



HAL
open science

Demonstrating the influence of sediment source in dredged sediment recovery for brick and tile production

Thomas Gillot, Isabelle Cojan, Haurine Frédéric, Poirier Catherine,
Marie-Anne Bruneaux

► To cite this version:

Thomas Gillot, Isabelle Cojan, Haurine Frédéric, Poirier Catherine, Marie-Anne Bruneaux. Demonstrating the influence of sediment source in dredged sediment recovery for brick and tile production. Resources, Conservation and Recycling, 2021, 10.1016/j.resconrec.2021.105653 . hal-03595683

HAL Id: hal-03595683

<https://hal.science/hal-03595683>

Submitted on 24 May 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Demonstrating the influence of sediment source in dredged sediment recovery for brick**
2 **and tile production**

3 GILLOT Thomas^{1,2}, COJAN Isabelle¹, HAURINE Frederic^{1,3,4}, POIRIER Catherine³,
4 BRUNEAUX Marie-Anne^{3,5}

5 ¹ MINES-ParisTech, PSL University, Geosciences, 35 rue Saint Honoré, 77300
6 Fontainebleau, France

7 ² presently, MAGMA Caraibes, 309 Lotissement La Caraibe, Case-Pilote 97222, Martinique,
8 France

9 ³ CTMNC, 17, rue Letellier, 75786 Paris Cedex 15, France

10 ⁴ presently, Université Paris-Saclay, CNRS, GEOPS, Orsay, 91405, France

11 ⁵ presently, Andra, 1 rue Jean Monnet, 92290 Châtenay- Malabry, France

12

13 *Corresponding author:* isabelle.cojan@mines-paristech.fr

14 ***Abstract***

15 The most important raw materials for the building industry are natural quarried rocks.

16 Preservation of this non-renewable resource needs valorizing products, the vast majority of
17 which is currently considered as waste. Among these, dredged sediments have gained much
18 attention and should play a key role in non-renewable natural resource preservation.

19 The aim of this paper is to achieve a resource-efficient evaluation for the re-use of fine-
20 grained dredged sediments in the heavy clay industry by investigating relationship between
21 sediment provenance and industrial properties. 86 spot samples from French dam reservoirs

22 and estuaries were studied, focusing on grain-size and mineralogy. Industrial technological
23 tests were performed on 53 samples representative of varied lithological sources. Following
24 PCA analysis, source fingerprinting in four categories is proposed, allowing for direct
25 evaluation of sediment for brick-tile making. Best technological scores, close to industrial
26 values, were obtained for source category (3) mixture of sedimentary, plutonic and
27 metamorphic rocks and low scores for two source categories, (1) sedimentary rocks (high
28 carbonate content), (2) plutonic and metamorphic rocks (lack melting compound). Extrusion
29 failed for samples from category (4) plutonic or metamorphic rocks (lack clay minerals).
30 Consistency between PCA fingerprinting categories, MIF (Mineralogical Industrial
31 Framework) and technological tests shows that even though the sediment source classification
32 is simplified, it constitutes a reference to predict the recovery of dredged sediment for tile or
33 brick making. Insights from this study can be particularly useful to the heavy clay industry
34 managers when making decision regarding the fossil resource preservation by substitution
35 with dredged sediments.

36 Keywords: dredged sediment recovery; brick and tile production; provenance fingerprinting;
37 technological properties; Principal Component Analysis.

38 ***1 Introduction***

39 In a context of sustainable development, waste management has become an important target
40 in terms of natural resource preservation and environmental issues (Azapagic et al., 2004).

41 Among the multiple non-hazardous wastes, this paper focuses on fine-grained dredged
42 sediments that can be recovered by substitution of natural material in tile and brick building
43 materials (Hamer and Karius, 2002; Agostini et al., 2007; Mezencevova et al., 2012;

44 Cappuyns et al., 2015). Composition of raw mixtures for ceramic materials has an influence
45 on the sintering temperature and final properties of the produced material (Dondi, 2003;
46 Cultrone et al., 2004). Mineralogical studies on fine-grained dredged harbor sediment (Hamer
47 and Karius, 2002; Mezencevova et al., 2012; Benyerou et al., 2015) or river material (Manap
48 et al., 2016) have shown that silt carried in suspension can be valuable material for the
49 ceramic industry based on appropriate grain-size distribution and significant content in clay
50 minerals combined with quartz and some carbonates (Xu et al., 2014; Cappuyns et al., 2015;
51 Haurine, 2015, Haurine et al., 2016).

52 Fine-grained sediments silting in dam reservoirs or estuaries are regularly dredged for harbor,
53 water resource or maintenance management, and a vast majority is disposed at sea or inland
54 as a waste product. The re-use of dredged sediments in the heavy clay industry as an
55 alternative to fossil sedimentary rocks requires further investigation to provide fingerprint of
56 these fine-grained sediment composition with respect to the geology of sediment source.

57 Provenance studies, traditionally focus on mineralogical composition of sand which is easier
58 to analyze with standard petrography techniques (Zuffa, 2013 and references therein).

59 Mineralogy of silt and clay carried in suspension by rivers is determined by X-ray powder-
60 diffraction analyses (XRD), composition is generally related to sediment provenance (Klages
61 and Hsieh, 1975; Benedetti et al., 2006; Garzanti et al, 2007; Garzanti et al., 2011), it may
62 change along the river course, influenced by sediment dilution or concentration from
63 tributaries, chemical weathering during transport and seasonal input (Walling et al., 1999).

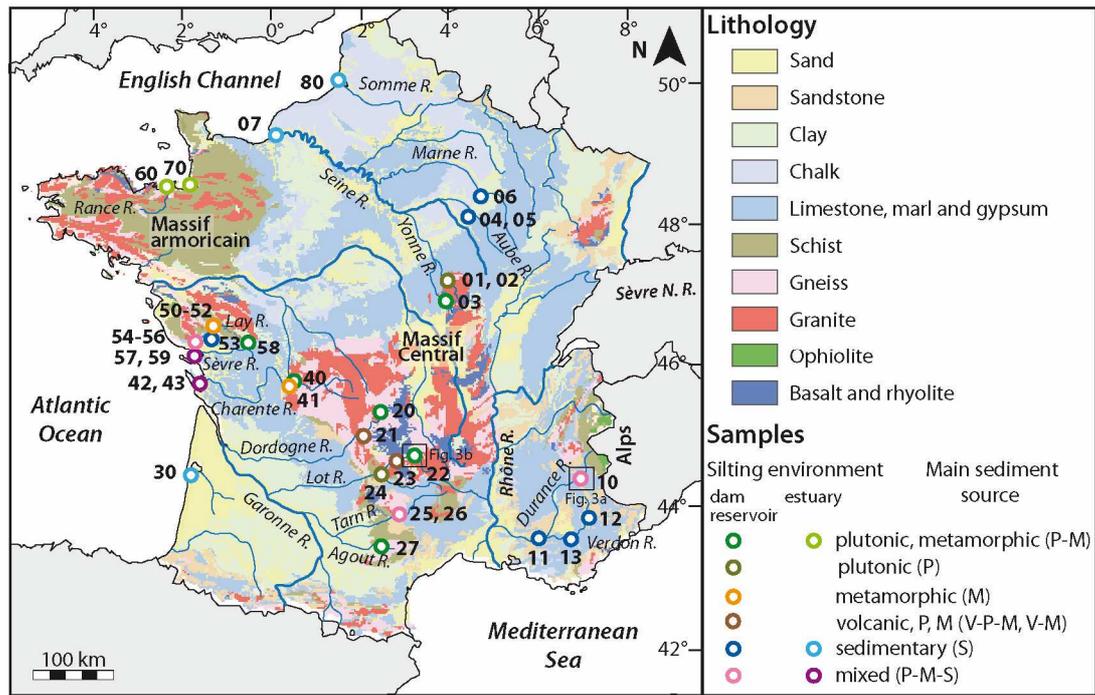
64 The aim of this study is to achieve a resource-efficient evaluation for the recovery of fine-
65 grained dredged sediments in the heavy clay industry by investigating relationship between
66 sediment provenance and industrial properties. Spot sampling of fine-grained sediment was

67 conducted in French dam reservoirs and estuaries, collecting sediments from a large diversity
68 of source rocks and geomorphic contexts. At first broad compositional pattern of surficial
69 sediments is described from two large dam reservoirs, Lake Serre Ponçon (Alps) and Lake
70 Grandval (Massif Central). Then, a resource-efficient evaluation using principal component
71 analysis (PCA) is conducted between provenance, geomorphic context, sediment composition
72 and scores during the technological tests of the heavy clay industry. Finally, consistency
73 between proposed fingerprint categories from PCA, Mineralogical Industrial Framework
74 domains (MIF, Haurine et al., 2016) and technological tests is discussed.

75 **2 *Setting***

76 Among the numerous dams built along the course of the French rivers and estuaries, we
77 selected sites fed from great diversity of sediment sources (plutonic, volcanic, metamorphic
78 and sedimentary rocks) and geomorphic contexts (active mountain range, remains of ancient
79 volcanoes and chains, sedimentary basins) (Fig. 1).

80



81

82

83 Fig. 1. Site location on the lithological map of France (BRGM, 2008). Sites labeled per river
 84 system and color-coded according to the geology of the dominant source (see supplementary
 85 material 1 for details).

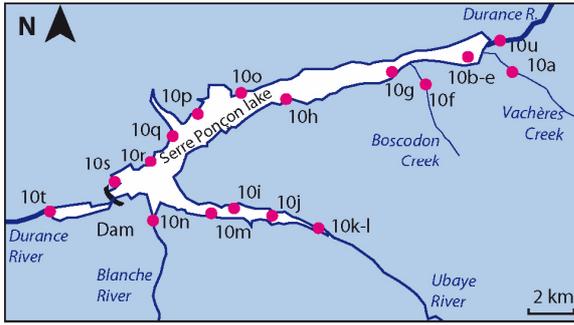
86

87 Variability of sediment composition was investigated from two large dam reservoirs located
 88 in an active mountain range (Lake Serre Ponçon, Alps), and in an ancient chain (Lake
 89 Grandval, Massif Central), respectively. Lake Serre-Ponçon (water volume $1,272 \cdot 10^6 \text{ m}^3$)
 90 (Fig. 1, site 10) gathers waters from two major streams; the Durance (watershed 2170 km^2)
 91 and Ubaye (watershed 1011 km^2) rivers, and a minor one the Blanche River (watershed 205
 92 km^2) and two mountain creeks (Vachères and Boscodon) (Fig. 2a). The watershed is
 93 characterized by mountain reliefs, heterogeneous lithologies (granite, metamorphic and

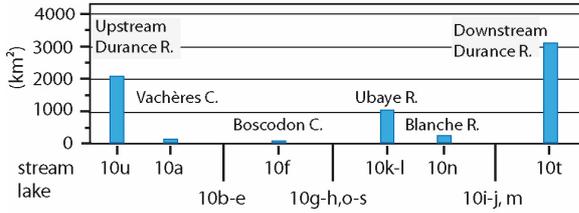
94 sedimentary rocks) and a high erosion rate (Alary, 1998; Colmar et al., 2010). Lake Grandval
95 is five times smaller (water volume $272 \cdot 10^6 \text{ m}^3$) (Fig. 1, site 22). It is fed by the Truyère River
96 (watershed 1782 km^2) and minor creeks (L'Ander, watershed 310 km^2 ; and Le Bès, watershed
97 283 km^2) (Fig. 2b). The watershed corresponds to low mountain reliefs, heterogeneous
98 lithologies (granite, gneiss with some volcanic rocks), the erosion rate is moderate (Colmar et
99 al., 2010). Climate in both watersheds is mountainous with some Mediterranean influence
100 favoring seasonal high peak discharges during which sediment accumulates at the mouth of
101 the feeding rivers forming deltas that prograde into the dam reservoir. Fine-grained sediment
102 accumulates in distal depositional environments fed by suspension.

a) Lake Serre Ponçon (sediment sampled 10 m below high lake level)

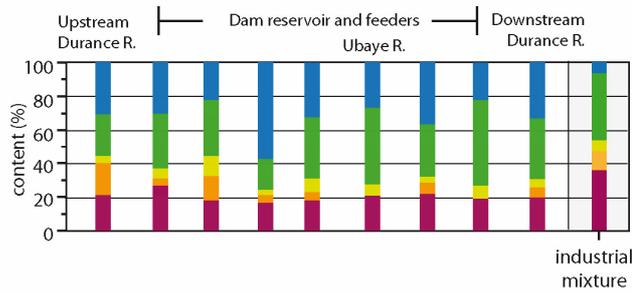
1) Sampling sites



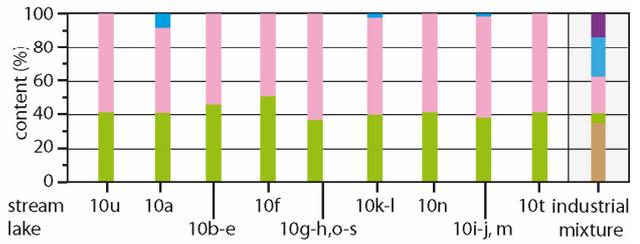
2) Watershed



3) Mineralogy (<40 µm fraction)

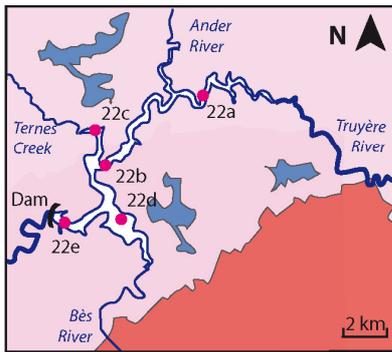


4) Clay minerals (<2 µm fraction)

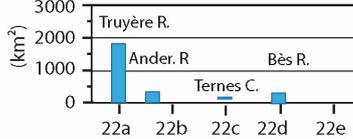


b) Lake Grandval (sediment from lake bottom)

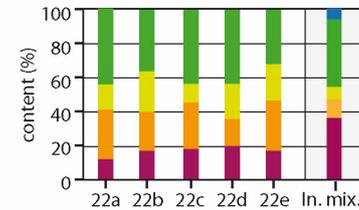
1) Sampling sites



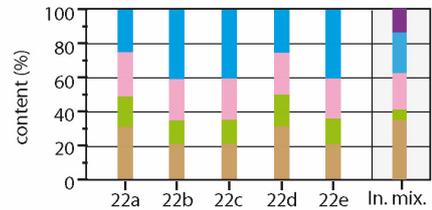
2) Watershed



3) Mineralogy (<40 µm fraction)



4) Clay minerals (<2 µm fraction)



103

104

105 Fig. 2. Sediment compositional pattern at the scale of large dam reservoirs: Lake Serre-
 106 Ponçon, sampling at intermediate water depth (a); and Lake Grandval, sampling on lake
 107 bottom (b) (see Fig. 1 for lake location, supplementary materials 3 and 4 for mineralogical
 108 composition).

110 Furthermore, several dam reservoirs and estuaries were selected to sample sediments from
111 varied provenances (Fig. 1). Dam reservoirs fed by sediment sources dominated by plutonic
112 rocks (sites 01, 02 and 24) or metamorphic ones (site 41) are located in the northern and
113 western parts of the ancient orogenic chain of the Massif Central and southern border of the
114 relict chain of the Massif Armoricain (sites 50 to 52). Selected dams impounding sediment
115 transfer on rivers flowing over plutonic and metamorphic substrates rich in volcanic rocks are
116 located in the Cantal volcanic province of the Massif Central, (sites 21 and 23). Sediment
117 sources comprising metamorphic and plutonic rocks are located north (site 03) and west (sites
118 20, 22, 27 and 40) of the Massif Central, and in the southern part of the Massif Armoricain
119 (site 58). Dam reservoirs collecting sediment originating from the erosion of sedimentary
120 rocks are located in the south-western part of the alpine range (sites 12 and 13), in the Paris
121 basin (sites 04 to 06). Dam reservoir fed by a river flowing over substrates of varied
122 geological lithologies (metamorphic, plutonic, volcanic and sedimentary rocks) are situated
123 on the Durance river in the outer Alpine chain (sites 10 and 11), the Tarn River in the Massif
124 Central (sites 25 and 26) and the Lay River along the southern border of the Massif
125 Armoricain (sites 50 to 52, 54 to 56).

126 Estuaries are located along the English Channel and the Atlantic coast (Fig. 1). To the north,
127 the Somme (site 80) and the Seine (sites 07) estuaries are fed by fluvial systems dominantly
128 flowing over sedimentary substrates (marl and limestone, clay and sand). Estuaries along the
129 north coast of the Massif Armoricain are fed by rivers flowing over mixed plutonic and
130 metamorphic rocks (sites 60 and 70). Those from the Atlantic coast are fed by rivers flowing
131 over mixed plutonic, metamorphic and sedimentary rocks (sites 42, 43, 57 and 59). Finally,

132 the Arcachon bay (site 30) is fed by a river flowing over sedimentary substrate composed of
133 sandy deposits.

134 Selected sites provide a variety of sediment sources in different physiographic settings: active
135 mountain range (Alps - sites 10 to 13), ancient chain (Massif Central - sites 01-03, 20 to 21,
136 40 to 41), remnant of a chain (Massif Armoricaïn - sites 50-55, 60 and 70) or sedimentary
137 basin (Paris basin - sites 04-07, 80; Aquitaine basin - sites 30, 42-43, 53, 56-59).

138 **3 Material and Methods**

139 **3.1 Material**

140 A total of 86 surficial spot samples were collected from 37 dam reservoirs and estuaries (Fig.
141 1; supplementary material 1). About two third of the samples come from dam reservoirs
142 (69%). Sediment sources are distributed as follow: sedimentary rocks (28%), plutonic and
143 metamorphic rocks (27%), plutonic, metamorphic and sedimentary rocks (28%), plutonic
144 rocks (7%), metamorphic rocks (4%) and dominant volcanic rocks (6%). In addition, 11
145 industrial mixtures from the French heavy clay industry were analyzed to enlarge the
146 industrial dataset built by Haurine (2015), now representative of 90% of the French
147 production over the last 15 years. For reasons of confidentiality, data from industrial mixtures
148 are not detailed in this paper.

149 Sampling (up to 20 kg per site) was conducted using a spade during low water levels to access
150 the distal part of the reservoir sediment wedge where fine-grained sediment accumulate by
151 silting. Lake Serre Ponçon sediment was sampled at the end of winter when lake level is at
152 minimum, some 10 m below the high level. Lake Grandval and Lake Sarran were sampled

153 during the maintenance period; the nearly emptied reservoir gave access to lake-bottom
154 sediment. Similarly, estuaries were sampled at low tide, away from tidal channels. In addition,
155 four samples of dredged sediments were included, three from the Seine estuary (provided by
156 Le Havre seaport) and one from the Cadarache settling pond (Durance River - provided by
157 EDF). Samples were first oven dried at 40°C and stored in a dry room. Analyses were
158 conducted on samples dried in a forced-air drying oven at 40°C for 4 to 8 days.

159 **3.2 Analytical methods**

160 **3.2.1 Particle size analysis**

161 Dried samples were suspended in an excess of water, mixed to separate particles, and
162 separation at 40 µm was obtained by wet sieving. Particle size distribution was determined by
163 dry sieving (fraction > 40 µm) and by sedimentation with SediGraph 5100 Particle Size
164 Analyser (Micrometrics) (fraction < 40 µm). A dispersing and deflocculating agent (sodium
165 polymetaphosphate, 1%, pH 6.5-7.2) was added to the aqueous suspension. Error is ± 10%.
166 Results are presented for the particle-size classes used in the heavy clay industry: 0.5, 2.5, 40,
167 200, 500 and >500 µm (supplementary material 2). Particle-size analysis was conducted on 53
168 sediment samples, representative of the varied sediment sources and geomorphological
169 contexts (supplementary material 2). Results are plotted on the Winkler diagram (Winkler,
170 1954), a ternary plot of three particle size fractions (< 2.5 µm, 2.5-25 µm and > 25 µm)
171 (Supplementary material 2). Domains from the French tile and brick raw materials are also
172 indicated on the ternary plot.

173

174 **3.2.2 Mineralogical analyses**

175 Mineralogical analyses were conducted on the silt fraction ($< 40 \mu\text{m}$). They were carried out
176 via X-ray diffraction (XRD) using PANalytical's X-ray diffractometer (Phillips), $\text{CuK}\alpha$
177 radiation. Quantitative mineral analysis of the bulk sample was performed using random
178 powder mounts. EVA software (Bruker DIFFRACPlus 2007) was used for identification and
179 quantitative phase analysis based on scan wavelength (λ) and the normalized intensity
180 ratio (RIR) method (Chung, 1974), (supplementary material 3). Relative Error is
181 $\pm 5\%$. Following the removal of carbonate by weak acid, particles smaller than $2 \mu\text{m}$ were
182 separated by sampling the upper 2 cm of the clay suspension after 100 min. Identification of
183 the clay minerals was performed according to the position of the (00l) series of basal
184 reflections on three XRD diagrams (air-drying, ethylene-glycol salvation and heating at
185 490°C for 2 h, Moore and Reynolds, 1997). Identification and relative proportion of clay
186 minerals was performed using recommended protocol by Kahle et al. (2002) (supplementary
187 material 4). Error estimate is $\pm 5\%$.

188 Mineralogical analyses were performed on the 86 samples (supplementary materials 3 and 4)
189 to investigate the compositional pattern within dam reservoirs (Lake Serre Ponçon, 21
190 samples, Fig. 2a, Lake Grandval, 5 samples, Fig. 2b); and to compare silting sites fed by
191 different lithological sources (Fig. 3a, b).

192 **3.2.3 Extrusion**

193 A representative subsample of 8 kg of dried sediment was gently crushed to eliminate the
194 aggregates that formed during the drying. The loose sediment was then weighted, mixed with
195 the suitable quantity of water to obtain a plastic paste with extrusion shaping capacity (for
196 shaping water content see supplementary material 6). For each sample, several specimen bars
197 were extruded to conduct tests at the laboratory scale ($10 \times 2 \times 2 \text{ cm}^3$ for shrinkage and water

198 absorption measurement, and $13 \times 2.5 \times 1 \text{ cm}^3$ for bending strength test) (supplementary
199 material 5). The plastic paste was weighted to evaluate the proportion of water in the paste
200 (water shaping). Raw specimen bar plasticity was appraised in a semi-quantitative way using
201 an index ranging from poor, fair, good, very good (plasticity raw) (supplementary material 6).

202

203 **3.2.4 Technological tests**

204 Technological tests were performed on the 24 successfully extruded samples (i.e. with a
205 suitable plasticity) (Fig. 4, 3c, supplementary material 5, 6 and 7). Extruded specimen bars
206 dedicated to the determination of the drying behavior were dried at room temperature for
207 24 h. During this period, the drying behavior was measured with a barrelatograph (Adamel),
208 which traces the Bigot's curve, representing the humidity in percentage of the dry weight (and
209 thus the moisture loss) as a function of the longitudinal shrinkage in percentage of the dry
210 length (shrinkage dry).

211 Specimen bars dedicated to the study of the characteristics of the material after firing (water
212 absorption, aspect changes, and mechanical resistance, i.e. flexural strength) were dried at
213 room temperature for one week. Then, they were placed for 48 h at $105 \text{ }^\circ\text{C}$ in ovens to
214 complete drying, before being fired. The firing cycle consisted in a slow heating gradient of
215 100°C/h followed by a 2 h steady stage at maximum temperature ($50 \text{ }^\circ\text{C}$ steps from 850 to
216 $1150 \text{ }^\circ\text{C}$), before cooling. Tests were only conducted on specimen bars fired at $950 \text{ }^\circ\text{C}$,
217 average temperature of industrial kiln between that of bricks (Johari et al., 2010) and tiles
218 (Cultrone et al., 2004). For each sample, a visual inspection of the fired specimen bar at 950
219 $^\circ\text{C}$ evaluated the bar alteration during the firing process by comparison with the crude

220 specimen bar: occurrences of cracks, scum, lime blowing, shape deformation (shape 950)
221 (supplementary material 5). Finally, flexural strength was investigated through 3-points
222 flexural bending tests (press LFPlus– Lloyd Instruments LTD- 1KN) on unfired (F. strength
223 dry) and fired at 950 °C (F. strength 950) specimen bars.

224 **3.3 PCA analysis**

225 Identification of indicator minerals from sampled sediments can help trace related sediment
226 source; identify sediment with the most appropriate properties for a use by the heavy clay
227 industry. With this scope, we carried out Principal Component Analysis (PCA) with XLStat
228 software, three dataset including sediment and industrial mixtures were considered:
229 mineralogy, clay minerals, and technical properties. Loading plot, scree plot and projection of
230 observations on the first two components (F1 vs. F2) are given in Fig. 3. Eigenvectors, factor
231 loadings for each component are given in supplementary material 8. Plot of the samples on F1
232 vs. F2 was coded according to the geology of the dominant sediment source and the results of
233 the extrusion process (Fig. 3, observations).

234 **4 Results**

235 **4.1 Particle-size distribution**

236 Particle-size analysis of the 53 samples representative of the varied sediment sources
237 showed that they correspond to silt (supplementary material 2). Half of the samples are
238 medium to fine silt with less than 5% of particles larger than 200 µm. Sediments showing a
239 poor sorting (30 to 50% of particles larger than 200 µm) correspond to 25% of the samples.
240 Plot of the particle size distribution on the Winkler diagram (Winkler, 1954) shows that most

241 of the samples fall within or close to the tile hollow brick or solid brick domains
242 (supplementary material 2). Samples with more than 70% of large particles (>25 μm) are
243 from dam reservoirs (plutonic and metamorphic sources); and those with less than 10% are
244 from dam reservoirs and estuaries (mainly mixed sources). Some contain a high percentage (>
245 60%) of particles between 2.5-25 μm , they were collected in dam reservoirs.

246 Particle-size distributions of industrial materials – i.e. crushed sedimentary rocks extracted
247 from quarries - are distributed between the three industrial domains (supplementary material
248 2). Those of industrial mixtures cluster within the respective industrial domains, industrial
249 mixtures for brick production contain slightly more coarse-grained particles than those
250 dedicated to tiles.

251 **4.2 Mineralogical composition**

252 **4.2.1 Compositional pattern at the scale of a dam reservoir – Lake Serre Ponçon** 253 **and Lake Grandval**

254 In Lake Serre Ponçon, the average mineralogical composition of the silt fraction (Fig. 2a)
255 comprises carbonate (29%), quartz (19%), and clay minerals (36%). Carbonate content
256 (dominantly calcite) shows the highest variability ($\sigma = 13$). Carbonates in the upstream reach
257 (30%) and lacustrine delta of the Durance (22%) are present in fairly similar proportion than
258 in the Ubaye River sediments (28%). The largest carbonate content is observed in the
259 Boscodon (58%) and Blanche (36%) delta sediments and close by beaches (36%).
260 Downstream of the Serre-Ponçon dam, the carbonate content (30%) of the Durance sediment
261 is very similar to that of the upstream Durance or Ubaye sediments, reflecting the major
262 contribution from these two streams draining large basins. Clay minerals and non-expandable

263 clay mineral chlorite, muscovite, quartz and feldspar contents are less variable, fluctuations
264 ($\sigma < 6\%$) are within the error range. The average clay mineral assemblages are composed of
265 illite (60%) and chlorite (40%) (Fig. 2a). Kaolinite is present in the upstream Durance delta
266 samples (20%) resulting in lower illite (50%) and chlorite (30%) contents. Mixed layers (I/S)
267 were identified in the Vachère creek sediment (10%).

268 In Lake Grandval, the average composition of lake-bottom sediment is dominated by clay
269 minerals (40%), feldspars (24%), muscovite (19%), quartz (17%) (Fig. 2b). Fluctuations are
270 within the error range ($\sigma \leq 7$). Clay mineral content shows the highest variability: from 38%
271 in the proximal sediments of the Truyères River and Ternes Creek, to 20% in the distal lake
272 deposits. The average clay mineral association comprises illite and mixed-layer clays
273 (illite/smectite and chlorite/smectite) in equal proportions (30%), then kaolinite (20%) and
274 chlorite (20%) (Fig. 2b). No smectite was identified. Mixed-layer clays are present in lower
275 proportion in the proximal delta sediment (25%) than in the distal ones (40%).

276 **4.2.2 Sediments**

277 Sediments are composed of a limited number of minerals, but with contrasted proportions.
278 Sediments comprise quartz (~ 30%) in association with K-feldspars (10 to 40%), clay minerals
279 (25 to 55%), muscovite (<10%) and calcite (0 to 35%) (supplementary material 3). Clay
280 mineral assemblages are composed of kaolinite (25 to 45%), illite (15 to 40%), chlorite (0 to
281 20%), and mixed-layer clays (0 to 40%); smectite (5 to 35%) is present in less than 25% of
282 the samples (supplementary material 4). Other minerals - albite, microcline and dolomite – are
283 generally present in very low proportion ($\leq 5\%$). In the following, albite and microcline are

284 included in the feldspar group with K-feldspars; and dolomite in the carbonate group with
285 calcite.

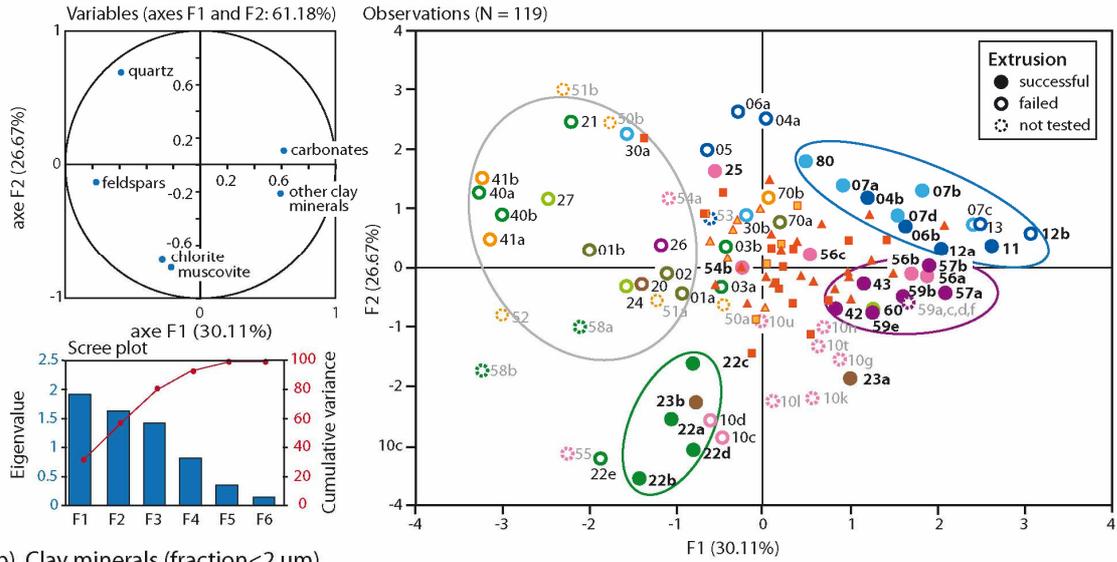
286 **4.2.3 Industrial mixtures**

287 Mean composition of industrial mixtures is dominated by clay minerals (39%) and quartz
288 (35%) associated to feldspar (10%), muscovite (7%) and calcite (6%). Clay mineral
289 assemblages comprise kaolinite (34%), mixed-layer clays (24%), illite (22%), smectite (14%)
290 and chlorite (6%).

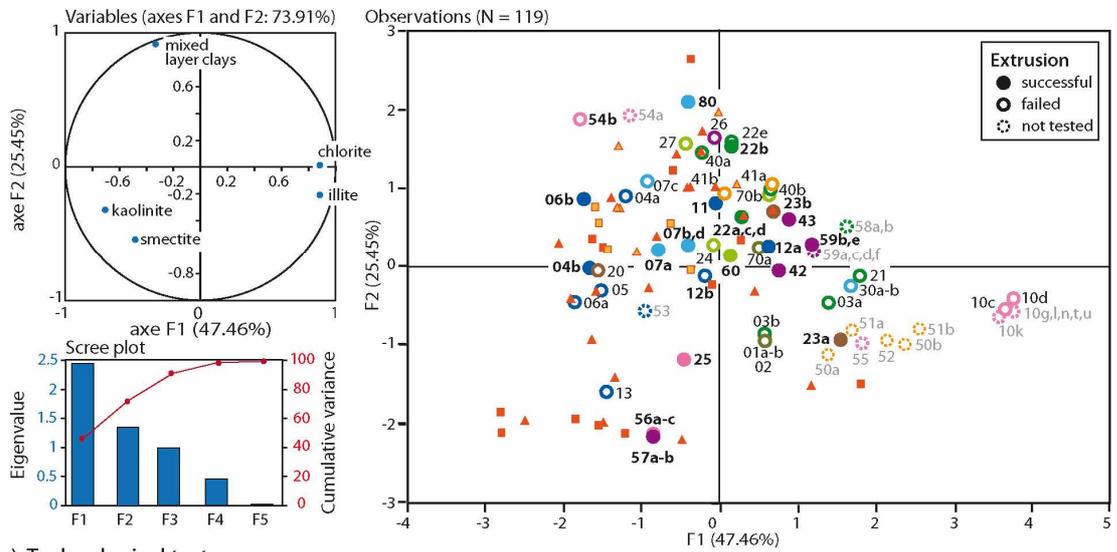
291 **4.3 Minerals as provenance indicators of sediments**

292 The PCA results of the mineralogical associations of the sediments and industrial mixtures are
293 presented in Figure 3a, b. In this study we only considered the first two eigenvalues,
294 accounting for 61% of the total variance of the mineralogy dataset (Fig. 3a); and 74% of the
295 clay mineral dataset (Fig. 3b).

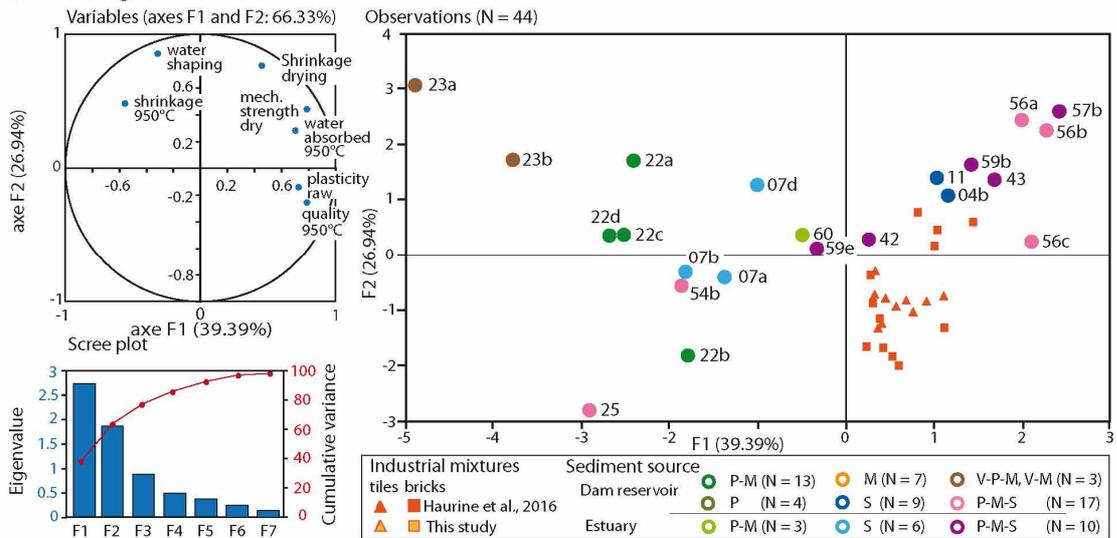
a) Mineralogy (bulk)



b) Clay minerals (fraction < 2 μm)



c) Technological tests



297 Fig. 3. PCA results from sediments and industrial mixtures (detailed results in supplementary
298 material 8).

299

300 In the mineralogical analysis, 32% of the total variance is captured by the first principal
301 component (F1) whereas the second component (F2) captures 29% (Fig. 3a). Variable plot
302 and associated factor loadings on F1 vs. F2 axes show that the first axis (F1) mostly exhibits
303 the opposition between the clay mineral and carbonate variables, and the feldspar and quartz
304 variables. The second component (F2) shows that the chlorite and muscovite variables are
305 coupled and negatively correlated to the quartz variable. Plot of the samples (observations) on
306 F1 vs. F2 shows that F1 allows a separation between the sediment sources dominated by
307 sedimentary (S sources), a mixture of plutonic, metamorphic and sedimentary rocks (P-M-S
308 sources), mixed plutonic-metamorphic-(volcanic) rocks (P-M-(V) sources) and plutonic (P
309 source) or metamorphic (M source) rocks. The second component F2 allows a fairly good
310 separation between the S and M sources, and those dominated by P, P-M-(V) and P-M-S
311 rocks. Four main sample clusters are identified in relation to the sediment provenance: 1) S
312 sources (F1, F2 positive values), 2) P-M-S sources (F1 positive and F2 negative values), 3) P-
313 M-(V) sources (F1 and F2 negative values), and 4) M sources and some samples from P-M
314 sources (F1 negative and F2 positive values). Industrial mixtures are mainly clustered in the
315 middle of the score plot with a slight distribution towards the right side of F1 and upper side
316 of F2.

317 In the clay mineral analysis, 39% of the total variance is captured by the first principal
318 component (F1) and 31% by the second one (F2) (Fig. 3b). Variable plot and associated factor

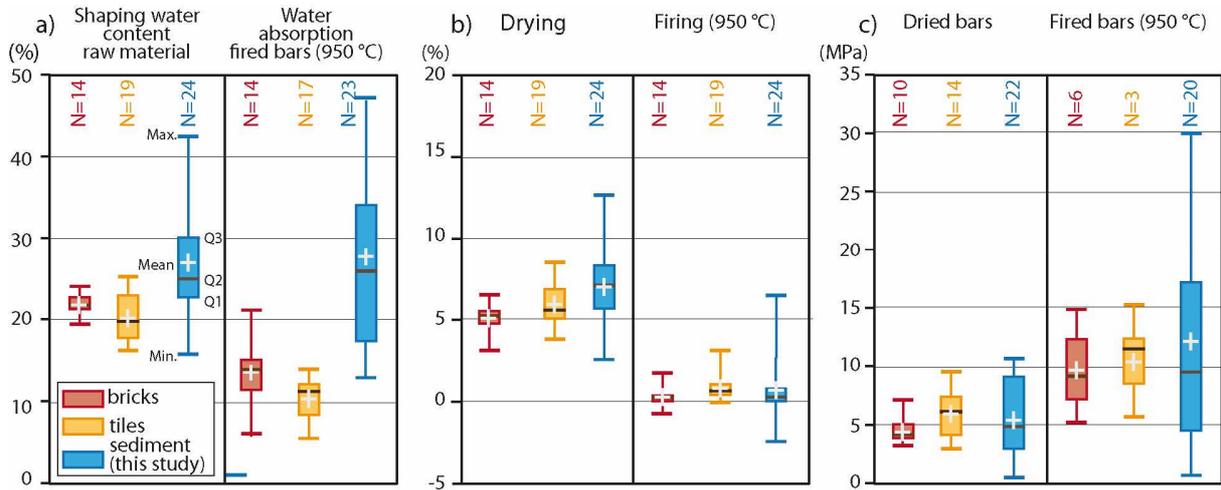
319 loadings on F1 vs. F2 axes show that the chlorite and illite variables are coupled, and
320 negatively correlated to the kaolinite and smectite variables (component F1). The second
321 component (F2) shows that the mixed-layer clay variable is negatively correlated to the
322 smectite variable. Plot of the samples (observations) on F1 vs. F2 shows that F1 allows a
323 slight separation between the sediment sources dominated by sedimentary rocks (S sources)
324 and the other sources (P, M, P-M-(V) and P-M-S sources). The second component F2 also
325 allows a slight separation between the sediment sources dominated by S sources or P source
326 or P-M-(V) sources, and those corresponding to M source, and P-M-S sources, in fluvial dam
327 reservoirs. Samples from coastal sites fed by P-M-S sources are scattered over the plot.
328 Despite some overlapping, it is possible to identify three main sample groups for the fluvial
329 samples: 1) S sources (F1 negative values); 2) P, P-M-(V) sources (F1, F2 positive or slightly
330 negative values); 3) M sources and P-M-S sources (F1 positive and F2 negative values).
331 Industrial mixtures are scattered on the left side of the score plot.

332 **4.4 Technological tests**

333 Extrusion success rate (24 samples out of 53) is very high for samples that plot within the tile
334 domain or show a lower content in particles larger than 25 μm . It is lower for samples that
335 plot within the brick domain (50%). Finally samples plotted within the solid brick domain or
336 with more than 50% of particles between 2.5 - 25 μm or $>25 \mu\text{m}$ could not be extruded
337 (supplementary material 2). Half of the specimen bars (12 samples) had excellent plasticity,
338 an even shape, sharp edges and a smooth surface (sample 22a presents some cracks). More
339 than half of the specimen bars with a medium plasticity (7 samples) presents irregular shapes
340 (samples 23a, 23b) or cracks along the edges (samples 22a, 22d). Specimen bars with low

341 plasticity show either a rough surface (samples 07b, 07d), an irregular shape (sample, 80), or
 342 cracks along the edges (sample 25).

343



344

345 Fig. 4. Box plot of technological tests of sediments and industrial mixtures: affinity with
 346 water (a), shrinkage (b) and mechanical strength (bending test) (c) (see supplementary
 347 materials 6, 7 for detailed results).

348 Results of the technological tests conducted on the specimen bars from sediment and
 349 industrial mixtures are presented together on Figure 4. The amount of water needed for
 350 shaping the raw material from the sediment samples shows a large dispersion (15 to 42%), far
 351 larger than that observed from the industrial mixtures (16 to 26%) (Fig. 4a), resulting in
 352 median (25%) and mean (27%) values higher than those of the industrial mixtures (21%
 353 bricks, 20% tiles). Shrinkage during drying shows similar trends (Fig. 4b), minimum values
 354 (around 2%) are comparable to the industrial ones (bricks 4%, tiles 2%), maximum ones
 355 (13%) are nearly two times larger (bricks 6.5%, tiles 7%). Mean values of sediment bars
 356 (15%) are also higher than those from the brick (5%) or tile (7%). Data from the bending

357 mechanical strength test on dried bars indicate a larger dispersion for the sediment values than
358 the industrial mixture ones, mean and median values are quite comparable for all materials
359 (sediment 5MPa, bricks 4 MPa, and tiles 6 MPa) (Fig. 4c).

360 Examination of the fired bars showed that more than half of the sediment bars of excellent to
361 good quality kept their original shape (supplementary material 5 and 6). Several fired bars of
362 good quality present some defects developed during firing such as deformation (samples 57a,
363 59b), cracks (samples 12a, 23a, 54b), lime blowing (samples 04b, 42), and deformation in
364 association to some lime blowing (samples 06b, 07a, 07b). Lime blowing can be easily
365 eliminated by immersion in slightly acidic water after firing, a process that is used in the
366 firing industry (Kornmann, 2005). One sample is of medium quality with soluble salts
367 efflorescence (80).

368 Data from water absorption of sediment specimen bars after firing at 950 °C show a large
369 dispersion (12 to 47%), mean values (around 37%), higher than those of the industrial
370 mixtures (bricks 13%, tiles 11%) (Fig. 4a). Mean values of shrinkage associated to firing
371 (0.9%) are very close of those obtained from the industrial mixtures (bricks 0.5%, tiles 0.7%)
372 with a good overlap (80% of the sediment data fall within the industrial values) (Fig. 4b).

373 Results from mechanical strength tests on fired bars are in the range of the industrial values
374 with a larger dispersion (Fig. 4c). Mean values from fired sediment bars (around 13 MPa) are
375 slightly higher than those from the industrial mixtures (around 10 MPa).

376 PCA results of the technological tests of the sediment samples and industrial mixtures are
377 presented in Figure 3c. The first principal component (F1) captures 39% of the total variance
378 whereas the second component (F2) captures 27% Variable plot and associated factor

379 loadings on F1 vs. F2 axes show that the first axis (F1) mostly exhibits that plasticity of
380 extruded material (plasticity raw), fired specimen bar quality (quality 950 °C) and water
381 absorption after firing at 950 °C (water absorbed 950 °C) variables are coupled. The second
382 component (F2) shows a high loading factor for the water shaping variable. Plot of the
383 samples (Fig. 3c, observations) on F1 vs. F2 shows that F1 allows a separation between the
384 sediment sources dominated by P-M-S rocks (fluvial and coastal sites) and those by P-M-(V)
385 rocks. Samples from S sources are scattered along F1. No specific distribution is observed
386 along the second component F2. It is possible to identify two main sample clusters: the first
387 one contains samples from P-M-S sources (F1, F2 positive values), the second one
388 corresponds to samples from P-M-(V) sources (F1 negative and F2 positive values). Industrial
389 mixtures are mainly clustered in the lower right-hand of the score plot (F1 positive values, F2
390 negative to slightly positive values).

391 **5 Discussion**

392 **5.1 Representativeness of spot sediment samples**

393 Particle-size distribution of spot samples in environment dominated by silting processes
394 shows some variability partly controlled by external parameters (erosion process, hydrological
395 regime) and internal ones (geometry of the water body and the sediment wedge) (Lane et al.,
396 2019; Loizeau et al., 2012; Valero-Garcés et al., 1999). Low variability at the scale of a dam
397 reservoir or estuary is attributed to efficient particle sorting such as series of dam along the
398 river or tidal currents in estuaries (Bertin et al., 2005).

399 Sediment composition - mineralogy and clay minerals does not vary significantly at the scale
400 of a dam reservoir or estuary. Changes in proportion are larger for minerals than clay

401 minerals; this is likely to be attributed to the lower dependence of the clay minerals to the
402 sampling site during silting. Sediment composition may be locally influenced by the input
403 from tributaries draining areas with distinct substrates and by calcite precipitation that may
404 occur in the lakes during summer (Filippi et al., 1998).

405 Despite their limitations, results of the spot sediment samples serve to demonstrate the
406 potential of the fingerprinting approach in establishing composition patterns - mineralogy and
407 clay minerals - from silted sediment in water bodies fed from a diversity of sediment sources.

408 5.2 *Sediment source fingerprinting*

409 In this study, attention focused on the <40 μm sediment fraction with the objective of the
410 recovery of dredged sediments, as full or partial substitution of fossil resource in the heavy
411 clay industry. Although particle-size distribution and proportion of plastic clays play a
412 significant role in the extrusion process, sediment composition is also crucial. Thus, extrusion
413 process failed on 52% of the sediments with particle-size distribution similar to those of the
414 industrial domains on the Winkler diagram (supplementary material 2).

415 Provenance fingerprinting method is based on sediment mineralogical composition. The
416 multivariate statistical analysis (PCA) is supportive in predicting the potential of sediment for
417 the heavy clay industry based on five broad provenances (S, P, M, P-M-(V), P-M-S). Four
418 groups of sediment sources have been categorized according to the sample clustering in the
419 principal component F1-F2 plot (Fig. 3).

420 The first category shows the fingerprint of particles produced by the erosion of sedimentary
421 rocks (S source). Composition varies widely between carbonate and siliciclastic sources, but
422 is dominated by quartz (20 to 70%), carbonates (20 to 60%) and clay minerals (5 to 40%).

423 Clay mineral assemblages comprise mixed-layer clays and kaolinite, with around 10% of
424 smectite. This group (despite being projected in the hollow brick domain on the Winkler
425 diagram) had poor technological results such as high water absorption and low shrinkage after
426 firing certainly because of carbonate decomposition between 700-900 °C observed on the
427 DTA/GTA diagrams, the loss of weight and the endothermic specific peaks of magnesium or
428 calcium carbonates decomposition (Haurine; 2015), or high quartz content associated to a low
429 clay mineral one (siliciclastic source).

430 The second category shows the fingerprint of detritus produced by the weathering of plutonic,
431 metamorphic and/or volcanic rocks of ancient orogen (P, M, P-M-(V) sources). Composition
432 consists of silicates (60 to 80% - quartz, feldspars, mica and chlorite) and clay minerals (20
433 and 40%). They include a large content of mixed-layer clays associated to chlorite and illite.
434 This group had also poor technological results despite particle-size distribution falling within
435 the brick and solid brick domains. The need of high quantity of water to be extruded without a
436 high drying shrinkage, high water absorption et low mechanical strength at 950°C are put in
437 relation to a lack of melting compounds like soda or potassic feldspars.

438 The third category corresponds to the fingerprint of the erosion of basement and sedimentary
439 cover of active or ancient orogen (P-M-S source). Composition comprises relatively high
440 percentages of clay minerals (40 to 60%) associated to quartz (20 to 50%) and low amount of
441 carbonates (10-20%) and feldspars and mica (10 to 30%). Clay mineral assemblages are quite
442 dispersed, mainly consisting of mixed-layer clay and smectite in association with some
443 chlorite and illite. High smectite content (35%) is observed in some samples. Best results for
444 the technological tests were obtained for this group of particle-size distribution mainly
445 characterized by a low content in particles > 25 µm. High mechanical strength on dried and

446 fired samples, poor firing shrinkage but high drying shrinkage (that could be problematic for
447 drying) are attributed to the smectite content and the presence of diatoms in the estuary
448 sediments (Paulmier, 1994), these are mechanically resistant, with a high porosity and without
449 transformation or decomposition during firing (Escalera et al., 2015).

450 The fourth one is composed of sediments from P, M and P-M-(V) sources that could not be
451 extruded. Composition is dominated by quartz and feldspars (60 to 100%), no specific pattern
452 is observed for the clay mineral association. Extrusion results may have also been influenced
453 by the particle-size distribution, mostly with a large amount of medium (2.5 to 25 μm) or
454 coarse grained particles ($> 25 \mu\text{m}$), certainly because of a lack of clay minerals that permits
455 sliding and cohesion between particles.

456 Mineral association reflects the sediment provenance from the rocks of the watershed. Clay
457 minerals are more complex to relate to a specific sediment source because they depend on
458 dominant weathering processes, i.e. physical in active mountain ranges (illite and chlorite) vs
459 chemical in ancient orogen (mixed-layer clays and smectite) or sedimentary basins (mixed-
460 layer clays and kaolinite). In addition to the fluvial input, a contribution from marine origin
461 may be observed in macrotidal estuaries as for example in the Seine estuary, where sediments
462 from the erosion of the Cotentin peninsula are brought in by the longshore drift (Walter-
463 Simmonet, 2008).

464 Although simplified, the proposed categories of sediment provenance help defining the
465 dredged sediment properties for substitution of fossil material in the heavy clay industry. Best
466 technological results are obtained from P-M-S sources either in fluvial or estuaries.

467 Dispersion suggests that refined classifications might capture specific sediment composition

468 in relation to provenance (e.g. siliciclastic vs carbonate-rich sedimentary rocks, types of
469 metamorphic or volcanic rocks).

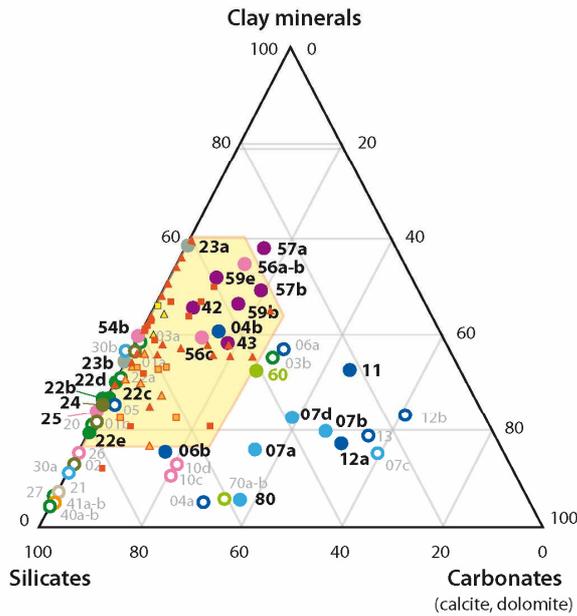
470 **5.3 Consistency between PCA results and the Mineralogical Industrial**

471 **Framework**

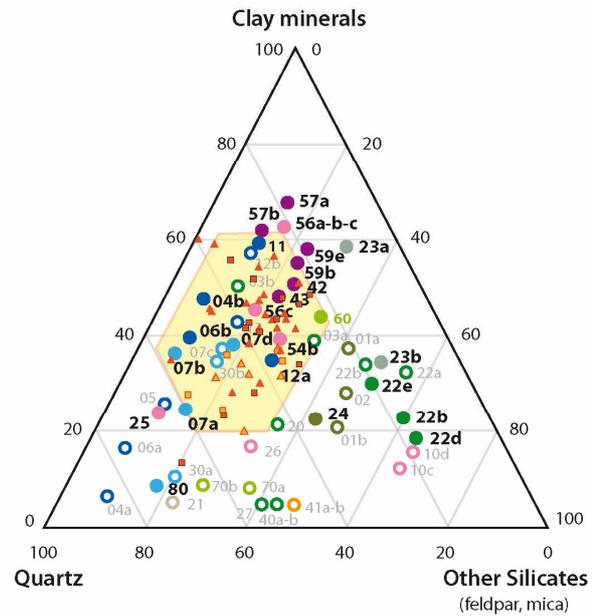
472 The Mineralogical Industrial Framework (MIF, Haurine et al., 2016) is a decision tool based
473 mineralogy and clay mineral assemblages of industrial mixtures clustering in domains on each
474 of four ternary diagrams (Fig. 5). Plot of the composition of the industrial mixtures analyzed
475 in this study falls within the originally defined industrial domains, complementing areas with
476 few data. As for the original data set, no specific pattern is observed between the tile or brick
477 industrial mixtures.

a) Mineralogy

including carbonates

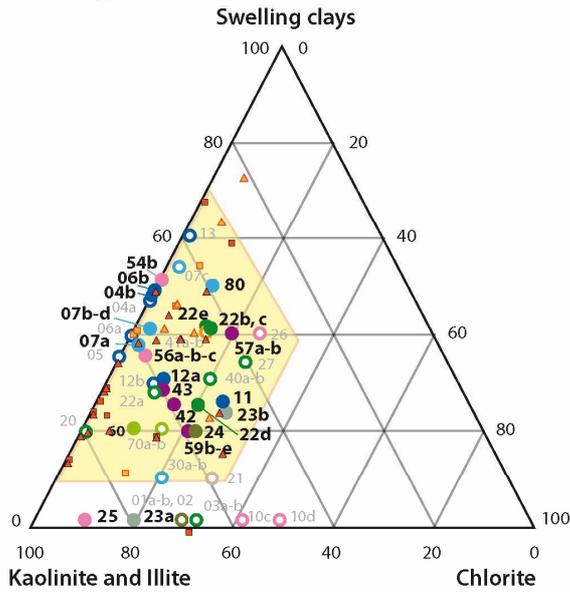


without carbonates

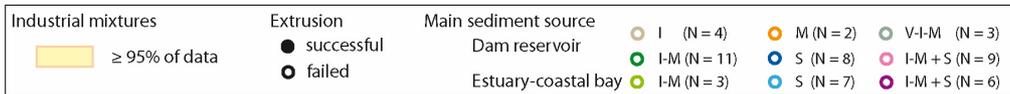
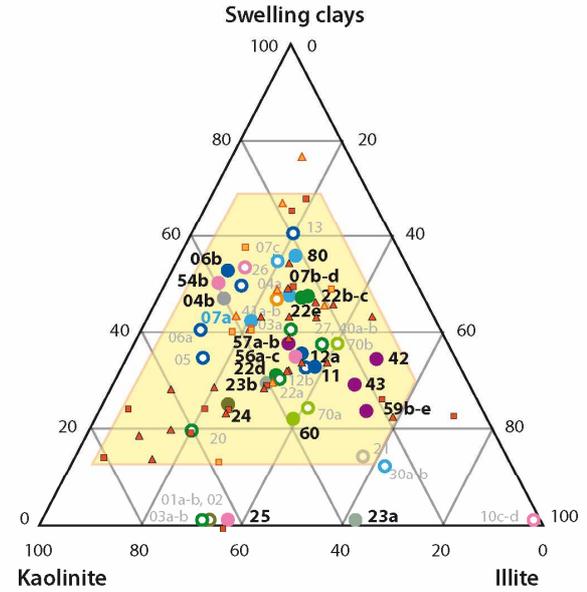


b) Clay minerals

including chlorite



without chlorite



478

479

480 Fig. 5. Projection of sediment samples on the Mineralogical industrial framework (MIF), a
481 decision tool developed from the composition of industrial mixtures (Haurine et al., 2016).
482 Provenance categories defined during PCA, cluster also on the MIF (dominant geology and
483 extrusion result) (Fig. 5). Samples from P-M-S sources which obtained the best technological
484 scores mostly plot within the industrial domains in each of the ternary diagrams. They show
485 quite high content in clay minerals, which is put in relation to their particle size distribution
486 dominated by particles smaller than 25 μm (90%). Samples from S sources largely plot
487 outside of the first diagram due to their high carbonate content; which explains the low results
488 of the technological tests because these high amounts of inert particles decrease the structure
489 cohesion by lack of clay minerals that act as a binder. Samples from P-M sources plot outside
490 of the second ternary diagram due to their high silicate content (feldspar and chlorite) that also
491 explains the low technological results for similar reasons as the high carbonate content.
492 Samples that could not be extruded (all samples from P, M sources and some samples from P-
493 M and S sources) plot outside of the ternary diagrams because of low clay content associated
494 to very high silicate content (quartz, or feldspar and mica) (P, M, P-M sources), or a very high
495 carbonate content (S source) (Fig. 5a). Nearly all samples fall within the industrial domains
496 on the clay ternary diagrams (Fig. 5b). These results indicate that the further the sediment
497 samples plot outside the industrial domains, the lesser is the possibility to extrude the wet
498 paste, or the lower are the scores of the technological tests.

499 Consistent results between the PCA categories for sediment source fingerprinting and the MIF
500 domains based on mineralogy and scores of technological tests indicate that sediments
501 originating from P-M-S sources show the closest properties to those of industrial mixtures.
502 Properties of other sediments could be easily enhanced by mixing with materials having

503 complementary properties (in-between sites or with fossil material), or by addition of
504 correcting agents (quartz sand, grinded calcined clay wastes...), a conventional practice in the
505 heavy clay industry (Haurine et al., 2016).

506 Environmental studies (emission, carbon, metals) are needed to further characterize the silted
507 sediments. Estuary sediments are rich in chlorine and sulphur, seawater containing more
508 dissolved ions than most rivers (supplementary material 9). Some compounds could be
509 transformed during firing between 850 and 1100 °C on gaseous pollutants and be emitted on
510 atmosphere; which environmental impact should be evaluated.

511 ***6 Conclusions***

512 Sediment provenance was identified as the main parameter controlling the recovery of
513 dredged sediment in the characterization of silted in the heavy clay industry, thus
514 contributing to reduce the proportion of quarried fossil materials by substituting part of a non
515 renewable resource by material from dredging in dams, canals and harbors, by material
516 presented considered as waste. Mineralogy plays an important role as indicated by the
517 contrasted results during technological tests of samples having similar particle-size
518 distributions.

519 In this context, PCA analyses (mineralogical composition) showed four categories of samples
520 based on their provenance, confirming the fingerprinting approach from spot sampling of fine
521 grained sediments in dam reservoirs and estuaries. Mineralogy proved to be more
522 discriminating than clay-mineral associations, the later being controlled by weathering
523 processes in geomorphic contexts. Samples from sites fed from the erosion of P-M-S rocks
524 obtained the best scores during the technological tests, close to the industrial values.

525 Composition is dominated by clay minerals and quartz with some carbonates, chlorite and
526 muscovite. Sediments from S and P-M sources obtained less effective scores attributed to the
527 high content in carbonates (S source) or silicates (P-M sources, chlorite, muscovite and
528 feldspars). Sediment from P or M sources could not be extruded partly due to the low clay
529 mineral content and coarser particle-size.

530 Consistent results between the PCA fingerprinting method, MIF industrial domains, and
531 technological tests show that even though the sediment source categories are simplified, they
532 constitute a reference to predict the potential of sediment as raw material for the heavy clay
533 industry. The MIF decision tool proved to be an efficient reliable tool as it only necessitates
534 sediment composition.

535 In an industrial scale perspective, environmental chemical analyses (such as S, F, Cl
536 compounds and CO₂) should be conducted to further characterize the silted sediments. Costs
537 associated to sediment transport and treatments should also be taken into account keeping in
538 mind that environmental standards of the industry are evolving due to the awareness of the
539 benefits of a sustainable environment policy. This classification should be useful to the heavy
540 clay industry managers when making decision regarding the fossil resource preservation by
541 substitution with dredged sediments.

542 *7 Acknowledgements*

543 This work benefited from an ANRT support (convention N°2012-093) and is associated to the
544 SEDIBRIC project financed by ADEME and Région Normandie, AMI funding CPIER VDS.

545 Authors wish to thank the heavy clay producers for providing industrial mixtures. We also
546 wish to acknowledge F. Théry, W. Pesle and G. Vuarand (EDF); F. Bourdin and S. Brasselet
547 (Le Havre harbor); and E. Philippe and B. Benatier (Vendée Eau) for giving us access to dam
548 reservoirs and providing dredged sediment. Finally, we would like to warmly thank L.
549 Vincent and V. Tchemoun (CTMNC), N. Martineau and L. Marlot (Mines-Paristech) for their
550 precious help in the field and during laboratory analyses.

551 *8 References*

552 Agostini, F., Skoczylas, F., Lafhaj, Z., 2007. About a possible valorisation in cementitious
553 materials of polluted sediment after treatment. *Cement and Concrete Composites*, 29(4),
554 270-278. <https://doi.org/10.1016/j.cemconcomp.2006.11.012>

555 Alary, C., 1998. Mécanismes et bilans de l'érosion dans le bassin versant méditerranéen
556 aménagé : le cas de la Durance (S-E France)., Doctoral dissertation, Université Aix-
557 Marseille III, France.

558 Azapagic, A., Perdan, S., Clift, R. (Eds.), 2004. Sustainable development in practice: case
559 studies for engineers and scientists. John Wiley Sons.

560 Benedetti, M. M., Raber, M. J., Smith, M. S., Leonard, L. A., 2006. Mineralogical indicators
561 of alluvial sediment sources in the Cape Fear River Basin, North Carolina. *Physical*
562 *Geography*, 27(3), 258-281. <https://doi.org/10.2747/0272-3646.27.3.258>

563 Benyerou, D., Boudjenane, N., Belhadri, M., 2015. Physicochemical characteristics of port
564 dredging sediment and of the brick slip used in the manufacture of bricks: a comparative

565 study. *Coastal Cities and their Sustainable Future*, 148, 289-296.
566 DOI:10.2495/CC150241 Bertin, X., Chaumillon, E., Sottolichio, A., Pedreros, R., 2005.
567 Tidal inlet response to sediment infilling of the associated bay and possible implications of
568 human activities: the Marennes-Oléron Bay and the Maumusson Inlet, France. *Continental*
569 *Shelf Research*, 25(9), 1115-1131. <https://doi:10.1016/j.csr.2004.12.004>
570 BRGM, 2008. Carte lithologique simplifiée de la France au 1/1 000 000, Bureau de
571 recherches géologiques et minières, Orléans, France
572 Cappuyns, V., Deweirt, V., Rousseau, S., 2015. Dredged sediments as a resource for brick
573 production: Possibilities and barriers from a consumers' perspective. *Waste management*,
574 38, 372-380. <https://doi.org/10.1016/j.wasman.2014.12.025>
575 Chung, F.H., 1974. Quantitative interpretation of X-ray diffraction patterns. I. Matrix
576 flushing method of quantitative multicomponent analysis. *Journal of Applied*
577 *Crystallography* 7, 519–525.
578 Colmar, A., Walter, C., Le Bissonnais, Y., Daroussin, J., 2010. Démarche de validation
579 régionale par avis d'experts du modèle MESALES d'estimation de l'aléa érosif. *Etude et*
580 *Gestion des Sols*, Association Française pour l'Etude des Sols, 2010, 17 (1), 19-32.
581 Cultrone, G., Sebastián, E., Elert, K., De la Torre, M. J., Cazalla, O., Rodriguez-Navarro, C.
582 (2004). Influence of mineralogy and firing temperature on the porosity of bricks. *Journal of*
583 *the European Ceramic Society*, 24(3), 547-564. <https://doi.org/10.1016/S0955->
584 [2219\(03\)00249-8](https://doi.org/10.1016/S0955-2219(03)00249-8).

585 Dondi, M., 2003. Technological and compositional requirements of clay materials for
586 ceramic tiles. In: Domínguez, E.A., Mas, G.R., Cravero, F. (Eds.), Proc. 12th Int. Clay
587 Conference Elsevier, Bahía Blanca, Argentina, pp. 23–30.

588 Escalera, E., Garcia, G., Terán, R., Tegman, R., Antti, M. L., & Odén, M., 2015. The
589 production of porous brick material from diatomaceous earth and Brazil nut shell ash.
590 *Construction and Building Materials*, 98, 257-264.
591 <https://doi.org/10.1016/j.conbuildmat.2015.08.003>

592 Filippi, M. L., Lambert, P., Hunziker, J. C., Kübler, B., 1998. Monitoring detrital input and
593 resuspension effects on sediment trap material using mineralogy and stable isotopes ($\delta^{18}\text{O}$
594 and $\delta^{13}\text{C}$): The case of Lake Neuchâtel (Switzerland). *Palaeogeography, Palaeoclimatology,*
595 *Palaeoecology*, 140(1-4), 33-50.[https://doi.org/10.1016/S0031-0182\(98\)00040-6](https://doi.org/10.1016/S0031-0182(98)00040-6).

596 Garzanti, E., Vezzoli, G., Andò, S., Lavé, J., Attal, M., France-Lanord, C., DeCelles, P.,
597 2007. Quantifying sand provenance and erosion (Marsyandi River, Nepal Himalaya). *Earth*
598 *and Planetary Science Letters*, 258(3-4), 500-515.
599 <https://doi.org/10.1016/j.epsl.2007.04.010>.

600 Garzanti, E., Andó, S., France-Lanord, C., Censi, P., Vignola, P., Galy, V., Lupker, M.,
601 2011. Mineralogical and chemical variability of fluvial sediments 2. Suspended-load silt
602 (Ganga–Brahmaputra, Bangladesh). *Earth and Planetary Science Letters*, 302(1-2), 107-120.
603 <https://doi.org/10.1016/j.epsl.2010.11.043>.

604 Hamer, K., Karius, V., 2002. Brick production with dredged harbour sediment. An
605 industrial-scale experiment. *Waste Management*, 22(5), 521-530.
606 [https://doi.org/10.1016/S0956-053X\(01\)00048-4](https://doi.org/10.1016/S0956-053X(01)00048-4).

607 Haurine, F., 2015. Caractérisation d'atterrissements d'argiles récents sur le territoire français,
608 en vue de leur valorisation dans l'industrie des matériaux de construction en terre cuite,
609 Doctoral dissertation, Paris, ENMP, France.

610 Haurine, F., Cojan, I., Bruneaux, M. A., 2016. Development of an industrial mineralogical
611 framework to evaluate mixtures from reservoir sediment for recovery by the heavy clay
612 industry: Application of the Durance system (France). *Applied Clay Science*, 132, 508-517.
613 <https://doi.org/10.1016/j.clay.2016.07.022>

614 Johari, I., Said, S., Hisham, B., Bakar, A., Ahmad, Z. A., 2010. Effect of the change of firing
615 temperature on microstructure and physical properties of clay bricks from Beruas
616 (Malaysia). *Science of Sintering*, 42(2), 245-254. <https://doi.org/10.2298/SOS1002245J>

617 Kahle, M., Kleber, M., Jahn, R., 2002. Review of XRD-based quantitative analyses of clay
618 minerals in soils: the suitability of mineral intensity factors. *Geoderma*, 109(3-4), 191-205.
619 [https://doi.org/10.1016/S0016-7061\(02\)00175-1](https://doi.org/10.1016/S0016-7061(02)00175-1)

620 Klages, M. G., Hsieh, Y. P., 1975. Suspended solids carried by the Gallatin River of
621 southwestern Montana: II. Using mineralogy for inferring sources. *Journal of Environmental*
622 *Quality*, 4(1), 68-73. <https://doi.org/10.2134/jeq1975.00472425000400010016x>

623 Kornmann, M., 2005. Matériaux de construction en terre cuite – fabrication et propriétés,
624 Septima, Paris, 119-120.

625 Lane, S. N., Bakker, M., Costa, A., Girardclos, S., Loizeau, J. L., Molnar, P., Silva, T.,
626 Stutenbecker, L. Schlunegger, F., 2019. Making stratigraphy in the Anthropocene: climate
627 change impacts and economic conditions controlling the supply of sediment to Lake
628 Geneva. Scientific reports, 9(1), 1-11. <https://doi.org/10.1038/s41598-019-44914-9>

629 Loizeau, J. L., Girardclos, S., Dominik, J., 2012. Taux d'accumulation de sédiments récents
630 et bilan de la matière particulaire dans le Léman (Suisse-France). Arch. Sci, 65, 81-92.

631 Mezencevova, A., Yeboah, N. N., Burns, S. E., Kahn, L. F., Kurtis, K. E., 2012. Utilization
632 of Savannah Harbor river sediment as the primary raw material in production of fired brick.
633 Journal of environmental management, 113, 128-136.
634 <https://doi.org/10.1016/j.jenvman.2012.08.030>.

635 Moore, D.M., Reynolds, R.C., 1997. X-Ray Diffraction and the Identification and Analysis
636 of Clay Minerals. Oxford University Press, New York.

637 Paulmier, G., 1997. Atlas des diatomophycées des côtes françaises et des aires océaniques
638 adjacentes. Direction des ressources vivantes, IFREMER, Concarneau.

639 Pereira, C. G., Castro-Gomes, J., de Oliveira, L. P., 2009. Influence of natural coarse
640 aggregate size, mineralogy and water content on the permeability of structural concrete.
641 Construction and Building Materials, 23(2), 602-608.
642 <https://doi.org/10.1016/j.conbuildmat.2008.04.009>.

643 Valero-Garcés, B. L., Navas, A., Machín, J., Walling, D., 1999. Sediment sources and
644 siltation in mountain reservoirs: a case study from the Central Spanish Pyrenees.
645 Geomorphology, 28(1-2), 23-41. [https://doi.org/10.1016/S0169-555X\(98\)00096-8](https://doi.org/10.1016/S0169-555X(98)00096-8).

646 Walter-Simonnet, A. V., 2008. Impacts sédimentaires de la présence humaine et des
647 variations climatiques. Exemples d'enregistrements lacustres, fluviatiles et estuariens
648 (Doctoral dissertation).

649 Walling, D. E., 1999. Linking land use, erosion and sediment yields in river basins. In *Man
650 and River Systems*, Garnier J. and Mouchel J.-M. (Eds), *Hydrobiologia*, 223-240.

651 Warr, L.N., 2020. Recommended abbreviations for the names of clay minerals and
652 associated phases. *Clay minerals*, 55, 261-264. doi:10.1180/clm.2020.30

653 Winkler, H.G.F., 1954. Bedeutung der Korngrößenverteilung und des mineral-bestandes
654 von Tonen für die Herstellung grobkeramischer erzeugnisse. *Ber. DKG* 31, 337–343.

655 Whitney, D. A. and Evans, B.W., 2010, Abbreviations for names of rock-forming minerals,
656 *American mineralogist*, 95, 185-187. DOI: 10.2138/am.2010.3371

657 Xu, Y., Yan, C., Xu, B., Ruan, X., Wei, Z., 2014. The use of urban river sediment as a
658 primary raw material in the production of highly insulating brick. *Ceramics International*,
659 40(6), 8833-8840. <https://doi.org/10.1016/j.ceramint.2014.01.105>.

660 Zuffa, G. G. (Ed.), 2013. Provenance of arenites (Vol. 148). NATO ASI Series C, 148,
661 Springer Science + Business Media, B.V. DOI 10.1007/978-94-017-2809-6