillot technique (Cassinol and Gillot, 1982). The latter
160 relies on the detection of tiny quantities of radiogenic argon ($^{40}\text{Ar}^*$) diluted by ^{40}Ar from atmospheric
161 contamination. The mass spectrometer is used to measure the ^{40}Ar and ^{36}Ar electrical signals extracted
162 from a sample, and to compare them with an aliquot of pure air measured under the same analytical
163 conditions. This approach renders the knowledge of the atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratio unnecessary for our
164 technique. The difference of the $^{40}\text{Ar}/^{36}\text{Ar}$ isotopic ratios acquired from the sample and the atmosphere
165 is used to quantify the amount of $^{40}\text{Ar}^*$ produced by the ^{40}K radioactive decay since the closure of the
166 isotopic system. Thus, the independent measurement of K-content, the ^{40}K relative isotopic abundance
167 in nature and its decay constant (Steiger and Jäger, 1977; Min et al., 2000) allow to calculate the age of
168 the sample. The Cassinol-Gillot technique is adequate to date young calc-alkaline volcanic products
169 that typically exhibit low $^{40}\text{Ar}^*$ contents (Gillot et al., 2006). This technique was successfully applied
170 to the Quaternary Ecuadorian volcanic arc (Alvarado et al., 2014; Bablon et al., 2018, 2019, 2020), in
171 the Andes (e.g., Germa et al., 2010; Samaniego et al., 2016; Grosse et al., 2018, 2020; Pallares et al.,
172 2019; Mariño et al., 2021), and worldwide (e.g., Germa et al., 2011; Hildenbrand et al., 2018; Dibacto
173 et al., 2020). Groundmass fraction is preferred for dating since it is the potassium-enriched phase that
174 crystallizes last following the eruption, and thus incorporated the initial argon with atmospheric isotopic
175 ratio. Furthermore, the use of groundmass avoids the possible contamination by inherited $^{40}\text{Ar}^*$
176 contained in phenocrysts, which could skew ages in young volcanic products (e.g., Singer et al., 1998;
177 Harford et al., 2002; Renne et al., 2012; Lahitte et al., 2019). Samples were prepared following the
178 protocols detailed in Bablon et al. (2018), where analytical procedures, standards used, and uncertainty
179 calculations are also supplied. Potassium and argon isotopic measurements were carried out at the
180 GEOPS laboratory in Orsay (Paris-Saclay University, France). The reproducibility under $1\text{-}\sigma$
181 confidence level was checked by performing the measurements at least twice. Fourteen new K-Ar ages
182 were acquired from the previous selected samples and are presented in Table 1.

183

184 **3.3. Geochemical analyses**

185 Nineteen additional samples were collected for geochemical analyses, following the sampling
186 strategy previously described, to provide a dataset of 40 new analyses presented in Appendix B. Whole-
187 rock contents of major and trace elements were measured from agate-grinded powders at the GEO-
188 OCEAN laboratory, University of Bretagne Occidental (Brest, France) via Inductively Coupled Plasma-
189 Atomic Emission Spectrometry (ICP-AES), following the procedure described by Cotten et al. (1995).
190 Relative standard deviations are <1% for SiO₂, <2 % for the other major elements, and < 5 % for trace
191 elements. To provide a complete dataset covering as much of the volcanic history as possible, we
192 included 73 analyses from Iliniza volcano obtained in the same laboratory and published by Hidalgo et
193 al. (2007).

194

195 **3.4. Geomorphological reconstructions**

196 Numerical methods allow to model the primary geomorphology of a volcanic edifice despite
197 the presence of intense erosive features. They are used to calculate the bulk volume of an edifice at the
198 end of each construction stage, as well as the volume removed by erosion. The morpho-structural
199 analyses were carried out using field observations, Google Earth® satellite images, orthophotography,
200 and a 4-m spatial resolution digital elevation model (DEM) developed by the Sigtierras program from
201 the Ministry of Agriculture and Livestock of Ecuador (<http://geoportal.agricultura.gob.ec>). A regular
202 30-m resolution point cloud was extracted from it to facilitate numerical calculations. We followed the
203 method developed in Lahitte et al. (2012) according to the descriptions provided by Germa et al. (2015)
204 and Dibacto et al. (2020), which are summarized below. The above-mentioned papers yield further
205 methodological details and comparisons with other numerical techniques.

206 The surface preceding the Iliniza construction (S_{t0}) was calculated using an ordinary kriging
207 interpolation method. Our approach uses the external points extracted from the basal outline of the
208 edifice, and theorized profiles of the paleo-topography. The elevation uncertainty at each point is
209 provided by the prediction standard error map resulting from ordinary kriging. We employed the
210 ShapeVolc software (Lahitte et al., 2012) to model the post-cone-building surfaces S_{t1} based on control

211 points extracted from reliable present-day remnants of pre-erosion topography such as the radial crests
212 and *planèzes*. Uncertainty at each point is defined by $\sigma_{St1-i} = \sqrt{\sigma_{mod}^2 + \sigma_{ed-i}^2}$, where σ_{mod} is the
213 elevation uncertainty of the modeled surface, and σ_{ed-i} is that derived from the spatial dispersion of
214 the control points determined by a prediction standard error map.

215 The construction stage volume v_{cs} corresponds to the integration of the elevation difference
216 between S_{t0} and S_{t1} surfaces multiplied by the pixel area, while the erosion stage volume v_{es} uses S_{t1}
217 and present-day S_{t2} surfaces. Volume uncertainty σ_v is given by the combination of the height
218 uncertainties of each point σ_{e-i} multiplied by the pixel area, where $\sigma_{e-i} = \sqrt{\sigma_{Stf-i}^2 + \sigma_{Sti-i}^2}$. Output
219 (R_o) and erosion (R_e) rates are obtained by dividing the v_{cs} and v_{es} volumes by the eruptive ΔT_{cs} and
220 quiescent ΔT_{es} period durations, respectively. Rate absolute uncertainty is defined by $\sigma_{Ri} =$
221 $\sqrt{\left(\frac{\sigma_v}{v}\right)^2 + \left(\frac{\sigma_T}{\Delta T}\right)^2}$, where σ_T is the uncertainty of the period duration ΔT .

222

223 4. RESULTS

224 4.1. Morphology

225 The twin peaks of Iliniza volcano correspond to two prominent superimposed stratovolcanoes
226 (Fig. 2). The **North Iliniza edifice** (5125 m asl), also called Tioniza (Hidalgo, 2001), stands on the
227 eastern edge of the Western Cordillera at 4000 m asl. This volcano has an elongated basal shape with a
228 radius ranging from 4 km over the Western Cordillera side to 6 km in the Inter-Andean Valley side.
229 The summit's southeastern flank is not preserved. Only a narrow and steep amphitheater (750 m wide
230 and slope angle $> 40^\circ$), probably formed by glacial erosion, remains in place (Fig. 2b). The North Iliniza
231 lavas partially cover the *Huayrapungo peak* (4585 m asl), a narrow pinnacle located 2.5 km northeast
232 from the summit (Fig. 2b). The **South Iliniza edifice** (5248 m asl) covers the southeast flank of the
233 North Iliniza edifice. This stratovolcano has a well-defined semicircular shape of 7 km of radius, whose
234 summit is located 1.5 km to the southeast of North Iliniza's summit. The base of the volcano ranges
235 from 3300 m asl to 3600 m asl in the inter-Andean valley. Lastly, the **Pilongo** and **Tishiguchi** satellite

236 lava domes are located at the northern and southern flanks of Iliniza volcano, about 5.2 km from its
237 highest summit.

238 The late Pleistocene glaciations strongly modified the morphology of Iliniza volcano (Hidalgo,
239 2001), as shown by the different stages of glacial erosion exhibited by its two edifices. The northern
240 edifice is dissected by wide U-shaped valleys creating a steep central horn surrounded by a low-sloping
241 *plateau* situated between 4100 and 4200 m asl, where its lowest points extend down to 3780 m asl.
242 Several well-defined ridges radiate from the central horn and separate each glacial valley (Fig. 3a). A
243 succession of moraines a few tens of meters thick is observable inside the main glacial valleys at
244 elevations ranging from 4100 m asl to 4500 m asl. The northwestern flank of the Huayrapungo peak is
245 contoured by a succession of lateral moraines that form a glacial fan at the base of this structure, i.e., at
246 about 4100 m asl at the head of the Pílongo Valley (Fig. 3b). In contrast, the South Iliniza glacial valleys
247 are narrow and less incised preserving the conical shape of the edifice. The lowest frontal and lateral
248 moraines are recognizable at the base of the cone at about 3700 m asl on the eastern flank and 3800 m
249 asl on the northern and southern flanks. Heine (2011) presented a summary of evidences describing
250 several glacial cycles in the Ecuadorian Andes (e.g., Clapperton, 1986, 1987; Heine, 1995, 2000). The
251 author inferred that the non-studied moraine sequences of the Iliniza, Cayambe and Antisana volcanoes
252 could include deposits from the Last Glacial Maximum (LGM; ~35-20 ka) and even from older cycles.
253 This hypothesis is supported by the moraine associations identified at Rucu Pichincha volcano, where
254 LGM and Younger Dryas (~12.5-10.2 ka) moraine series were recognized via radiocarbon dating in the
255 interior of pre-existing wide glacial valleys between 4000 and 3800 m.asl. (Heine, 1995). Observed at
256 similar elevations, the moraine sequences described at Chimborazo volcano and in the Papallacta valley
257 (Chacana caldera; Fig. 1) have been attributed to the LGM and others possibly to previous glacial cycles
258 (Clapperton, 1987, 1990; Heine, 1995). Comparing the moraine elevations in the Ecuadorian Andes,
259 we also consider that those observed at Iliniza volcano were emplaced during the LGM (and possibly
260 during earlier glacial cycles), where its northern edifice suffered a more extended erosion, thus
261 explaining its more conspicuous erosional morphology. Nonetheless, further documentation is required
262 to confirm the ages of these glacial deposits.

263

264 **4.2. Eruptive Chronology**

265 The evolution stages of Iliniza volcano and its relationship with the nearby Santa Cruz volcano
266 are presented below, together with a simplified geological map shown in Figure 4. Volcanic units
267 description is based on the previous studies of Hidalgo (2001, 2002) and Hidalgo et al. (2007), and our
268 new morphologic, stratigraphic, and geochronological data summarized in Table 2.

269

270 **4.2.1. Santa Cruz Volcano**

271 **Santa Cruz (SC)**, is a highly eroded stratovolcano (3978 m asl) mainly comprising successions
272 of andesitic lava flows (e.g., 19EQ44: 56.4 wt.% SiO₂). It is located in the Inter-Andean valley, 10 km
273 east of the South Iliniza edifice (Fig. 2). Only the southern flank of the volcano is exposed, where the
274 preserved gently dipping slopes (8-14°) are dissected by wide and deep valleys. Highly weathered and
275 altered dacitic lava domes are found in the summit area (e.g., 19EQ04: 65.6 wt.% SiO₂). The northern
276 flank, where preserved, is covered by the Inter-Andean valley deposits (*Qiv*), which are 300 m higher
277 compared to the *Qiv* average elevation at the base of the southern flank. A K-Ar age of 702 ± 11 ka is
278 obtained from an andesitic lava flow of the southern ridge (19EQ44), representing an intermediate age
279 of the Santa Cruz edifice.

280 **Loma Saquigua (LS)** is an isolated summit peak (3839 m asl) of Santa Cruz volcano. The base
281 of Loma Saquigua is formed by a dacite lava dome (LS_D; 63.7 wt.% SiO₂). A block taken in its eastern
282 flank (20EQ69) yields a relatively young K-Ar age of 79 ± 2 ka. The upper structure of Loma Saquigua
283 consists of andesitic lava flows (LS_A; 57.8 wt.% SiO₂) dated at 60 ± 3 ka (19EQ03). The Santa Cruz
284 volcanic products, including those of Loma Saquigua, show a mineral assemblage composed of
285 plagioclase, orthopyroxene, clinopyroxene, and Fe-Ti oxides, whereas amphibole is more common in
286 the dacitic lavas.

287

288 **4.2.2. Iliniza Volcano**

289 **4.2.2.1. Early satellite lavas**

290 **The Pilongo lava dome (Pi)** is located on the lower north-western flank of Iliniza volcano,
291 along the western edge of the homonymous valley (Fig. 2). This satellite lava dome is 600 m in basal
292 diameter and reaches a height of 3935 m asl., i.e., 250 m above the valley floor. Due to its low elevation
293 and location, the lava dome does not show evidence of substantial glacial erosion. Erosion caused by
294 fluvial processes created steep slopes on its eastern and southern flank. The northern and western flanks
295 are surrounded by a gently sloping plain consistent in elevation and dip with the northern flank of
296 Iliniza. The Pilongo lava dome is formed by porphyritic rhyodacites (68-69 wt. % SiO₂; Table 2). A
297 sample taken from the southern base of the lava dome (ILI25) yields an age of 353 ± 6 ka.

298

299 **4.2.2.2. North Iliniza edifice (NI)**

300 This edifice is formed by two thick sequences of andesitic to dacitic (62-65 wt.% SiO₂) lava
301 flows, monolithological breccias and scarce proximal pyroclastic deposits (Fig. 4; Table 2). The highest
302 portion of the edifice is characterized by widespread hydrothermal alteration. In addition, the lavas
303 sourced from the Huayrapungo satellite peak appear interspersed between the two above-mentioned
304 sequences of North Iliniza.

305 **The Lower NI stage (NI-Ls)** is defined by a sequence of monolithological breccias, 5-30 m-
306 thick lava flows, and scarce pyroclastic successions, displaying andesite to dacite compositions (62-64
307 wt.% SiO₂). This sequence is well exposed in the glacial ridges around the North Iliniza edifice specially
308 on the Western Cordillera side (e.g., Quilloto and Ninarrumi hills; Fig. 3a). The NI-Ls maximum
309 thickness is estimated at 200-300 m in the Western Cordillera side, and 700-800 m in the Inter-Andean
310 Valley side. The NI-Ls succession overlies the Mio-Pliocene volcano-sedimentary sequences of the
311 Western Cordillera (i.e., Silante and Zumbahua Formations). Two blocks taken from two
312 monolithological breccia layers (ILI20, ILI11) in the northern flank give ages of 122 ± 6 and 123 ± 6
313 ka.

314 **The Huayrapungo stage (NI-Hs)** is represented by an eroded peak formed by voluminous
315 andesitic lavas (62 wt.% SiO₂) cropping out in the northern NI flank. Huayrapungo lavas exhibit meter-
316 scaled flow banding textures, well-exposed in the southern flank of the peak (Fig. 4b), whereas flow
317 foliation and subvertical columnar jointing are common close to the summit areas. Although field
318 relationships are unclear, it seems that Huayrapungo lavas, of at least 250 m in thickness, overly a
319 pyroclastic succession probably related to the Lower NI stage clearly observed in the southern flank of
320 the Huayrapungo peak. Based on the morphological and structural characteristics of Huayrapungo and
321 its stratigraphic position, we consider this peak as a satellite vent of the NI edifice. A sample (19EQ17)
322 collected south of the Huayrapungo peak is dated at 121 ± 2 ka.

323 **The Upper NI stage (NI-U)** consist of a 600–700 m-thick pile of viscous lava flows (30-60
324 m in thickness) that shape the upper structure of the North Iliniza edifice above 4400 m asl (Fig. 4a).
325 This lava succession is andesite to dacite in composition (62-65 wt.% SiO₂). A notable feature is a
326 voluminous 100 m-thick lava exposed in the summit area which flowed down 1500 m northwestwards
327 (Fig. 3a). Erosion reveals the flow foliation structure and fractures associated with a secondary summit
328 vent located at 4800 m asl. A sample collected at the base of this massive lava yields an age of 116 ± 2
329 ka (ILI18). Another 90 m-thick lava is located on the western flank in the Quillotoiro hill, overlying the
330 NI-Ls succession. It is cut by a glacial valley on its highest portion. We suggest an emplacement age
331 similar to that of the ILI18 lava flow.

332

333 **4.2.2.3. South Iliniza edifice (SI)**

334 This edifice corresponds to a compound volcano formed by a basal stratovolcano discordantly
335 overlain by a summit lava dome complex and massive lava flows (Fig. 5). These successions define the
336 three cone-building stages of the South Iliniza edifice (Table 2). The lower flanks of the edifice are
337 covered by a thick pyroclastic succession associated with the second stage.

338 **The Lower SI stage (SI-Ls)** corresponds to an early cone constructed on top of the NI
339 successions and the remnants of the Santa Cruz volcano. It consists of a 1100 m-thick succession of

340 dacitic (62-65 wt. % SiO₂) massive lavas, sparse inter-layered breccias, and semi-consolidated PDC
341 deposits. Outcrops near the center of the edifice show moderated hydrothermal alteration. Two
342 consistent ages of 45 ± 2 ka and 46 ± 1 ka are obtained from lavas located on the northern (19EQ18)
343 and eastern (19EQ02) flanks, respectively. Glacial striations preserved on the northern lava flow
344 confirm its pre-LGM age (roughly 35-20 ka; Clapperton, 1986; Heine, 2011). This basal stratovolcano
345 is disrupted above 4700 m asl where the radial slope decreases top-down from 35° to less than 10°
346 forming a truncated cone. The change in slope is especially noticeable on the southern flank where a
347 saddle shape structure, called the Cantarilla height (Fig. 3a), marks a structural unconformity (Fig. 4a
348 and 5b).

349 **The Upper SI stage (SI-U_s)** incorporates a pyroclastic succession surrounding the lower flanks
350 of the basal cone, and the summit lava domes located above the Cantarilla unconformity (Table 2).

351 *The Jatuncama ignimbrite (SI-J_i)* is a widespread PDC succession that crops out at the lower
352 flanks of the South Iliniza edifice (Fig. 6). Widespread outcrops occur in the Jatuncama valley, to the
353 southwest of Iliniza volcano (Fig. 4). The Jatuncama pyroclastic deposits overlie semi-consolidated
354 pyroclastic deposits ascribed to the Lower SI stage to the east, and inorganic consolidated soils to the
355 south of the SI edifice. The Jatuncama ignimbrite consists of a thick multiple bedded *block-and-ash*
356 *PDC sequence* (SI-J_{BA}) overlaid by *pumice-and-ash flow deposits* (SI-J_{PA}). The SI-J_{BA} deposits are
357 continuous, typically normal graded to massive, poorly sorted, slightly consolidated, and gray to pinkish
358 in color. No interlayered paleosoils are observed in the Jatuncama sequence. Degassing pipes are
359 commonly observed in the upper beds (Fig. 6b). The SI-J_{BA} deposits are constituted by poorly
360 vesiculated juvenile dacite blocks (63-67 wt.% SiO₂; Table 2) showing radial and prismatic-jointed
361 structures, and varying amounts of pumice lapilli. Both clast types are supported in a fine-grained ash-
362 matrix bearing glass shards and free crystals of plagioclase, amphibole, and scarce pyroxene. Low-
363 density pumice lapilli are generally scarce in the lower beds of the SI-J_{BA} deposit, whereas clasts with
364 textural banding of glassy and high-density pumice are common (Fig. 6c). The SI-J_{BA} average thickness
365 is ~30-40 m with a maximum of 120 m in the Jatuncama valley. The reconstructed area covered by the
366 SI-J_{BA} deposits reaches ~60 km² with an average thickness of 35 m, yielding an estimated volume of

367 2.1 km³. These values suggest an eruptive phase with a volcanic explosivity index (VEI) of at least 5.
368 We should stress that no tephra fallout deposits have been observed, thus the estimated volume should
369 be considered as a minimum. The high-density pumice sample (19EQ19a) collected from an
370 intermediate bed of the SI-J_{BA} in the Jatuncama valley exhibit high atmospheric contamination
371 preventing K-Ar dating.

372 Two 7-10 m-thick pumice-and-ash PDC units (SI-J_{PA}) overlie the SI-J_{BA} deposits at the
373 Jatuncama valley (site 20EQ92; Fig. 6d) and the northeastern SI flank (site 20EQ96). The SI-J_{PA} units
374 are massive, poorly consolidated, and light gray to beige in color. They are composed of fibrous dacite
375 pumice lapilli (65-67 wt.% SiO₂) and occasional high-density dacite blocks up to 10 cm in diameter
376 (Fig. 6e), supported in a matrix formed by fine glass shards and crystals of plagioclase, amphibole, and
377 pyroxene. In addition, a 25 cm-thick rhyolite pumice-and-ash flow PDC deposit (71-72 wt.% SiO₂)
378 crops out on the northeastern SI flank was described as the *Santa Rosa pumice-and-ash PDC (SI-J_{SR})*
379 by Hidalgo et al. (2007). We identified a ~1-2 m-thick matrix-supported deposit (site 20EQ81), with a
380 poorly-sorted texture, outcropping on top of the northern SI-J_{PA} (site 20EQ96). The collected samples
381 reveal a mixture of rhyolitic pumiceous blocks (20EQ81a) and poorly vesiculated dacite blocks
382 (20EQ81b, c) all ranging from 10-30 cm in diameter, suggesting a probable reworking of the primary
383 deposit described by Hidalgo et al. (2007).

384 The Jatuncama ignimbrite sequence is preserved as a gently sloping surface (4-12°) intersected
385 by shallow fluvial channels. The heads of these streams are commonly covered by moraines or
386 intersected by glacial valleys at elevations above ~3750 m asl, i.e., above the LGM limit observed in
387 other volcanoes of the region (Clapperton, 1986, 1990; Heine, 2000, 2011). The Jatuncama succession
388 is overlain by a thick sequence of paleosoils, tephra fallout deposits from Cotopaxi, and other reworked
389 materials of broadly Holocene age (Fig. 5a). Notably, the Cotopaxi F2 and F4 rhyolitic tephra fall
390 deposits (7770 ± 70 to 5830 ± 80 ¹⁴C yr BP; Hall and Mothes, 2008) were identified in the Planchaloma
391 and Pastocalle areas (Fig. 4). Minor landslide scarps affecting these shallow deposits are recognizable
392 on the eastern and southeastern SI flanks.

393 Two *consolidated PDC deposits (SI-U_{CP})* crop out east of the Cantarilla height, on the
394 southwestern flank of the cone (Fig. 4b). These deposits, which are ~100 m-thick each, overlie the
395 Lower SI sequence forming the conspicuous Cantarilla angular unconformity. The summit lava domes
396 and its related deposits overlie this pyroclastic sequence. Unfortunately, no samples could be collected
397 due to the terrain roughness.

398 *The Summit Lava Dome Complex (SI-U_{SDC})* is located on top of the remnants of the Lower SI
399 edifice (Fig. 5b), between 4710 and 5060 m asl, reaching a basal diameter of ~1.7 km. The SI-U_{SDC}
400 vent, inferred as the geometrical center of the structure, occurs 250 m to the north with respect to that
401 of the basal cone. As a result of the erosion, only the main core of the summit lava domes has been
402 preserved. Multiple lava lobes and remnants of the SI-U_{SDC} talus are exposed in the summit southern
403 flank, forming a sequence of thinner strata lying unconformably upon the older cone in the Cantarilla
404 height (Fig 5b). The summit lava domes are dacitic in composition (64–67 wt.% SiO₂) and. A sample
405 taken at the northern base of the SI-U_{SDC} (19EQ23b) yields an age of 34 ± 1 ka. The higher sections of
406 the South Iliniza edifice are covered by *undifferentiated dacitic breccias (SI-U_{DL})* interpreted as
407 reworked PDC deposits related to the SI-U_{SDC} dome-forming eruptive activity.

408 **The Terminal SI stage (SI-Ts)** is represented by several massive lava flows and
409 monolithological breccias that overlie the SI-U_{SDC} deposits and descend mainly along the western flank
410 into the Providencia valley (Fig. 4b and 5). This lava succession shapes the SI edifice summit above
411 5000 m asl, reaching a thickness of ~250 m. The SI-Ts lavas are mostly andesitic in composition (SI-
412 T_A; 61–63 wt.% SiO₂). Two voluminous lava flows, called the Termancucho lavas (Hidalgo, 2001),
413 outcrop on the summit's western flank and can be traced 3 km downslope into the upper Providencia
414 valley (Fig. 3a and 4b). The lower 70 m-thick lava flow (20EQ79) is composed by a porphyritic dacite
415 (SI-T_D; ~67 wt.% SiO₂), whereas the upper 50 m-thick lava flow (ILI 29) has an andesitic composition
416 (~62 wt.% SiO₂) consistent with the overlying SI-T_A series (Table 2). A sample collected from the lower
417 Termancucho lava (20EQ79a) was discarded for K-Ar measurements due to its high phenocryst and
418 low groundmass contents. Another andesitic lava flow outcrops on the southern SI flank at the
419 headwaters of the Tiliche river (site 20EQ72; Fig. 4), is partially overlaid by a LGM moraine. The

420 upstream trace of the Tiliche lava flow is intersected by the Providencia valley, hiding the source of this
421 flow. Nevertheless, we relate this lava flow to the summit's terminal lavas given their similar
422 petrological characteristics and stratigraphic position (Table 2). A sample taken from the base of the
423 Tiliche lava flow (20EQ72) yields an age of 31 ± 4 ka. A comparable, albeit younger, age of 25 ± 3 ka
424 was obtained from an andesitic block (19EQ25) collected from a monolithological breccia on the
425 northern SI flank.

426

427 4.2.2.4. Late satellite lavas

428 **Tishigcuchi (T)**, also called Rasuyacu (Hall and Beate, 1991), is a satellite dome *coulée* located
429 on the southern flank of the South Iliniza edifice (Fig. 7a). It is composed of a 1100 m-wide lava dome
430 (4185 m asl), and at least 3 viscous lava flows reaching 90 m-thick and 1800 m-long. The lava SI-J_{BA}
431 was constructed over a 7° slope at 3850 m asl formed by the SI-J_{BA} and the Tiliche lava flow (Fig. 4).
432 The Tishigcuchi lava *coulée* is andesitic in composition (62-63 wt.% SiO₂). No collapse or explosion
433 crater structures are observed, and no pyroclastic deposits related to the Tishigcuchi lava dome are
434 found in our study. The dome shows no evidence of glacial erosion and is covered by soils intercalated
435 with Cotopaxi's rhyolitic Holocene lapilli and ash fall deposits. Attempts to obtain a K-Ar age from the
436 selected samples (19EQ22, 20EQ74) were unsuccessful due to the high atmospheric contamination
437 exhibited by the groundmass.

438 **Pongo (Pg)** is a voluminous lava forming a 4 km-long terrace between the Pongo and
439 Providencia rivers, in the Jatuncama valley (Fig. 7b). The erosion caused by the Pongo river has exposed
440 a 60-m-high cliff with columnar jointing at the southwestern edge of the lava. Exposures of the
441 Jatuncama ignimbrite are observed on the valley walls next to the Pongo lava. The Pongo lava is
442 composed by aphanitic andesites (59 wt.% SiO₂). Although the sample collected at the Providencia
443 River (19EQ20) is highly contaminated by atmosphere, a second sample taken at the base of the
444 columnar jointing exposures (20EQ75) provides an age of 6 ± 4 ka. The source of the lava flow cannot
445 be clearly identified upstream into the glacially carved Providencia valley. Given the size of the Pongo

446 lava and its Holocene age, its upper parts should be still observable as they could not have been
447 completely eroded or covered by younger deposits. Thus, an origin from a satellite vent located at the
448 southwestern base of Iliniza volcano is suspected.

449

450 **4.3. Reconstructed morphology for volume estimations**

451 **4.3.1. Basement surface reconstruction**

452 Defining the substratum morphology is an essential step for volume calculations, as minor
453 changes in the basement morphology could lead to volume errors greater than 50% in stratovolcanoes
454 (e.g., Ceboruco volcano; Frey et al., 2004; Tungurahua volcano; Bablon et al., 2018). The basement
455 shape of Iliniza volcano (S_{I-t_0} surface) was reconstructed using a theorized topographic profile
456 modeled from four parallel auxiliary profiles located to the north and to the south of the volcano . The
457 auxiliary profiles intersect the hills of Ninarrumi and Quillotoro to the north, and Chilcapamba to the
458 south of the Iliniza volcano (Fig. 2 and 8a), which form the northwestern-southeastern ridge of the
459 Western Cordillera. Further to the east, at the eastern and southeastern foothills of the South Iliniza
460 edifice, the auxiliary profiles intersect a slight elevation of the Santa Cruz volcano and the Loma La
461 Cruz ridge (Fig. 8a).

462

463 **4.3.2. Iliniza volcano paleosurface reconstruction and volume calculations**

464 The total reconstructed area for Iliniza volcano is 127 km², which corresponds to a present-day
465 bulk volume of 34 ± 14 km³. This volume represents the amount of volcanic products preserved between
466 the present-day topography and the modeled basement surface S_{I-t_0} . Considering an activity range of
467 98 ± 7 kyr, corresponding to the growth of the North and South Iliniza edifices between 123 ± 6 ka and
468 25 ± 3 ka, an apparent bulk output rate of 0.35 ± 0.14 km³/kyr was determined. Nevertheless, our results
469 have shown that the eruptive activity of Iliniza volcano was seemingly interrupted by long-term
470 quiescence periods between each construction stage. Therefore, volume calculations, and growth or

471 output rates, require to be adjusted for each construction and erosion stages (Table 2). Appendix C
472 provides several topographic profiles comparing the modeled cones of the Iliniza edifices, the modeled
473 basement surface, and the present-day surface.

474 The first construction stage of the Iliniza volcano corresponds to the extrusion of the Pilongo
475 lava dome, which has a present-day volume of $18 \pm 5 \times 10^3 \text{ km}^3$. The next stage corresponds to the
476 construction of the North Iliniza edifice. The modeled cone S_{NI-t1} has a semicircular base with a
477 concave profile that reached 5200 m asl. The symmetry axis is located 200 m southwest of the present-
478 day summit and is coincident with the narrow amphitheater of the eastern flank. The volume of the
479 modeled cone v_{NI-CS} is $28 \pm 9 \text{ km}^3$, a relatively small value compared to the volcano's height of ~ 1700
480 m above the Inter-Andean Valley. This value is explained by the presence of the Western Cordillera
481 basement, which makes its base level ~ 400 m higher than the Inter-Andean valley. Considering a period
482 of activity occurring between $124 \pm 5 \text{ ka}$ and $116 \pm 2 \text{ ka}$, the output rate obtained R_{NI-o} is 3.5 ± 2.6
483 km^3/kyr .

484 La Virgen plain (LV), located northeast of Iliniza volcano (Fig. 2 and 5), was originally
485 interpreted as part of the South Iliniza edifice (Hidalgo et al., 2007). However, a detailed analysis of its
486 geometry reveals that the slope gradient direction of La Virgen points to a source located to the west,
487 coinciding with the location of the North Iliniza edifice. We support this hypothesis by the discordant
488 position of the northern lava flow from the SI-Ls stage (19EQ18, ILI 34). This lava flowed into the
489 Pilongo valley between La Virgen plain and the Huayrapungo peak (Fig. 4), implying a pre-South
490 Iliniza construction for the northeastern sector. Overlapping of other products of the South Iliniza
491 edifice is not excluded during the formation of La Virgen plain.

492 The reconstruction of the eastern sector of the North Iliniza edifice at $\sim 45 \text{ ka}$ (i.e., before South
493 Iliniza construction) was not straightforward given that this area is covered by the South Iliniza deposits.
494 This area completes the surface S_{NI-t2} corresponding to the relief at the end of the quiescence period
495 between growth of both edifices. We used two auxiliary topographic profiles based on radial sections
496 of the present-day northeastern sector La Virgen and the southwestern sector Pongo alto (Fig. 8b) to
497 compute the surface S_{NI-t2} . The eroded volume v_{NI-es} , calculated between the modeled cone S_{NI-t1}

498 and the eroded surface S_{NI-t2} , is $6 \pm 2 \text{ km}^3$. Only the western sector was exposed to non-stop weathering
499 during the ~ 116 kyr quiescence of North Iliniza. Then, the eroded volume in the western sector v_{es-W}
500 is $3 \pm 1 \text{ km}^3$, implying an erosion rate R_{NI-e-W} of $0.03 \pm 0.01 \text{ km}^3/\text{kyr}$.

501 The construction of the South Iliniza edifice comprises the lower cone-building, the upper cone-
502 building, and the terminal effusive stages. The former two cones were modeled independently as a first
503 approach, but we selected a simpler geometry involving a single cone given the poor geometric
504 constrains. A volume v_{SI-CS} of $18 \pm 6 \text{ km}^3$ was obtained for the modeled cone S_{SI-t1} . As in the case of
505 the North edifice, this volume appears to be rather small given the volcano height of ~ 1850 m measured
506 from the Inter-Andean valley bottom. The modeled paleo-summit is located 250 m east of the current
507 summit and reaches 5300 m asl. Considering a 21 ± 3 kyr-long cone-building period (from 46 ± 1 to 25
508 ± 3 ka), the South Iliniza edifice yields an output rate R_{SI-o} of $0.8 \pm 0.3 \text{ km}^3/\text{kyr}$. The volume difference
509 between the present-day surface S_{SI-t2} and the reconstructed cone S_{SI-t1} gives an eroded volume v_{SI-es}
510 of $6 \pm 2 \text{ km}^3$ implying an erosion rate R_{SI-e} of $0.24 \pm 0.09 \text{ km}^3/\text{kyr}$. Figure 8c shows that the northern
511 contact between the South Iliniza modeled cone and the partially eroded North Iliniza edifice occurs
512 along the Rio Blanco valley in the northern sector and along the Pongo Alto valley in the southern sector
513 (see also Fig. 11c-f). Lastly, the Tishigcuchi lava dome yields a present-day volume of $339 \pm 41 \times 10^{-3}$
514 km^3 , whereas the Pongo lava flow reaches a volume of $73 \pm 18 \times 10^{-3} \text{ km}^3$.

515

516 4.4. Geochemical characterization

517 The Iliniza volcanic products are classified in the SiO_2 vs. K_2O diagram (Fig. 9a; Peccerillo and
518 Taylor, 1976) as medium-K andesites and dacites, which are similar to those observed in other Volcanic
519 Front edifices (VF, Fig. 1b). Some scarce andesites and rhyolites, corresponding to the Pongo and Santa
520 Rosa units, fall outside the VF field. Each construction stage shows narrow silica content ranges.
521 Negative correlations are observed in Harker diagrams including MgO , Fe_2O_3^* , CaO , TiO_2 and Al_2O_3
522 *versus* silica, used as differentiation index, while K_2O and Na_2O show positive correlations (Fig. D.1).
523 The North Iliniza and South Iliniza eruptive products typically form well-defined trends. Samples from

524 the Pilongo and Santa Rosa units plots along or near the prolongation of the Iliniza trend. In contrast,
525 the eruptive products of Tishigcuchi and Pongo show K_2O enrichment and Na_2O depletion compared
526 to the andesitic lavas of the Terminal SI stage(SI-T_A).

527 Variations in trace element contents in relation to silica increase for the North and South Iliniza
528 tend to form well-correlated trends (Fig. D.2). Some transition metals (e.g., V, Sc) show a marked
529 compatible behavior as well as Heavy Rare-Earth Elements (HREE; e.g., Yb) and Y. However, the
530 Large-Ion Lithophile Elements contents (LILE; e.g., Rb, Ba) remain relatively constant, except for
531 South Iliniza edifice which shows an overall incompatible behavior with the andesitic SI-Ts values
532 being the lowest. High contents of Light Rare-Earth Elements (LREE; e.g., La, Ce), Th and Sr are
533 observed in the products of Santa Rosa, Tishigcuchi and Pongo. Cr and Ni are also high for these
534 samples, as well as in the andesitic SI-Ts lavas. Only a few samples are available for lower South Iliniza
535 edifice, making its geochemical signature poorly constrained. Its northern lava flow (19EQ18, ILI 34)
536 exhibits unusually high LREE, Th and Sr contents.

537 Incompatible elements and Rare-Earth Elements (REE) spider diagrams normalized to
538 primitive mantle/chondrites (Sun and McDonough, 1989) are shown in Figure 9b-e. Overall, the
539 chondrite-normalized REE diagram for North and South Iliniza dacites exhibit similar, slightly
540 fractionated patterns with LREE enrichment and HREE depletion, and no Eu anomaly. The South
541 Iliniza samples present an overall, albeit slight, REE depletion relative to North Iliniza, except for the
542 northern Lower SI stage lava flow (19EQ18, ILI 34) which has a strong LREE enrichment. The highest
543 HREE depletions are observed for the most evolved products of Iliniza volcano, i.e., the dacitic
544 Termancucho lava (dacitic SI-Ts), Pilongo and Santa Rosa units. The primitive mantle-normalized plot
545 reveals a similar pattern for all samples with positive Ba, K and Rb anomalies and negative Nb and P.
546 Lower Ti, Dy, Y and Yb signatures characterize the dacitic SI-Ts, Pilongo and Santa Rosa units. The
547 low HREE (e.g., Yb<0.61 ppm) and Y (<7.8 ppm) concentrations observed in the Pilongo and Santa
548 Rosa units, coupled with the high LREE (e.g., La>12 ppm) contents, result in elevated La/Yb ratios
549 compared to other units (Fig 10e). Conversely, samples from the Tishigcuchi and Pongo eruptive
550 products show similar ratios but also higher mafic signatures (e.g., SiO_2 <63 wt.%, Mg#>50). Overall,

551 the La/Yb ratio show a slight increase over time (excluding Pilongo), whereas fluid-mobile to fluid-
552 immobile ratios (e.g., Ba/Th) decrease (Fig. 10b, d). Further detailed descriptions regarding the
553 geochemistry and petrography of Iliniza volcano are provided in Hidalgo (2001, 2002) and Hidalgo et
554 al. (2007).

555

556 **5. DISCUSSION**

557 **5.1. Iliniza and Santa Cruz geochronological evolution**

558 Although a rather limited number of ages have been obtained here, their key stratigraphic
559 position allows us to propose a complete geochronological evolution of Iliniza and Santa Cruz
560 volcanoes. Our stratigraphic, geochronological, and geochemical data suggest that the Iliniza volcano
561 had a relatively short lifetime span. We propose that Iliniza volcano was constructed in short eruptive
562 intervals separated by long repose periods throughout late Pleistocene (from ~350 ka to the Holocene)
563 as summarized below. Prior to the construction of the Iliniza volcano, the Santa Cruz volcano was
564 constructed in the Inter-Andean valley. The predominantly effusive activity of the Santa Cruz volcano,
565 dated at 702 ± 11 ka, is represented by the thick lavas exposed on its southern flank and the dacitic lava
566 domes present in the summit area. We found no other evidence of volcanic activity in this area until the
567 extrusion of the Pilongo lava dome, the earliest stage of Iliniza volcano, which took place close to the
568 Machachi fault (Fig. 3) at 353 ± 6 ka.

569 After an apparent quiescence period of ~230 kyr, the North Iliniza volcano started the
570 construction of a ~1600 m-high edifice, in the southern prolongation of the Machachi fault (Fig. 11a).
571 Two lava successions characterize the effusive activity occurring between 123 ± 6 and 116 ± 2 ka (Table
572 1), after the Penultimate Glacial Maximum (Shackleton et al., 2003). Nevertheless, we interpret this age
573 range with caution as no basal lava could be sampled. Based on morphological and stratigraphic
574 evidence, we attribute the formation of the Huayrapungo peak to a satellite vent contemporary with the
575 lower lava sequence. Later, the erosion caused by Pleistocene glaciations, presumably from pre-LGM
576 glacial cycles (>49 ka; Heine, 2011), shaped the wide radial glacial valleys around the North Iliniza

577 summit, and incised the Pilongo and Providencia-Pongo paleo-valleys (Fig. 4). After an apparent ~620
578 kyr-long quiescence period, activity resumed on the Santa Cruz volcano when the dacitic lava dome of
579 Loma Saquigua was extruded at 79 ± 2 ka, followed by the emission of andesitic lavas at 60 ± 3 ka (Fig.
580 11b).

581 The South Iliniza edifice was constructed on top of the partially eroded North Iliniza. A
582 conspicuous structural unconformity marks the two growth phases of this edifice. The earliest phase
583 corresponds to the emplacement of the Lower SI stage eruptive products, which are constituted by thick
584 lavas and pyroclastic successions dated at about 45 ka, forming a basal edifice (Fig. 11c). Remnants of
585 this edifice are exposed in the southern flank and in the center of the South Iliniza edifice. According
586 to the stratigraphic position of the Jatuncama ignimbrite deposits covered by LGM moraines, and its
587 radial distribution fanning away from the South Iliniza edifice, we propose that this unit represents an
588 explosive phase prior to the second growth phase of this edifice (Fig. 11d). As discussed below, the
589 geochemistry of the dacitic components of the Jatuncama ignimbrite is comparable to the SI summit
590 lava domes (SI-U_{SDC} unit), thus supporting our hypothesis. During the second growth phase, a summit
591 lava dome complex and its related pyroclastic deposits subsequently filled the depression caused by the
592 Jatuncama eruption (crater rim, Fig. 4) and reconstructed the volcanic cone since 34 ± 1 ka. Then, a
593 final mostly effusive stage involved the emission of several andesitic lavas covering the uppermost parts
594 of the volcanic cone (Fig. 11e). Our K-Ar ages suggest that this activity extended up to 25 ± 3 ka.

595 The Tishigcuchi lava dome coulée and Pongo lava flow extrusions represent the youngest
596 eruptive stages of the Iliniza volcano (Fig. 11f), as previously suggested (Hall and Beate, 1991). The
597 Tishigcuchi lava dome was extruded on the southern flank of the volcano along the southern
598 prolongation of the Machachi fault. Although no radiometric age could be obtained, a stratigraphic age
599 between 20 to 8 ka can be proposed due to the presence of the underlying Tiliche lava flow dated at 31
600 ± 4 ka, the lack of LGM glacial erosion or associated deposits (maximum extents reached at 34.8-27.9
601 ka and 19.2 ka; Heine, 2011), and the overlying Cotopaxi F2 and F4 fallout deposits (~8.5 and ~6.7 cal
602 ka; Hall and Mothes, 2008). Finally, the age obtained from the Pongo lava flow (6 ± 4 ka) demonstrates
603 that Iliniza volcano was still active during the Holocene.

604 The available ages in the central part of the Ecuadorian arc point to the existence of two types
605 of volcanism based on the extent of their eruptive chronology. The long-lived volcanic complexes,
606 which exhibit multiple edifices and cone-building stages as old as 1 Ma, extending their activity to more
607 recent times even up to the Holocene (e.g., Pichincha and Cayambe volcanic complexes; Samaniego et
608 al., 2005; Robin et al., 2010), and the short-lived compound volcanoes, which were rather formed in
609 briefer cone-building stages of few tens of ka and were mostly emplaced in relatively recent times (e.g.,
610 Cotacachi and Imbabura volcanoes; Le Pennec et al., 2011; Almeida et al., 2019). Our new K-Ar ages
611 reveal that the age and extent of Iliniza volcanic activity is in good agreement with this group of young
612 short-lived volcanoes, whereas Santa Cruz could be considered as a long-lived volcano.

613

614 **5.2. The Jatuncama explosive phase**

615 The Jatuncama ignimbrite samples exhibit a dacitic composition similar to that of the South
616 Iliniza upper stage (Fig. 12). However, the compositional dispersion of the SI-J_{BA} points to a more
617 intricate deposit, as indicated by the SiO₂ content ranging between 63 and 67 wt.%. Figures 12a and
618 12b show the geochemical distribution of the SI-J_{BA} dacitic juvenile clasts compared to the South Iliniza
619 units. For similar SiO₂ and Mg# values, the low-density pumices are slightly enriched in K₂O compared
620 to the high-density pumices and dacites. Furthermore, the high-density pumices generally fall within
621 the SI-U_{SDC} field, while low-density pumices are more correlated with the SI-T_D pole. The few glassy
622 juvenile clasts available are relatively scattered without any clear relationship. The SI-J_{BA} composition
623 also shows slight variations according to the location of the sampling site (Fig. 12d). A relatively higher
624 dispersion degree is observed in the Jatuncama valley and on the southern flank (sites 7-9) compared to
625 the southeastern flank where low K₂O samples seem to be absent (sites 3-5). This difference may be
626 explained by the fact that the lower SI-J_{BA} beds, with higher participation of high-density pumices and
627 dacites, are not well exposed on the southeastern flank. In addition, the plots of the SI-J_{PA} units
628 (20EQ92, 20EQ96) fall in the fields of slightly K₂O enriched clasts. Therefore, on the basis of this
629 geochemical evidence, the petrographic descriptions provided above, and the fact that neither
630 discordances, nor interlayered paleosoils are observed in the Jatuncama succession, we argue that the

631 Jatuncama ignimbrite units correspond to an intricate deposit formed during an explosive dome-forming
632 eruption followed by a pumiceous phase both associated with the upper SI stage, as suggested by
633 Hidalgo et al. (2007). The Jatuncama eruption was followed by the extrusion of the Summit Lava Dome
634 Complex (SI-U_{SDC}). Based on the estimated volume of the Jatuncama deposits, we infer the formation
635 of a 1.5-2 km-wide crater (Figures 4 and 11d) related to the Jatuncama explosive phase (minimum VEI
636 ~5), which agrees with the top surface diameter of the truncated basal cone (i.e., SI-Ls). The Cantarilla
637 discordance marks the inferred crater rim created during the Jatuncama explosive phase (Fig. 11d).

638 In the lack of direct measurement, geomorphological, stratigraphic, and geochemical data can
639 provide an approximate age for the Jatuncama ignimbrite. Considering that the SI-Ji sequence overlies
640 the SI-Ls deposits and its distribution around the basal SI edifice, a lower bound is defined by the Lower
641 SI stage at 45 ± 2 ka. The overlaying Tiliche lava flow (20EQ72) constrains the upper bound at 31 ± 1
642 ka. Such pre-LGM age is supported by the glacial morphology affecting the highest sections of the
643 ignimbrite deposit, and by the thick Holocene tephra fallout sequence. Finally, considering the
644 geochemical affinity with the SI-U_{SDC} unit, we propose that the Jatuncama explosive phase, and the
645 formation of the SI-Ji pyroclastic sequence, occurred shortly before the extrusion of the summit lava
646 domes dated at 34 ± 1 ka (19EQ23b).

647

648 **5.3. Growth and erosion patterns of Iliniza Volcano**

649 Volcanic edifices are composed of a wide variety of eruptive products including lava flows,
650 lava domes, PDC successions, and fallout deposits accumulated around a central vent. The destruction
651 of part of the volcanic edifice during highly explosive events and/or sector collapses, and the re-
652 mobilization of unconsolidated materials are other factors to consider during or in between the growth
653 phases. Therefore, the bulk volume of the main edifice does not represent the entire volcanic products
654 emitted and thus the calculated values should be considered as minima. Nevertheless, volumes obtained
655 in numerical reconstructions provide a first-order approximation, allowing recognition of fluctuations

656 in its spatial and temporal output patterns, and allowing comparison with other eruptive centers, as
657 discussed below.

658 According to our numerical reconstructions both Iliniza edifices reached similar heights and
659 volumes. The combined v_{cs} volumes of the Iliniza edifices and satellite lava domes reaches a total bulk
660 volume of $46 \pm 15 \text{ km}^3$ of accumulated material (Table 2). This value includes the volume of material
661 removed by erosion during the quiescence periods (v_{es}). About 61 vol.% of this volume belongs to the
662 North Iliniza edifice, 38 vol.% to the South Iliniza edifice, and the remaining 1 vol.% to the satellite
663 lavas. Due to the complex topography of the Iliniza basement, our results exhibit a relatively high
664 uncertainty of ~ 35 vol.%. The volume of the SI-Ji deposits is implicitly included in our calculations as
665 its estimated value is within the volume uncertainty range.

666 The bulk volume of Iliniza volcano is similar to those reported for the other compound
667 volcanoes located at the Ecuadorian northern cross-arc segment, e.g., Cushnirumi, Cusin, Fuya-Fuya
668 and Imbabura, which range from $31 \pm 19 \text{ km}^3$ to $61 \pm 24 \text{ km}^3$ (Bablon et al., 2020). Large volcanic
669 complex such as Pichincha, Cayambe and Mojanda accumulated larger volumes ranging from 115 ± 5
670 to $\sim 160 \text{ km}^3$ (Robin et al., 2010; Samaniego et al., 2005; Bablon et al., 2020), which is not the case of
671 Iliniza volcano. In contrast, Antisana has a bulk volume of $\sim 61 \text{ km}^3$, but has a lifespan longer than 400
672 ka (Hall et al., 2017b). Volcanoes with volumes similar to those of Iliniza volcano are also found in the
673 southern cross-arc segment. Effectively, each Iliniza edifice is comparable in volume to the Mulmul or
674 Huisla stratovolcanoes, which show values of 22 ± 7 and $25 \pm 11 \text{ km}^3$ (Bablon et al., 2018, 2020).
675 Nevertheless, Iliniza volcano has a smaller volume relative to Chimborazo (Samaniego et al., 2012) and
676 the whole Tungurahua (Bablon et al., 2018) volcanoes. Compared to other worldwide volcanoes, Iliniza
677 could be considered as a medium-size compound volcano, whose volume and shape are typical of
678 continental arcs (Grosse et al., 2009). Similar bulk volumes to Iliniza are found in volcanoes such as
679 Parinacota (Hora et al., 2007), Ampato-Sabancaya (Samaniego et al., 2016), Yucamane-Calientes
680 (Rivera et al., 2020), Ceboruco (Frey et al., 2004), or Katmai (Hildreth et al., 2003b) volcanoes.
681 Nonetheless, the lifespans of these volcanoes differ by several tens of thousands of years.

682 The output rates calculated for the North Iliniza ($3.5 \pm 2.6 \text{ km}^3/\text{kyr}$) and South Iliniza (0.8 ± 0.3
683 km^3/kyr) edifices are quite variable, although both structures show comparable volumes and shapes.
684 The higher growth rate of North Iliniza is explained by the short range of activity displayed by our
685 radiometric ages. The lack of outcrops and/or sampling of the lower units might have biased the activity
686 range towards the late-stage ages, then, the impact on output rates can be significant. Nevertheless, the
687 sampling distribution and the small age range observed do not exclude a short-term (few tens of ka)
688 construction of the North Iliniza edifice. In fact, high growth rates have also been documented for
689 several Ecuadorian volcanoes such as Cubilche, Cusin, Imbabura (Bablon et al., 2020), Tungurahua III
690 (Bablon et al., 2018), Cotopaxi (Hall and Mothes, 2008), and Guagua Pichincha (Robin et al., 2010)
691 volcanoes, with R_o values ranging from 2.0 ± 1.5 to $3.6 \pm 2.1 \text{ km}^3/\text{kyr}$. In contrast, the South Iliniza
692 growth rate is comparable to those of other Ecuadorian arc volcanoes. R_o values between 0.6 ± 0.3 and
693 $0.8 \pm 0.2 \text{ km}^3/\text{kyr}$ were reported for volcanoes such as Pichincha (Robin et al., 2010), Tungurahua I and
694 II (Bablon et al., 2018), Mulmul (Bablon et al., 2019), and Chimborazo (Samaniego et al., 2012). Similar
695 output rates were reported for other Andean volcanoes such as Misti (Thouret et al., 2001), Parinacota
696 (Hora et al., 2007), and Ampato-Sabancaya (Samaniego et al., 2016); although they are comparatively
697 higher than in other continental arc systems such as the Cascades Range, Central Andes, Mexico, Japan,
698 or Alaska (e.g., Crisp, 1984; Hildreth et al., 2003a, 2003b; Frey et al., 2004; Ownby et al., 2007). Output
699 rate comparisons should be taken with caution as R_o values ($> 1\text{-}2 \text{ km}^3/\text{kyr}$) are typical of short-term
700 growth episodes (of few ka), whereas low values are typical of bulk eruptive rates (i.e., long periods
701 including the quiescense periods; Bablon et al., 2020).

702 The eruptive history of the Iliniza edifices developed separately in time, in contrast to other
703 twin-peaked volcanoes such as Mojada-Fuya Fuya (Robin et al., 2009) in the Ecuadorian arc, or
704 Yucamane-Calientes (Rivera et al., 2020) in the Peruvian arc. In fact, the evolution of Iliniza and Santa
705 Cruz volcanoes included long-lasting quiescence periods, which is also the case for other volcanoes in
706 the Ecuadorian Andes such as Cotopaxi (Hall and Mothes, 2008), Pichincha (Robin et al., 2010),
707 Atacazo-Ninahuilca (Hidalgo, 2006), and Tungurahua (Bablon et al., 2018). Long resting periods
708 (several tens of thousands of years) are also reported in other twin volcanoes and compound volcanoes

709 in the region and worldwide such as San Pedro-San Pablo (Bertin and Amigo, 2015; González-Maurel
710 et al., 2019), Ampato-Sabancaya (Samaniego et al., 2016), Yucamane-Calientes (Rivera et al., 2020),
711 and Colima (Robin et al., 1987; Cortés et al., 2010). These observations suggest that eruptive hiatuses
712 are also common in this type of compound volcanoes from volcanic arcs, contrasting with models of
713 sustained eruptive activity throughout their lifetimes (e.g., Conway et al., 2016; Pure et al., 2020), while
714 increasing the potential for reactivation in present-day dormant volcanoes.

715

716 **5.4. Overall geochemical nature**

717 Overall, samples from the North and South Iliniza (NS-I) edifices exhibit rather little
718 geochemical variability along a single evolutive trends (Fig. A.1) suggesting neither a change in
719 magmatic sources nor in the magmatic process active at crustal levels. In contrast, important differences
720 arise when NS-I trace element contents are compared to the early and late satellite lavas and the Santa
721 Rosa rhyolites, in which HREE depletions and LREE enrichments were identified. Notably, the Iliniza
722 rocks do not show a continuous increase in SiO₂ or decrease in Mg# over time (Fig. 10a) as observed
723 at other volcanoes from the central segment of the arc (e.g., Pichincha volcano; Robin et al., 2010). The
724 silica-poor units (i.e., SI-T_A, T and Pg units) occur during the late evolutionary stages of Iliniza.

725 As presented in Table 2, the common mineral assemblages exhibit by the North Iliniza lavas
726 include plagioclase, orthopyroxene, clinopyroxene, Fe-Ti oxides and scarce amphibole, whereas the
727 South Iliniza eruptive products include plagioclase, amphibole, clinopyroxene, Fe-oxides and rare
728 orthopyroxene. Based on a geochemical modelling approach, Hidalgo et al. (2007) and Schiano et al.
729 (2010) proposed that the NS-I magmatic series could result from an amphibole-dominated fractional
730 crystallization process of typical calc alkaline arc magmas. Their models also showed that the silica-
731 rich products of Pilongo and Santa Rosa units require more complex petrogenetical models. In fact, the
732 trace element contents of these units were unable to be reconciled with a parental melt with NS-I
733 composition through a single fractional crystallization process, thus, implying the occurrence of an
734 additional parental melt and a mixing process involving both magmas. The petrogenetic processes

735 related to the origin of such silica-rich magmas are widely discussed as they could be produced by
736 several processes including partial melting of the subducted slab and the metasomatism of the mantle
737 wedge caused by the derived silicate melts (e.g., Bourdon et al., 2003; Samaniego et al., 2005, 2010;
738 Hidalgo et al., 2007, 2012), crustal melting and/or assimilation of the lower crust (Garrison and
739 Davidson, 2003; Garrison et al., 2006; Sainlot et al., 2020), and intra-crustal fractionation of the required
740 high-pressure assemblages (e.g., Bryant et al., 2006; Chiaradia et al., 2009; Bellver-Baca et al., 2020).
741 However, a comprehensive analysis of these petrogenetic processes and their temporal behavior is
742 beyond the scope of this paper. Nonetheless, the whole Iliniza magmatic series could be thus explained
743 by a fractional crystallization process coupled with magma mixing between mafic and silica-rich end-
744 members (Hidalgo et al., 2007; Schiano et al., 2010); where the geochemical signatures of both end-
745 members seem to occur throughout the geochronological evolution of Iliniza volcano, rather than being
746 restricted to its final stages.

747

748 **5.5. Exploring the implications for the hazard assessment**

749 Unlike other active and potentially active volcanoes from the Volcanic Front (e.g., Pululahuá,
750 Guagua Pichincha, Ninahuilca), whose eruptions involved dacitic magmas and dome-forming eruptive
751 dynamics, the Holocene activity of Iliniza mainly released andesitic lavas. Based on the proposed
752 eruptive chronology, we infer that the most probable eruptive scenario could be dominated by the
753 emission of lava flows and/or the formation of low-viscosity lava domes, whose subsequent collapse
754 may produce PDCs and regional tephra fallout deposits. The apparent migration of the active vents
755 through time, from northern to southern locations, favors an eruptive scenario possibly taking place on
756 the southern flank of Iliniza volcano. However, an active vent located in higher areas close to the summit
757 cannot be discarded. In such case, an eruption in these steeper slope areas would favor the
758 destabilization of the newly emitted lavas increasing the risk of PDC formation, potentially
759 accompanied by explosive phases and widespread tephra fallouts (Voight et al., 2002; Harnett et al.,
760 2018). Such events could affect the 200,000 inhabitants living within 20 km of the volcano (INEC,
761 2010), including the populations of Chaupi, Pastocalle and Toacazo (Fig. 2).

762 Although a high explosive phase was identified at Iliniza volcano, this event was unique
763 throughout its eruptive history and are absent in the Holocene eruptive chronology. Therefore, we
764 expect that a scenario involving a highly explosive eruption (e.g., VEI 5), such as the Jatuncama event,
765 is less probable in the short term. In addition, the Iliniza eruptive history does not include any major
766 flank collapse, as no avalanche deposits or morphological remains suggesting a collapse amphitheater
767 were identified. However, the occurrence of the Iliniza volcano above an active strike-slip fault system,
768 the potential weakening of its flanks caused by weathering and hydrothermal alteration, and the steeply
769 inclined slopes of its uppermost areas increase the risk of a potential collapse promoted by a tectonic
770 event.

771 Finally, the Cotopaxi fallout deposits covering the Iliniza volcano slopes is an additional hazard
772 to consider, although it is not intrinsically related to the Iliniza activity. The Holocene tephra layers
773 deposited on the flanks of Iliniza could be easily remobilized, especially during the rainy season
774 (December to April), forming secondary lahars that flow into the ravines of the volcano. The Cotopaxi
775 tephra sequence, reaching up to 10 m in thickness, may slide due to the low cohesion of the lower and
776 thicker tephra layers. This hazard is supported by the multiple landslide deposits observed on the
777 southern flank of the Santa Cruz volcano (Hall et al., 2017a), and by the small scarps observed on the
778 east and southeast slopes of the South Iliniza edifice.

779

780 **6. CONCLUSIONS**

781 This work provides the first geochronological data for the Iliniza volcano and allows to establish
782 a comprehensive overview of its development over time. The first volcanic manifestations in the area
783 correspond to the adjacent Santa Cruz volcano dated at 702 ± 11 ka. After a long quiescent period, its
784 activity resumed at 79 ± 2 ka and 60 ± 3 ka forming the small-volume Loma Saquigua lava dome.

785 Iliniza shows a young episodic activity that began with the extrusion of the rhyodacite Pilongo
786 lava dome occurring at 353 ± 6 ka. The Iliniza compound volcano (46 ± 15 km³) comprises two andesitic
787 to dacitic edifices formed in several cone-building stages. The older North Iliniza edifice (28 ± 19 km³)

788 was first constructed by a succession of thin lavas and breccias during the Lower NI stage at 123-122
789 ka, followed by the formation of the Huayrapungo satellite peak at 121 ± 2 ka. Then, thick viscous lava
790 sequence dated at 116 ± 2 ka built the higher portion of the edifice through the Upper NI stage. The
791 North Iliniza edifice showed a relatively high output rate of 3.5 ± 2.6 km³/kyr.

792 After a ~ 70 kyr quiescence period, the South Iliniza edifice (18 ± 6 km³) grew over the remnants
793 of the North Iliniza edifice in three main cone-building stages, with an output rate of 0.8 ± 0.3 km³/kyr.
794 A basal edifice was constructed during the Lower SI stage by a series of massive lavas of dacitic
795 composition, dated between 46 ± 1 and 45 ± 2 ka. The Upper SI stage started with the Jatuncama
796 explosive phase, in which the uppermost portion of the basal stratovolcano was destroyed and a 30-40
797 m-thick dacitic pyroclastic succession was deposited. The estimated minimum bulk volume of the
798 Jatuncama ignimbrite deposits is 2.1 km³, corresponding to a VEI ~ 5 eruption. The subsequent eruptive
799 activity rebuilt the South Iliniza edifice with the emplacement of a summit lava dome complex and its
800 related PDC deposits. The Terminal SI stage corresponds to the emission of several lava flows of
801 andesitic composition dated between 31 ± 4 and 25 ± 3 ka. Finally, higher K andesite magmas were
802 emitted from satellite vents located to the south of Iliniza forming the Tishigcuchi lava dome probably
803 in the Holocene, and the Pongo lava flow dated at 6 ± 4 ka. Contrary to other volcanoes of the volcanic
804 front, the Iliniza magmas show a compositional transition from dacites (63-67 wt.% SiO₂) to andesites
805 (60-63 wt.% SiO₂) in the later eruptive stages. Based on these lines of geological and geochronological
806 evidences, we support the hypothesis that the Iliniza volcano must be considered as a potentially active
807 volcanic center.

808

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823

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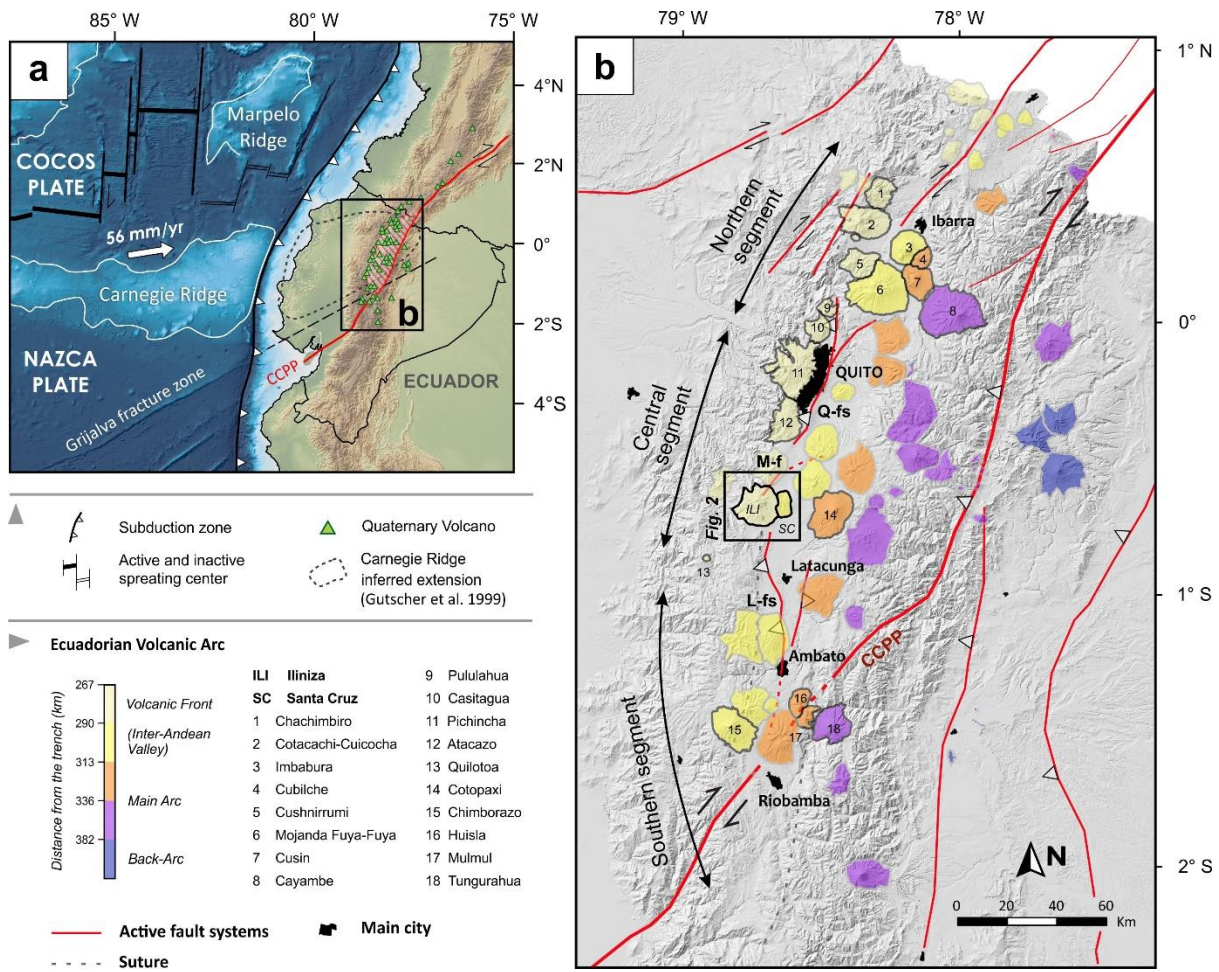
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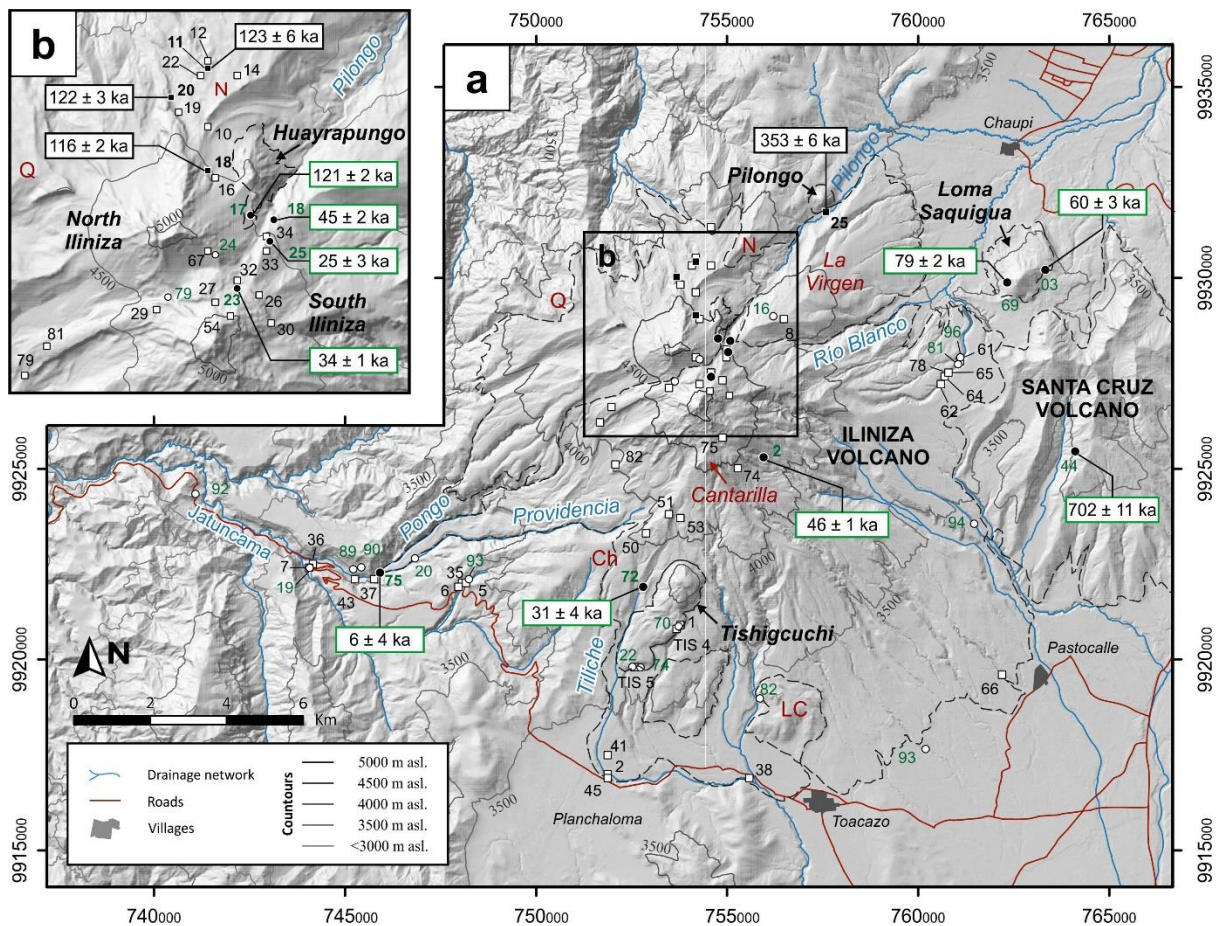
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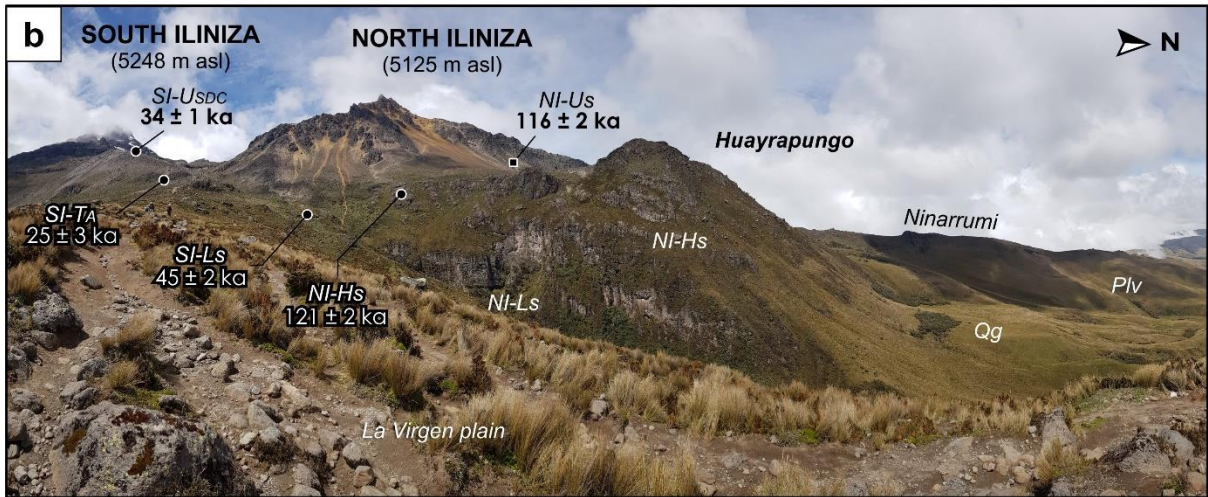
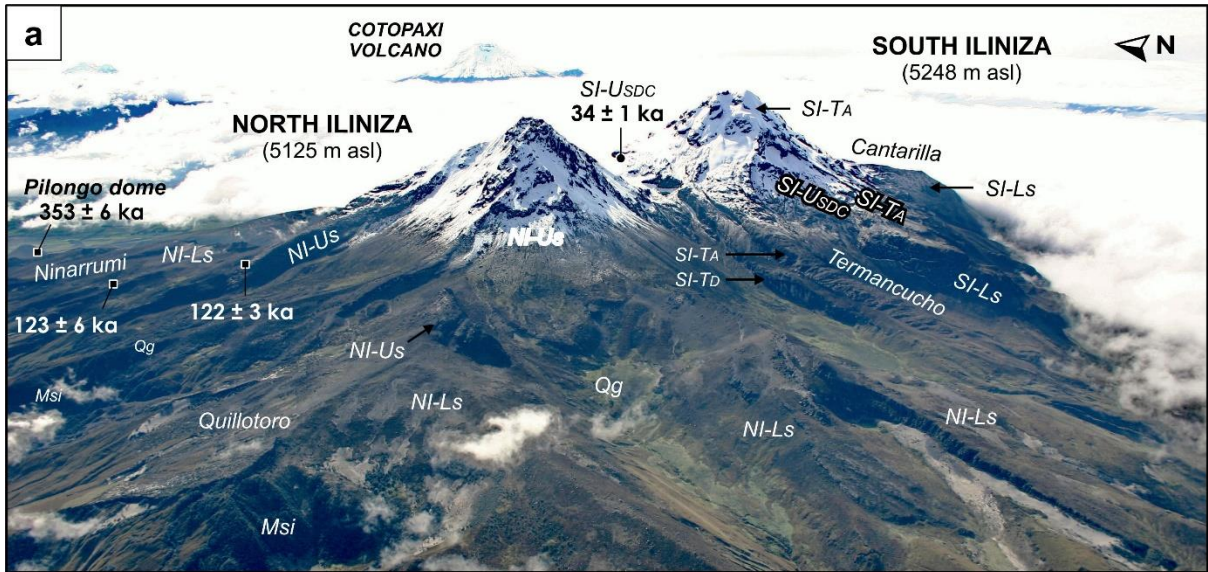
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1206 **Figure 1. a)** Geodynamic setting of the Ecuadorian arc (Modified from Gutscher et al., 1999).
 1207 Arrows indicate the direction of the Nazca plate motion relative to the South American
 1208 continental margin according to DeMets et al. (2010). **b)** Schematic map of the Ecuadorian
 1209 volcanic arc. Volcanoes are colored according to their distance from the trench comprising the
 1210 N-S alignments of the Volcanic Front (Western Cordillera), Inter-Andean Valley, Main Arc
 1211 (Eastern Cordillera), and Back-Arc. Variability in the number of volcanic centers is represented
 1212 by the northern, central, and southern across-arc segments. Iliniza (ILI) and Santa Cruz (SC)
 1213 volcanoes, as well as those mentioned in the text, are outlined with black and grey borders,
 1214 respectively. Active fault systems are represented with red lines according to Alvarado et al.
 1215 (2016). CCPP: Chingual-Cosanga-Pallatanga-Puná Fault System; Q-fs: Quito Fault System;
 1216 M-f: Machachi Fault; L-fs: Latacunga Fault System.



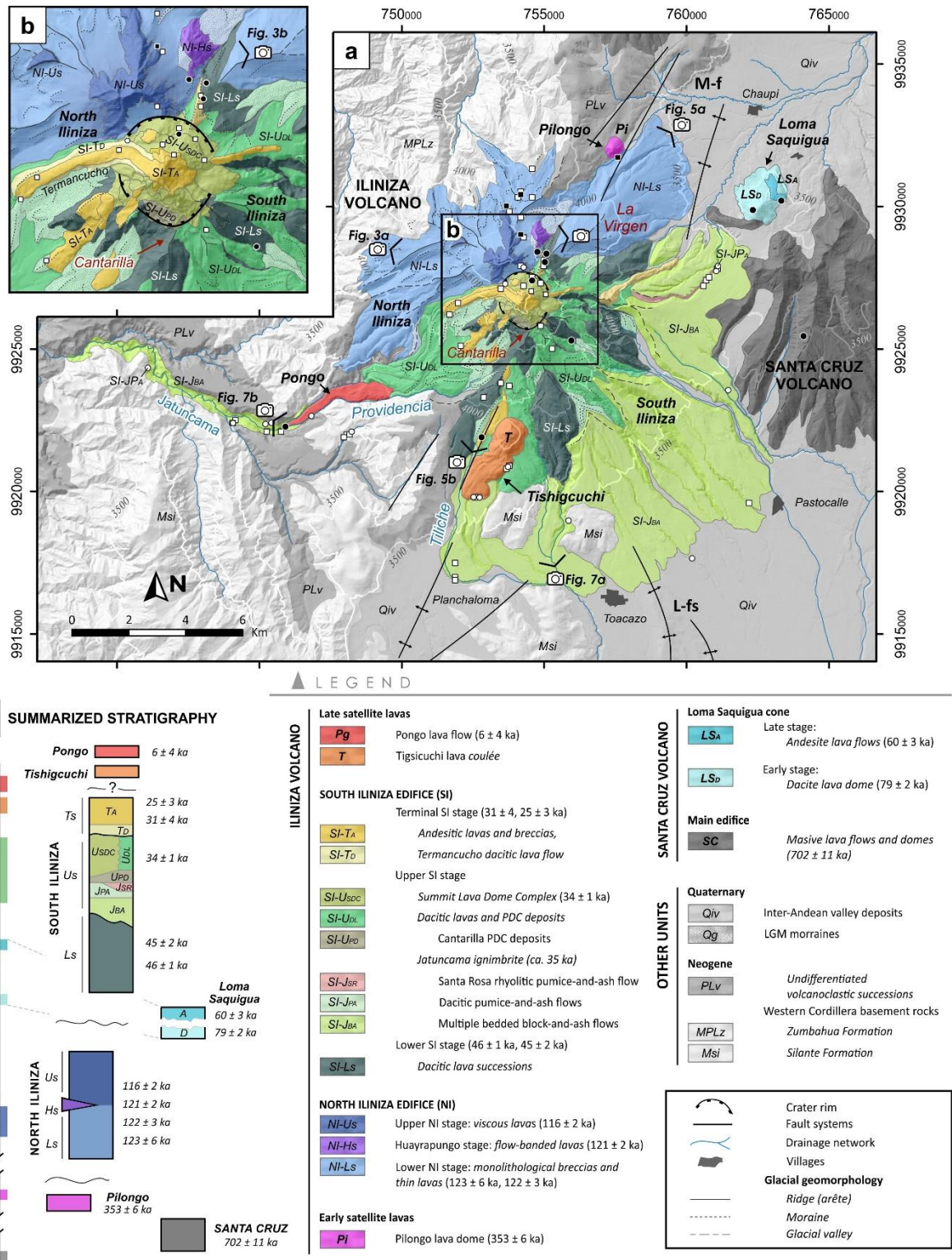
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1218 **Figure 2.** Hill-shaded digital surface model of Iliniza volcano showing the locations of new
 1219 samples (circles; green numbers) and those from Hidalgo et al. (2007) (squares; black
 1220 numbers). K-Ar dated samples are represented with solid symbols. Volcanic peaks shown as
 1221 black letters. Ridges and hills shown as red letters. Ch: Chilcapamba; LC: Loma La Cruz; N:
 1222 Ninarrumi; Q: Quilloto. Rivers and valleys are labelled with blue letters.



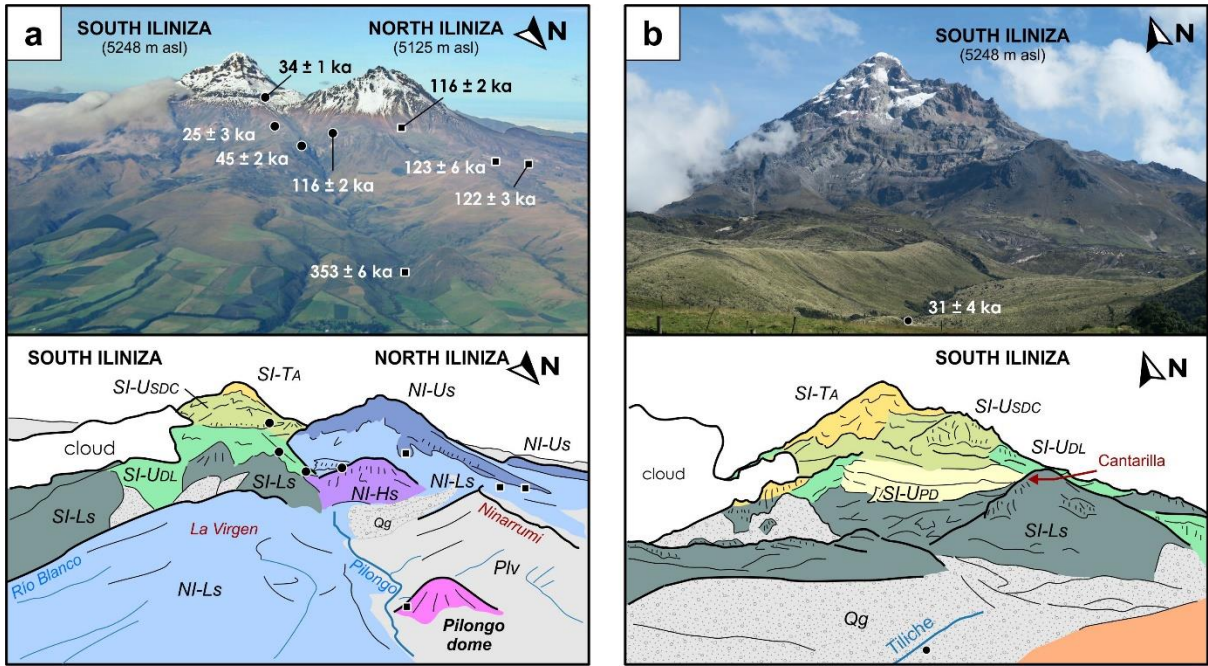
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1224 **Figure 3. a)** Aerial view of Iliniza volcano, looking east (photography by Patricio Ramon, IG-
 1225 EPN). **b)** Panoramic view of the North Iliniza edifice, looking west from La Virgen plain.
 1226 Geological unit abbreviations as in Figure 4.



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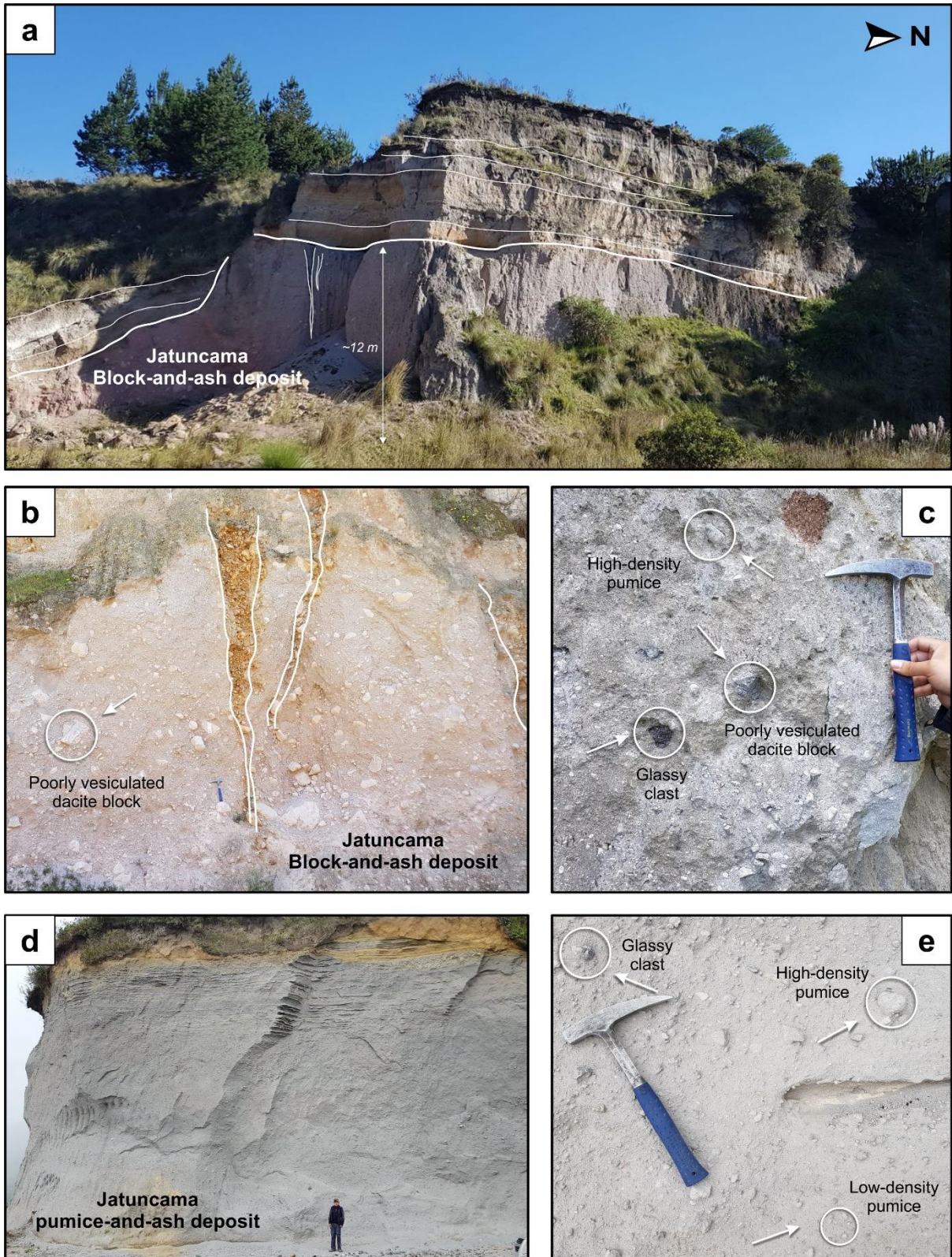
1228 **Figure 4.** Simplified geological map of Iliniza volcano after considering our new ages (Table
 1229 1) and field observations, as well as those from Hidalgo (2001) and Hidalgo et al. (2007).
 1230 Sample sites are shown according to figure 2 caption. Local fault systems are symbolized with
 1231 black lines. M-f: Machachi Fault; L-fs: northern segment of Latacunga Fault System.



1232

1233 **Figure 5.** View of **a)** Iliniza volcano, looking south (photography by Patricio Ramon, IG-EPN),
 1234 and **b)** South Iliniza edifice, looking north, showing the relationships between the main
 1235 stratigraphic units represented according to Figure 4.

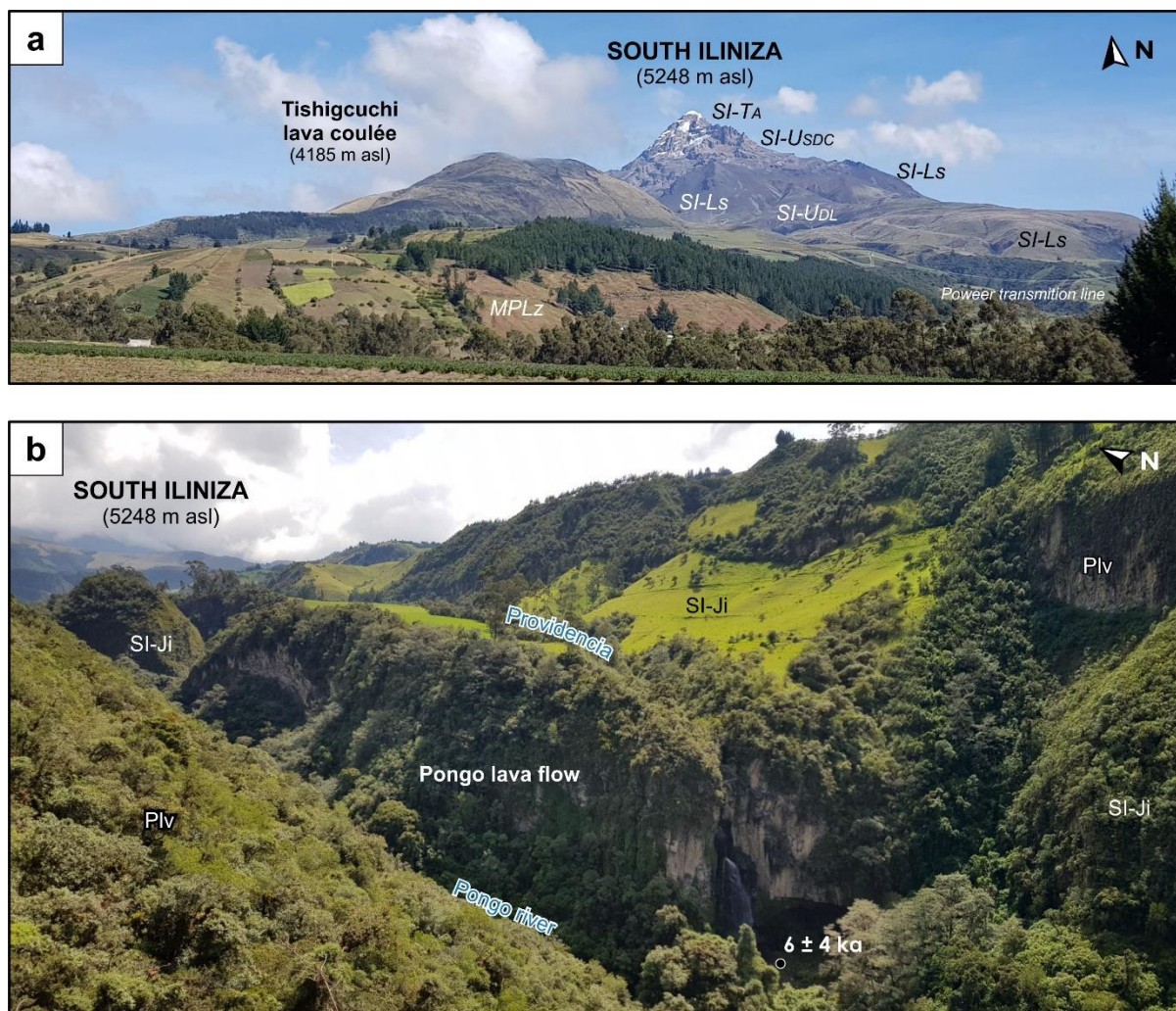
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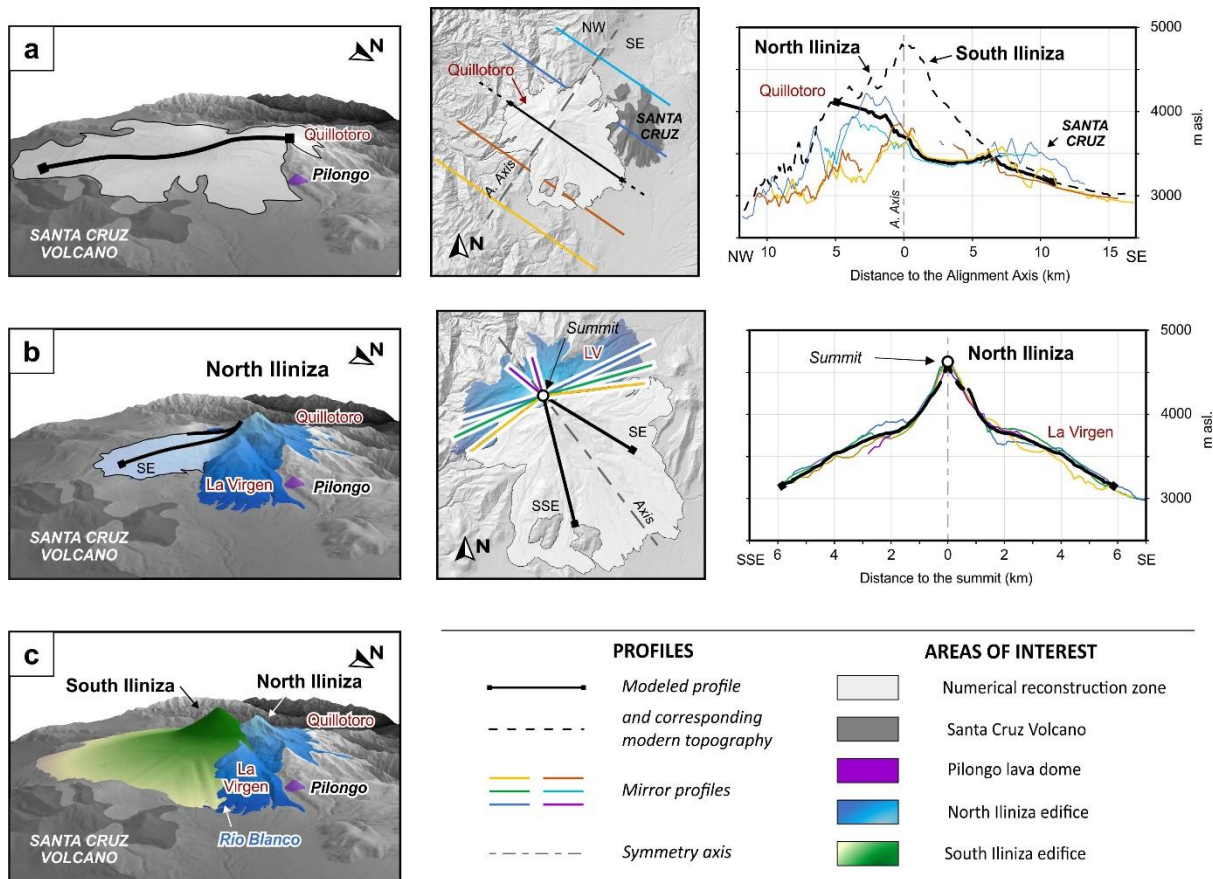
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1238 **Figure 6.** a) Jatuncama ignimbrite deposit at Planchaloma (site ILI 2), and b) detailed view of
 1239 its degassing pipes structures. The deposit is discordantly overlain by lahars, Cotopaxi tephra
 1240 fallouts, and soils. c) Types of clasts observed in a lower section of the ignimbrite deposit at

1241 the Jatuncama valley (site 19EQ19). **d)** Pumice-and-ash flow observed at Jatuncama valley
1242 (site 20EQ92), and **e)** detailed view of its clastic components.

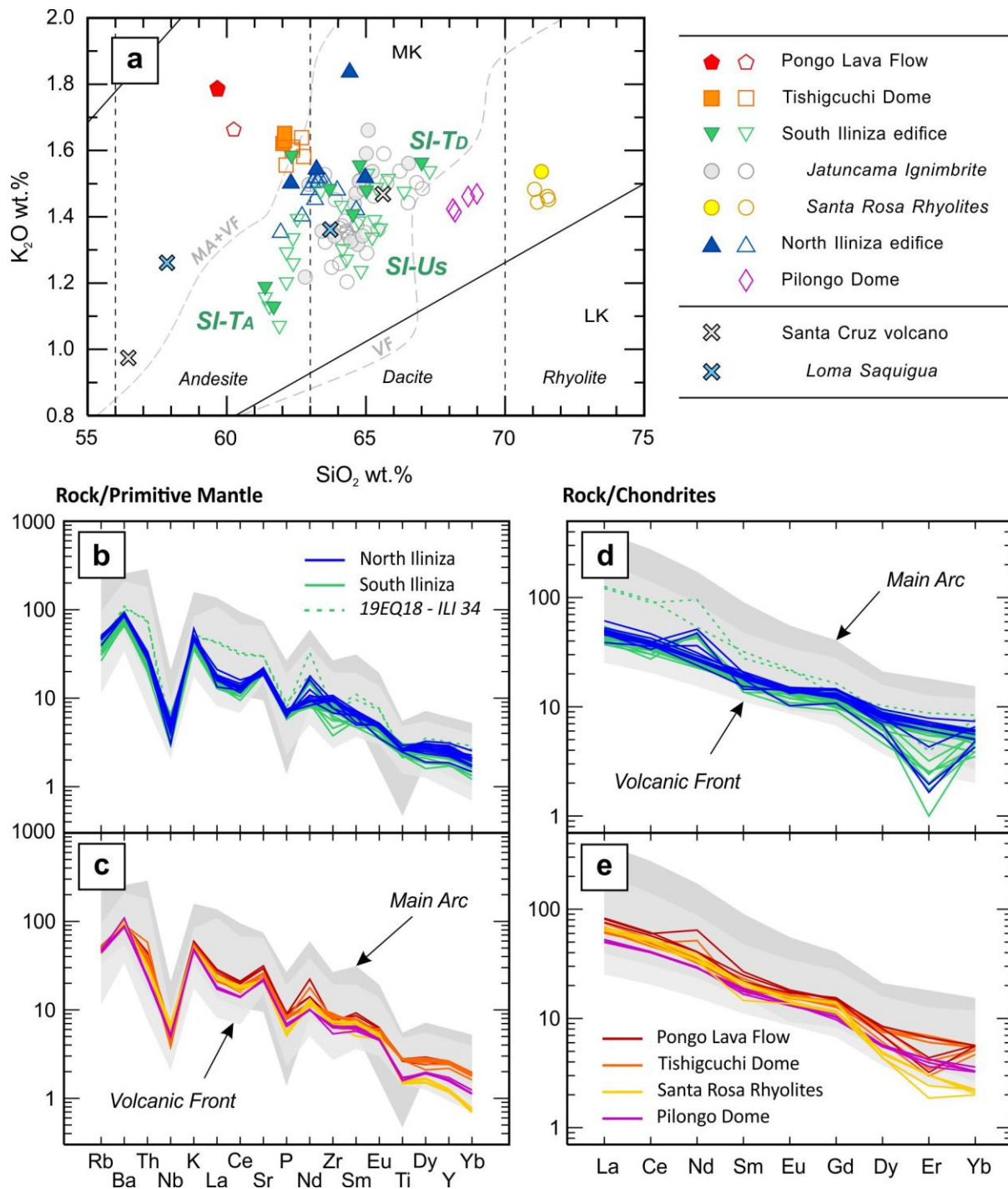


1243
1244 **Figure 7. a)** Panoramic view of the Tishigcuchi lava dome and the South Iliniza, looking north.
1245 **b)** View of the Pongo lava flow from the Jatuncama valley. Volcanological unit abbreviations
1246 as in Figure 4.



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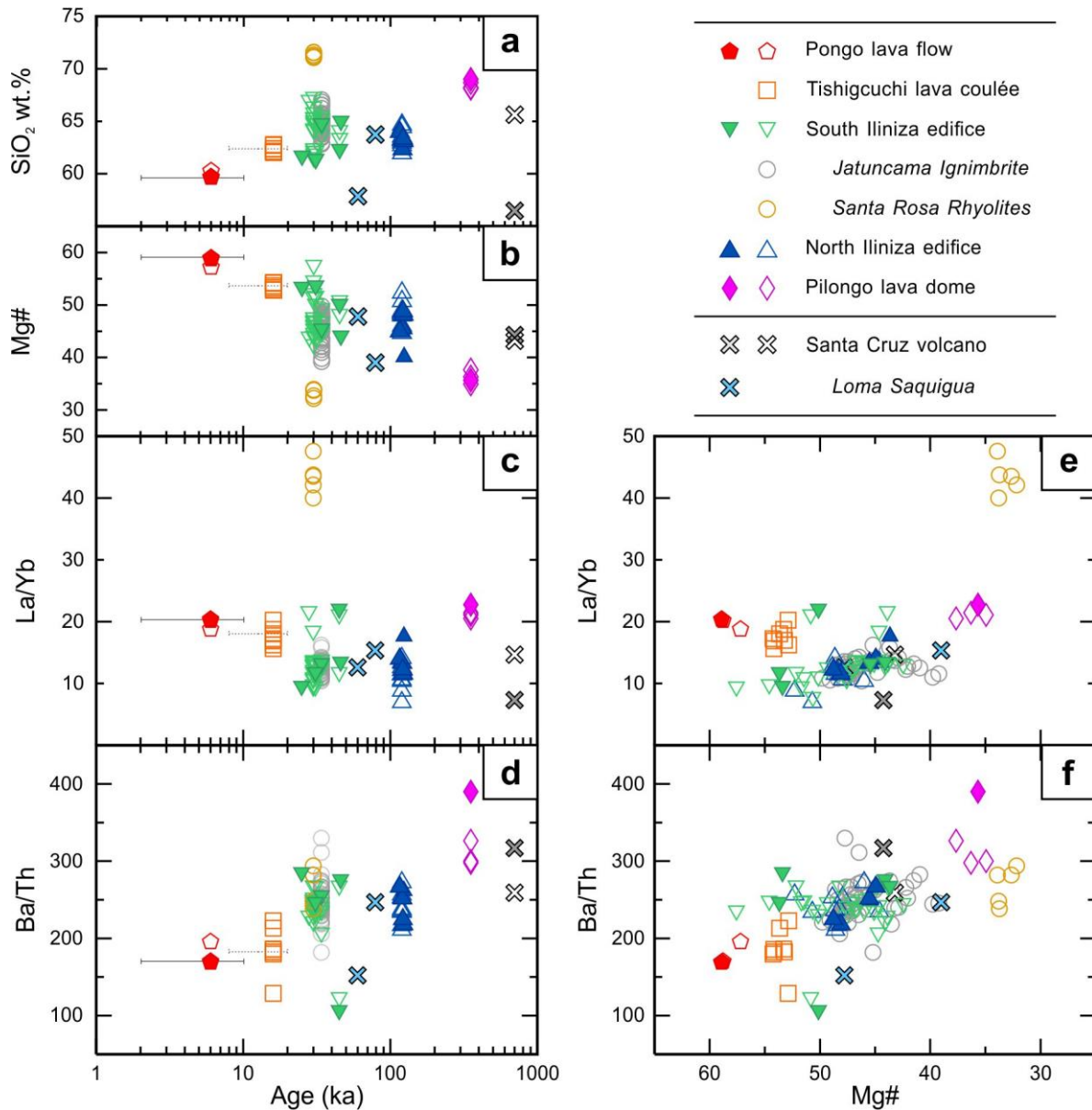
1248 **Figure 8.** Model topographic profiles used for the reconstruction of the basement surface area
 1249 of **a)** North Iliniza and **b)** South Iliniza edifices. Figures correspond, from left to right, to
 1250 perspective and plan views of the reconstructed area, and to the mirror profiles used to create
 1251 the modeled profile. **c)** Aerial view of the South Iliniza modeled cone fitted next to the partially
 1252 eroded North Iliniza edifice.



1253

1254 **Figure 9. a)** K_2O vs SiO_2 diagram (Peccerillo and Taylor, 1976) for eruptive products of Iliniza
 1255 and Santa Cruz volcanoes. MK: medium-K, and LK: low-K calc-alkaline series. The late
 1256 evolutionary stages of the South Iliniza edifice are shown with green symbols. Volcanological
 1257 unit abbreviations as in Figure 4. Gray dashed lines indicate the composition fields created by
 1258 the Volcanic Front (VF) and Main Arc (MA) whole-rock data obtained from the Georoc
 1259 database. Open symbols are for data from Hidalgo et al. (2007). **b-c)** Incompatible trace
 1260 elements normalized to primitive mantle spider diagrams (Sun and McDonough, 1989) for

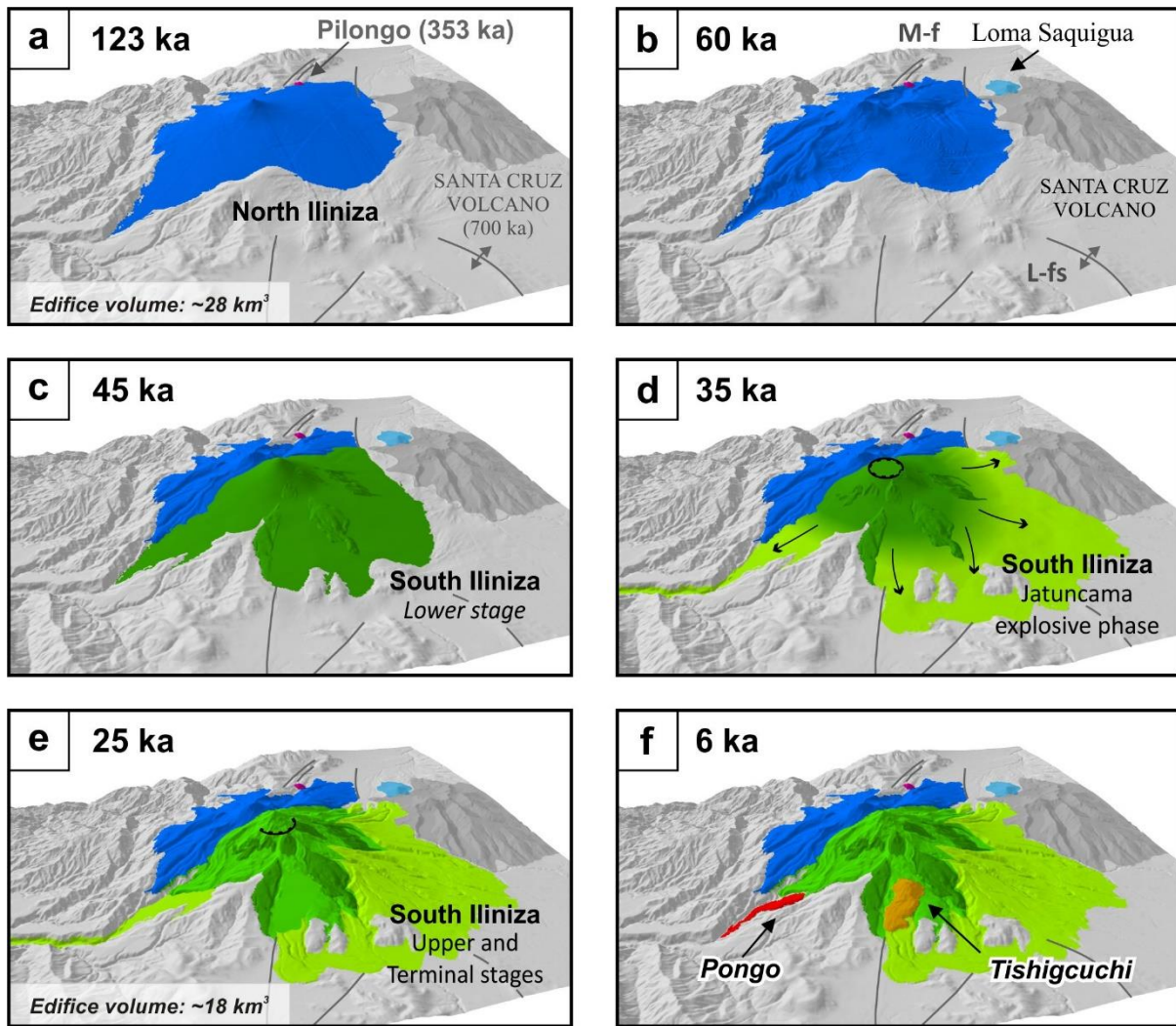
1261 North and South Iliniza edifices, and Iliniza satellite lavas and the SI-J_{SR} units, respectively. **d-**
 1262 **e)** Rare Earth Elements normalized to chondrites diagram (Sun and McDonough, 1989) for the
 1263 same arrangements. Dark grey and light grey areas represent the composition fields depicted
 1264 by the Volcanic Front and Main Arc whole-rock data (Georoc database), respectively.



1265

1266 **Figure 10.** Temporal variations of **a)** Mg# ($=100 \cdot \text{Mg}/(\text{Mg} + \text{Fe}^{2+})$), **b)** SiO₂ (wt.%), and **c)**
 1267 La/Yb and **d)** Ba/Th ratios. Horizontal axis represents the timeline (ka) in logarithmic scale. **e)**
 1268 La/Yb and **f)** Ba/Th ratios plotted against Mg#. Filled symbols are for dated samples (Table 1).
 1269 The 1σ age uncertainty is shown with a solid line for Pongo lava flow, while the age estimation
 1270 range is shown as a dashed line for Tishigcuchi lava coulée.

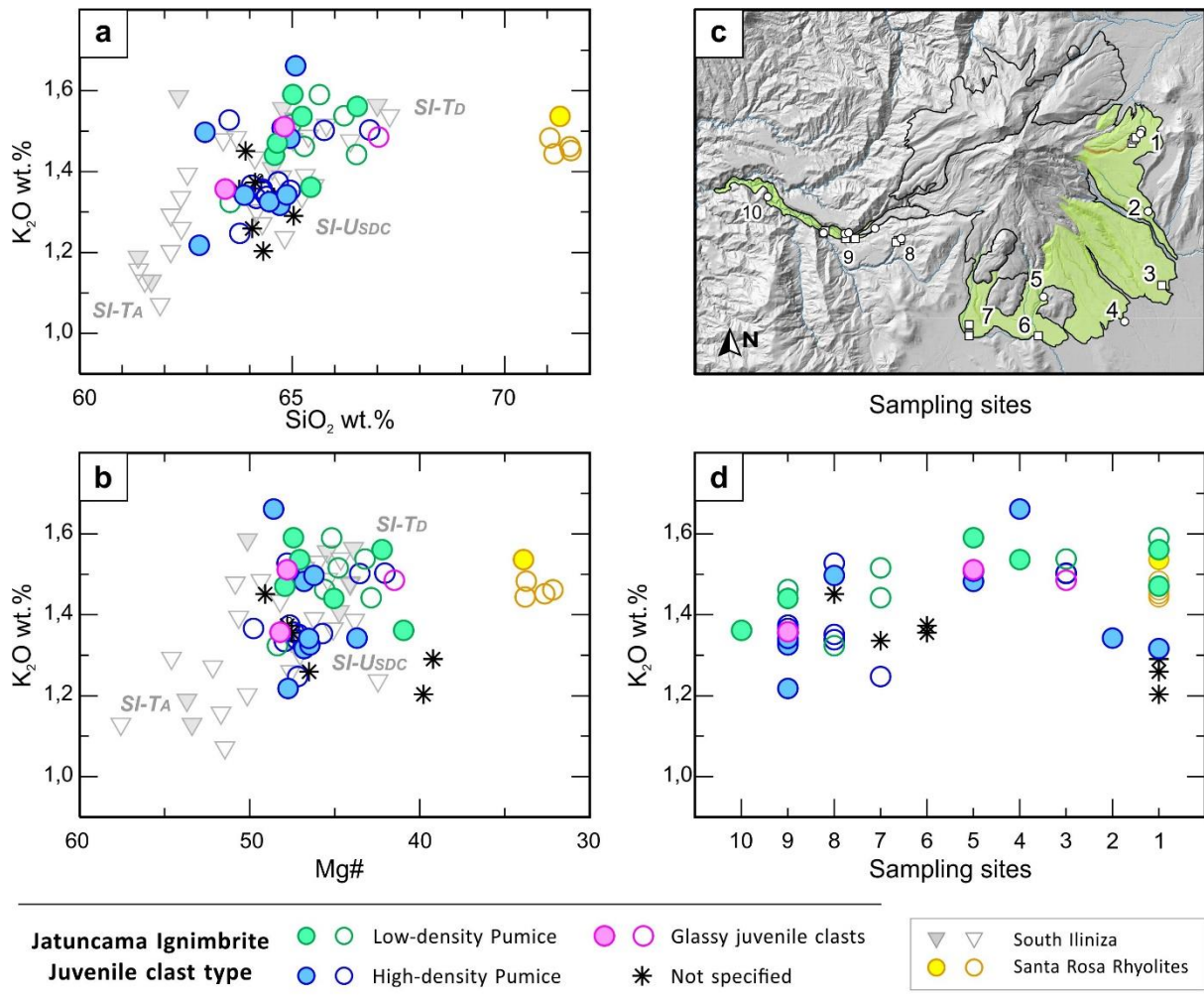
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1273 **Figure 11.** Synthetic charts showing the evolution of Iliniza and Santa Cruz volcanoes through
 1274 time based on our numerical reconstructions. **a)** North Iliniza edifice construction; **b)** Santa
 1275 Cruz volcano reactivation with the Loma Saquigua lavas emission; **c)** South Iliniza Lower Cone
 1276 construction; **d)** the Jatuncama highly explosive eruptive phase creating a thick pyroclastic
 1277 deposit; **e)** South Iliniza Upper cone construction and terminal lavas emission; and **f)** Holocene
 1278 Tishigcuchi lava coulée and Pongo lava flow. Note that illustrations of phases c and d are
 1279 mostly schematic, see text for details. Local fault systems are symbolized with black lines. M-
 1280 f: Machachi Fault; L-fs: northern segment of Latacunga Fault System

1281



1283

1284 **Figure 12.** Geochemical diagrams for Jatuncama pyroclastic samples classified by clast type.
 1285 K_2O versus **a)** SiO_2 and **b)** $Mg\#$ ($=100 * Mg / (Mg + Fe^{2+})$) diagrams. SI-USDC: South Iliniza upper
 1286 cone; SI-T_D: Dacite Terminal Lavas; SI-T_A: Andesite Terminal Lavas. **C)** Geographical
 1287 distribution of sampling sites around the base of South Iliniza and **d)** their variation in K_2O
 1288 content. Open symbols are for data from Hidalgo et al. (2007).

1289

1291 Table 1. (caption provided bellow the table)

Sample	Location and Unit	Longitude (m)	Latitude (m)	K (%)	⁴⁰ Ar* (%)	⁴⁰ Ar* (10 ¹¹ at/g)	Age ± 1σ (ka)	Mean age (ka)
ILINIZA VOLCANO								
<i>Pilongo lava dome</i>								
ILI 25	Lava dome, Pilongo valley	757550	9931731	1.641	10.0%	6.0596	354 ± 6	353 ± 6
					16.4%	6.0422	352 ± 5	
<i>North Iliniza edifice</i>								
ILI 11	Monolithological breccia, N flank, NI-Ls	754150	9930434	2.404	2.0%	3.0594	122 ± 6	123 ± 6
					2.1%	3.1022	124 ± 6	
ILI 20	Monolithological breccia, N flank, NI-Ls	753648	9930031	2.148	5.5%	2.7666	123 ± 3	122 ± 3
					5.0%	2.6825	120 ± 3	
19EQ17	Lava flow, Huayrapungo peak, NI-Hs	754734	9928425	2.226	7.3%	2.8472	122 ± 2	121 ± 2
					6.8%	2.7715	119 ± 2	
ILI 18	Lava flow, N flank, NI-Us	754151	9929036	1.878	8.6%	2.2906	117 ± 2	116 ± 2
					8.7%	2.2671	116 ± 2	
<i>South Iliniza edifice</i>								
19EQ02	Lava flow, E flank, SI-Ls	755922	9925321	1.728	3.7%	0.8557	47 ± 1	46 ± 1
					3.1%	0.8006	44 ± 2	
19EQ18	Lava flow, N flank, SI-Ls	755052	9928362	1.667	1.9%	0.7908	45 ± 2	45 ± 2
					1.9%	0.7826	45 ± 2	
19EQ23b	Lava dome, summit area, SI-Us _{DC}	754550	9927424	2.302	3.1%	0.8144	34 ± 1	34 ± 1
					3.1%	0.8078	34 ± 1	
20EQ72	Lava flow, S flank (Tiliche river), SI-T _A	752778	9921934	1.206	0.8%	0.3788	30 ± 4	31 ± 4
					0.9%	0.3921	31 ± 4	
19EQ25	Monolithological breccia, N flank, SI-T _A	754997	9928069	1.311	0.9%	0.3273	24 ± 3	25 ± 3
					0.9%	0.3631	27 ± 3	
<i>Pongo lava flow</i>								
20EQ75	Lava flow, Pongo valley	745904	9922305	1.534	0.2%	0.0922	6 ± 4	6 ± 4
					0.2%	0.1017	6 ± 4	
SANTA CRUZ VOLCANO								
19EQ44	Lava flow, S flank, SC	764061	9925476	1.096	14.7%	7.9746	697 ± 11	702 ± 11
					15.4%	8.0858	706 ± 11	
<i>Loma Saquigua</i>								
20EQ69	Lava dome, LS-d	762285	9929891	1.480	5.8%	1.2233	79 ± 2	79 ± 2
					6.8%	1.2283	79 ± 2	
19EQ03	Lava flow, N flank, LS-a	763281	9930218	1.417	1.8%	0.8927	60 ± 3	60 ± 3
					2.2%	0.8868	60 ± 3	

1293 **Table 1.** K-Ar ages obtained in this study for Iliniza and Santa Cruz volcanoes listed in
1294 decreasing order from oldest to youngest. Column headings indicate sample name, outcrop and
1295 relative location, volcanological unit (abbreviations as in Figure 4), sample coordinates,
1296 potassium (K) content in percent, radiogenic argon content ($^{40}\text{Ar}^*$) in percent and in 10^{11} atoms
1297 per gram, age obtained for each measurement, and weighted mean age in ka given with a $1-\sigma$
1298 uncertainty.

1299

1300 **Table 2.** Generalized chronostratigraphy showing the main stages of the Iliniza volcano

Edifice	Cone-building stage/Unit	Age (ka)	Volcanology	Petrography
Late satellite lavas	Pongo lava flow	6 ± 4 ka	Effusive eruption: voluminous lava flow	Aphanitic andesite (59 wt.% SiO ₂): pl, opx and cpx, ± pl
	Tishigcuchi lava dome	>20 and <8 ka	Lava dome-forming eruption	Andesite (62-63 wt.% SiO ₂): pl, amp, opx, ± cpx
	Terminal stage	31 ± 4 to 25 ± 3 ka	Mainly effusive activity: voluminous lava flows and related pyroclastic deposits	Mostly andesites (61–63 wt.% SiO ₂): pl, opx, cpx, ± amp
South Iliniza	Summit lava dome complex	34 ± 1 ka	Lava dome-forming eruptions and related PDC	Dacites (64–67 wt.% SiO ₂): pl, amp, ± Fe–Ti oxides, ± cpx
	Upper stage		Explosive dome-forming eruption followed by a pumiceous phase:	- Scarce rhyolites (71-72 wt.% SiO ₂): pl, ± cpx (aegirine), ± Fe-Ti oxides
	Jatuncama explosive phase	~35 ka	- Dacitic and rhyolitic pumice-and-ash flows - Multiple bedded block-and-ash flows	- Dacites (63-67 wt.% SiO ₂): pl, amp, ± cpx
<i>Cantarilla unconformity</i>				
	Lower stage	45 ± 2 to 46 ± 1 ka	Mainly effusive activity: basal edifice construction	Dacites (62-65 wt. % SiO ₂): pl, amp, cpx, ± opx, ± Fe-oxides
North Iliniza	Terminal stage	116 ± 2 ka	Mainly effusive activity: viscous lava flows	Acid-andesites to dacites (62-65 wt.% SiO ₂): pl, cpx, opx, ± Fe-Ti oxides, ± amp
	Huayrapungo stage	121 ± 2 ka	Mainly effusive activity: voluminous flow-banded lava flow	Andesites (62 wt.% SiO ₂): pl, opx, and scarce cpx, ± Fe-Ti oxides
	Lower stage	122 ± 6 to 123 ± 6 ka	Mainly effusive activity: thin lava flows	Acid-andesites to dacites (62-64 wt.% SiO ₂): pl, opx, cpx, ± amp, ± Fe-Ti oxides
Early satellite lavas	Pilongo lava dome	353 ± 6 ka	Lava dome-forming eruption	Porphyritic rhyodacite (68-69 wt.% SiO ₂): pl, amp, opx, ± cpx, ± Fe-Ti oxides

1301 Abbreviations: pl=plagioclase, amp=amphibole, cpx =clinopyroxene, opx=orthopyroxene.

1302

1303

1304

1305 **Table 3.** Construction and erosion volumes calculated based on numerical reconstructions
 1306 together with their corresponding rates. Numerical results given with a 1- σ uncertainty (see
 1307 text for details).

Unit	Volume (km ³)	Period (ka)	Duration (kyr)	Output rate (km ³ kyr ⁻¹)	Volume (km ³)	Period (ka)	Duration (kyr)	Erosion rate (km ³ kyr ⁻¹)
ILINIZA VOLCANO								
<i>Main edifices</i>								
North Iliniza	28 ± 9	124 - 116	8 ± 5	3.5 ± 2.6	6 ± 2			
<i>Western flank</i>					3 ± 1	116 - 0	116 ± 2	0.03 ± 0.01
South Iliniza	18 ± 6	46 - 25	21 ± 4	0.8 ± 0.3	6 ± 2	25 - 0	25 ± 3	0.24 ± 0.09
<i>Satellite Vents</i>								
Pilongo lava dome	18 ± 5 × 10 ⁻³				339 ±			
Tishigcuchi lava dome	41 × 10 ⁻³							
Pongo lava flow	73 ± 18 × 10 ⁻³							
<i>Present-day whole volcano</i>	34 ± 14	123 - 25	98 ± 7	0.3 ± 0.1				

1308

1309