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1 **Pliocene-to-Holocene volcano-tectonic activity on Mohéli Island (Comoros archipelago)**  
2 **constrained by new K-Ar ages**

3  
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17  
18 **Keywords**

19 Comoros archipelago, K-Ar dating, Mohéli Island, Holocene volcanism, volcano subsidence,  
20 melilitite, Lwandle/Somali plate boundary

21  
22 **Highlights**

- 23 - New robust K-Ar ages constraints on the volcano-tectonics of Mohéli Island  
24 - Two construction stages at  $\geq 3.8$ –3 Ma and 2–0.008 Ma, separated by a main subsidence  
25 - Volcano-tectonic shift, from N070°E in Stage 1 to N110°E in Stage 2  
26 - Moderate silica-undersaturation in Stage 1 magmas, high undersaturation in Stage 2  
27 - Holocene volcanism in Mohéli implies that the entire Comoros archipelago is active

28  
29 **Abstract**

30 The volcanism of the Comoros archipelago (from west to east: Grande Comore, Mohéli,  
31 Anjouan, and Mayotte islands) has been under renewed scientific scrutiny since the eruption of  
32 a new submarine volcanic edifice (Fani Maoré) which begun in May 2018 east of Mayotte.  
33 West of Mayotte, Mohéli island has received little attention from the geoscience community,  
34 despite its largely uneroded volcanic landscapes suggesting a recent activity that has not been  
35 dated. Here we address this gap in knowledge by applying K-Ar geochronology on groundmass  
36 and major-trace element analyses to subaerial and submarine rocks, in an attempt to reconstruct  
37 the volcano-tectonic and geochemical evolution of Mohéli. Our results show that Mohéli's  
38 volcano-tectonic evolution proceeded in two constructional stages, including a primary  
39 edification along a N070°E axis from before ca. 3.8 Ma to ca. 3 Ma (Stage 1), and a second  
40 construction along a N110°E ridge shaping the present-day island since ca. 2 Ma (Stage 2). The  
41 two stages were separated by an increased subsidence ( $\geq 0.2$  mm/yr) that drowned a large part

42 of the N070°E primary edifice. The two identified volcano-tectonic stages are reflected also in  
43 the geochemical evolution of emitted magmas, which were moderately silica-undersaturated in  
44 Stage 1 and moderately to highly silica-undersaturated in Stage 2. Silica undersaturation  
45 increases with time up to the olivine melilitite field, together with enrichments in Ca, P, and  
46 incompatible trace elements, suggesting the increasing contribution of a metasomatized mantle  
47 in melts. The coeval changes of construction orientations and magmas compositions of Mohéli  
48 suggest a modification in the tectonics of the Comoros related to magmatism at about 2 Ma.  
49 The most recent volcanic morphology investigated is an olivine nephelinite lava flow on the  
50 north coast of the island dated at  $8 \pm 2$  ka. This finding of Holocene volcanism on Mohéli  
51 implies that the entire Comoros archipelago should be considered as an active zone in any  
52 volcanic hazard assessment. The melilitite-bearing rocks of Mohéli share geochemical  
53 similarities with those of Mayotte and of the Cenozoic volcanic provinces of Madagascar,  
54 further pointing to similar melting sources and magmatic processes over the Mozambique  
55 channel.

56

## 57 **1. Introduction**

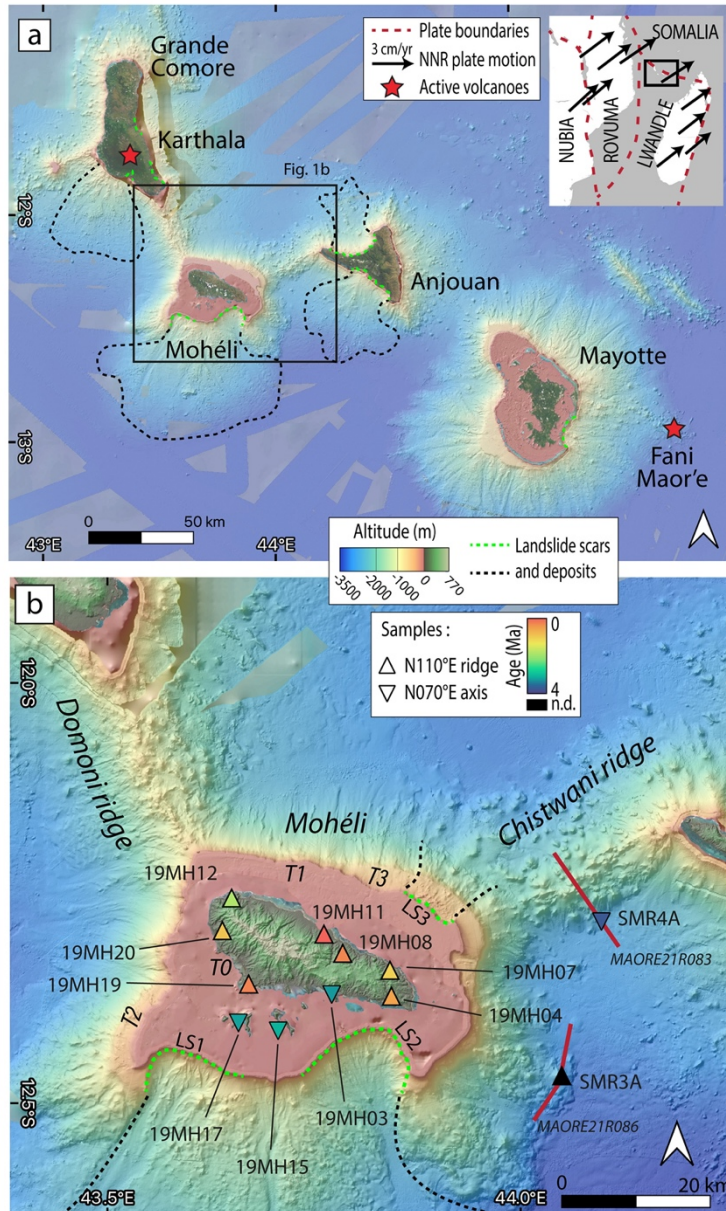
58

59 The Comoros archipelago, located in the northern Mozambique channel (Fig. 1a) has regained  
60 attention from the scientific community since 2018 due to the birth of a fast-building submarine  
61 volcanic edifice, 50km east of Mayotte, Fani Maoré volcano (Lemoine et al., 2020; Feuillet et  
62 al., 2021; Berthod et al., 2021a). Marine geophysical surveys have since revealed that the  
63 archipelago is only the emerged portion of a much wider province of volcanic ridges and  
64 seamounts extending north and east of the islands (Tzevahirtzian et al., 2021; Thinon et al.,  
65 2022). The origin of volcanism in the Comoros archipelago remains enigmatic in many aspects  
66 since none of the proposed interpretations can explain all the observations. For instance, the  
67 archipelago has been interpreted as an east-to-west propagating hotspot track, related to the  
68 moving Somali plate over a mantle plume (Hajash and Armstrong, 1972; Emerick and Duncan,  
69 1982; 1983; Class et al., 2005). This hypothesis is supported mainly by the apparent westward  
70 progression of volcanism from Mayotte (eroded and surrounded by a barrier reef) to Grande  
71 Comore (hosting the recurrently erupting Karthala volcano), and by the enriched mantle  
72 isotopic signature of Grande Comore magmas. However, the NE-directed motion of the Somali  
73 plate in an absolute reference frame does not match the E-W alignment of the archipelago,  
74 which contradicts the hotspot hypothesis (Fig. 1a). Alternatively, the magmatism of the  
75 Comoros archipelago has been interpreted to be controlled by reactivation of deep lithospheric  
76 fractures (Nougier et al., 1986). More recently, magmatism has been proposed to delineate the  
77 boundary between the Somali and Lwandle plates (Fig. 1a, Stamps et al., 2018; Famin et al.,  
78 2020), in connection with the East African Rift System (Michon, 2016; Michon et al., 2022).  
79 These tectonic interpretations, however, do not account for the plume-compatible isotopic  
80 signature of magmas.

81 For any discussion about the origin of the Comoros, the chronology of volcanic construction is  
82 of central importance. Unfortunately, despite significant effort, radiometric ages reported for  
83 the Comoros archipelago are still sparse and unevenly distributed. The majority of  
84 geochronological data come from Mayotte and include 33 K-Ar whole-rock ages (Hajash and  
85 Armstrong, 1972; Emerick and Duncan, 1982; 1983; Nougier et al., 1986) and 24 groundmass  
86  $^{40}\text{Ar}/^{39}\text{Ar}$  (Pelleter et al., 2014). The island of Anjouan has been the subject of recent  
87 geochronological investigations by Quidelleur et al. (2022), resulting in an updated database of  
88 13 new K-Ar ages on groundmass, 5 K-Ar whole-rock ages, and one  $^{14}\text{C}$  age. This most recent  
89 study revealed the occurrence of Holocene volcanism in Anjouan, but also demonstrated that

90 whole-rock K-Ar dating of Comorian magmatic rocks is challenging due to the presence of  
91 xenoliths, which may affect the accuracy of results. In comparison, only 10 ages are available  
92 for Mohéli and 2 for Grande Comore (Hajash and Armstrong, 1972; Emerick and Duncan,  
93 1982; 1983; Nougier et al., 1986), all obtained by K-Ar whole-rock analyses made prior to the  
94 development of the K-Ar Cassignol-Gillot technique on groundmass (Gillot and Cornette,  
95 1986; Gillot et al., 2006). Regarding the hypothesis of a geographic migration of volcanism in  
96 the Comoros, it is therefore important to ascertain the accuracy of existing ages and to build a  
97 robust and more complete geochronological database on these two islands.

98 In this study, we focus on Mohéli because this island displays both eroded reliefs and developed  
99 carbonate platforms like in Mayotte, but also well-preserved volcanic morphologies similar to  
100 those of Anjouan (Fig. 1b). These contrasting morphologies indicate a protracted volcanic  
101 activity on Mohéli, spanning from the early construction of the Comoros archipelago up to very  
102 recent times. The objective of this study is to develop a more robust geochronological  
103 framework for the volcano-tectonic evolution of Mohéli, by providing new radiometric data for  
104 the different morphologies. For that purpose, we adopted a multi-disciplinary approach that  
105 involved geomorphological fieldwork, K-Ar dating of groundmass by the Cassignol-Gillot  
106 technique, and major-trace element analyses of whole rocks. In addition, we also took  
107 advantage of the offshore bathymetric surveys, reflection seismic profiles and dredges  
108 performed during the oceanographic cruise SISMAORE onboard R/V Pourquoi Pas? (Thinon  
109 et al., 2021) to investigate the submarine slopes of the Mohéli edifice. The joint use of  
110 geomorphological, geochronological, and geochemical data on submarine and subaerial reliefs  
111 allows us to reconstruct the volcano-tectonic history of Mohéli, with implications for the  
112 geodynamics and volcanic hazards of the Comoros archipelago.



113

114 **Figure 1:** a- Map of the Comoros archipelago, bathymetric compilation (from Tzevahirtzian et al., 2021 and  
 115 references therein; MAYOBS campaigns Rinnert et al., 2019; Ifremer Geo-ocean, 2022; Thinson et al., 2022;  
 116 Berthod et al., 2021b, and GEMCO data), GNSS plate motions in a no-net rotation (NNR) framework (King et al.,  
 117 2019). b- Topographic and bathymetric map of Mohéli and the Chistwani ridge showing the location of analyzed  
 118 samples. Also shown are fringing reef (T0), carbonate shelves (T1 to T3), landslide scars (LS1 to LS3), and  
 119 landslide deposits recognized by Tzevahirtzian et al. (2021). The color and orientation of triangles correspond to  
 120 the age of samples and their attribution to volcanic lineaments, respectively, as shown in the legend. Red lines  
 121 correspond to the location of seismic reflection profiles MAOR21R086 and MAOR21R083.

122

## 123 2. Geological setting

124

125 The Comoros archipelago is located on the northern part of the Mozambique Channel, to the  
 126 east of Mozambique and northwest of Madagascar (Fig. 1). The Comoros archipelago is  
 127 considered to be built on an oceanic lithosphere (e.g. Phethean et al., 2016; Rolandone et al.,  
 128 2022; Masquelet et al., 2022), although there is debate about the possible existence of a  
 129 continental remnant of Madagascar's drift underneath Mayotte (Dofal et al., 2022). According

130 to trace element compositions and Sr-Nd-Pb isotopic ratios, the magmas of Mohéli, Anjouan,  
131 and Mayotte may be explained by mixing of a high  $\mu = {}^{238}\text{U}/{}^{204}\text{Pb}$  (HIMU) component and a  
132 depleted MORB-mantle (DMM) component at variable degrees of partial melting (Späth et al.,  
133 1996; Pelleter et al., 2014; Bachèlery and Hémond, 2016). Grande Comore is the only island  
134 showing isotopic evidence of a plume contribution in magmas added to the HIMU and DMM  
135 components (Class et al., 2005 and references therein, see Bachèlery and Hémond, 2016 for a  
136 review). None of the Comorian lavas displays any evidence of continental crust contamination  
137 (e.g. Bachèlery and Hémond, 2016). The HIMU signature is sought to be introduced in the  
138 Comorian mantle reservoir through delamination or thermal erosion of a continental lithosphere  
139 during Gondwana break-up (Späth et al., 1996; Class et al., 2005; Pelleter et al., 2014;  
140 Bachèlery and Hémond, 2016). Incompatible element relative enrichments of all the magmatic  
141 products throughout the Comoros indicate that metasomatism of the HIMU-DMM mantle is a  
142 common feature of all the parental magmas (Späth et al., 1996; Deniel, 1998), an inference  
143 confirmed by  $\text{CO}_2$ -metasomatized mantle xenoliths found in Grande Comore (Coltorti et al.,  
144 1999).  $\text{CO}_2$  metasomatism is also supported by the occurrence of P-rich olivine melilitites (i.e.,  
145 alkaline and ultracalcic mafic igneous rocks rich in melilite, a calcic sorosilicate, and devoid of  
146 feldspar) on the northwest side of Mayotte (Pelleter et al., 2014). Building on partial melting  
147 experiments that position the origin of melilititic primary melts in the domain of garnet stability,  
148 in the presence of  $\text{CO}_2$ , at pressures ranging from 3 to 4 GPa (Dasgupta et al., 2007;  
149 Gudfinnsson and Presnall, 2005; Hirose, 1997), Pelleter et al. (2014) have interpreted melilite-  
150 bearing magmas as coming from very low partial melting of apatite-dolomite-rich zones in the  
151  $\text{CO}_2$ -metasomatized lithospheric mantle. A similar conclusion was reached for the origin of  
152 Cenozoic melilitites from northern, central, and eastern Madagascar (Melluso et al., 2011;  
153 Cucciniello et al., 2016; Mazzeo et al., 2021). Though undated, olivine melilitites are thought  
154 to be related to rifting on Mayotte during the postshield stage (<4 Ma, Pelleter et al., 2014).

155 Mohéli is considered to be one of the oldest islands in the archipelago, along with Mayotte,  
156 based on its eroded reliefs and its well-developed insular shelves (Fig. 1; Tzevahirtzian et al.,  
157 2021). The history of Mohéli has been subdivided into two volcanic stages and three series  
158 (Pavlovsky and De Saint Ours, 1953; De Saint Ours, 1960; Esson et al., 1970; Strong, 1972a).  
159 De Saint Ours (1960) noticed the radiating shape of elongated islets and extended promontories  
160 on the south coast. He suggested that these morphologies represent valleys eroded into the  
161 flanks of an early sub-circular volcano, later filled with lava flows. The products of this early  
162 volcano, mostly basanitic, have been classified as a basal or lower series. In a later stage,  
163 repeated eruptions along WNW fissures shaped the present-day N110°E elongation of the  
164 island, with rugged topographies attributed to an intermediate series of hawaiites, basanites,  
165 and ankaramites, and more subdued reliefs of an upper series of olivine nephelinites and basalts.  
166 Based on K-Ar whole-rock dating, Nougier et al. (1986) estimated the lower, intermediate and  
167 upper series to be >5 Ma, 3.8–3.2 Ma, and 2–0.5 Ma old, respectively. The composition and  
168 differentiation trends of Mohéli's magmatic products are thus relatively similar to those of  
169 Mayotte (Bachèlery and Hémond, 2016), even though highly-silica undersaturated rocks such  
170 as melilitites have not been described yet.

171 Bathymetry map shows that the submarine slopes of Mohéli are prolonged by two ridges (Fig.  
172 1), a N160°E “Domoni ridge” on the northwest connecting Mohéli to Grande Comore, and a  
173 N055°E “Chistwani ridge” on the northeast connecting Mohéli to Anjouan (Thinon et al., 2022;  
174 Tzevahirtzian et al., 2021). Two submarine terraces are described at 400 to 600 m depth on the  
175 southwestern and northeastern slopes of Mohéli's edifice (T2 and T3 in Fig. 1b; Tzevahirtzian  
176 et al., 2021). These terraces indicate that a strong subsidence affected Mohéli prior to the  
177 construction of the main shelf (T1). Mohéli is also surrounded by a fringing reef (T0) found on  
178 many islands of the Indian Ocean and known to be constructed by the last sea level rise since

179 8-9 ka (Camoin et al., 2004). Two landslide scars (LS1 and LS2 in Fig. 1b) also affect the  
180 southern flank of the submarine edifice, cutting both the subsided terraces and the modern shelf.  
181 A third, smaller landslide scar (LS3) also cuts T1 north of Mohéli, with debris avalanche  
182 deposits on T3.

183

### 184 3. Methods

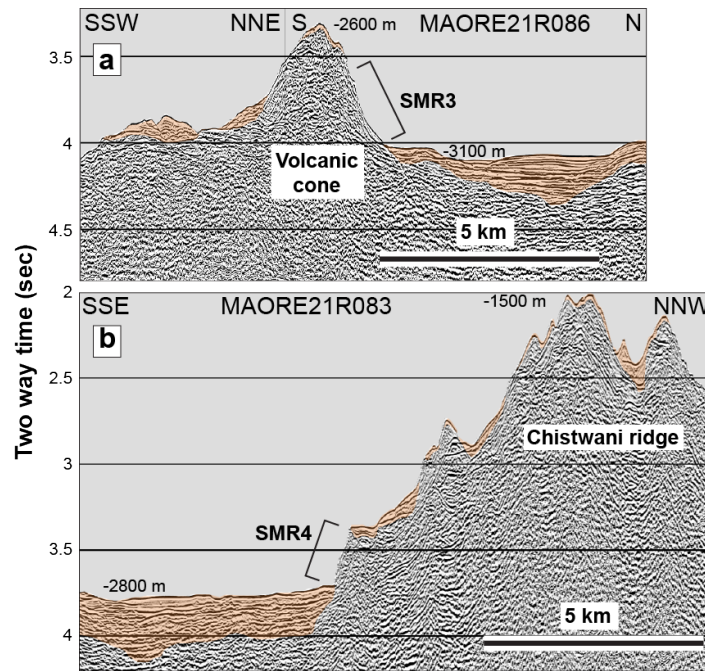
185

#### 186 3.1 Sampling

187 Samples of volcanic rocks for geochronological and geochemical investigations were first  
188 collected onshore on Mohéli Island during a field trip in 2019 (samples labelled 19MHXX, Fig.  
189 S1). Great care was taken to select only massive rock samples with the best possible freshness  
190 and the lowest vesicularity on visual inspection, as these two selection criteria are of paramount  
191 importance for successful K-Ar dating. Three samples belong to the islets and eroded remnants  
192 of the flanks of the early volcano on the southern coast of Mohéli (Fig. 1b). Three other samples  
193 were collected on eroded flanks, often covered with lateritic soils, forming the N110°E-  
194 elongated shape of the island. Four other samples were taken from uneroded volcanic features  
195 throughout the island, such as Strombolian volcanic cones and lava flows barely covered by  
196 soils.

197 Two offshore sites were dredged east of Mohéli during the SISMAORE oceanographic cruise  
198 (Thinon et al., 2021). The first dredge site is located on a ~500 m-tall volcanic cone at the base  
199 of the Mohéli edifice in the eastward prolongation of its N110°E axis (SMR3, Fig. 1b). The 48-  
200 channel seismic reflection profiles show an acoustic basement covered sometimes by a thin  
201 layered seismic unit, which is interpreted as shallow sediment or volcano-sediment deposits.  
202 This acoustic basement across the volcanic cone east of Mohéli (Fig. 2a) and across the  
203 Chistwani ridge (Fig. 2b), characterized by unreflective seismic facies (no coherent reflectors)  
204 and at its top by an irregular surface with high amplitude, is assumed to be magmatic in nature  
205 (Thinon et al., 2022; Masquelet et al., 2022). In addition to weakly-consolidated carbonate  
206 sediment, dredge SMR3 collected polygenic volcanic products including rounded pebbles of  
207 basalt covered by 1 mm-thick iron-manganese oxide concretions, blunted-edged cobbles of  
208 altered ankaramite volcanic breccia, and fresh, angular fragments of aphyric basalt pillow lavas  
209 (Thinon et al., 2021). As these latter elements are the freshest of the dredge and show no trace  
210 of transport, they were selected for further analyses (sample SMR3A, Fig. S1). The other dredge  
211 site is a ~300 m-high cliff on the southern flank of the Chistwani ridge (SMR4, Fig. 1b), cliff  
212 shown on the seismic profile (Fig. 2b). Dredge SMR4 recovered indurated and unconsolidated  
213 carbonate sediment and polygenic volcanic products, but only as angular elements indicating  
214 an absence of significant sedimentary transport (Thinon et al., 2021). The recovered volcanic  
215 products include elements of palagonitized olivine basalt volcanic breccia, and fragments of  
216 unaltered, olivine basalt pillow lavas selected for geochronology and chemical analyses (sample  
217 SMR4A; Fig. S1).

218 Subaerial and submarine samples underwent a second selection for K-Ar dating at the GEOPS  
219 laboratory (Orsay, France) based on thin section observation (Fig. S2). Sample SMR3A did not  
220 pass this second selection as it showed evidence of minor alteration. Consequently, SMR4A  
221 was the only remaining submarine sample deemed suitable for K-Ar dating.



222

223 **Figure 2:** Sections of time-migrated 48-channel seismic reflection profiles MAOR21R086 across the volcanic  
 224 cone east of Mohéli dredged by SMR3 (a) and MAORE21R083 across the Chistwani ridge dredged by SMR4 (b),  
 225 represented at the same scale with vertical exaggeration ~5.4 using velocity of 1500 m/s (see Fig. 1b for location).  
 226 Orange layers represent the shallow sedimentary deposits on the acoustic basement interpreted as volcanic. The  
 227 seismic reflection profiles and dredges have been acquired during the SISMAORE campaign (Thinon et al., 2021).  
 228 Note, at the toe of the volcanic cone or the cliff, the acoustic basement is overlapped by a layered seismic unit (thick  
 229 of ~0.1 sec in two-way travel time). On the abrupt slopes, the acoustic basement outcrops.

230

### 231 3.2 K-Ar dating

232 Thin sections of the 11 samples (10 subaerial and 1 submarine) selected for K-Ar dating were  
 233 inspected to determine which fraction size would be the most suitable for analysis based on the  
 234 size and abundance of phenocrystals (Fig. S2). The K-Ar technique applied to carefully  
 235 separated groundmass has the main advantage of avoiding the drawbacks of sample irradiation  
 236 and its recoil effect and interfering production of  $^{36}\text{Ar}$ , which affects the precision of  $^{40}\text{Ar}/^{39}\text{Ar}$   
 237 dating applied to young (<1 Ma), low-K and high-Ca-rich rocks such as basalts (Gillot et al.,  
 238 2006). For this reason, the K-Ar technique on groundmass is the most powerful technique for  
 239 dating volcanic rocks in the Holocene realm in the absence of material suitable for other  
 240 techniques such as charcoal for  $^{14}\text{C}$ , or zircon for (U-Th)/He. K-Ar on groundmass has been  
 241 successfully applied to many Holocene low-K volcanic rocks ( $K \leq 2$  wt.%), including  
 242 Chimborazo volcano in Ecuador ( $4 \pm 2$  ka; Bablon et al., 2019), Merapi volcano in Indonesia  
 243 ( $4.8 \pm 1.5$  ka; Gertisser et al., 2012), Guadeloupe Island in the Lesser Antilles ( $6 \pm 2$  ka; Samper  
 244 et al., 2009), Tromen volcano in Argentina ( $7 \pm 2$  ka; Pallares et al., 2019), and Etna volcano  
 245 in Italy ( $10 \pm 3$  ka; Blard et al., 2005). Recently, Quidelleur et al. (2022) have documented  
 246 Holocene volcanism in Anjouan (Comoros) by dating a lava flow by K-Ar at  $11 \pm 1$  ka, which,  
 247 together with a tephra dated by  $^{14}\text{C}$  at  $9.2 \pm 0.3$  ka, demonstrate that volcanism is sub-active in  
 248 this island. Consequently, we have applied here the K-Ar technique to carefully selected  
 249 groundmass separated from submarine and subaerial samples. In both cases, the outer parts of  
 250 the samples in contact with water or air were removed, to prevent the incorporation of K from  
 251 seawater, and of excess radiogenic  $^{40}\text{Ar}$  from the outermost few cm of rapidly cooled rocks  
 252 (e.g., Duncan and Hogan, 1994).



253 Samples were manually crushed and sieved, and ultrasonically cleaned in a 10% HNO<sub>3</sub>  
254 solution. Selected fractions were isolated within a narrow density interval by heavy liquid  
255 separation using diiodomethane, to remove dense xenocrysts and the lightest phases in the  
256 eventuality of undetected alteration. Indeed, the incorporation of xenocrysts or altered phases  
257 may yield calculated K-Ar ages older than the “true” ages. Potassium and Ar measurements  
258 were acquired following the unspiked Cassignol-Gillot method (Cassignol and Gillot, 1982;  
259 Gillot and Cornette, 1986; Gillot et al., 2006), with duplicated measurements. The K content  
260 for each sample was measured via flame-absorption spectrometry with BCR-2 (Raczek et al.,  
261 2001; K = 1.481 %) and MDO-G (Gillot et al., 1992; K = 3.51 %) as reference standards. Argon,  
262 along with other gases, was extracted after complete melting of the sample at high temperature  
263 (above 1400°C). Then, a three-step procedure was followed to remove all gases but noble gases  
264 (i.e., mainly Ar). First, gas clean-up was performed with a large amount (15 g) of pure Ti foam  
265 heated at 800°C for one hour, then cooled to room temperature for about 20 min. Two  
266 successive clean-up steps of 2 min long each were then performed using Al-Zr AP10GP SAES  
267 getters to further purify gases prior to analysis. Argon 36 and 40 isotopes were measured using  
268 a multi-collector 180° sector mass spectrometer by comparing the samples and atmospheric  
269 aliquots (for details see Germa et al., 2010). The <sup>40</sup>Ar signal was calibrated by an air pipette  
270 compared to the HD-B1 standard (Fuhrmann et al., 1987; Hess and Lippolt, 1994) using the  
271 age of 24.18 Ma (Schwarz and Trieloff, 2007). The <sup>40</sup>K decay constants and K isotopic ratio of  
272 Steiger and Jäger (1977) were used for calculation. Age uncertainties reported here are at the  
273 1σ level, unless otherwise stated.

274 For the submarine sample SMR4A, we applied the approach of Henri et al. (2022) to get rid of  
275 possible seawater Ar contamination. Prior to Ar measurements, the submarine sample was pre-  
276 degassed during 30 min at low temperature (about 200°C) to remove superficial Ar  
277 contamination. This protocol was set after multiple trials to make sure no radiogenic Ar was  
278 lost through the process (see Henri et al., 2022 for details).

### 279 3.3 Major and trace element geochemistry

280 The 12 samples (10 subaerial and 2 submarine, including SMR3A rejected for K-Ar dating)  
281 were analyzed for major and trace elements, to classify the rocks according to international  
282 charts, as well as to compare their chemistry with the existing literature. Whole-rock major and  
283 trace elements measurements were conducted at the University of Bretagne Occidentale (Brest,  
284 France) via ICP-AES (Thermo Electron IRIS Advantage) and ICP-MS (Thermo Elemental x7).  
285 Prior to analysis, samples were fused with LiBO<sub>2</sub> in Pt-Au crucibles before being dissolved  
286 with HNO<sub>3</sub>. International standards used for calibration (BCR-2 and BHVO-2) underwent the  
287 same process as samples (Carignan et al., 2001). Relative 2σ uncertainties are lower than 2%  
288 for major elements and lower than 5% for trace elements. Geochemical major and trace  
289 elements data from the surrounding islands of Grande Comore (Flower, 1971; Strong, 1972b;  
290 Späth et al., 1996; Class and Goldstein, 1997; Claude-Ivanaj et al., 1998; Deniel, 1998; Class  
291 et al., 1998, 2005), Mohéli (Strong, 1972a; Nougier et al., 1986; Späth et al., 1996), Anjouan  
292 (Thompson and Flower, 1971; Flower, 1971, 1973; Nougier et al., 1986; Quidelleur et al., 2022)  
293 and Mayotte (Nougier et al., 1986; Späth et al., 1996; Pelleter et al., 2014), were extracted from  
294 the GEOROC database for comparison purposes with our new samples.

295

## 296 4. Results

297

### 298 4.1 K-Ar dating results

299 New K-Ar ages on 11 samples range from  $3.738 \pm 0.054$  Ma to  $8 \pm 2$  ka (Table 1). Potassium  
300 content of the groundmass ranges between 0.922% and 2.037%, and radiogenic  $^{40}\text{Ar}$  between  
301 0.3% and 61.5%. For subaerial Mohéli samples, three ages fall in the 3.3–3.1 Ma range  
302 (19MH03, 19MH15, and 19MH17), one is at  $1.845 \pm 0.026$  Ma (19MH12), and seven are  
303 younger than 1.050 Ma (19MH04, 19MH07, 19MH08, 19MH11, 19MH19, and 19MH20). One  
304 sample (19MH11) revealed a Holocene age of  $8 \pm 2$  ka. Submarine sample SMR4A from the  
305 Chistwani ridge gave an age of  $3.738 \pm 0.054$  Ma, which is slightly older than the oldest ages  
306 measured on subaerial Mohéli samples.

#### 307 4.2 Major and trace element chemistry

308 Major and trace element data are reported in Table 2 and displayed in Figures 3 and 4 together  
309 with literature data. In a total alkali versus silica (TAS) diagram with the sum of oxides  
310 normalized to 100 wt.% (Fig. 3a), all our analyses are in the field of alkali series, consistent  
311 with published analyses. Subaerial samples from Mohéli fall in the fields of basalts (19MH03,  
312 19MH07, 19MH15, and 19MH17), basanites (19MH04 and 19MH20), and in the  
313 undersaturated field of foidites (19MH08, 19MH11, 19MH12, and 19MH19). The two  
314 submarine samples are very close in major-element composition to subaerial data from the  
315 literature and from the present study. Sample SMR3A, from the volcanic cone at the base of  
316 Mohéli, is at the junction of the foidite and tephri-basanite fields, close to published analyses  
317 from subaerial Mohéli. Sample SMR4A, from the Chistwani ridge, is in the basanite/basalt  
318 field, and within the field of subaerial data from Mohéli as well as Anjouan. Except SMR3A,  
319 all the samples from Mohéli have losses on ignition (LOIs) of -0.29 to 2.87 wt.%, in the lower  
320 range of fresh basanites, nephelinites, and melilitites (e.g. Jung et al., 2019). In particular,  
321 19MH11, the sample which yields the youngest K-Ar age of  $8 \pm 2$  ka, is also the one with the  
322 most negative LOI of -0.29 wt.%, typical of freshly emitted lavas from Karthala (e.g. Späth et  
323 al., 1996; Class et al., 2005). Sample SMR3A has a LOI of 4.94 wt.%, about 1.5 wt.% above  
324 unaltered foidite (e.g. Mertz et al., 2015).

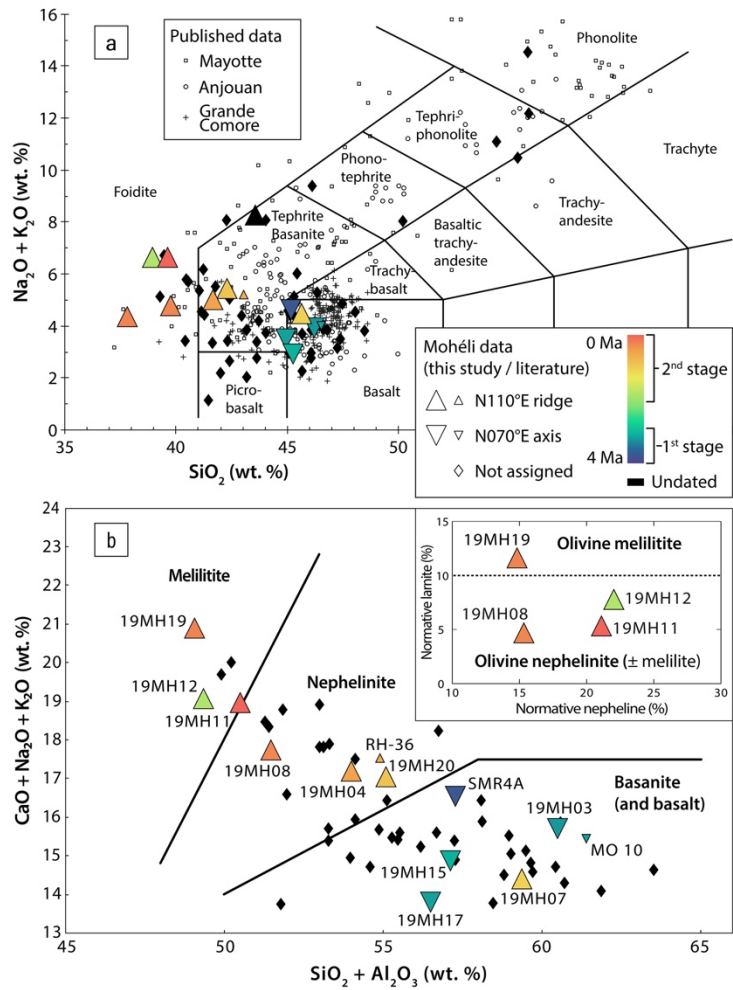
325 Mafic rocks ( $\text{MgO} > 5\%$ ) are presented in the basanite-nephelinite-melilitite classification  
326 schemes of Woolley et al. (1996) to highlight their undersaturated composition (Fig. 3b). In a  
327  $\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$  vs  $\text{SiO}_2 + \text{Al}_2\text{O}_3$  diagram, some samples fall in the field of nephelinites  
328 (19MH04, 19MH08, and 19MH20) and others in the field of melilitites (19MH11, 19MH12,  
329 and 19MH19). All are subaerial and from the mainland of Mohéli. According to Woolley et al.  
330 (1996), CIPW normative larnite ( $N_{\text{larnite}}$ :  $\text{Ca}_2\text{SiO}_4$ , the calcic pole of melilite) may be used to  
331 further classify olivine nephelinites ( $<10\% N_{\text{larnite}}$ ) from olivine melilitites ( $\geq 10\% N_{\text{larnite}}$ ).  
332 Among the samples that can be represented in this classification, one (19MH19) is an olivine  
333 melilitite at 12%  $N_{\text{larnite}}$ , whereas the others (19MH08, 19MH11, and 19MH12) are in the field  
334 of olivine nephelinites.

335 In spider diagrams normalized to primitive mantle (Fig. 4), our new data from Mohéli and the  
336 Chistwani ridge plot within the range of those published for the less silica-rich rocks of this  
337 island (i.e., for  $\text{SiO}_2 < 50$  wt.% after oxide sum normalization to 100%), except for U, Ta, and  
338 Pb for which there is no literature data. Nevertheless, our data may be subdivided in two groups.  
339 The first group of five samples (SMR4A, 19MH03, 19MH07, 19MH15, and 19MH17) shows  
340 a moderate enrichment in the most incompatible elements relative to primitive mantle, whereas  
341 a second group of seven samples (SMR3, 19MH04, 19MH08, 19MH11, 19MH12, 19MH19,  
342 and 19MH20) display steeper slopes in spider diagrams and hence stronger enrichments.

343 Plotted as a function of time, major element concentrations such as  $\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ , or  
344 concentration ratios of highly to moderately incompatible trace elements such as Ba/Ti or  
345 La/Yb, show an evolution of Mohéli's erupted products toward increased proportions of  
346 incompatible elements (Fig. 5a-c). Other ratios such as Nb/U, Ce/Pb, or Ta/Th do not show any

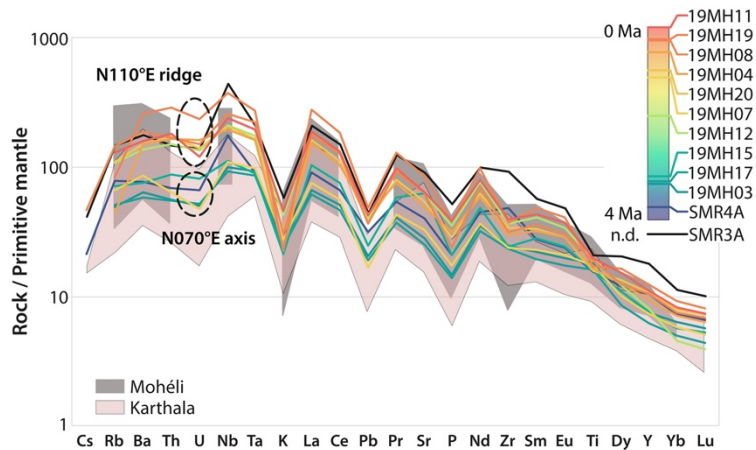
347 obvious correlation with time (Fig. 5d-f). Nb/U and Ce/Pb generally fall between the ranges of  
 348 normal MORB/OIB (Nb/U  $\sim 47 \pm 10$ , Ce/Pb  $\sim 25 \pm 5$ , Ta/Th  $> 0.6$ ) and HIMU (Ce/Pb  $\sim 28 - 48$ ,  
 349  $0.4 < \text{Ta/Th} < 0.6$ , Hofmann, 1997; Willbold and Stracke, 2006; Farmer et al., 2020).

350



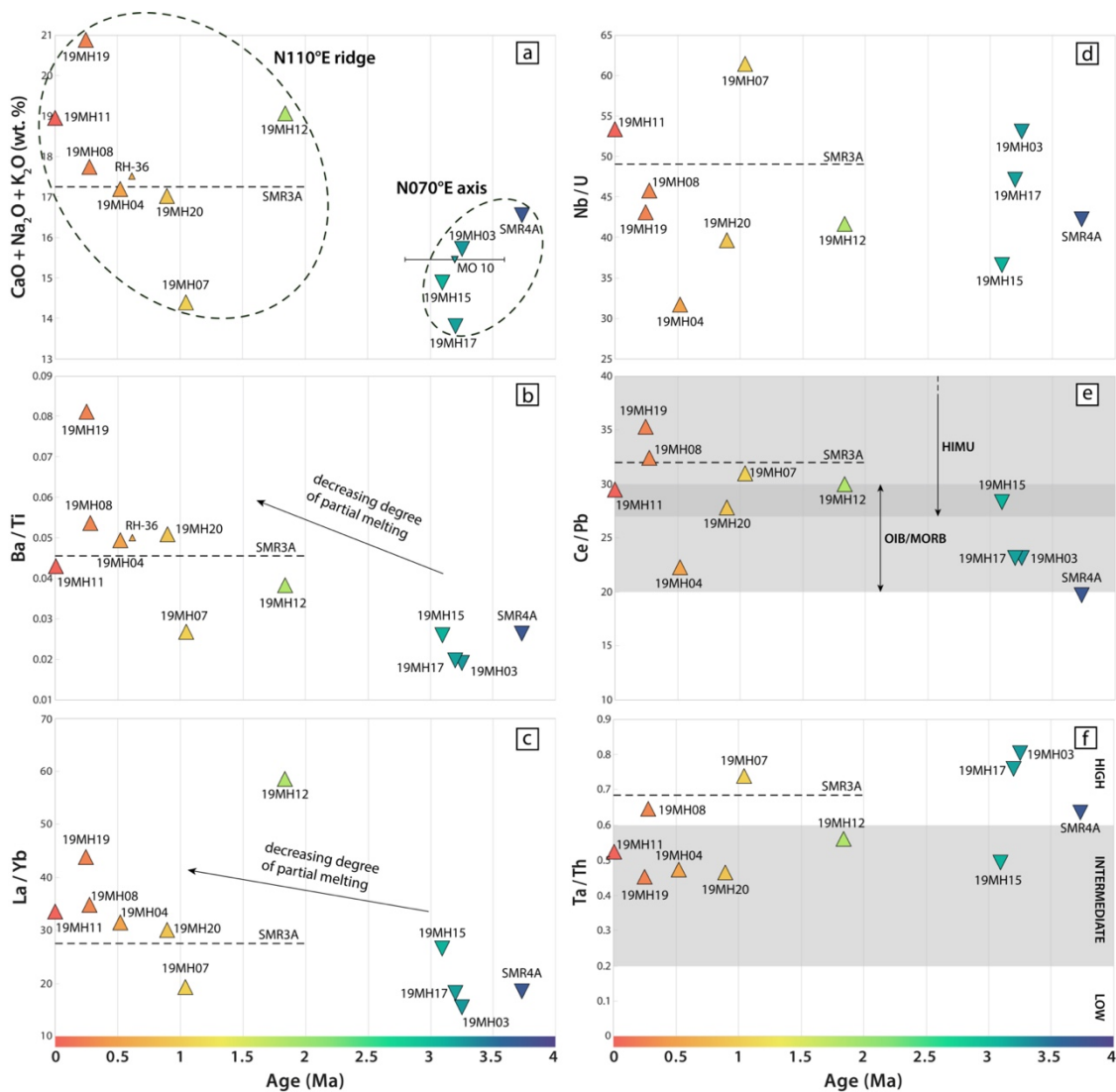
351

352 **Figure 3:** a- Major element compositions of Mohéli and Chistwani ridge samples represented in a total alkali  
 353 versus silica (TAS) diagram (Le Bas et al., 1986) compared with volcanic rocks from the Comoros islands  
 354 (GEOROC database and Quidelleur et al., 2022). b- Melilitites classification diagrams for mafic samples ( $\text{MgO} >$   
 355  $5 \text{ wt.}\%$ , after Le Bas, 1989 and Woolley et al., 1996). Also added are the two literature samples with validated K-  
 356 Ar whole-rock ages and available major  $\pm$  trace element data (MO10 from Nougier et al., 1986, and RH-36 from  
 357 Emerick and Duncan, 1982, 1983 with major and trace element data from Späth et al., 1996). The color chart of  
 358 symbols refers to the K-Ar age of samples.



359

360 **Figure 4:** Spider diagram of trace element concentrations in the studied samples, normalized to primitive mantle  
 361 (using the values of Lyubetskaya and Korenaga, 2007). The grey and pink fields correspond to published data for  
 362 Mohéli Island and Karthala volcano, respectively (GEOROC database). The color chart refers to the K-Ar  
 363 groundmass age of each sample, except for SMR3A (not dated, n.d.). The N070°E axis and N110°E ridge  
 364 correspond to the two volcano-tectonic stages of Mohéli's edification.



365 **Figure 5:** CaO+Na<sub>2</sub>O+K<sub>2</sub>O concentration (a), Ba/Ti ratio (b), La/Yb ratio (c), Nb/U (d), Ce/Pb (e), and Ta/Th (f)  
 366 of dated samples as a function of time. Color chart is the same as in Figs 1 – 4. Also included are literature data  
 367 for samples whose age and major or trace elements are available (MO10 from Nougier et al., 1986; RH-36 from  
 368 Emerick and Duncan, 1982, 1983; Späth et al., 1996). Error bars are smaller than symbol size, except for MO10.  
 369 Also represented are values for sample SMR3A (grey dashed line), undated but interpreted as belonging to the  
 370 second stage N110°E ridge according to its location and chemistry. The Ce/Pb compositional fields for  
 371 OIB/MORB and HIMU are from Hofmann (1997) and Willbold and Stracke (2006), and high/intermediate/low  
 372 Ta/Th fields are from Farmer et al. (2020).  
 373

374  
 375 **5. Discussion**

376  
 377 **5.1 Comparison with published ages**

378 As already discussed in Quidelleur et al. (2022), whole-rock K-Ar dating may be prone to  
 379 inaccuracy due to the presence of excess Ar in xenocrysts, or to K loss and contamination by  
 380 atmospheric Ar in alteration phases, leading to calculated ages older than the “true” ages. This  
 381 is especially true for volcanic rocks of the Comoros islands, including Mohéli, because they

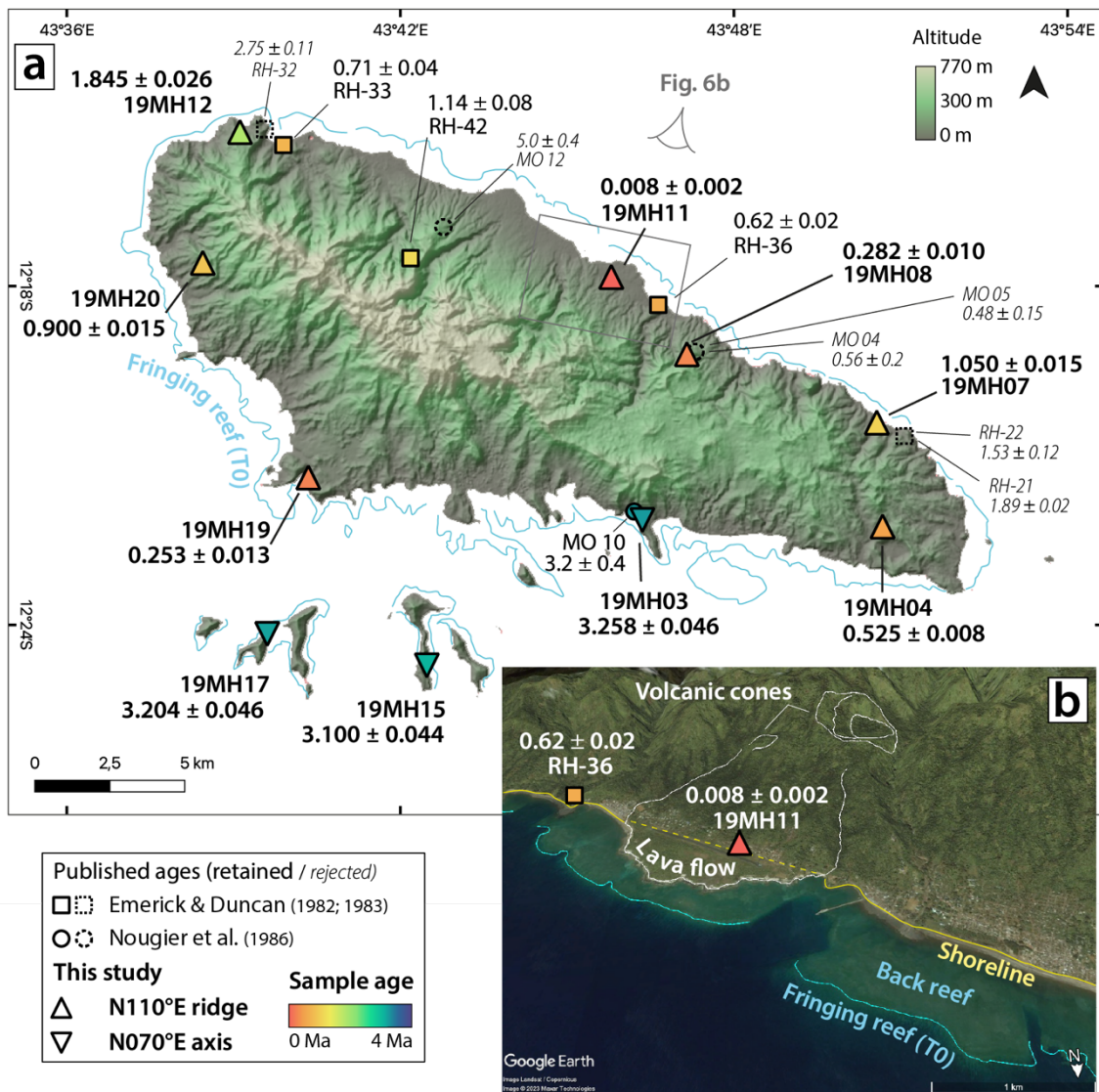
382 contain large quantities of peridotite and/or quartzite xenoliths (Lacroix, 1922; De Saint Ours,  
383 1960; Flower and Strong, 1969; Montaggioni and Nougier, 1981). As a matter of fact, several  
384 whole-rock K-Ar ages from Anjouan (Hajash and Armstrong, 1972; Emerick and Duncan,  
385 1982; 1983; Nougier et al., 1986) have been found in disagreement with paleomagnetic  
386 polarities (Hajash and Armstrong, 1972) and with K-Ar ages on groundmass using the  
387 Cassinol-Gillot technique, the two latter being concordant with each other (Quidelleur et al.,  
388 2022). We therefore first compare our new Cassinol-Gillot K-Ar data on groundmass with  
389 published ages on Mohéli.

390 Ten whole-rock K-Ar ages have been reported from Mohéli (Emerick and Duncan, 1982, 1983;  
391 Nougier et al., 1986). Our age of  $3.258 \pm 0.046$  Ma on aphyric basalt sample 19MH03 from the  
392 southern shore of Mohéli is in excellent agreement with the age of  $3.2 \pm 0.4$  Ma reported by  
393 Nougier et al. (1986) for an aphyric basalt (their sample MO 10) from the same locality (Fig.  
394 6). Our sample 19MH07, a lava flow of aphyric basalt from the northeast coast of Mohéli dated  
395 at  $1.050 \pm 0.015$  Ma, is located near the samples RH-21 and RH-22 of Emerick and Duncan  
396 (1982, 1983) dated at  $1.53 \pm 0.12$  Ma and  $1.89 \pm 0.02$  Ma, respectively (Fig. 6). Our K-Ar age  
397 on groundmass is thus 0.5 to 0.9 Ma, respectively, younger than the two whole-rock ages in  
398 this area, even though all the samples are located on the same geomorphological structure and  
399 have similar compositions. A similar discrepancy is observed on the north coast of Mohéli,  
400 between our sample 19MH08 ( $0.282 \pm 0.010$  Ma), of which age is younger and more precise  
401 than the samples MO 04 and MO 05 of Nougier et al. (1986) dated at  $0.56 \pm 0.2$  Ma and  $0.48 \pm$   
402  $0.15$  Ma, respectively, collected at the same location. Finally, our sample 19MH12 ( $1.845 \pm$   
403  $0.026$  Ma) on the northwest coast of Mohéli is also younger than the age of  $2.75 \pm 0.13$  Ma  
404 reported by Emerick and Duncan (1982, 1983) for the same morphological unit (their sample  
405 RH-32). These three examples provide typical cases where thorough groundmass selection  
406 yielded younger, more precise, and likely more accurate ages than whole-rock analyses due to  
407 their possible contamination by xenocrysts and/or the incorporation of weathered phases.

408 We note the existence of two ages available in the same area of the northern flank of Mohéli,  
409 in a zone we did not investigate (Fig. 6a): a basanite dated at  $5.0 \pm 0.4$  Ma (sample MO 12 in  
410 Nougier et al., 1986) and a boulder of unknown composition dated at  $1.14 \pm 0.08$  Ma (RH-42  
411 in Emerick and Duncan, 1982, 1983). These ages differ by nearly 4 Myrs despite being collected  
412 on the same geomorphological feature. Furthermore, the  $5.0 \pm 0.4$  Ma age is much older than  
413 our groundmass ages of  $1.845 \pm 0.026$  Ma (sample 19MH12) and  $0.900 \pm 0.015$  Ma (19MH20)  
414 obtained on the same western massif from geomorphological features with a similar erosional  
415 surface (Fig. 6a). Finally, our submarine sample from the Chistwani ridge, likely related to the  
416 early volcanism of Mohéli (see below), is only  $3.738 \pm 0.054$  Ma old (SMR4A). Collectively,  
417 this evidence suggests that the age of  $5.0 \pm 0.4$  Ma is inaccurate.

418 The cross-comparison of whole-rock K-Ar ages among themselves, with new groundmass K-  
419 Ar ages, and with geomorphological criteria of relative chronology demonstrates that whole-  
420 rock K-Ar ages are often “too old” compared to other techniques, and should be regarded only  
421 with great caution, a conclusion already reached for samples from Anjouan (Quidelleur et al.,  
422 2022) and from other locations (e.g., Quidelleur et al., 1999; Samper et al., 2007). Based on the  
423 discussion above, six out of ten whole-rock ages (i.e., RH-21, RH-22, RH-32, MO 04, MO 05,  
424 and MO 12) are excluded from the geochronological database of Mohéli for interpretation  
425 purposes. Three ages (RH-42:  $1.14 \pm 0.08$  Ma; RH-33:  $0.71 \pm 0.12$  Ma; RH-36:  $0.62 \pm 0.02$   
426 Ma; Emerick and Duncan, 1982; 1983) are not categorically invalidated, and only one age  
427 (MO10:  $3.2 \pm 0.4$  Ma; Nougier et al., 1986) is confirmed by our new data.

428



429  
 430 **Figure 6:** a- Topographic map of Mohéli showing new groundmass K-Ar ages, together with retained and rejected  
 431 published whole-rock K-Ar ages. b- Google Earth view of the Fomboni airport lava flow (at x2 vertical  
 432 exaggeration). Ages and  $1\sigma$  uncertainties are quoted in Ma.

433  
 434

## 5.2 Volcanic history of Mohéli and the Chistwani ridge

435 Based on the 11 new and 4 revised K-Ar ages from subaerial and submarine samples from  
 436 Mohéli and the Chistwani ridge, we propose that at least two construction stages shaped the  
 437 submarine and subaerial slopes of Mohéli (Fig. 7). The first stage (Stage 1), starting before 3.8  
 438 and lasting to ca. 3 Ma, corresponds to the construction of volcano-tectonic structures along a  
 439 N070°E axis. The Chistwani ridge was edified in this stage as inferred from age of  $3.738 \pm$   
 440  $0.054$  Ma (sample SMR4A). The drowned carbonate platform T3 covering the SW tip of the  
 441 ridge (Fig. 1b) indicates that the Chistwani ridge predates the construction of Mohéli's edifice.  
 442 Stage 1 also includes the edification of the early volcano forming the southern flank of Mohéli,  
 443 probably concomitant with the activity of the Chistwani ridge. As noticed by Saint Ours (1960),  
 444 radial islets and peninsulas of the south coast of Mohéli are eroded remnants of the early  
 445 volcano. These morphological features are inverted topography, in which valleys were infilled  
 446 by lavas dated at 3.3–3.1 Ma (Fig. 6). Therefore, the early volcano of Mohéli must have been  
 447 emerged and eroded before 3.3 Ma (Fig. 7). At that time, this early volcano was roughly of

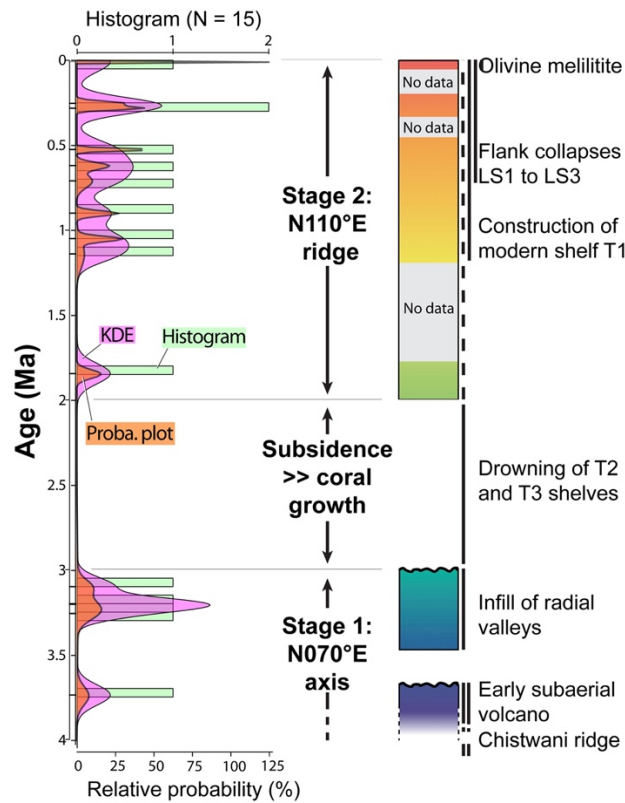
448 elliptical shape according to the SW and NE tips of the submarine slopes supporting the T2 and  
449 T3 drowned platforms, with an eruptive center aligned in the N070°E prolongation of the  
450 Chistwani ridge (Fig. 1b). Stage 1 ended up after the filling of erosional valleys ca. 3 Ma ago,  
451 and was followed by a period of volcanic quiescence and subsidence (see below).

452 Stage 2 of the volcano-tectonic construction, postdating the N070°E morphology, corresponds  
453 to the N110°E elongated ridge shaping the present-day subaerial island (Figs 1b, 6a). The oldest  
454 age within this second stage is at  $1.845 \pm 0.026$  Ma, which suggests a volcanic renewal starting  
455 at ca. 2 Ma (Fig. 6). However, a majority of the ages belonging to this stage are in the range  
456 1.14–0.25 Ma, which we consider as the main phase of reconstruction of subaerial Mohéli (Fig.  
457 7). Unfortunately, alteration in sample SMR3A prevented any K-Ar dating to be attempted.  
458 However, given the location of the SMR3 volcanic cone in the eastern prolongation of Mohéli's  
459 N110°E ridge, we attribute the edification of this seamount to the volcano-tectonic Stage 2.  
460 There may have been some periods of low volcanic activity during Stage 2 where ages are  
461 currently lacking, for instance in the intervals 1.8–1.1 Ma, 0.52–0.28 Ma, and 0.25–0.008 Ma  
462 (Fig. 7), hence additional fieldwork and geochronological data are required to confirm that these  
463 hiatuses are true volcanic lulls. Importantly, there are many uneroded volcanic morphologies  
464 on the northern and eastern sides of Mohéli, indicating that Stage 2 was still active until very  
465 recent times. One of these features is a fresh lava flow on the north coast, on which the airport  
466 was built, which we dated at  $8 \pm 2$  ka (Fig. 6). This age is the average of two reproducible K-  
467 Ar analyses (Table 1), made on a perfectly unaltered rock in macroscopic and microscopic  
468 views (Figs S1, S2), with a low negative LOI (-0.29 wt.%, Table 2) indicative of freshly erupted  
469 nephelinite. This Holocene age is further supported by the morphology of the lava flow filling  
470 the back of the modern fringing reef (T0, Fig. 6b). The construction of modern fringing reefs  
471 in the Indian ocean has initiated 8 – 9 ka ago due to the last post-glacial sea level rise (Camoin  
472 et al., 2004). The lava flow is thus younger than 9 ka, in consistency with its K-Ar age at  $8 \pm 2$   
473 ka. There are thus Holocene volcanic deposits on Mohéli, as on Grande Comore, Anjouan, and  
474 perhaps Mayotte (Zinke et al., 2003; Quidelleur et al., 2022).

475 Our geochronological results may also be used to constrain the timing and magnitude of vertical  
476 movements. Indeed, the radial islets south of Mohéli imply that the erosional valleys of the  
477 early volcano, filled at 3.3–3.1 Ma, then subsided after ~3 Ma and before the construction of  
478 the N110°E ridge (Fig. 6a). Drowned carbonate platforms T2 and T3 at 400–600 m depth on  
479 the SW and NE of Mohéli (Fig. 1b) confirm the subsidence of the N070°E structure at a rate  
480 greater than the growth rate capacity of coral reefs. Based on the depths of these drowned reefs,  
481 and after subtracting the depth at the base of the modern shelf (100–200 m), we calculate a  
482 long-term subsidence rate of 0.2–0.6 mm/yr in the ca. 1 Myrs period between Stages 1 and 2.  
483 Similar long-term subsidence rates have been found for volcanic edifices worldwide in various  
484 geodynamic settings (e.g., 0.25–0.39 mm/yr over 500 kyrs for Tahiti, Thomas et al., 2012; 0.2  
485 mm/yr over 3 Myrs for the Kahouanne seamounts, Carey et al., 2020; 0.4 mm/yr over 125 kyrs  
486 in Les Saintes, Leclerc et al., 2014). In the case of Mohéli, however, this long-term subsidence  
487 rate must be considered as a very minimum, given the capacity of coral reefs to grow at rates  
488 of up to 7 mm/yr nearby in Mayotte (Camoin et al., 2004). Reef drowning must have been much  
489 more rapid than estimated by our long-term subsidence rate. Drowned carbonate platforms are  
490 also reported on the lower slopes of Mayotte at 400–800 m depth (Audru et al., 2006), the ages  
491 of which are unknown, and further work is obviously needed to compare the chronology of  
492 subsidence on the two islands in order to draw geodynamic inferences.

493 The modern carbonate insular shelf T1, less than 100 m-deep, is built on the slopes of the second  
494 stage N110°E ridge as well as on the slopes of the first stage N070°E axis (Fig. 1b). We  
495 therefore interpret T1 to be under construction since less than 2 Ma. This modern shelf indicates  
496 that, after sudden drowning between 3 and 2 Ma, subsidence halted or slowed down during the

497 volcano-tectonic Stage 2, allowing coral reef growth to catch up vertical movement. Using our  
 498 age constraints, we calculate a long-term subsidence rate of less than 0.2 mm/yr since the  
 499 beginning of Stage 2 ca. 2 Ma ago, which is about the sea-level-corrected subsidence rate  
 500 calculated for Mayotte in the Holocene (Camoin et al., 2004).



501  
 502 **Figure 7:** Chronostratigraphic chart of Mohéli and the Chistwani ridge based on criteria of relative chronology  
 503 (geomorphology, unconformities, etc.) and on age frequency in three different representations (age-probability  
 504 spectra after Deino and Potts, 1992; Kernel density estimation – KDE – at 0.05 Ma bin, and histogram at 0.05 Ma  
 505 bin). Abbreviations T1 to T3 and LS1 to LS3 refer to structures shown in Figure 1b. Color chart is the same as in  
 506 Figs 1 – 6.

507  
 508 **5.3 Geochemical evolution of Mohéli’s magmas**

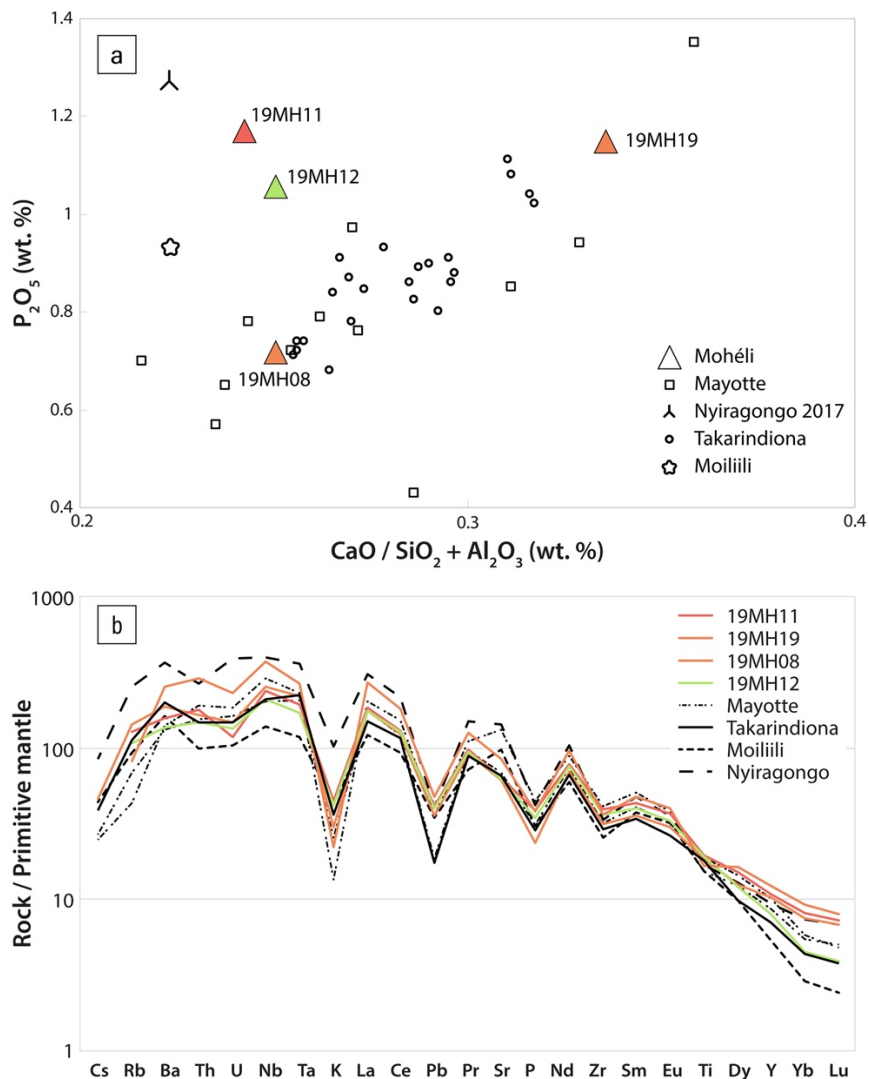
509 Major and trace elements show that the two volcano-tectonic stages identified above are  
 510 characterized by two distinct major and trace element signatures of eruptive products (Figs 4,  
 511 5). The magmas emitted during Stage 1 (including MO 10, the only validated K-Ar whole-rock  
 512 age of the first stage with major element data available) are moderately silica-undersaturated  
 513 basalts and basanites (Fig. 3a), with mild enrichments in incompatible elements relative to  
 514 primitive mantle (Fig. 4). These characteristics are similar to those of mafic magmas from the  
 515 Karthala volcano in Grande Comore, Anjouan, and to the moderately undersaturated trend of  
 516 Mayotte (Class et al., 1998; Pelleter et al., 2014; Bachèlery and Hémond, 2016). Stage 2, in  
 517 contrast, is characterized by highly silica-undersaturated eruptive products (Fig. 3), with  
 518 marked enrichments in incompatible elements compared to the first stage (Figs 4, 5). Sample  
 519 RH-36 (Emerick and Duncan, 1983, 1982), the only validated whole-rock K-Ar age of Stage 2  
 520 with major and trace element analyses available (Späth et al., 1996), is a tephri-basanite sharing  
 521 this enrichment in incompatible elements (Figs 3, 4, 5a-b). The volcanic seamount dredged by  
 522 SMR3 is also a silica-undersaturated rock (Fig. 3), with trace-element signatures similar to  
 523 those of the Stage 2 (Figs 4, 5). These compositional characteristics further confirm that the



524 volcanic cone dredged by SMR3 is a volcanic structure of the N110°E ridge, belonging to the  
525 volcano-tectonic Stage 2 of Mohéli.

526 The question arises about which melting processes are responsible for the geochemical diversity  
527 of Mohéli's magmas. Ratios such as Nb/U and Ce/Pb, which are insensitive to variable partial  
528 melting, are comparable to normal MORB/OIB (e.g. Rasoazanamparany et al., 2021, 2022) and  
529 do not show any variation with time (Fig. 5d-e). This suggests that the temporal enrichment in  
530 incompatible elements is not the result of increasing crust assimilation. Intermediate Ta/Th  
531 values (0.4-0.9), uncorrelated to rock ages (Fig. 5f), argue against a pure asthenospheric source  
532 and suggest the presence of metasomatic apatite and/or rutile (Farmer et al., 2020). Moreover,  
533 highly silica-undersaturated rocks from Mohéli, and in particular melilite-bearing lavas, display  
534 similar major and trace element characteristics to those described by Pelleter et al. (2014) for  
535 Mayotte, namely high CaO and/or P<sub>2</sub>O<sub>5</sub> contents (Fig. 8a), strong enrichments in incompatible  
536 elements such as F, Ba, Sr, Nb, and relative enrichments in MREE with respect to the other  
537 mafic rocks (Figs 4, 8b). Mohéli's and Mayotte's olivine melilitites also share minor and trace  
538 element similarities with those of central and eastern Madagascar (Melluso et al., 2011; Mazzeo  
539 et al., 2021, and references therein), like K and Pb troughs (Fig. 8b). Following Pelleter et al.  
540 (2014) for Mayotte, and Mazzeo et al. (2021) for eastern Madagascar, we thus interpret  
541 Mohéli's undersaturated magmas as generated by very low partial melting of a peridotitic  
542 source located in the lithospheric mantle, enriched in highly incompatible elements by CO<sub>2</sub>  
543 metasomatism. As for Mayotte's melilitites and for one melilitite in northern Madagascar  
544 (Cucciniello et al., 2016), Mohéli's olivine melilitite is among the most enriched in P (1.15  
545 wt.%) of worldwide melilitites (max 1.35 wt.% in Mayotte and 1.27 wt.% in Nyiragongo, Fig.  
546 8a, see compilation by Mazzeo et al., 2021). For Mayotte, Pelleter et al. (2014) interpreted this  
547 geochemical feature as contribution of apatite ± dolomite in magmas, either from the partial  
548 melting source or by assimilation during melt ascent. CO<sub>2</sub> metasomatism, already evidenced  
549 beneath Grande Comore (Coltorti et al., 1999) and Mayotte (Pelleter et al., 2014; see Bachèlery  
550 and Hémond, 2016 for a review), and now found in Mohéli, is thus a general feature of magmas  
551 from the Comoros archipelago. It is also a general feature of Cenozoic and Recent magmas  
552 from northern Madagascar, suggesting analogies in mantle sources and/or enrichment  
553 processes, as recently proposed by Cucciniello et al. (2022).

554



555

556 **Figure 8:** Comparison of highly silica-undersaturated lavas from Mohéli with those of Mayotte (Pelleter et al.,  
 557 2014) and with melilitites worldwide (compilation from Mazzeo et al., 2021). a-  $P_2O_5$  vs  $CaO / (SiO_2 + Al_2O_3)$ . b-  
 558 Spider diagram. Color chart is the same as in Figs 1 – 7.

559

560 Despite the appearance of highly silica-undersaturated magmas, it is worth noting that the  
 561 moderately undersaturated, basanitic magmas do not disappear in Stage 2, as shown by our  
 562 sample 19MH07 ( $1.05 \pm 0.02$  Ma; Figs 4, 5). This situation is again reminiscent to that of  
 563 Mayotte, where the moderately and highly silica-undersaturated melts coexisted in the same  
 564 time intervals (Pelleter et al., 2014). Pelleter et al. (2014) interpreted this duality as reflecting  
 565 variable partial melting of the same metasomatized lithospheric mantle. Applying this concept  
 566 to Mohéli, age correlations with incompatible element concentration ratios (Figs 5b-c) suggest  
 567 that partial melting of the lithosphere decreases over time from the N070°E axis to the N110°E  
 568 ridge, even though batches of the initial magma are still erupting in the second stage.

569

#### 570 5.4 Volcano-tectonic hazard assessment and geodynamic implications

571 The first implication of our study concerns the assessment of volcanic hazards in the Comoros  
 572 archipelago. One of the most silica-undersaturated samples – the 19MH11 olivine nephelinite,  
 573 is also the youngest dated lava flow ( $8 \pm 2$  ka; Fig. 3), consistent with its morphology younger  
 574 than 9 ka (Fig. 6b). Holocene volcanic activity has recently been identified on Anjouan

575 (Quidelleur et al., 2022), and present-day activity occurs on Grande Comore and offshore  
576 Mayotte (Feuillet et al., 2021). Following the definition of the Smithsonian Global Volcanism  
577 Program, our discovery of Holocene volcano-tectonic activity  $<10$  ka on Mohéli implies that  
578 all the islands of the archipelago must be considered as active in any assessment of volcanic  
579 hazard in the area. This finding should be kept in mind when interpreting the origin of volcanic  
580 deposits in the northern Mozambique channel. For instance, Zinke et al. (2003) described ash  
581 layers in cores of coral platforms in Mayotte dated between 7 and 4 ka. Many authors have  
582 attributed it to the latest volcanic activity of Petite Terre in Mayotte (e.g., Nehlig et al., 2013).  
583 However, that is called into question by a new study focused on the explosive phonolitic  
584 volcanism of Petite-Terre suggesting that it may have occurred 25 ka ago or earlier (Lacombe  
585 et al., 2023). In the absence of systematic chemical analyses, these ash layers found in cores  
586 could as well come from Grande Comore, Mohéli, or Anjouan. Care should be taken to include  
587 compositional constraints to assess the source of tephra anywhere in the Comoros archipelago.

588 Another volcano-tectonic implication of our study is related to the destabilization history of  
589 Mohéli's edifice. Tzevahirtzian et al. (2021) described two large ( $>20$  km-long) collapse scars  
590 in the modern shelf T1, with up to  $0.5$  km<sup>3</sup> associated debris avalanche deposits on the southern  
591 slopes of Mohéli (Fig. 1). A smaller ( $<5$  km-long) collapse scar is also described at the NE tip  
592 of T1, with debris flows or avalanche deposits partially covering the drowned platform T3 (Fig.  
593 1b). Because all these flank collapses affected T1, they must be more recent than the main  
594 construction of the N110°E ridge, i.e., younger than ca. 1 Ma. These events should be put in  
595 the perspective of other flank collapses occurring on nearby volcano-tectonic structures. For  
596 instance, based on their new radiometric dating, Quidelleur et al. (2022) estimated the major  
597 collapses of the northern and southern slopes of Anjouan to have occurred after 0.9 Ma. Our  
598 results imply that at least two additional flank collapses occurred during the same time interval  
599 nearby on Mohéli, with the possibility that all these events might be chronologically or even  
600 genetically related. Destabilizations have also been evidenced on the slopes of Mayotte (Audru  
601 et al., 2006; Thinon et al., 2022), but their timing relative to Mohéli's and Anjouan's events is  
602 yet to be established.

603 By providing new age constraints on the volcano-tectonic history of Mohéli, our work also asks  
604 an important question: Why did Mohéli's volcano-tectonics shift from a N070°E structure  
605 emitting moderately silica-undersaturated magmas before 3 Ma, to a N110°E ridge emitting  
606 both highly silica-undersaturated and moderately-undersaturated magmas after 2 Ma? If, as  
607 proposed by Famin et al. (2020), the Comoros archipelago represents a dextral strike-slip  
608 boundary between the Somali and Lwandle plates, then the kinematics of this boundary seems  
609 to have changed from  $\geq 3$  Ma to  $\leq 2$  Ma in the Mohéli area. According to plate motion  
610 reconstructions from the spreading of the Southwest Indian Ridge, the Lwandle/Somali relative  
611 motion did not experience significant variation during this period (DeMets et al., 2021). Thus,  
612 the cause of this kinematic change has to be searched in relation to magmatic processes and the  
613 decrease of lithosphere partial melting. Further geochronological and geochemical work is  
614 needed to elucidate this question, at the broader scale of the Comoros province, encompassing  
615 the many newly discovered seamounts in the area (Thinon et al., 2022).

616

## 617 **6. Conclusion**

618

619 Our new K-Ar ages obtained by the Cassinot-Gillot approach on groundmass, combined with  
620 major and trace element whole-rock analyses, suggest that the volcano-tectonics of Mohéli has  
621 one of the most protracted histories among the islands of the Comoros archipelago. This history  
622 includes a first stage with the emersion of an early volcano and the activity of a submarine ridge

623 along a N070°E axis from before 3.8 Ma to ca. 3 Ma. This first volcano-tectonic Stage 1 was  
624 followed by ~1 Myrs of repose and increased subsidence of the island ( $\geq 0.2$  mm/yr), causing  
625 the drowning of carbonate shelves. Then, a Stage 2 of submarine and subaerial volcanic activity  
626 resumed from ca. 2 Ma to Holocene times along a N110°E ridge, shaping the present-day  
627 morphology of the island and supporting the modern shelf. This two-stage shift of volcano-  
628 tectonics is accompanied by a chemical evolution of emitted magmas, from moderately silica-  
629 undersaturated and incompatible-element-enriched in the first stage, to the predominance of  
630 highly silica undersaturated and incompatible-element-enriched products in the second stage.  
631 The chemical characteristics of magmas and their evolution suggest that melts originate from a  
632 CO<sub>2</sub>-metasomatized lithospheric mantle, with decreasing partial melting over time. One of the  
633 most silica-undersaturated products, a melilite-bearing lava, revealed the youngest age of  $8 \pm 2$   
634 ka. This Holocene age implies a possible volcanic hazard in Mohéli Island, and thus a potential  
635 resumption of volcanism anywhere in the Comoros archipelago. The report of melilite-bearing  
636 lavas in Mohéli further supports the hypothesis that volcanism in the Comoros archipelago  
637 shares similarities in magmas sources and ascent processes with the Cenozoic volcanism of  
638 northern and eastern Madagascar.

639

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665 **Table captions**

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667 **Table 1:** New K-Ar ages performed on groundmass separates. Column headings indicate  
 668 sample names; latitude and longitude in decimal degrees; potassium (K) concentration in  
 669 percent; concentration of radiogenic argon ( $^{40}\text{Ar}^*$ ) in percent; concentration of  $^{40}\text{Ar}^* \times 10^{11}$  in  
 670 number of atoms per gram; age (in Ma);  $1\sigma$  uncertainty (Un., in Ma); weighted mean age (in  
 671 Ma);  $1\sigma$  weighted mean uncertainty (in Ma).

<b>Sample</b>	<b>Latitude (S)</b>	<b>Longitude (E)</b>	<b>K (%)</b>	<b><math>^{40}\text{Ar}^*</math> (%)</b>	<b><math>^{40}\text{Ar}^*</math> (<math>10^{11}</math> at/g)</b>	<b>Age (Ma)</b>	<b>Un. (Ma)</b>	<b>Mean age (Ma)</b>	<b><math>\pm 1\sigma</math> (Ma)</b>
<b>SMR4A</b>	44.09840	-12.28448	1.080	49.45	42.121	3.729	0.053	<b>3.738</b>	<b>0.054</b>
Duplicate				39.50	42.348	3.749	0.054		
<b>19MH03</b>	43.77262	-12.36906	0.922	57.84	31.460	3.264	0.046	<b>3.258</b>	<b>0.046</b>
Duplicate				58.66	31.355	3.253	0.046		
<b>19MH04</b>	43.84465	-12.37112	1.134	16.29	6.2448	0.527	0.008	<b>0.525</b>	<b>0.008</b>
Duplicate				17.20	6.2025	0.524	0.008		
<b>19MH07</b>	43.84292	-12.34042	1.277	35.03	14.096	1.056	0.015	<b>1.050</b>	<b>0.015</b>
Duplicate				44.83	13.942	1.045	0.015		
<b>19MH08</b>	43.78596	-12.32026	1.088	2.88	3.3024	0.29	0.011	<b>0.282</b>	<b>0.010</b>
Duplicate				3.18	3.1256	0.275	0.009		
<b>19MH11</b>	43.76331	-12.29747	2.037	0.34	0.17876	0.008	0.002	<b>0.008</b>	<b>0.002</b>
Duplicate				0.30	0.14158	0.007	0.002		
<b>19MH12</b>	43.65196	-12.25466	1.538	45.02	29.475	1.834	0.026	<b>1.845</b>	<b>0.026</b>
Duplicate				47.91	29.812	1.855	0.027		
<b>19MH15</b>	43.70800	-12.41180	1.106	61.50	35.846	3.099	0.044	<b>3.100</b>	<b>0.044</b>
Duplicate				56.48	35.866	3.101	0.044		
<b>19MH17</b>	43.66015	-12.40251	1.203	47.26	40.199	3.197	0.046	<b>3.204</b>	<b>0.046</b>
Duplicate				47.39	40.369	3.211	0.046		
<b>19MH19</b>	43.67247	-12.35664	1.150	1.89	3.0352	0.253	0.014	<b>0.253</b>	<b>0.013</b>
Duplicate				2.28	3.0391	0.253	0.012		
<b>19MH20</b>	43.64081	-12.29331	1.470	9.73	13.934	0.907	0.016	<b>0.900</b>	<b>0.015</b>
Duplicate				12.08	13.743	0.895	0.015		

672

673 **Table 2:** Major (in percent) and trace element (in ppm) compositions of whole-rock samples.

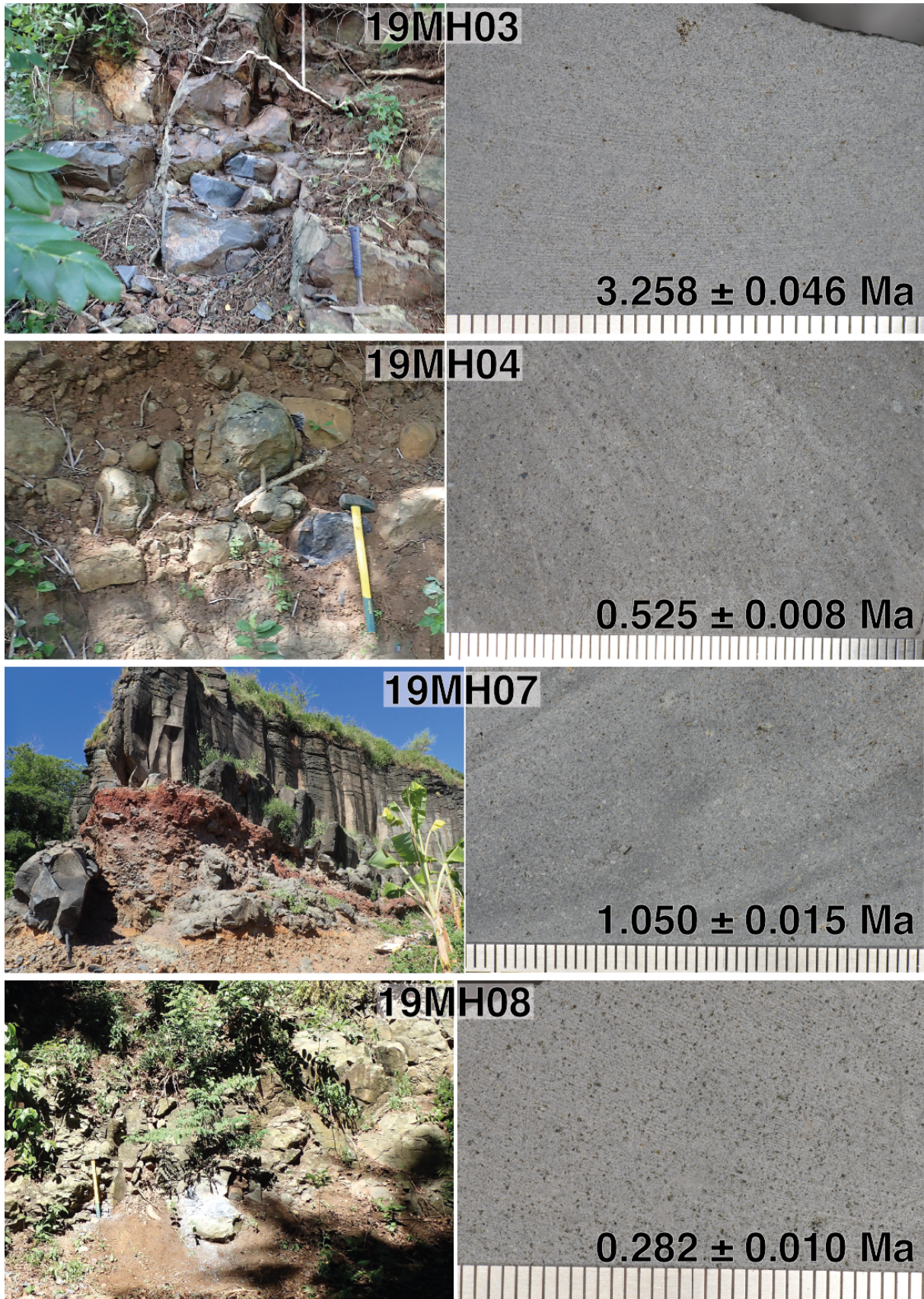
674 L.O.I.: loss on ignition.

Sample	SMR3A	SMR4A	19MH03	19MH04	19MH07	19MH08	19MH11	19MH12	19MH15	19MH17	19MH19	19MH20
(wt.%)												
SiO <sub>2</sub>	41.11	44.17	45.54	41.05	45.39	39.13	39.67	39.24	44.20	44.88	36.87	42.28
TiO <sub>2</sub>	3.28	2.45	2.84	2.58	2.74	2.97	3.12	3.03	2.48	2.52	2.66	2.50
Al <sub>2</sub> O <sub>3</sub>	13.58	11.86	14.11	12.16	13.68	11.57	10.91	10.55	11.61	11.54	11.02	12.81
Fe <sub>2</sub> O <sub>3</sub>	14.30	13.12	14.27	14.62	14.40	14.90	15.36	15.91	13.28	13.97	15.39	14.75
MnO	0.242	0.196	0.192	0.225	0.183	0.232	0.254	0.210	0.164	0.186	0.302	0.233
MgO	4.02	9.19	5.68	9.99	8.23	11.45	10.66	11.67	10.77	12.52	9.82	9.51
CaO	8.43	11.67	11.59	11.98	9.83	12.72	12.28	12.49	11.67	10.29	16.10	11.55
Na <sub>2</sub> O	5.19	3.23	2.79	3.87	3.20	3.35	4.60	4.80	1.87	2.35	3.23	3.98
K <sub>2</sub> O	2.64	1.26	1.08	1.07	1.27	1.37	2.05	1.92	0.97	1.11	1.02	1.47
P <sub>2</sub> O <sub>5</sub>	1.56	0.63	0.44	0.94	0.52	0.71	1.17	1.05	0.62	0.42	1.15	0.86
LOI	4.94	1.13	1.06	1.62	0.31	1.50	-0.29	-0.11	2.87	0.68	2.40	0.38
Total	99.29	98.91	99.59	100.09	99.75	99.90	99.79	100.70	100.49	100.47	99.96	100.33
(ppm)												
Be	4.92	2.74	1.82	2.40	1.60	2.96	3.11	3.62	2.07	1.69	3.47	3.01
Sr	1414	623	432	756	501	982	985	985	966	389	1313	845
Y	60.4	35.0	25.2	31.1	24.6	34.8	36.7	27.0	25.5	20.7	41.7	35.8
Zr	450	234	208	247	200	265	331	307	202	195	308	282
Mo	6.00	4.71	1.80	4.66	1.74	3.89	3.75	5.36	2.53	1.63	0.76	6.19
Cs	0.66	0.34				0.73						
Ba	891	385	322	761	436	952	800	693	382	295	1289	758
La	106	45.8	33.4	76.8	37.9	89.4	94.7	90.3	51.8	30.9	139	82.0
Ce	200	88.2	67.3	138	73.8	168	176	172	100	62.3	244	149
Pr	25.0	10.9	8.25	15.1	8.73	18.7	19.8	19.4	11.8	7.54	25.9	16.1
Nd	98.8	44.1	34.8	58.7	36.2	69.5	78.2	75.8	47.6	31.5	95.9	61.4
Sm	18.3	8.88	7.11	10.4	7.34	11.6	14.0	13.1	9.01	6.28	15.5	10.7
Eu	5.85	2.89	2.42	3.47	2.54	3.68	4.55	4.10	2.98	2.12	4.96	3.52
Gd	17.2	8.72	7.06	10.4	7.44	10.9	13.3	12.5	8.75	6.34	14.7	11.0
Tb	2.28	1.24	1.06	1.41	1.08	1.41	1.77	1.56	1.21	0.92	1.89	1.49
Dy	10.9	6.41	5.44	6.80	5.40	6.70	8.22	6.54	5.79	4.59	8.81	7.12
Ho	1.97	1.17	1.01	1.22	0.97	1.21	1.45	1.04	1.01	0.84	1.58	1.31
Er	4.69	2.89	2.52	2.95	2.35	2.96	3.42	2.17	2.39	2.02	3.82	3.18
Tm	0.63	0.41	0.35	0.40	0.32	0.42	0.46	0.26	0.32	0.28	0.52	0.44
Yb	3.87	2.47	2.17	2.45	1.97	2.57	2.83	1.55	1.96	1.70	3.18	2.74
Lu	0.54	0.35	0.30	0.34	0.27	0.37	0.39	0.21	0.28	0.23	0.43	0.39
Hf	11.5	6.41	4.95	5.12	4.65	7.04	6.59	6.03	4.57	4.53	6.10	5.31
W	2.71	1.41	0.51	1.79	0.63	0.73	1.61	1.76	0.58	0.59	0.42	3.25
Pb	6.27	4.49	2.92	6.20	2.39	5.19	6.01	5.76	3.54	2.70	6.93	5.37
Th	9.16	4.27	3.49	10.3	3.99	10.4	11.3	9.30	5.46	3.41	18.0	10.6
U	2.38	1.13	0.86	2.80	0.82	2.58	2.07	2.32	1.40	0.90	4.00	2.39
Li	23.9	11.0				11.0						
Sc	14.2	39.6				34.1						
V	152	388	317	235	237	387	238	263	269	257	258	240
Cr	3.27	713	29.7	284	214	463	357	522	567	443	337	308
Co	34.6	76.3	47.7	55.6	58.2	80.4	56.9	68.5	61.2	64.5	54.9	59.1
Ni	9.62	258	86.2	184	183	273	215	276	278	354	160	198
Cu	20.8	130	111	65.4	62.7	96.9	57.6	79.1	90.7	89.0	68.5	63.8
Zn	205	146	127	130	136	143	154	177	125	121	155	146
Ga	24.6	23.5				21.3						
Rb	66.7	35.7	22.3	19.8	30.3	65.6	58.5	49.0	32.4	23.2	37.6	49.4
Nb	116	47.6	45.8	88.3	50.2	118	110	96.3	51.2	42.3	172	94.4
Ta	6.24	2.70	2.79	4.86	2.94	6.72	5.89	5.18	2.68	2.58	8.14	4.91

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677 Supplementary Material

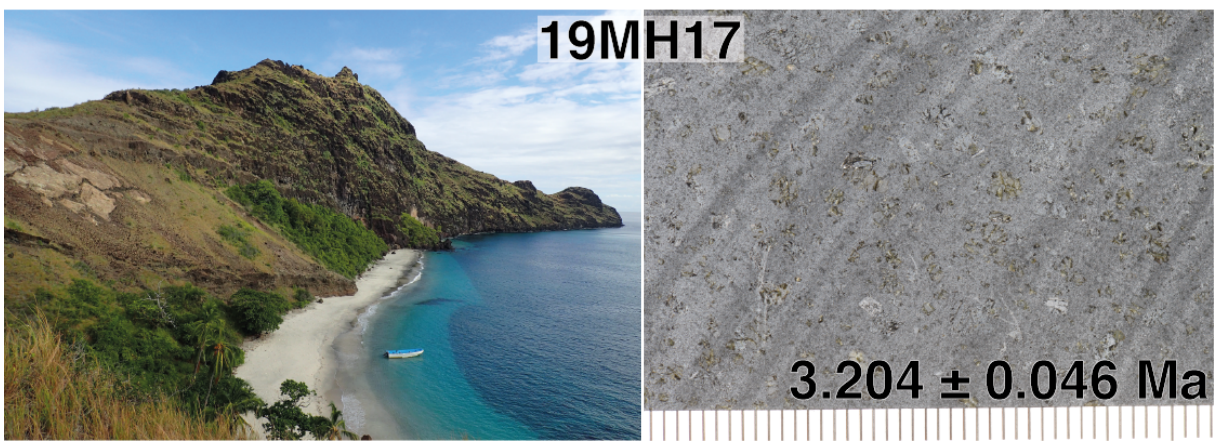
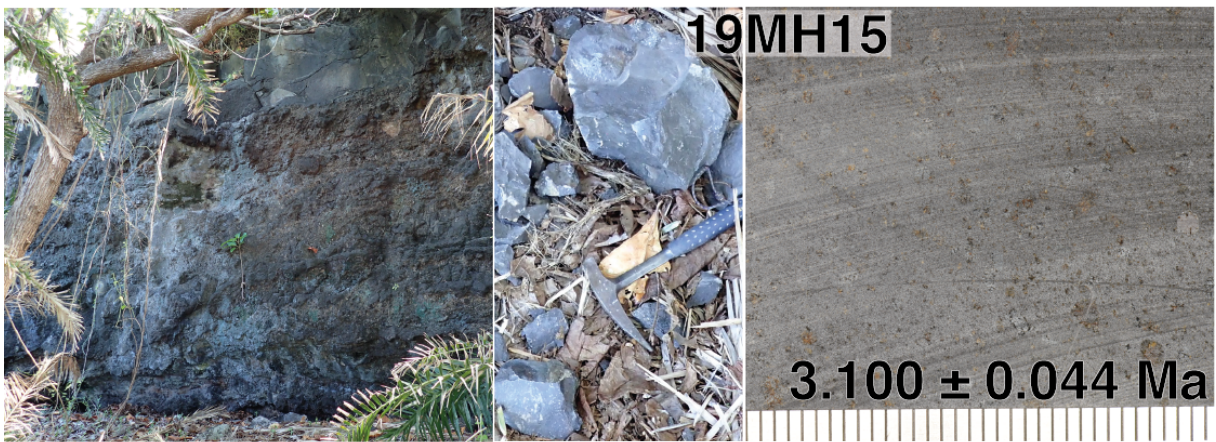
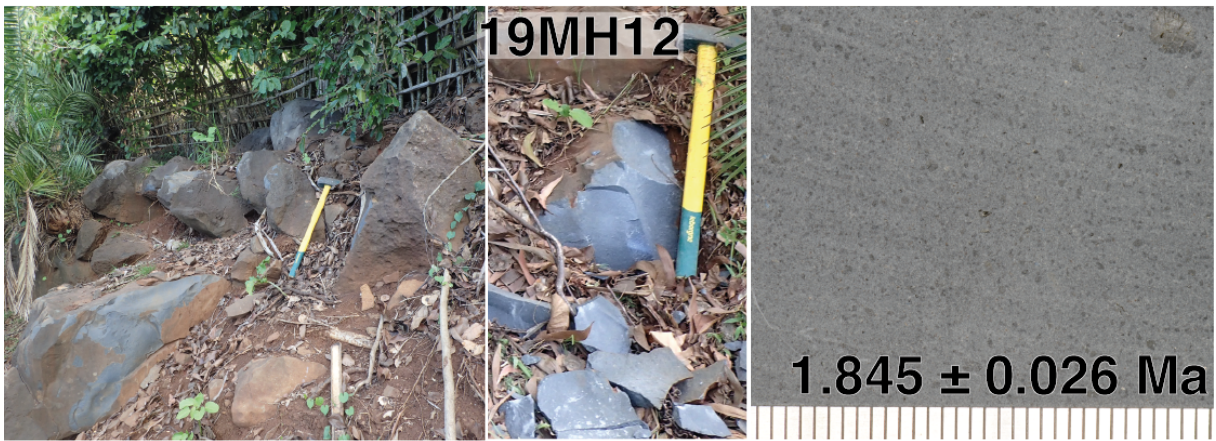
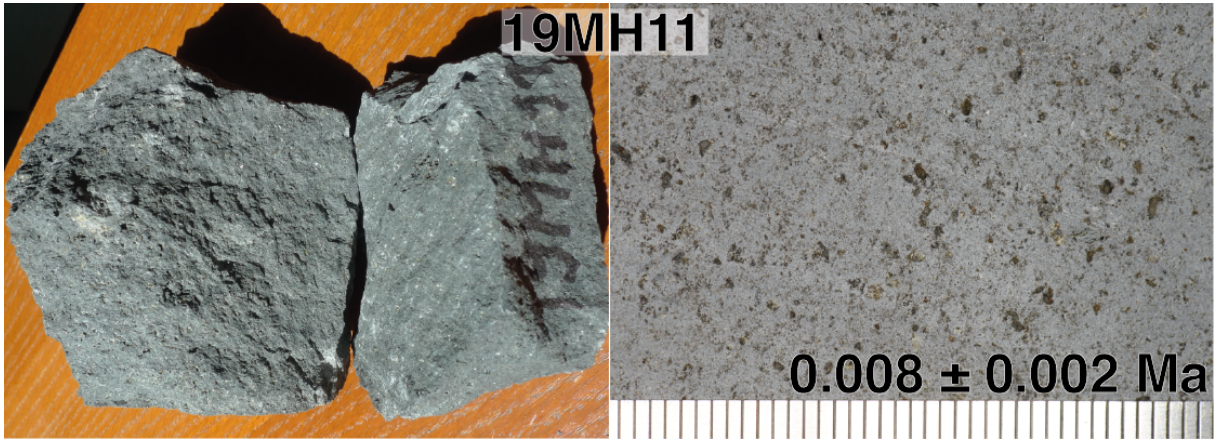


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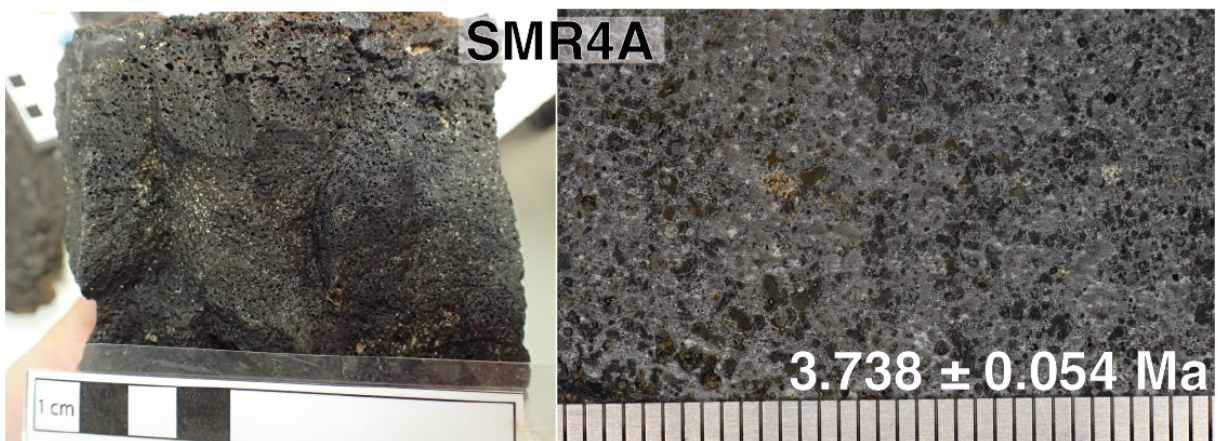
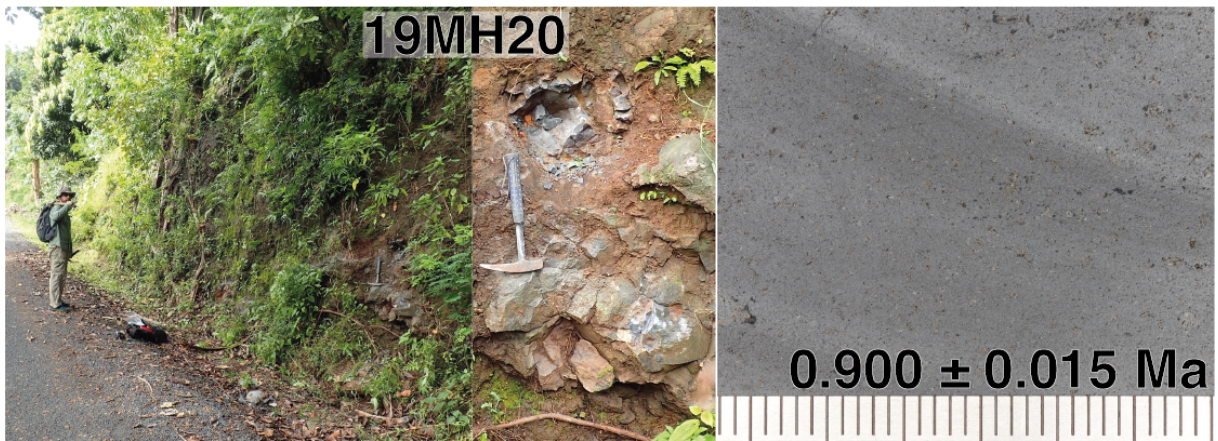
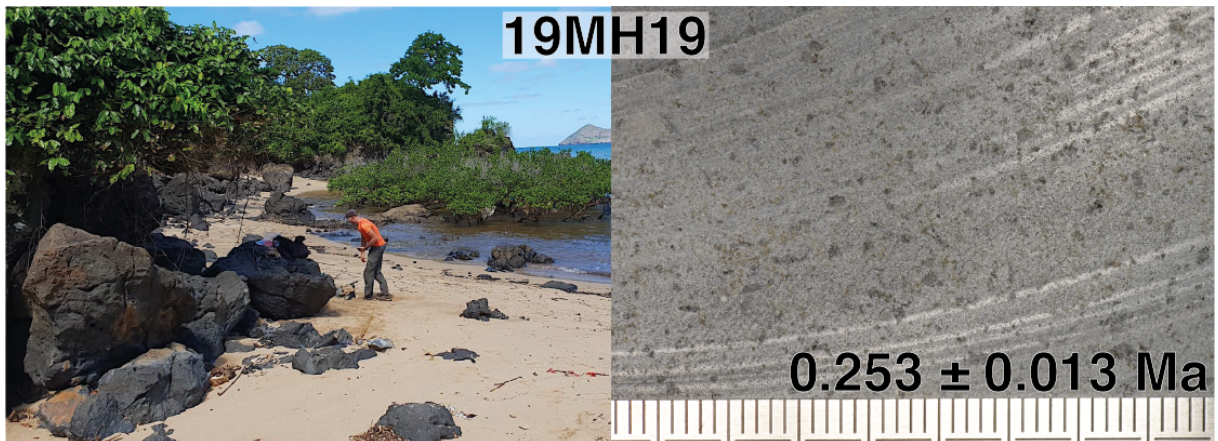
**Figure S1:** Outcrop and/or hand specimen pictures of the rocks sampled in Mohéli, and corresponding macroscopic pictures of saw-cut slabs with their K-Ar age on groundmass.



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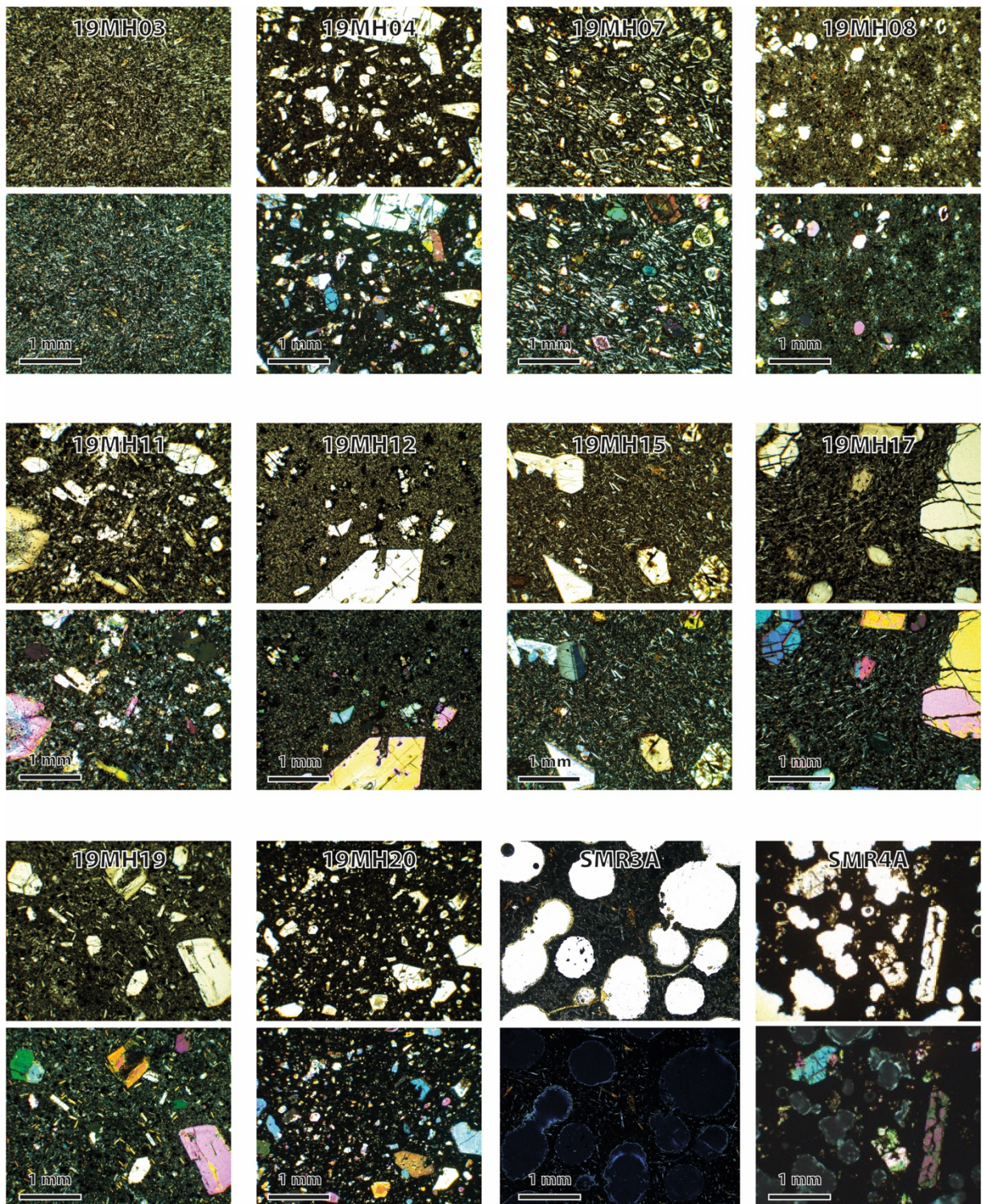
682 **Figure S1 (continued)**





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Figure S1 (continued)



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687 **Figure S2:** Optical microphotographs of submarine and subaerial samples used for K-Ar  
 688 dating. Top: plane-polarized light; bottom: cross-polarized light.

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