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1 **The growth process of saponite: A study based on particle size distributions and**
2 **morphological evolution**

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28 **Abstract**

29 Smectite growth is of great importance for the geochemistry of clay minerals
30 on the Earth's surface and their applications in industries. However, the growth
31 process and mechanism controlling the physicochemical properties of smectite are
32 still poorly understood. Through an effective integration of particle size distributions
33 (PSDs) and morphology of particles, this study has enhanced the understanding of
34 smectite growth by investigating the growth processes of a synthetic tri-octahedral
35 smectite (saponite). The starting materials were equimolar Mg-saponite and Ni-
36 saponite that had been hydrothermally synthesised at 220°C. Two Mg–Ni-saponite
37 samples were obtained through further hydrothermal treatment of the starting
38 materials at 400 and 500°C. A systematic measurement of the size in the *ab*-plane of
39 numerous saponite particles was performed to obtain their PSDs. The parameters α
40 and β^2 , derived from PSDs and the morphology of saponite, indicate that saponites
41 grow mainly via surface-controlled growth and likely via supply-controlled growth in
42 open systems. Particle attachment via the edge surfaces of saponite is an
43 accompanying growth mechanism, and talc-like layers favour the “three-dimensional
44 growth”. In addition, the heterogeneous tetrahedral Al distribution of saponite could
45 lead to the formation of elongated laths.

46 **Keywords:** Crystal growth; particle size distribution (PSD); saponite; particle
47 attachment; smectite morphology

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52 **1. Introduction**

53 The smectite group of clay minerals, composed of a central octahedral sheet
54 and two tetrahedral sheets, has attracted particular attention due to their geochemical
55 significance (Eberl, 1984; Tardy et al., 1987; Sposito et al., 1999; Merriman et al.,
56 2005; Christidis and Huff, 2009; Voigt et al., 2020) and wide applications (Odom,
57 1984; Murray, 1991; Bergaya and Lagaly, 2013). Its formation processes, including
58 phase transformation and crystal growth, not only affect its applications in industries
59 but also respond to the physicochemical environment where it formed. The alteration
60 of other minerals into smectite has been extensively studied (e.g., Badaut, et al., 1983;
61 Banfield et al., 1994; Cuadros et al., 2012; Tao et al., 2019). However, only a few
62 studies on smectite growth have been made available thus far, owing to the limitations
63 of its special properties (e.g., complex compositions, hydrated layers, and small
64 particle size) (Christidis 2001; Decarreau et al., 2014; Zhang et al., 2020; Besselink et
65 al., 2020).

66 The particle size distribution (PSD) of a mineral has a distinctive shape related
67 to its growth history. It is possible to describe the mineral growth processes based on
68 their measured PSDs (Wagner, 1961; Baronnet, 1982). Eberl et al. (1998) simulated
69 PSDs of different crystal growth patterns in closed and open systems. An open system
70 is defined as a system in which matter is supplied to the growing crystals by a source
71 other than the growing phase; whereas a closed system is defined as a system where a
72 single phase is involved, and the less stable crystals dissolve to supply materials for
73 the growth of other crystals. Eberl et al. (1998) defined surface-controlled growth in
74 open systems when crystals grow with an essentially unlimited supply of nutrients,
75 and the dissolution rate of the “source” is not the limiting factor. Supply-controlled
76 growth in open systems refers to the rate of crystal growth, which is controlled by the

77 rate of nutrients. Ostwald ripening in closed systems is a recrystallisation process in a
78 closed system that is characterized by the simultaneous dissolution and growth of a
79 mineral in a single medium (Wagner et al., 1961). In such a system, large particles
80 grow at the expense of dissolving small particles, resulting in the minimization of
81 surface free energy (Lifshitz and Slyozov, 1961).

82 Środoń et al. (2000) measured PSDs of natural illite and illite-smectite using
83 transmission electron microscopy (TEM) and concluded that illite grew through
84 surface-controlled growth in open systems. Christidis (2001) also applied the PSD
85 model of Eberl et al. (1998) to the investigation of the growth mechanisms of smectite
86 in a natural system. Their results indicated that smectite experiences supply-controlled
87 growth in an open system and random ripening in a closed system. Zhang et al. (2020)
88 studied the growth process of synthetic saponite by combining PSDs of particle
89 measurements obtained from scanning transmission electron microscopy (STEM)
90 images, argon adsorption, and crystal chemistry. Obtained results implied that
91 saponite growth proceeds via a lateral extension of layers by surface-controlled
92 growth in an open system.

93 Natural smectite has complex compositions, and in particular its early stages
94 of growth cannot be reprised. Thus, a synthetic laboratory approach has been
95 extensively used to investigate the crystal growth of smectite (e.g., Kloprogge et al.,
96 1999; Zhang et al., 2010; Petit et al., 2017). It should be noted that a smectite ‘crystal’
97 is more comparable to an assemblage of layers than a true crystal (Lagaly and Dékány,
98 2013), and smectite growth essentially consists of a two-dimensional lateral extension
99 of layers (Decarreau et al., 2014; Zhang et al., 2020). Thus, the PSDs obtained by
100 recording the crystal size in the *ab*-plane of particles are useful for studying smectite
101 growth.

102 In this study, the growth processes of endmember Mg-saponite and Ni-
103 saponite synthesised at 220°C, and two Mg–Ni-saponites synthesised at 400 and
104 500°C, respectively, were investigated through a combination of PSDs and
105 morphologies. The diameters of numerous synthetic saponite particles were measured
106 from STEM images to obtain a series of PSD models. These PSD models were further
107 used to discuss the growth history of saponite.

108 **2. Materials and Methods**

109 *2.1. Synthesis of samples*

110 The synthesis and characterisation of the saponites used in this study have
111 been described in detail by Zhang et al. (2021). Briefly, Mg-saponite and Ni-saponite
112 precursors were synthesised by the hydrothermal treatment (220°C, 1 d) of a co-
113 precipitated gel with a theoretical molar ratio of Si:Al:Mg = 3.7:0.3:3. The Mg-
114 saponite and Ni-saponite precursors were named pMg220 and pNi220, respectively.
115 The starting material for Mg–Ni-saponite synthesis was prepared by mixing identical
116 molar weights of pMg220 and pNi220, and named pMg220+pNi220. Two samples
117 were obtained by hydrothermal treatment of the starting material at 400 and 500°C,
118 and were named 220-400 and 220-500, respectively.

119 *2.2. Characterizations of synthetic saponites*

120 Powder X-ray diffraction (XRD) patterns were obtained using a Bruker D8
121 advance diffractometer (CuK α radiation, 40 kV and 40 mA) over the range of 2–65°
122 (2 θ) with a 0.025° (2 θ) step size and 0.6 s per step, while the patterns of the oriented
123 samples and ethylene glycol treated samples were collected over the range of 2–15°
124 (2 θ). The randomly oriented samples were prepared by pressing the saponite powder
125 inside a cavity up to the reference level of the sample holders. The oriented samples

126 were prepared by carefully pipetting the clay suspension onto a glass slide and
127 allowing it to dry at ambient temperature. Ethylene glycol treated samples were
128 prepared by treating the oriented samples in a glass desiccator with ethylene glycol at
129 25°C for 24 h.

130 High-angle annular dark-field scanning transmission electron microscopy
131 (HAADF-STEM) observations were performed to investigate the morphology of the
132 saponite particles in the *ab*-plane. A mixture of 1 mg of sample and 10 ml of
133 deionised water was lightly stirred for one week to obtain a diluted colloidal
134 suspension. The specimens were prepared by dispersing the colloidal suspension in 40
135 ml of ethanol and treating them ultrasonically for 30 min. A drop of the resultant
136 suspension was placed on a porous carbon film supported by a copper grid, then water
137 and ethanol were evaporated. STEM images were obtained using an FEI Talos F200S
138 high-resolution transmission electron microscope operated at 200 kV.

139 ***2.3. Measurement of PSDs***

140 The saponite growth studied in this study was based on the two-dimensional
141 extension of the particles in the *ab*-plane. Zhang et al. (2020, 2021) successfully
142 observed well-dispersed particles of synthetic saponite by STEM and measured the
143 size of a series of particles to obtain their PSDs by taking the mean value of length
144 plus width in the *ab*-plane. Because saponite particles are generally irregularly shaped,
145 we have developed a new method to measure the particle size of saponite, which is
146 more accurate than that in Zhang et al. (2020) (Fig. 1). After obtaining well-dispersed
147 saponite particles from STEM images, the area of the *ab*-plane of a particle was
148 calculated using Image-ProPlus 6.0 software package in a manual mode. Then, the
149 obtained area was treated as a circle with a calculable diameter (*d*) that represents the
150 mean size of the particle. The number of measured saponite particles to obtain PSDs

151 was close to 1500 (1508 for 220-400, 1434 for 220-500, 1325 for pMg220, and 1499
152 for pNi220). The experimental PSD curves were simulated using a log-normal
153 distribution function. Parameter α describes the mean of natural logarithms of
154 observations d (diameter), with $\alpha = \sum(\ln d)f(d)$; while β^2 describes the variance of
155 natural logarithms of observations d , with $\beta^2 = \sum[\ln(d) - \alpha]^2 f(d)$; where $f(d)$ is the
156 frequency of d (Eberl et al., 1998).

157 **3. Results and discussion**

158 **3.1. Crystal habit**

159 Powder XRD patterns of Mg-saponite (pMg220) and Ni-saponite (pNi220)
160 precursors displayed characteristic reflections of tri-octahedral smectite with the (001)
161 reflection at ~ 1.25 nm, the (06, 33) at 0.153 nm, and asymmetric (hk) reflections (Fig.
162 2), as described by Zhang et al. (2021). Compared with that of pMg220, the broader
163 reflections for pNi220 suggested that the coherent scattering domains in the layer
164 plane, as well as the number of stacked layers, are smaller for Ni-saponite than for
165 Mg-saponite. The XRD patterns of the oriented samples display the characteristic
166 reflections of saponites with a basal spacing $d(001)$ at ~ 1.2 nm, which shifts to 1.72
167 nm after exposure to ethylene glycol (Fig. 3) (Zhang et al., 2021). For 220-500,
168 reflections at 2.58 nm and 3.07 nm are observed before and after ethylene glycol
169 treatment (Fig. 3), respectively. The difference between these two values is ~ 0.5 nm,
170 comparable to the difference between 1.20 nm and 1.72 nm, presumably due to the
171 occurrence of interstratified non-swelling layers (Whitney, 1983). The non-swelling
172 layers are likely low-charge talc-like layers according to the low pre-set layer charge
173 of saponite (0.3) (Christidis and Mitsis, 2006; Petit et al., 2008; Fonteneau et al.,
174 2020).

175 The STEM images provided detailed morphological information on the *ab*-
176 plane of the particles of all saponites (Figs. 4-5). The layers of pMg220 were
177 generally irregular in shape (Fig. 4a), whereas those of pNi220 exhibited
178 geometrically hexagonal shapes (Fig. 4b). It was noted that some elongated laths and
179 120° angles between lateral faces occur in sample pMg220, which were also observed
180 in Kozákov natural saponite (Suquet et al., 1975). The elongated laths were also
181 observed in nontronite and hectorite, and were identified as elongations along the *a*-
182 axis (Mering and Oberling, 1967). Figure 5 reveals an increase in particle size from
183 the starting materials to obtained samples (220-400 and 220-500), providing evidence
184 of saponite particle growth. At higher temperatures, more euhedral elongated particles
185 were observed.

186 ***3.2. PSDs of Mg-saponite, Ni-saponite, and Mg-Ni saponite***

187 The shape of the PSDs and the reduced PSD profiles of Mg-saponite, Ni-
188 saponite, and Mg-Ni saponite were approximately log-normal (Figs. 6-8). The
189 diameters of the pMg220 particles were in the range of 10–450 nm, with most of them
190 fell within the range of 10–200 nm (Fig. 6a). In contrast, the diameter of the pNi220
191 particles varied from 5 to 250 nm, and most of them were in the range of 5–120 nm
192 (Fig. 6c). The mean particle diameter in pNi220 was 36.7 nm, which was far less than
193 that of pMg220 (87.2 nm) (Table 1).

194 The PSD of sample 220-400 had a log-normal shape with a range of 10–500
195 nm (Fig. 7a). Meanwhile, from the starting materials to 220-400, the mean diameter
196 of the particles increases from 58.2 to 79.2 nm (Table 1), which indicates the growth
197 of saponite layers. The PSD of sample 220-500 overall displayed a log-normal shape
198 with several secondary maxima in the range of 30–850 nm (Fig. 8a). From the starting
199 material to 220-500, the mean diameter increased from 58.2 to 156.8 nm (Table 1),

200 suggesting a strong growth of saponite particles. Zhang et al. (2021) provided a
201 comprehensive FTIR analysis on the evolutionary processes of the starting material
202 (pMg220+pNi220) into the samples (220-400 and 220-500). The results indicated that
203 partial dissolution (~0.59) of the starting material and recrystallisation of Mg–Ni-
204 saponite occurred in sample 220-400, whereas a total dissolution of the starting
205 material and recrystallisation of Mg–Ni-saponite occurred in sample 220-500. Thus,
206 saponite growth for both samples proceeded via dissolution of the starting material
207 and the recrystallisation of Mg–Ni-saponite.

208 **3.3. Ripening process**

209 Eberl et al. (1998) summarised the crystal growth (ripening) mechanisms
210 based on the dissolution–recrystallisation mechanism. The log-normal shape of PSDs
211 (Figs. 6–8) and the coordinates of (α , β^2) (Fig. 9) can be used to discuss the ripening
212 processes of the saponite (Eberl et al., 1998; Środoń et al., 2000). Generally, a log-
213 normal shape may imply that crystal growth follows either Ostwald ripening or
214 random ripening in a closed system, and surface-controlled growth or supply-
215 controlled growth in an open system, according to the α and β^2 values (Fig. 9).
216 Following the definitions of open or closed systems (see Introduction), the systems
217 discussed in this study are open systems, because the source and the growing crystals
218 are not in the same phase. The source of pMg220 and pNi220 were co-precipitated
219 gels, comprising Mg-saponite and Ni-saponite compositions, respectively; whereas
220 the source of Mg–Ni-saponites (220-400 and 220-500) was the starting material
221 (pMg220+pNi220). Furthermore, the log-normal shape of PSD and reduced PSD
222 profiles for pMg220, pNi220, and 220-400 are heavily skewed to the left (Figs. 6–7),
223 which indicates supply-controlled growth or surface-controlled growth in open
224 systems (Eberl et al., 1998).

225 The coordinates of (α , β^2) provided more information about the ripening
226 processes. For pMg220 and sample 220-400, the coordinates of (α , β^2) (Table 1) in
227 open systems placed them close to the line of surface-controlled growth (Fig. 9).
228 These results are also consistent with the surface-controlled growth of Mg–Ni-
229 saponite reported by Zhang et al. (2020). For pMg220, the source refers to the co-
230 precipitated gel and the growing crystals of Mg-saponite, whereas for 220-400, the
231 starting material (pMg220+pNi220) is the source and Mg–Ni-saponite form the
232 growing crystals. Surface-controlled growth proceeds through incorporating the
233 species from the dissolution/disarticulation of the source into the growth surface, and
234 the concentration of the species on the growth surface is the same as that in the source
235 (Konak et al., 1974; Eberl et al., 1998). Thus, for pMg220 and 220-400, the
236 dissolution/ disarticulation rate of the source is not the limiting factor (Eberl et al.,
237 1998). In such systems, the surface free energy then tends toward a minimum by the
238 dis-articulation/dissolution of the source and growth of the neofomed saponite. As a
239 result, the mean diameter increases (e.g., from 58.2 nm to 79.2 nm in sample 220-400)
240 (Table 1; Fig. 5), and finally, the level of supersaturation in the solution decreases
241 (Lifshitz and Slyozov, 1961; Wagner, 1961).

242 For pNi220, the point of (α , β^2) locates on the line of supply-controlled growth
243 in open systems, near the intersection with the line of surface-controlled growth in
244 open systems (Fig. 9). Decarreau (1985) demonstrated that Ni-smectites are generally
245 less soluble than Mg-smectites in a hydrothermal environment. pMg220 and pNi220
246 were synthesised from co-precipitated gels containing "embryos" (germs) of saponite
247 (Zhang et al., 2021). Consequently, Mg-containing gels dissolved more easily than
248 Ni-containing gels. The mean diameter of the pNi220 particles was half that of
249 pMg220 (Table 1), indicating a less efficient crystal growth process for Ni-saponite.

250 The low kinetics of pNi220 crystal growth are likely linked to the low solubility of
251 Ni-containing gel, which limits the transformation of the gel into Ni-saponite in the
252 aqueous system and induces a partially supply-controlled growth process.

253 ***3.4. Non-classical crystal growth of saponite***

254 The PSD and reduced PSD profile of sample 220-500 displayed a mean log-
255 normal shape with several small secondary maxima (Fig. 8). However, the coordinate
256 of (α, β^2) for sample 220-500 is placed neither on the surface-controlled line nor the
257 supply-controlled line, suggesting that this sample may undergo complex ripening
258 processes (Fig. 9). Eberl et al. (1998) proposed that agglomeration growth may occur
259 simultaneously with ripening, leading to multimodal distributions. The STEM
260 observations provided direct evidence for attachments between saponite particles (Fig.
261 10). As shown in Figure 10a, a smaller particle (marked by 1) attaches to a larger
262 particle (marked by 2) by their edge surfaces (marked by red arrows), where the gap
263 (red dotted line) suggests that the fusion between both particles is likely ongoing. The
264 irregularly shaped particle in Figure 10b is composed of at least three sub-particles,
265 that is, the elongated lath (labelled “3”) and two irregular particles (labelled “1” and
266 “2”). In sample 220-500, several secondary maxima resulted from non-classical
267 crystal growth (i.e., particle attachment) (Wang et al., 2014). Thus, both indeterminate
268 ripening and particle attachment were involved in the formation of Mg–Ni-saponite in
269 sample 220-500. Particle attachment was also sporadically observed in the STEM
270 images of sample 220-400 (Fig. S1), where saponite growth proceeded via the fusion
271 of the particle edges (red dotted line). Thus, in sample 220-400, particle attachment
272 occurred simultaneously with surface-controlled ripening but was too imperceptible to
273 be recorded by the PSD model (Fig. 7). For two adjacent particles (Figs. 10 and S1),
274 there is the possibility that one particle is preferentially growing at the expense of the

275 other one, because heterogeneity in composition from one particle to another may
276 drive such preferential dissolution and growth. Such viewpoint could be confirmed by
277 *in situ* observation during saponite growth processes when the technology is feasible.

278 It was reported that crystal growth by particle attachment occurs widely in
279 geochemical, biological, and synthetic material systems (De Yoreo et al., 2015).
280 However, there is little research on the non-traditional growth of clay minerals.
281 García-romero et al. (2018) used a TEM to locate and identify smectite and kaolinite
282 particles that seemed to originate from non-classical crystal growth. Furthermore, the
283 authors proposed for the first time that growth by particle attachment is present in clay
284 minerals, and such growth patterns are related to the depositional environments.
285 Zhang et al. (2020) found that the size of Mg–Ni-saponite layers significantly
286 increased with a slight increase in the degree of dissolution in its corresponding
287 precursors, and proposed the existence of non-classical growth during the formation
288 of Mg–Ni-saponite in a hydrothermal synthesis system. He et al. (2021) performed
289 TEM on natural biotite, natural muscovite, and synthetic fluorophlogopite. Their
290 results showed that in addition to the traditional crystal growth mechanism, the
291 oriented attachment of particles is common in the growth process of mica. A non-
292 classical crystallisation model was proposed for the formation of phyllosilicates at
293 elevated temperatures in magmatic and metamorphic environments, where the
294 oriented attachment of building blocks occurs; frequently along the (001) plane or the
295 [001] direction, or both simultaneously (He et al., 2021). Such a study not only
296 showed that non-classical crystal growth patterns are widespread in phyllosilicates,
297 but also extended the observations of particle attachment to magma and high-grade
298 metamorphic processes. In this study, the combination of PSDs and morphology
299 provided evidence that the non-classical growth of clay minerals may exist in high-

300 temperature hydrothermal environments. These results provide important references
301 for further research on the genesis of complex clay minerals and related geochemical
302 processes.

303 *3.5. Crystal growth process*

304 Meunier (2006) had applied the periodic bond chain (PBC) theory of Hartman
305 (1973) to the crystal growth in clay minerals, which essentially implied a two-
306 dimensional extension of clay minerals within the (001) plane. For smectite, it is not
307 clear whether the extensional crystals are composed of stacked multi-layers or a single
308 layer (Meunier, 2006; Decarreau et al., 2014).

309 In this study, in the saponite synthesised at 220°C, it appears that the well-
310 dispersed particles are single layers (Fig. 4). For saponite, [the hydrated interlayer](#)
311 [cations could hinder a stack and thus](#) the dominant growth pattern is the two-
312 dimensional lateral growth of single layer (or a few layers). [These saponite layers](#)
313 [stack layer by layer randomly during the process of water loss, leading to](#)
314 [heterogeneous saponite particles](#). In the sample synthesised at 500°C, some observed
315 particles clearly consisted of several stacked layers (Fig. 10), suggesting a different
316 crystal growth process. The XRD patterns of 220-500 indicated the occurrence of
317 talc-like layers (Fig. 3), [which have low \(no\) interlayer charge and easily stack into](#)
318 [relatively homogeneous crystals with similar dissolution/growth behaviour](#).
319 Consequently, 220-500 can grow following, at least partly, a three-dimensional
320 structure, similar to other clay minerals.

321 The PBCs present in this study were those within the (001) plane, that is, the
322 PBCs of [100], [110], and $[\bar{1}10]$. The growth faces of the crystal were observed lying
323 parallel to one or more continuous PBCs. Al distribution can affect the shape of

324 saponite by controlling the development of PBCs (Meunier, 2006). In this study,
325 saponite with a very low charge (0.3) most likely led to the heterogeneous distribution
326 of tetrahedral Al, which induced defects in the saponite layers. Such defects may
327 hinder the development of PBCs in saponite structures. The occurrence of elongated
328 laths in saponites (pMg220, 220-400, and 220-500) likely suggests that only one PBC
329 is favoured in the saponite structure. For Ni-saponite (pNi220), the small layers with a
330 relatively regular shapes like hexagons may indicate that all PBCs are affected.

331 **4. Conclusions**

332 The present study combines the PSD model and STEM observations to
333 investigate the growth processes of synthetic saponite. The results have indicated that
334 saponite particle growth proceeds mainly via surface-controlled growth and possibly
335 via supply-controlled growth in closed systems, based on the shape of the PSDs and
336 the plotted coordinates of (α, β^2) following Eberl et al. (1998)'s model. Particle
337 attachment, which leads to a multimodal PSD shape, is probably a corresponding
338 growth mechanism. The heterogeneous Al distribution of the low-charge saponite
339 could lead to the formation of elongated laths, and talc-like layers which favour the
340 "three-dimensional growth" of saponite in high-temperature environments.

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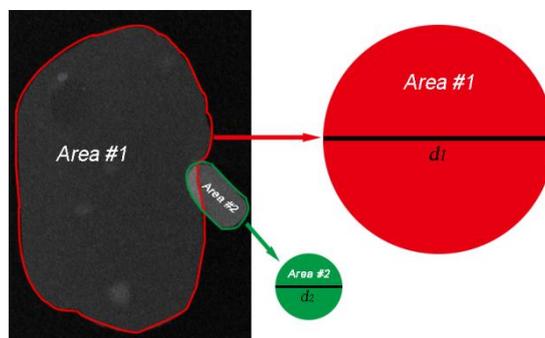
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Figures and Tables

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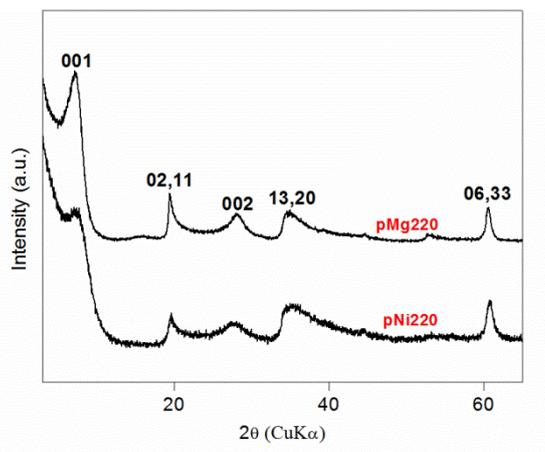
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461 Fig. 1. Schematic measurement process of saponite particle size (diameter) in the *ab*-
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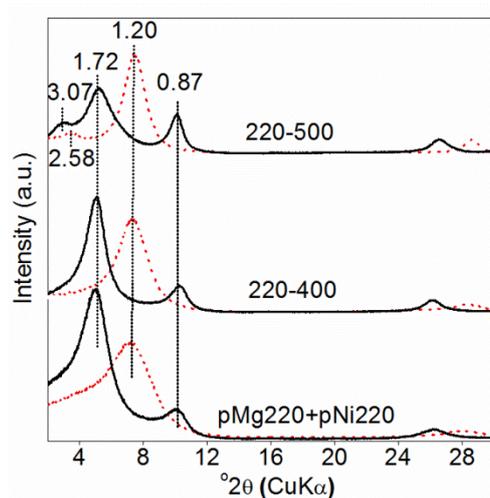
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468 Fig. 2. Powder XRD patterns of synthetic Mg-saponite (pMg220) and Ni-saponite
469 (pNi220) precursors.

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474 Fig. 3. XRD patterns of oriented samples (air-dried — red dot; after glycolation —
475 black solid).

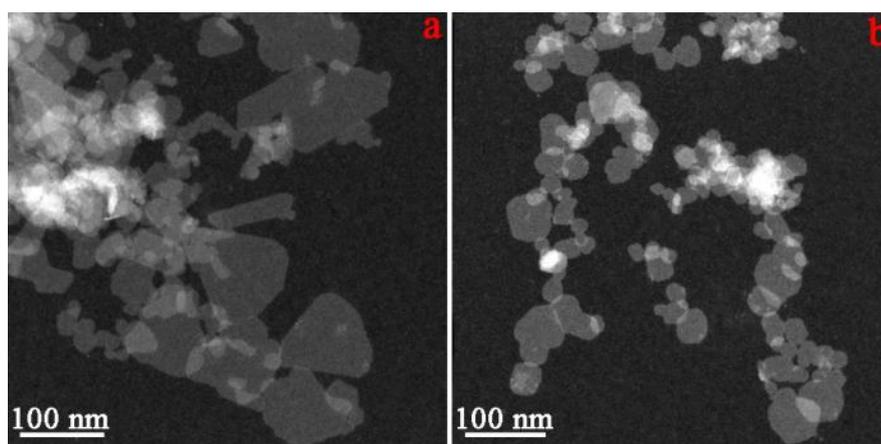
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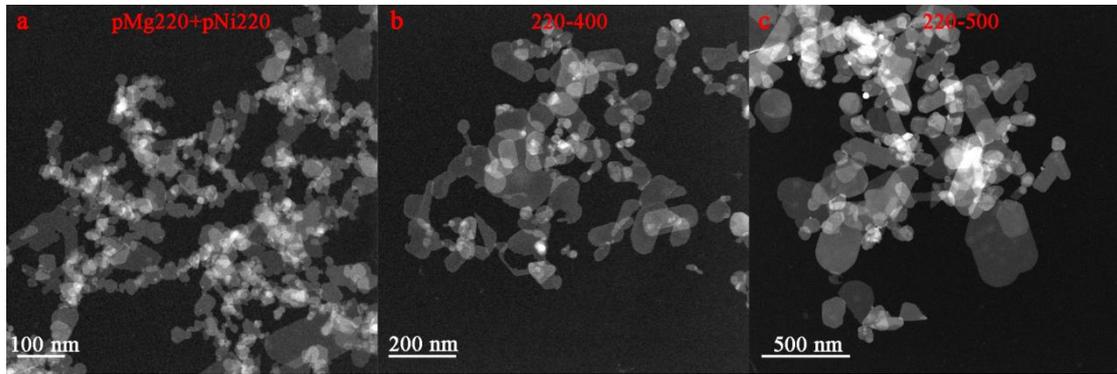


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482 Fig. 4. STEM images of synthetic precursors: (a) Mg-saponite (pMg220), and (b) Ni-
483 saponite (pNi220).

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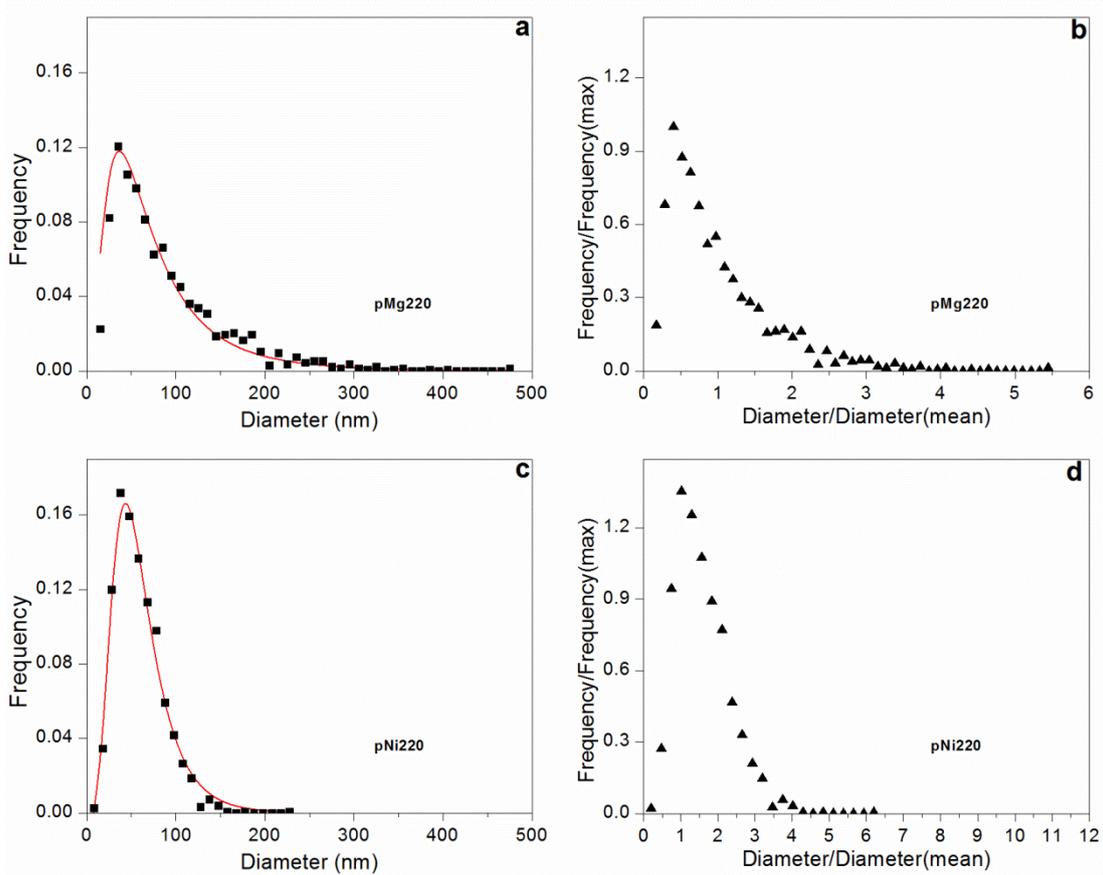


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491 Fig. 5. STEM images of the starting materials (a) (pMg220+pNi220), (b) sample 220-
492 400, and (c) sample 220-500.

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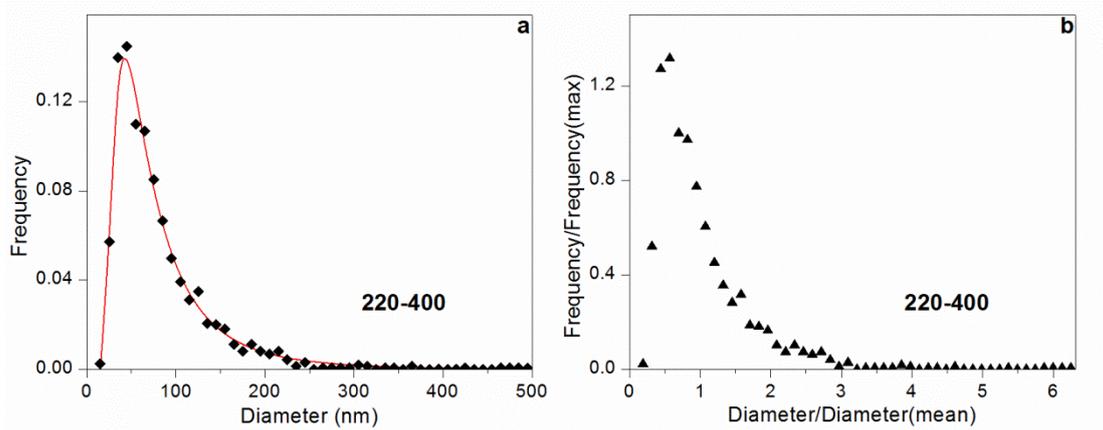


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Fig. 6. Particle size distributions (PSDs) and PSD reduced profiles of synthetic saponites: (a–b) Mg-saponite (pMg220), and (c–d) Ni-saponite (pNi220).



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Fig. 7. PSD (a) and PSD reduced profile (b) of sample 220-400.

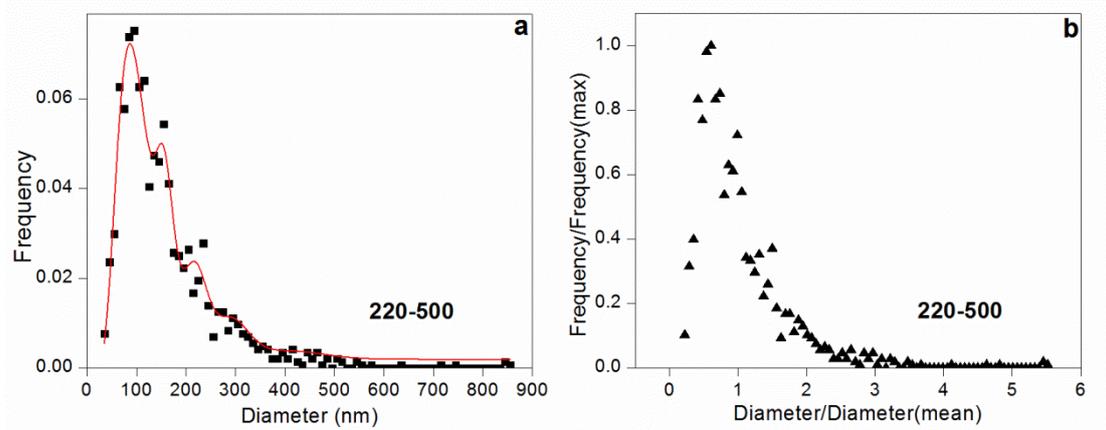
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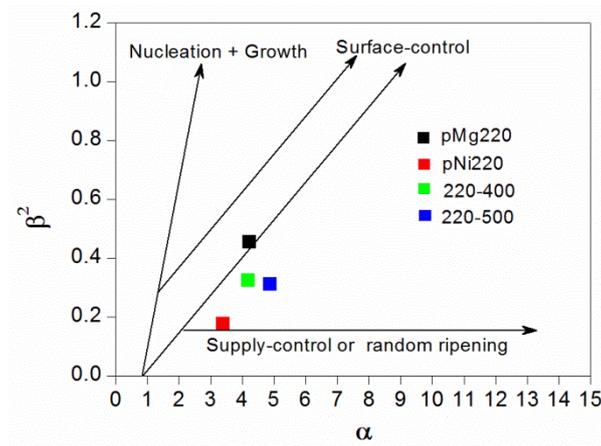
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Fig. 8. PSD (a) and PSD reduced profile (b) of sample 220-500.



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508 Fig. 9. Simple diagram of variations in α - β^2 of synthetic Mg-saponite (pMg220), Ni-

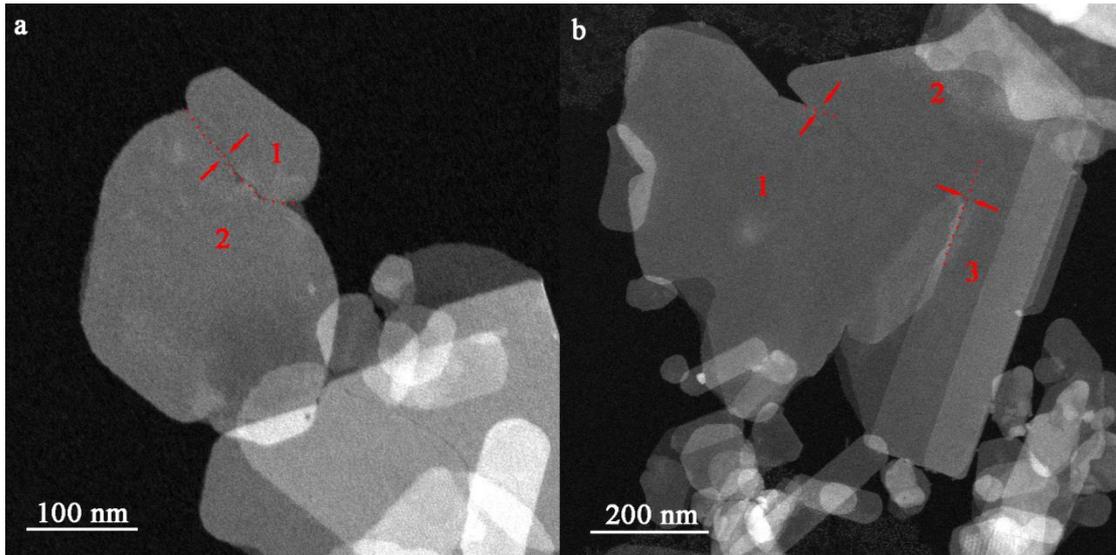
509 saponite (pNi220), and Mg-Ni-saponite (220-400, and 220-500), plotted on the

510 diagram of Eberl et al. (1998).

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Fig. 10. STEM images of characteristic particle attachment in sample 220-500.

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535 Table 1. Mean diameter in *ab*-plane of particles, α , β^2 of synthetic saponites. α and β^2
536 are the mean and variance of the natural logarithms of the observed diameters,
537 respectively.

Samples	Mean diameter (nm)	α	β^2
pMg220	87.2	4.24	0.454
pNi220	36.7	3.40	0.177
pMg220+pNi220	58.2	/	/
220-400	79.2	4.20	0.325
220-500	156.8	4.88	0.312

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