

1 **Regional phytoliths from the Coastal Cordillera of the Atacama Desert, Chile,**
2 **and their potential for paleoecological reconstructions**

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21

22 **Abstract**

23 Siliceous phytoliths are frequently used in archaeology and Quaternary paleoecology. In order to
24 validate the potential of phytoliths to reconstruct the vegetation history in the Atacama Desert, Chile,
25 we analyzed the occurrence and morphotypes of phytoliths in different organs of 97 plant species from
26 36 families living in the Coastal Cordillera of the Atacama Desert. Phytolith extraction was conducted
27 by a new protocol using microwave digestion, which is rapid, provides clean and well preserved

28 phytoliths and can be employed on plant material as well as sediments. Phytoliths were found only in
29 Poaceae and Bromeliaceae. Although this limited occurrence restricts their value for the
30 reconstruction of past vegetation diversity, their identification to sub-family and species levels
31 provides detailed information on the occurrence of grasses and monocot flowering plants. These taxa
32 are sensitive to environmental factors, such as climatic conditions, i.e. temperature and water
33 availability. Comparisons of the phytolith morphotypes isolated here with those described in the
34 literature suggest that the characteristics of the phytoliths in the Atacama Desert may not only depend
35 on species and plant organs, but may also be dependent on the specific regional environmental
36 conditions.

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38 Keywords: Phytoliths; Poaceae; Bromeliaceae; Atacama Desert; Coastal Cordillera; Microwave

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41 **1. Introduction**

42 Microscopic siliceous plant bodies (phytoliths) originate from monosilicic acid (H_4O_4Si), which is
43 absorbed by plant roots and becomes deposited as solid silica (SiO_2) in and around cells of various plant
44 tissues, mainly leaves, stems and roots (Kumar et al., 2017). Following the decay of plants organic
45 matter, phytoliths may be deposited in the soil and become part of the sedimentary record, thus
46 reflecting past plant communities over geological timescales (Piperno, 2006). Therefore, phytolith
47 analysis as a micropaleontological technique has been widely used as a tool in archaeology and
48 Quaternary paleocology. Reconstructions based on phytoliths range from the domestication of crop
49 plants (e.g., Piperno, 2009; Ball et al., 2015), faunal paleodiets (e.g., Gobetz and Bozardt, 2001;
50 Norström et al., 2019) and grass evolution (e.g., Strömberg, 2011; Strömberg and McInerney, 2011),
51 to vegetation history (e.g., Strömberg et al., 2018; Barboni et al., 2007; Piperno et al., 2021) and past
52 climatic conditions (e.g., Bremond et al., 2005; Lu et al., 2007).

53

54 In the Atacama Desert of northern Chile, the use of phytoliths as a proxy for vegetation history and
55 associated shifts in climatic conditions is promising because of their good preservation-potential under
56 arid conditions, even on longer timescales (Morgan-Edel et al., 2015). Nevertheless, only single
57 phytolith-bearing records are reported from the literature (e.g., Pfeiffer et al., 2018; McRostie et al.,
58 2022), and the knowledge of the regional phytolith taxonomy is restricted to only few plant families
59 (McRostie, 2013). Because of the long-lasting aridity of the Atacama Desert, which may date back as
60 far as the Oligocene (Dunai et al., 2005), paleo-archives from ancient lakes, wetlands or caves are
61 extremely scarce. Paleoclimate information from the Atacama Desert, therefore, still is very sparse
62 and discontinuous. Detailed paleoclimate information is mainly available for the last glacial-interglacial
63 cycle, derived from multi-disciplinary studies of dunes (e.g., Finstad et al., 2018), fluvial sediments (e.g.,
64 Nester et al., 2007), spring deposits (e.g., Grosjean et al., 2003, Sáez et al. 2016), lacustrine records
65 (Grosjean et al., 2001; Valero-Garcés et al., 1999), colluvial sediments (e.g., Medialdea et al., 2020)
66 and, in particular, macrofossils and pollen from rodent middens (e.g., Betancourt et al., 2000;
67 Maldonado et al 2005; Holmgren et al., 2001; Latorre et al., 2002; 2003; 2005; 2006; Diaz et al., 2012;
68 De Porras et al., 2017). It is important to note that most of the paleoecological studies in the Atacama
69 Desert have been done in the Pre-Cordillera or Western Cordillera, but very few in the hyperarid core
70 or even the Coastal Cordillera. The older plaeoclimatic history is known only very sporadically and
71 discontinuously, relying on few geomorphological studies and cosmogenic nuclide dating (e.g., Binnie
72 et al., 2020; Ritter et al., 2018a; 2018b; 2022).

73

74 In the Coastal Cordillera of the Atacama Desert, more continuous records may exist in clay pans, which
75 irregularly occur in the deepest parts of endorheic basins. According to geophysical site surveys, the
76 sediment thicknesses in the clay pans PAG, Huara and Paranal (Fig. 1) comprise about 80 - 100 m, $64 \pm$
77 10 m, and 160 ± 10 m, respectively (Ritter et al., 2019; Diederich et al., 2020; Blanco-Arrué et al., 2022,
78 Wennrich et al. *subm*). First short sediment cores of 1.9 m, 4.1 m and 6.2 m lengths from the Paranal,
79 Huara and PAG clay pans have basal ages of about 20 ja, 68 ka and 215 ka, respectively. They show
80 variations in sedimentological and geochemical compositions that reflect changes in the amount of

81 precipitation, and at least the core from the PAG clay pan contains phytoliths (Ritter et al., 2019;
82 Diederich et al., 2020). Longer deep drilling cores have recently been recovered from the PAG and
83 Paranal clay pans, extending to depths of 52 m (Blanco-Arrué et al., 2022) and 174 m (Wennrich,
84 unpubl.), respectively.

85

86 Here, we investigate the potential of phytoliths to provide more detailed information on the
87 vegetation and associated climate history of the Atacama Desert. For this purpose, we have modified
88 and improved the phytolith extraction and conducted the first systematic analyzes of the phytolith
89 morphotypes that occur in 97 species from 36 families living in the desert today. The results shall
90 contribute to establish a phytolith reference collection for the Atacama Desert. Furthermore, they shall
91 be utilized to reconstruct its Neogene vegetation history based on the phytolith assemblages in long
92 sediment records from clay pans in the hyperarid core of the Atacama Desert.

93

94

95 **2. Study area**

96

97 The Atacama Desert in northern Chile is framed by the Andes to the east and the Pacific Ocean to the
98 west (Fig. 1). The Atacama Desert extends from about 15° S to 30° S, with its hyperarid climate
99 occurring in the whole area between 15° and 30°S, from the sea level to 3.500 m.a.s.l. encompassing
100 the coast, the Coastal Cordillera and part of the Central Depression (Houston and Hartley, 2003;
101 Houston, 2006). The desert is morphologically structured into a coastal zone, followed by the Coastal
102 Cordillera (1500-2000 m a.s.l.), the Central Depression (1000 m a.s.l.), the Pre-Cordillera (3000-4000
103 m a.s.l.), the Preandean Depression (mainly below 3000 m a.s.l.) and the Western Cordillera (5000-
104 6000 m a.s.l.) (Houston, 2006). This study focuses on the coastal Atacama Desert, from the Tarapacá
105 region (19°S) to the Coquimbo region (29° S).

106

107 In the Tarapacá Region, the coastal area receives seasonal rain in winter, where the mean annual
108 precipitation is less than 1 mm/yr (Houston and Hartley, 2003; Houston, 2006). The mean annual
109 temperature in the region is 18°C and the altitudes between 650 m and 1060 m are strongly influenced
110 by the occurrence of fog. Due to the fog, the vegetation, highly endemic, is xerophitic and mostly
111 presents cactus, mainly individuals of the genus *Eulychnia*, some shrub flora like *Ephedra breana* and
112 *Frankenia chilensis*, and other genera like *Cristaria*, *Tetragonia*, *Nolana* (Rundel et al., 1991; Pinto and
113 Luebert, 2009), and the ecosystem called “lomas”, which mainly is characterized by the occurrence of
114 *Tillandsia* sp. (Cereceda et al., 1999; 2008).

115

116 In the coastal area of Antofagasta Region, which is also part of the hyper-arid core (Houston and
117 Hartley, 2003; Houston, 2006) a persistent fog zone occurs around 900 m.a.s.l. The vegetation is
118 restricted to the coast and quebradas, and that reaches up to distances of 5 to 20 km inland. As altitude
119 increases, the flora does not extend beyond the fog zone (Rundel et al., 1991). The vegetation in the
120 Taltal-Paposo site shows in particular a high biodiversity and endemism due to the fog oases. The most
121 representative flora is *Eulychnia taltalensis*, *Copiapoa cinerea*, *Solanum chilense*, *Nolana* spp., *Puya*
122 *bolivianensis*, *Tillandsia landbeckii*, *Alstromeria* spp., most of them endangered (Pedrós-Alió 2021).

123

124 The Atacama Region is well known for the peculiar event of the flowering desert, that occurs randomly
125 over time due to sporadic rainfall in winter, mainly in the south part of the Atacama Region. The main
126 vegetational formations correspond to *Cistanthe*, *Cristaria*, *Nolana* spp., *Chaetanthera* spp.,
127 *Chuirea acicularis*, *Franquenilla chilensis*, *Oxalis gigantea*, of which 40-60% are endemic to Chile
128 (Pedrós-Alió 2021). In the locality of Huasco, coastal area of the region, the dune formations support
129 halophytic species (Rundel et al., 1991).

130

131 The Coquimbo region represents the southern limit of the Atacama Desert. Its coastal zone and Coastal
132 Cordillera are characterised by a mean annual temperature of 14.7°C and rain events restricted to the
133 winter season, which amount to a total of less than 130 mm but show a high variability, and additional

134 humidity input by fog (Rundel et al., 1991). Moreover, the coastal fog is the main source of water that
135 maintains the isolated relict forest “Fray Jorge” as the south limit of the vegetational formations along
136 the Atacama Desert (Garreaud et al., 2008). Consequently, the climate is very humid (85%) and cloudy
137 (mostly during the morning). The vegetation basically is semiarid coastal scrub (Rundel et al., 1991).
138 Due to the higher precipitation, the vegetation can persist longer than further north. To the north of
139 La Serena (Fig. 1), dune formation supports halophytic species, notably *Salicornia fruticosa*,
140 *Carpobrotus chilensis* and *Distichlis spicata* (Kohler, 1970). To the north of the Elqui River Valley, near
141 La Serena (Fig. 1), coastal semiarid scrub vegetation is replaced by desert succulent communities with
142 floristic affinities to the regions northwards (Rundel et al., 1991).

143

144

145 **3. Material and methods**

146

147 Phytolith characterization was conducted on different plant parts, mostly leaves, stems, and roots, but
148 also Cactaceae spines, from 97 species that occur in the Atacama Desert today. The majority of the
149 samples were taken in November 2021 during a field campaign from La Serena (30°), Coquimbo
150 Region, to Carrizal Bajo (28°), Atacama Region, in a transect passing through the localities of La Higuera,
151 Freirina and Huasco, Chile (Fig. 1). The sample set was complemented by samples from the Herbarium
152 of the Nees Institute at the University Bonn, Germany (BONN), and from the Heidelberg Botanic
153 Garden of the University Heidelberg, Germany (HEID).

154

155 For phytolith extraction, we adapted and modified the method suggested by Parr et al. (2001) to
156 extract phytoliths from herbarium specimens (Table 1). Phytoliths were extracted from approximately
157 0.5 g of dry plant samples using a microwave (GO Plus, Anton Paar) digestion. For pre-treatment,
158 samples were cut into pieces around 0.5 cm length or less and 5 to 7 ml of Alconox was added for 24
159 hours to remove dirt and dust. The cleaned sample was then isolated by sieving through a 63 µm mesh
160 and washed five times with distilled water to remove the Alconox. An exception was only made for the

161 specimens of the genus *Tillandsia*, since they did not deliver phytoliths using this protocol, although
162 this genus is known to carry phytoliths (Benvenuto et al., 2015; Piperno, unpubl). Therefore, we
163 processed all material from the four *Tillandsia* species available (i.e. 3 to 4 g of dry plant material each)
164 and incinerated it at 500°C for 3 hours.

165

166 For the digestion, samples in all cases were placed into the microwave vessels with 4 ml of distilled
167 water, 7 ml of HNO₃ (65%) and 2 ml of HCl (37%). With the program 'Organic B' of the microwave
168 digestion system the samples were heated steadily to 180° C for 10 min to remove organic matter.
169 Following cooling (about 10 min), the remaining liquid phases with the suspended particles were
170 drained onto paper filters with 2.5 µm pore size and washed several times with distilled water to
171 remove all the chemical remains (acids).

172

173 The paper filters were placed in an oven at 40°C for ~20 minutes to evaporate the water stock.
174 Subsequently, the material on the filters was carefully brushed with a soft make-up brush through a
175 funnel into a flask with 3 ml of ethanol (95%). After evaporating the ethanol for 12 hours in the oven,
176 0.5 ml of ethanol (95%) were added again to harmonize the ethanol amounts. For microscopic
177 phytolith analysis, one drop of the suspended sample was put on a microscope slide with a transfer
178 pipette, and the particles became embedded with Norland optical adhesive 61 under UV light after
179 evaporation of the ethanol.

180

181

182 Phytoliths were analyzed using a microscope Zeiss AxioScope.A1 with 40x magnification. Pictures were
183 taken with a Cannon EOS 700D digital camera and processed using the software ImageJ. All pictures
184 were calibrated with the corresponding magnification and pixels were put into equivalent
185 micrometers. Phytoliths were described and identified following the classification criteria of Twiss et
186 al (1969), Piperno and Pearsall (1998), Piperno (2006), Lu and Liu (2003a, b) and the International Code
187 for Phytolith Nomenclature (Neumann et al., 2019).

188

189 4. Results

190

191 Of the 97 investigated species from 36 families, only plant organs of the seven Poaceae species and
192 the three Bromeliaceae species contained phytoliths (Tables 2 - 4). Their morphotypes show distinct
193 shapes that facilitate identification.

194

195 4.1 Phytolith morphotypes from Poaceae

196

197 Three of the Poaceae grasses investigated belong to the sub-family Pooideae (Table 3). Of those, the
198 analysis of leaves of *Avena barbata* revealed two distinctive phytolith morphotypes: a crenate,
199 formally called wavy trapezoid (Fig. 2a) and a circular rondel (Fig. 2b). In stems of *Jarava plumosula*
200 acute rondels (Fig. 2c-e) were found. Phytoliths in caryopses of *Jarava plumosula* are more diverse.
201 They range from a very narrow rondel with two horns at the top (Fig. 2f) to different polylobate
202 morphotypes with two holes in the central part (Fig. 2g) and four or three waves at opposing sites,
203 respectively (Fig. 2h). In leaves of *Stipa annua*, we found two-horned tower (Fig. 2i) and polylobate
204 (Fig. 2j) morphotypes.

205

206 Of the Arundinoideae sub-family, the species *Cortaderia atacamensis* and *Cortaderia speciosa* were
207 investigated (Table 3). Five different types of phytolith morphotypes were found in leaves of
208 *Cortaderia atacamensis*. The most common ones are bilobates (Fig. 3a). Furthermore, nodular
209 bilobates, which exhibits a half lobe on the shank, resulting in three waves restricted to one of its sides
210 (Fig. 3b), occurred, as well as multiple-pointed rondels (Fig 3c), saddles with multiple lobes (Fig. 3d)
211 and non-pointed rondels (Fig. 3e). Leaves of *Cortaderia speciosa* revealed bilobates with a short shank
212 (Fig. 3f), trilobates that show a wavy margin on both sides (Fig. 3g), nodular bilobates (Fig. 3h), and

213 bilobates/saddle (Fig. 3i). In the stem of *Cortaderia speciosa* only non-pointed rondels (Fig. 3j) were
214 found.

215

216 Of the Chloridoideae sub-family, leaves of the species *Distichlys spicata* and *Munroa andina* were
217 investigated (Table 3). In *Distichlys spicata*, they revealed a diversity of rondels (Fig. 4a) as well as
218 towers (Fig.4b). From the leaves of *Munroa andina*, in contrast, different types of cross-shaped
219 phytolith bodies were isolated, showing 4-lobed (Fig. 4c-d) or 3-lobed crosses (Fig. 4e).

220

221 4.2 Phytolith morphotypes from Bromeliaceae

222

223 Of the family Bromeliaceae, three species were investigated (Table 4). All phytoliths found are
224 ellipsoidal to spheroid ornate morphotypes (Fig. 5a-c). They show little differences in shape, but they
225 differ in size. Phytoliths from roots of *Puya chilensis* are bigger (in average 11 μm diameter) and may
226 form clusters (Fig. 5a), whereas those from leaves of the same species are smaller (in average 8 μm
227 diameter) and always occur isolated (Fig. 5b), but all present a spheroidal shape. Phytoliths from *Puya*
228 *berteroniana* are smallest with a mean diameter of 5 μm and show a tendency to a more ellipsoidal
229 shape (Fig. 5c). Phytoliths from *Puya coerulea* (Fig. 5d) show a spheroidal shape and a mean diameter
230 between 5 and 6 μm .

231

232 Of the genus *Tillandsia* four species were investigated. Of those, *Tillandsia landbeckii* and *Tillandsia*
233 *usneoides* did not exhibit phytoliths, despite the larger sample volume investigated, whereas *Tillandsia*
234 *latifolia* and *Tillandsia virescens* host phytoliths, albeit very small ones. The morphotypes found in
235 *Tillandsia latifolia* are ornate spheroids (Fig.6a) and smooth spheroids (Fig.6b), with a diameter not
236 larger than 4 μm . Those found on *Tillandsia virescens* are much rarer, mostly consisting of smooth
237 spheroids.

238

239 **5. Discussion**

240 *5.1 Quality of revised phytolith extracting method*

241

242 The phytoliths isolated from the seven Poaceae, and five Bromeliaceae (Figs 2, 5 and 6) show no signs
243 of contamination, chemical dissolution, or mechanical disturbance. Hence, the protocol applied here
244 to extract phytoliths using microwave digestion, which was adapted and modified from [Parr et al.](#)
245 [\(2001\)](#), who employed the technique on herbarium specimens, works very well also on plant material
246 from the field.

247

248 The main advantages of this technique are that it provides very clean and well-preserved phytoliths
249 and at the same time is rather rapid. Compared with the original dry ashing technique proposed by
250 [Twiss et al. \(1969\)](#), slightly modified by [Hart \(1998\)](#), or the wet ashing technique proposed by [Rovner](#)
251 [\(1972\)](#), with the addition of Schulze solution (a combination of nitric acid and potassium chlorate or
252 sodium chlorate) ([Pearsall, 1989](#)), we have reduced the preparatory steps, in particular rinsing,
253 centrifuging and decanting, and employed microwave digestion instead of dry and wet ashing
254 techniques (Table 1).

255

256 As learned from the *Tillandsia* species, 0,5 g of sample to process may not be not enough to isolate a
257 sufficient number of phytoliths. On the other hand, the results from *Tillandsia* evidence that also
258 very small phytoliths can be isolated in good quality.

259

260 *5.2 Significance of phytoliths for plant detection*

261

262 Although we found phytoliths only in Poaceae, and Bromeliaceae, the absence of phytoliths in the
263 other plants studied was also detected in previous work on the same families and genera in other
264 regions of the world ([Piperno, 2006](#); [Piperno and McMichael, 2020](#)), confirming a constancy of
265 phytolith presence/absence in taxa. For the sub-family Pooideae of the Poaceae, the crenates and

266 rondels isolated from leaves of *Avena barbata* (Fig. 2a-b) have previously been described to be
267 distinctive morphotypes for this sub-family (Twiss et al., 1969; Brown, 1984; Mulholland, 1989; Piperno
268 and Pearsall, 1998; Piperno, 2006). In our study, the sub-family Pooideae lacked bilobates although
269 they are found in Pooideae from the Atacama and other regions (McRostie, 2013). Our results suggest
270 that also the species *Jarava plumosula* contains distinctive phytoliths, which have not been described
271 so far. This concerns the rondels with peculiar acute shapes from the leaves (Fig.2c-e) as well as the
272 particularly narrow rondels (Fig.2f), the polylobates exhibiting two holes in the central part (Fig.2g),
273 and the polylobates without holes in the central part (Fig.2h) from the caryopsis of *Jarava plumosula*.
274 Moreover, from our results the Pooideae seem to be devoid not only of bilobates and saddles but also
275 of bilobate/saddle and cross-shaped morphotypes, even if they are present in Pooideae sub-family
276 from other regions. The two-horned towers (Fig. 2i) (Lu and Liu, 2003b) isolated from *Stipa annua*, on
277 the other hand, was found in very similar shape in the species *Distichlis spicata* of the subfamily
278 Chloridoideae, but are lacking in *Stipa chrysophylla* (McRostie, 2013). Hence, it cannot be excluded
279 that due to multiplicity and redundancy individual morphotypes are present also in other grass species
280 (Piperno, 2006).

281
282 The sub-family Arundinoideae is known for the occurrence of bilobate and saddle morphotypes, which,
283 however, are not distinctive (Brown, 1984; Mulholland, 1989; Barboni and Bremond, 2009; McRostie,
284 2013). The bilobate/saddle morphotype isolated from leaves of the species *Cortaderia speciosa* (Fig.
285 3i) has previously been described as common in Arundinoideae (Piperno and Pearsall, 1998) and may
286 be distinctive, taking its specific shape. The same may hold true for the trilobates (Fig. 3g) from leaves
287 of *Cortaderia speciosa* as well as the multiple-pointed rondels (Fig. 3c) and the saddles with multiple
288 lobes (Fig. 3d) from leaves of *Cortaderia atacamensis*. Another characteristic of Arundinoideae may be
289 the absence of crenates, circular or acute rondels, polylobate or cross-shaped morphotypes. The rather
290 short shanks in the bilobates of both *Cortaderia atacamensis* and *Cortaderia speciosa* may be specific
291 to the Atacama Desert, since xerophytic grasses in China and the southeastern USA, according to Lu
292 and Liu (2003a), tend to produce lobates with very long shanks.

293

294 In the sub-family Chloridoideae, phytoliths isolated from the species *Distichlis spicata* are restricted to
295 flat towers (Fig. 4a) and two-horned towers (Fig. 4b), as reported before by [Lu and Liu \(2003b\)](#). On the
296 other hand, rondels and saddles as described for these species by [McRostie \(2013\)](#), are lacking. The
297 cross-shaped morphotypes with 4-lobes (Fig. 4c-d) that were isolated from leaves of *Munroa andina*
298 were reported also from other sub-families of Poaceae, whereas the ones with 3-lobes (Fig. 4e) may
299 be distinctive for this sub-family and Panicoideae ([Barboni and Bremond, 2009](#)). The Chloridoideae
300 seem to be devoid of crenate, circular or acute rondels, polylobate, bilobates, nodular bilobates and
301 bilobate/saddle morphotypes, although studies made on Chloridoideae in other regions show the
302 presence of bilobates ([Bourel and Novello, 2020](#)).

303

304 The phytoliths isolated from three species of the sub-family Puyoideae show a low diversity with only
305 spheroid ornate phytolith morphotypes (Fig. 5), which seems to be characteristic for Bromeliaceae in
306 general, since the phytoliths investigated by [Benvenuto et al. \(2015\)](#) in five other species of
307 Bromeliaceae from South America, i.e., Argentina, have a very similar shape and differ only in their
308 somewhat smaller size than the ones investigated here (diameter range of 2.6 – 4.9 μm compared to
309 5 - 11 μm).

310

311 Our results from *Tillandsia latifolia* and *Tillandsia virescens* confirm recent investigations on *Tillandsia*
312 sp., which suggest that phytoliths occur, albeit very rarely ([Piperno, unpubl.](#)). Comparing our findings
313 with those obtained by [Benvenuto et al. \(2015\)](#) on *Tillandsia aëranthos* from Argentina, the
314 morphotype described as globular echinate is similar to our spheroid ornate, but we also report
315 spheroid smooth phytoliths showing a tendency to form small clusters.

316

317 *5.3 Phytoliths as a tool for paleoecological studies in the Atacama Desert*

318

319 Since phytoliths could only be extracted from plant organs of two of the 36 families investigated,
320 namely Poaceae and Bromeliaceae, investigation of phytoliths in sedimentary records of the Atacama
321 Desert cannot provide as comprehensive information on the vegetation history as palynological and
322 phytolith investigations in more humid, diverse regions. This includes the investigated species of
323 Cactaceae, which seem to be devoid of siliceous phytoliths (Table 2). Other cacti species, however, are
324 known to produce phytoliths made both of silica and calcium oxalate (oxalates) (Jones and Bryant,
325 1992; McRostie, 2013). Moreover, it cannot be excluded that the sample set investigated here misses
326 plant species producing siliceous phytoliths, or that phytoliths were overseen due to their small
327 number or size. For instance, in contrast to previous studies (McRostie, 2013), we did not find
328 phytoliths in the species *Schinus molle* of the family Anacardiaceae (Table 2), which in the Atacama
329 Desert reflects wetlands and riparian areas, with groundwater and water availability (Gayo et al.,
330 2012). Same holds true also for other species indicative for precipitation and elevation, like *Baccharis*
331 spp., *Ephedra* spp., *Adesmia* spp., *Dinemandra ericoides*, *Huidobria* spp. and *Cistanthe* spp. (De Porras
332 et al., 2017), which according to our results are devoid of phytoliths.

333

334 On the other hand, phytoliths occurring in sedimentary records can provide important and
335 independent palaeoenvironmental interpretations (Piperno, 2006). This does not only concern the
336 presence of individual plant taxa, but also the dominance of grasses or the ratio between C3/C4 grasses
337 and their implications regarding temperature and moisture regimes (Mulholland, 1989). For instance,
338 most of the members of the Pooideae sub-family belong to the C3 photosynthetic pathway, whereas
339 members of the Arundinoideae and Chloridoideae sub-families belong to the C4 photosynthetic
340 pathway (Barboni and Bremond, 2009).

341

342 We found phytoliths in all seven species investigated of Poaceae, with distinct characteristics in sub-
343 family (Pooideae, Arundinoideae and Chloridoideae) and in some cases even species (*Avena barbata*,
344 *Jarava plumosula*, *Cortaderia* spp. and *Munroa andina*) levels. In the genus *Puya* of the family
345 Bromeliaceae, all three species investigated contain phytoliths. These phytoliths show similar spheroid

346 ornate morphotypes, as reported before by [Benvenuto et al. \(2015\)](#), but differ in sizes. Even if the
347 determination of fossil Bromeliaceae phytoliths is limited to the sub-family level, this would provide
348 important information concerning past climatic settings, since *Puya* is very restricted to the coast and
349 quebradas today with specific climatic conditions ([Zizka et al. 2009](#)).

350

351 **6. Conclusions**

352

353 From this collection and consequent analysis of the presence and characteristics of siliceous phytoliths
354 in 97 modern plant species occurring in the Atacama Desert today the following conclusions can be
355 drawn:

356

357 1. We have conducted a comprehensive analysis of the presence and absence of siliceous phytoliths
358 on modern plants from the Atacama Desert, which sheds new light on the potential of phytolith
359 analyses on sedimentary records for palaeoecological reconstructions.

360

361 2. We applied a new protocol for phytolith extraction from plants using microwave digestion, which
362 has advantages compared to published protocols with respect to time consumption speed as well
363 as phytolith cleanliness for microscopic analysis.

364

365 3. Phytoliths were found only in Poaceae and Bromeliaceae families (Puyoideae sub-family), but not
366 in 34 other families investigated. Hence, they can reflect only a small part of past vegetation, if
367 employed in sedimentary records to reconstruct past ecological settings, but they are probably
368 better preserved than other plant remains such as pollen.

369

370 4. Phytoliths in Poaceae (in sub-families Pooideae, Arundinoideae and Chloridoideae) and
371 Bromeliaceae (on the genus *Puya*) are diagnostic at varying taxonomic levels, and thus can provide

372 important information from sedimentary records concerning past changes of fog, rain regimes
373 and temperatures.

374

375 5. Differences in the phytolith size from the genus *Puya*, (Bromeliaceae family), compared to their
376 occurrence in other regions, suggests that the characteristics of some phytoliths do not only
377 depend on species and plant organs, but also on the specific regional environmental conditions.

378

379

380 **Author contributions**

381

382 **Bárbara D. Vargas-Machuca:** Sampling, laboratory work, microscopy, interpretation, writing. **Dolores**
383 **R. Piperno:** Validation of data and interpretation, contribution to writing. **Tim Böhnert:** Contributions
384 to sampling and writing. **Alexandra Stoll:** Contributions to sampling and writing. **Antonio Maldonado:**
385 Contributions to sampling and writing. **Gina Arancio:** Contributions to sampling and writing. **Volker**
386 **Wennrich:** Project administration and supervision, contributions to writing. **Martin Melles:** Project
387 administration and supervision, contributions to writing.

388

389 **Data availability**

390

391 The data presented will be made available in the database of the CRC 1211 after publication.

392

393 **Declaration of competing interest**

394

395 The authors declare that they have no known competing financial interests or personal relationships
396 that could have appeared to influence the work reported in this paper.

397

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399

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664
665 **Fig 1:** Map of the Atacama Desert, Chile, showing the locations of the clay pans Huara, PAG and
666 Paranal (yellow hemicircles) along with other geographical terms mentioned in the text and the main
667 morphological regions: CC - Coastal Cordillera; CD - Central Depression; PC - Pre-Cordillera; PD -
668 Preandean Depression; WC - Western Cordillera.

669
670
671 **Fig 2:** Microscope images showing examples of phytolith morphotypes isolated from the Poaceae sub-
672 family Pooideae. a) crenate and b) rondel from leaves of the species *Avena barbata*; c) to e) rondels
673 from leaves of the species *Jarava plumosula*; f) rondel, g) polylobate with two holes in the central part,
674 and h) polylobate from caryopses of *Jarava plumosula*; i) two-horned tower and j) polylobate from
675 leaves of the species *Stipa annua* (400 x magnification). Scale bars are 10 µm.

676
677
678 **Fig 3:** Microscope images showing examples of the phytolith morphotypes isolated from the Poaceae
679 sub-family Arundinoideae. a) bilobate, b) nodular bilobate, c) multiple-pointed rondel, d) saddle with
680 multiple lobes, and e) rondel from leaves of the species *Cortaderia atacamensis*; f) bilobate, g)
681 trilobate, h) nodular bilobate, and i) bilobate/saddle from leaves of the species *Cortaderia speciosa*; j)
682 rondel from stem of the species *Cortaderia speciosa* (400 x magnification). Scale bars are 10 µm.

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684
685 **Fig 4:** Microscope images showing examples of the phytolith morphotypes isolated from the Poaceae
686 sub-family Chloridoideae. a) flat towers and b) two-horned towers from leaves of the species *Distichlys*
687 *spicata*; c) and d) 4-lobed cross-shaped bodies; e) 3-lobed cross from leaves of the species *Munroa*
688 *andina* (400 x magnification). Scale bars are 10 µm.

689
690
691 **Fig 5:** Microscope images showing examples of the phytolith morphotypes isolated from Bromeliaceae.
692 a) ellipsoidal ornate phytolith from roots of *Puya chilensis*; b) spheroid ornate phytoliths from leaves
693 of *Puya chilensis*; c) spheroid/ellipsoidal ornate phytolith from leaves of *Puya berteroniana*; d) spheroid
694 ornate phytolith from leaves of *Puya coerulea* (400 x magnification). Scale bars are 10 µm.

695
696 **Fig 6:** Scanning Electron Microscope images of the phytolith morphotypes isolated from *Tillandsia*
697 *latifolia*. a) spheroid ornate phytolith; b) spheroid smooth phytolith from leaves of *Tillandsia latifolia*
698 (11.48K x magnification). Scale bar is 1 µm.

699
700
701 **Table 1:** Steps used to extract the phytoliths from the plant samples and to prepare microscopic slides.

702
703
704 **Table 2:** List of taxa analyzed for phytolith presence.

705
706 *A: plant material collected from La Serena in 2021; BONN: Bonn Herbarium; Bonn BG: Bonn Botanic
707 Garden; HEID: Heidelberg University Botanic Garden; L: leaves; S: stems; Fl: flowers; C: caryopsis; Fr:
708 fruits; R: roots; Mix: samples that were impossible to separate into different parts due to their size;

709 life form according to Raunkiær's life-form system. All the data up dated from the world-wide
710 database: powo.science.kew.org

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712

713 **Table 3:** List of Poaceae species investigated for their phytolith characteristics

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715

716 **Table 4:** List of Bromeliacea species investigated for their phytolith characteristics

717